# RESOURCE ASSESSMENT AND DEVELOPMENT POTENTIAL OF CONTRASTING AQUIFERS IN CENTRAL NORTHERN NAMIBIA

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## ABSTRACT

Expanding demand has led to the need to assess groundwater resources in central northern Namibia. Future development of the region is dependant on locating aquifers with the potential to support large scale water supply schemes.

In the region to the north and west of Tsumeb are two contrasting aquifers with potential to fulfil these requirements. The first is the Damara carbonate aquifer and the second is the Kalahari aquifer.

The Damara carbonate aquifer is a fissured, inhomogeneous and leaky to unconfined aquifer. It has variable recharge from 0% to 4% of rainfall, averaging at 2% of rainfall. The aquifer characteristics are variable, being less favourable towards the base of the aquifer. The inhomogeneity of the aquifer coupled to the variable recharge, mean that in times of protracted drought, the potential for groundwater abstraction is severely reduced. Current abstraction is considered to be $14.1*10^6$ $m^3$ p.a. Additional abstraction should be limited to $2.5*10^6$ $m^3$ p.a., because of the recharge characteristics. The hydrochemistry indicates the groundwater to be of the calcium - magnesium bicarbonate type.

Where The Kalahari aquifer is suitable for exploitation, it is confined, homogeneous and intergranular. Recharge is dependable, being 2% of rainfall and is caused by through - flow from the unconfined portion of the aquifer. The sustainable yield of this aquifer is considered to be $2.0*10^6$ $m^3$ p.a. The hydrochemistry of the groundwater confirms the confined nature of the aquifer, with cationic exchange and mixing occurring. This is evident in the shift from the calcium bicarbonate type groundwater found close to the recharge zone to sodium chloride type groundwaters occurring distal to the recharge zone.

The development options are restricted by the variability of recharge to the Damara carbonate aquifer and the unfavourable hydrochemistry of the Kalahari aquifer. The former problem makes an abstraction policy difficult to determine, while the latter means that the groundwater is unsuitable for general irrigation. Development of the groundwater resources can be undertaken if the limitations of these aquifers are recognised and planning takes account of them.

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## ACKNOWLEDGEMENT

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# 1. INTRODUCTION

## 1.1 REPORT PURPOSE

The population in Namibia is concentrated in the northern portion of the country and the increasing expectations of this expanding population has placed an increased demand on the current water supply, so there is a need to locate further sources of water to satisfy future requirements. In addition, there is some potential for irrigation to the north and north west of Tsumeb and this would add to the water demand.

The area to the north and west of Tsumeb has two aquifers, the Damara carbonate aquifer and the Kalahari aquifer ( Figure 1 ). In this respect this area is unusual, as most of Namibia does not have aquifers suitable for large scale abstraction. These aquifers could be viable for large scale abstraction to meet future demand. The groundwater resources of the area should be evaluated to establish the sustainable yield and how the aquifers can be best exploited. For this purpose a comparison between these aquifers is warranted.

## 1.2 SCOPE AND OBJECTIVES

This study addresses the evaluation of the groundwater resources. It describes the natural conditions prevailing in the area necessary to build up the hydrogeological picture. The methods used to investigate the area are discussed and the historical hydrogeological background is described. The groundwater conditions and the effects of current abstraction are considered separately. The greater part of the report covers the description of each aquifer. A comparison of the aquifers potential leads to a possible strategy for abstraction.

## 1.3 PREVIOUS INVESTIGATION

Evidence of the groundwater potential prior to this study was limited to sporadic and incomplete information, but the impression was that the area had some scope for development.

Since 1989 the collection of data has started in a systematic fashion. The background hydrogeological literature to this specific area is very limited, with no published reports and only two Department of Water Affairs reports. In addition to these general reports, a certain amount of unprocessed Department of Water Affairs data was available. In view of the lack of data, most data had to be collected by the author.

There is no shortage of published data on all other aspects concerning the natural conditions, such as climate, vegetation and geology, but for detail the original raw data such as rainfall figures and geological borehole logs have been consulted. An excellent and comprehensive set of published maps provide a useful medium to plot information.

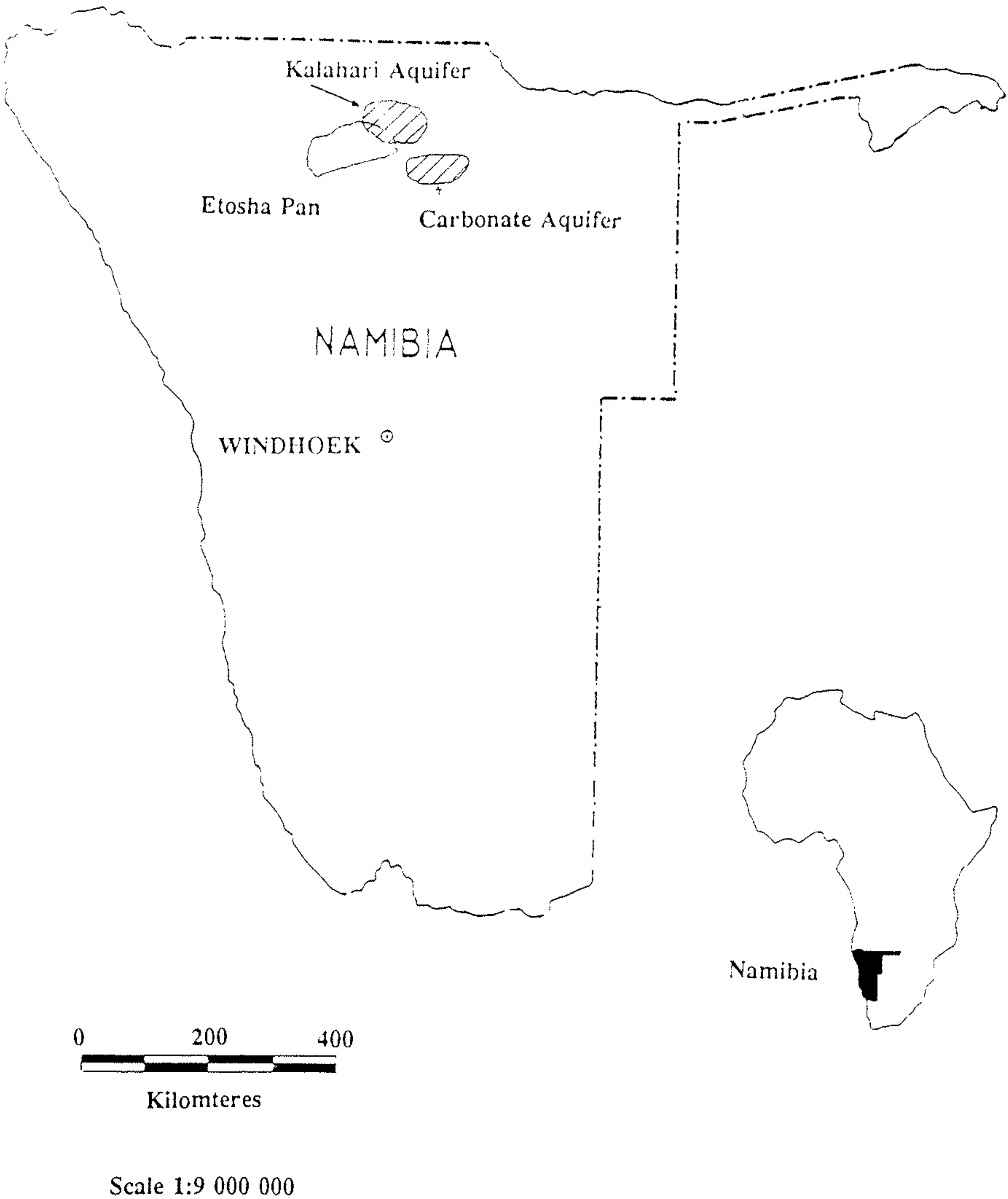



FIGURE 1. Locality map of the area of study in Namibia in Africa.

## 1.4 GUIDE TO NOMENCLATURE

The location of places described in the text is taken either from farm name and farm number or the communal area name or National Park name. Boreholes drilled receive numbers referenced to a 1:50 000 topographic map ( eg. 1817 CC is a map, with a borehole 1 on it, hence 1817 CC 1 ). In addition boreholes drilled or monitored by the Department of Water Affairs have an extra number with a WW prefix. Boreholes with a WW prefix usually have more reliable information.

This report mostly uses the WW prefix borehole numbering system.

# 2. NATURAL ENVIRONMENT

## 2.1 GEOLOGY

The Tsumeb - Oshivelo area is part of the Owambo basin. In this area a wide suite of rocks occur in terms of lithology and age. The geology of this area is described to show the setting of the two aquifers. Table 1 gives a summary of the stratigraphic column. The late Proterozoic Damara Sequence is at the base of the basin and is overlain by Karoo, Cretaceous and Kalahari sequences. Some intrusive and extrusive rocks are believed to be of Karoo age ( Figure 2 ).

| GEOLOGIC AGE | SEQUENCE | FORMATION OR GROUP | AGE ( Ma ) | HYDROGEOLOGICAL SIGNIFICANCE |
|---|---|---|---|---|
| Tertiary | Kalahari | Andoni | 2.0 | |
| | | Olukonda | - | Aquitard<br>Aquifer |
| | | Beiseb | 65 | |
| Mesozoic | Cretaceous | Nanzi | 65 - 140 | |
| | Karoo | Etendeka | 180 | |
| Palaeozoic | | Dwyka | 400 | |
| Proterozoic | Damara | Mulden | 600 - 650 | |
| | | Otavi | 700 - 730 | Aquifer |
| | | Nosib | 900 | |

**TABLE 1.** Summary of the Stratigraphic Sequence illustrating the major hydrogeological units.

The Damara Sequence evolved on a rifting margin, sedimentation starting at 900 Ma ago with fluvial sandstones of the Nosib Group ( ed. McG Miller ). This was subsequently followed at 730 to 700 Ma ago with carbonates of the Otavi Group. The Otavi Group carbonates are dominantly dolomites with some limestones believed to be the result of differences in the salinity of the environment of deposition. These carbonates are subject to karstification. Finally between 650 and 600 Ma ago deposition of erosion products of uplift produced the Mulden Group rocks. During and after the deposition of the Damara Sequence, a period of tectonism resulted in faulting and folding, followed by a period of erosion. The Otavi Group of the Damara Sequence contains the Damara carbonate aquifer, one of the primary aquifers in the area.

The Karoo rocks do not outcrop at surface. The evidence available from boreholes suggest that the Karoo consists of fluvioglacial units of the Dwyka Group, giving rise to tillites, sandstones and shales ( McG Miller ). In late Karoo times ( 170 Ma ago ) basalts were formed, termed the Etendeka Group. Intrusive dykes considered contemporaneous with the basalt extend throughout the area. Periods of erosion occurred before and after the formation of the basalts.

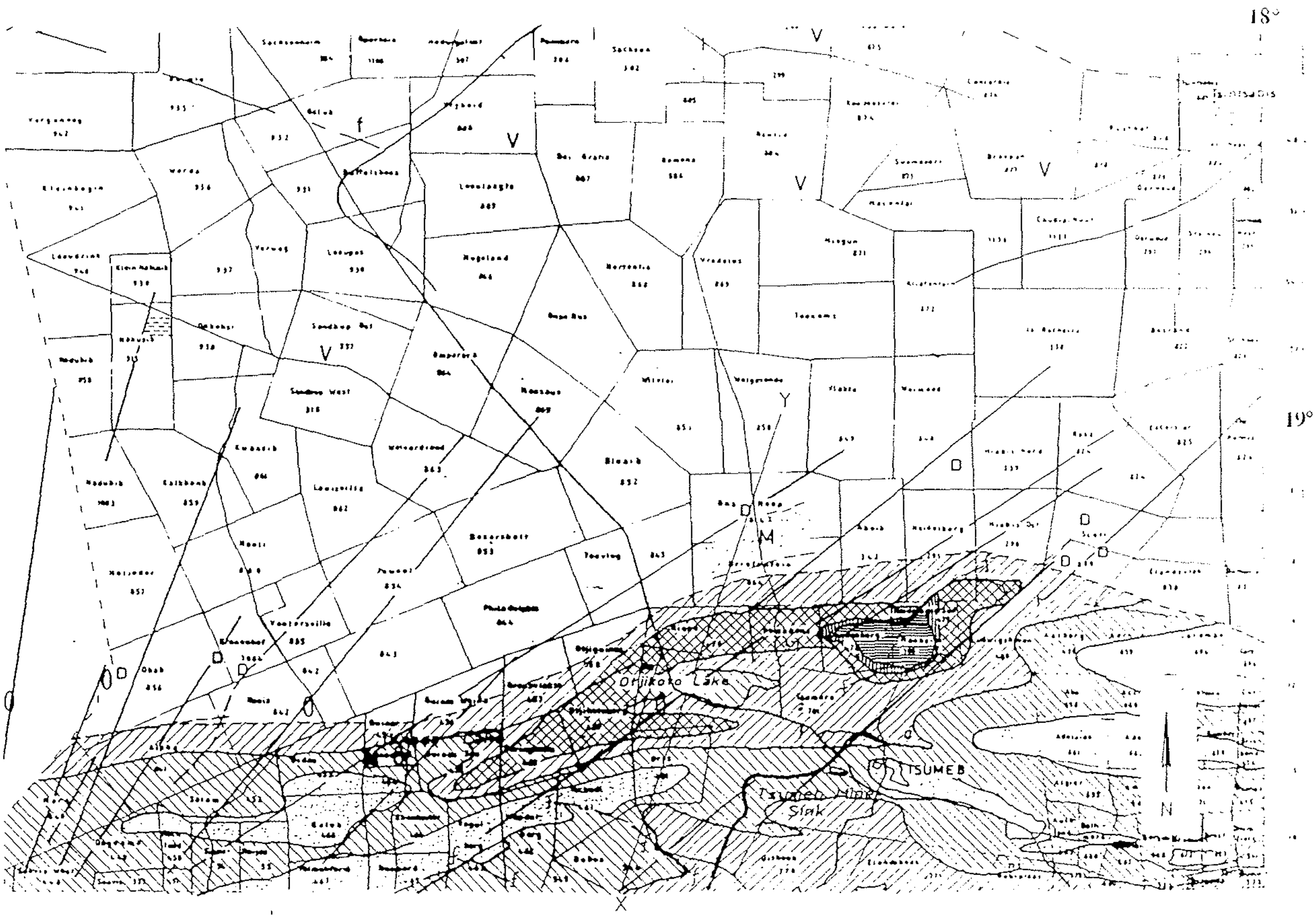



**FIGURE 2.** Geological map of the Damara carbonate aquifer. Key and diagramatic cross section are on the following page.

0 5 10 15 20

SCALE 1 : 387 000

## GEOLOGICAL LEGEND

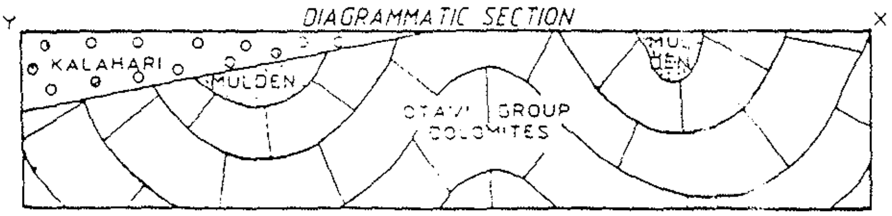
| Group | Formation | Description |
|---|---|---|
| KALAHARI GROUP | | SAND, CLAY, SHALE, CALCRETE |
| KAROO GROUP | | BASALTS, LAVAS |
| | | OMIGONDO SHALES |
| MULDEN GROUP | OVAMBO TSHUDI FORMATION | RED SHALE, FELDSPATHIC SANDSTONE |
| | HUTTENBERG FORMATION | MINOR BLACK LIMESTONE, BEDDED LIGHT GREY DOLOMITE, SHALE, OOLITIC, CHERT |
| | ELANDSHOEK FORMATION | MASSIVE TO LAMINATED LARGE GREY DOLOMITE CHERT |
| OTAVI GROUP | MAIEBERG FORMATION | BEDDED GREY DOLOMITE, LIMESTONE, SLUMP BRECCIA |
| | AUROS FORMATION | GREY DOLOMITE, THIN BEDDED LIMESTONE |
| | GAUSS FORMATION | MASSIVE LARGE GREY DOLOMITE CHERT SANDSTONE |

KEY

M BOREHOLE DRILLED TO MULDEN GROUP

D BOREHOLE DRILLED TO DOLOMITE

/ POSITION OF DYKES FROM AEROMAGNETIC INTERPRETATION




Geology north of 18° 54' S is based on aerial geophysical interpretation.

A sequence of sandstones and shales believed to be Cretaceous in age and called the Nanzi Formation is only known from boreholes ( Figure 3 ).

Overlying these sediments is the Tertiary Kalahari Group ( McG Miller ). These sediments are entirely continental, ranging from aeolian to fluvial. The aeolian material consists of fine grained well sorted sands, while the material laid down in a fluvial environment ranges from gravels to clays and often represents braided stream conditions. The fluvial environment is seen to dominate most sedimentation, with some reworking of aeolian sand. The fluvial infilling of the basin in this area is from the high ground in the south. With braided stream conditions the lithology is seen to be very variable, both vertically and horizontally. Gravels found at the base of the Kalahari called the Beiseb Formation, possibly of Eocene age, are overlain by a sequence dominated by sands called the Olukonda Formation. The sedimentation process was not continuous, as there were periods of erosion in between. These erosional periods result in palaeosols and fossil peneplains, which get reworked. In the Olukonda Formation the primary aquifer is believed to be one such palaeosol. The Andoni Formation overlies the Olukonda Formation. Calcrete has formed in all sediments of the Kalahari, and in particular this commonly forms a hard carbonate layer at the top of the Andoni Formation, locally being karstified. Recent aeolian sand covers much of the area to various depths, especially in the north of the area where relic longitudinal dunes are observed.

## 2.2 STRUCTURAL GEOLOGY

Tectonic activity is evident in all sequences. The faulting and folding observed in the Damara sequence is a result of failed continental break up. The result of this is folding with an east - west strike, while faults are sub vertical and generally show a north east - south west strike ( Figure 4 ). It is believed that some of these faults formed the conduit for invading Karoo dolerite ( Figure 2 ).

Evidence of recent faulting is seen with surface displacement controlling drainage in the Kalahari, as in the Omaramba Owambo and the southern side of the Etosha Pan. It is suggested that these may be rejuvenated Karoo or Damara aged faults ( Figure 4 ).

## 2.3 CLIMATE

The climate of the area is important as it controls the amount of water available for recharge to the aquifers. In detail the climatic aspects that control the availability of water for recharge are rainfall, potential evaporation, humidity, temperature, amount of sunshine and wind.

The area has a continental climate with distinct dry and wet seasons, described as Hot Steppe according to the Koppen Classification ( van der Merwe ). The weather of Namibia is dominated by high pressure centred over the sub continent which accounts for dry winds blowing from the south and west off the cold Benguela ocean current. Occasionally in summer this dominant high pressure is replaced by low pressure which results in winds blowing from the north and north east. This brings in damp air from the Mozambique Channel which can result in convectional rainfall from cumulonimbus clouds ( Shaw ). The wet season lasts from October to March. Tsumeb in the south of the area records an average rainy season rainfall of 525 mm over a 74 years period, but an average of only 438 mm per

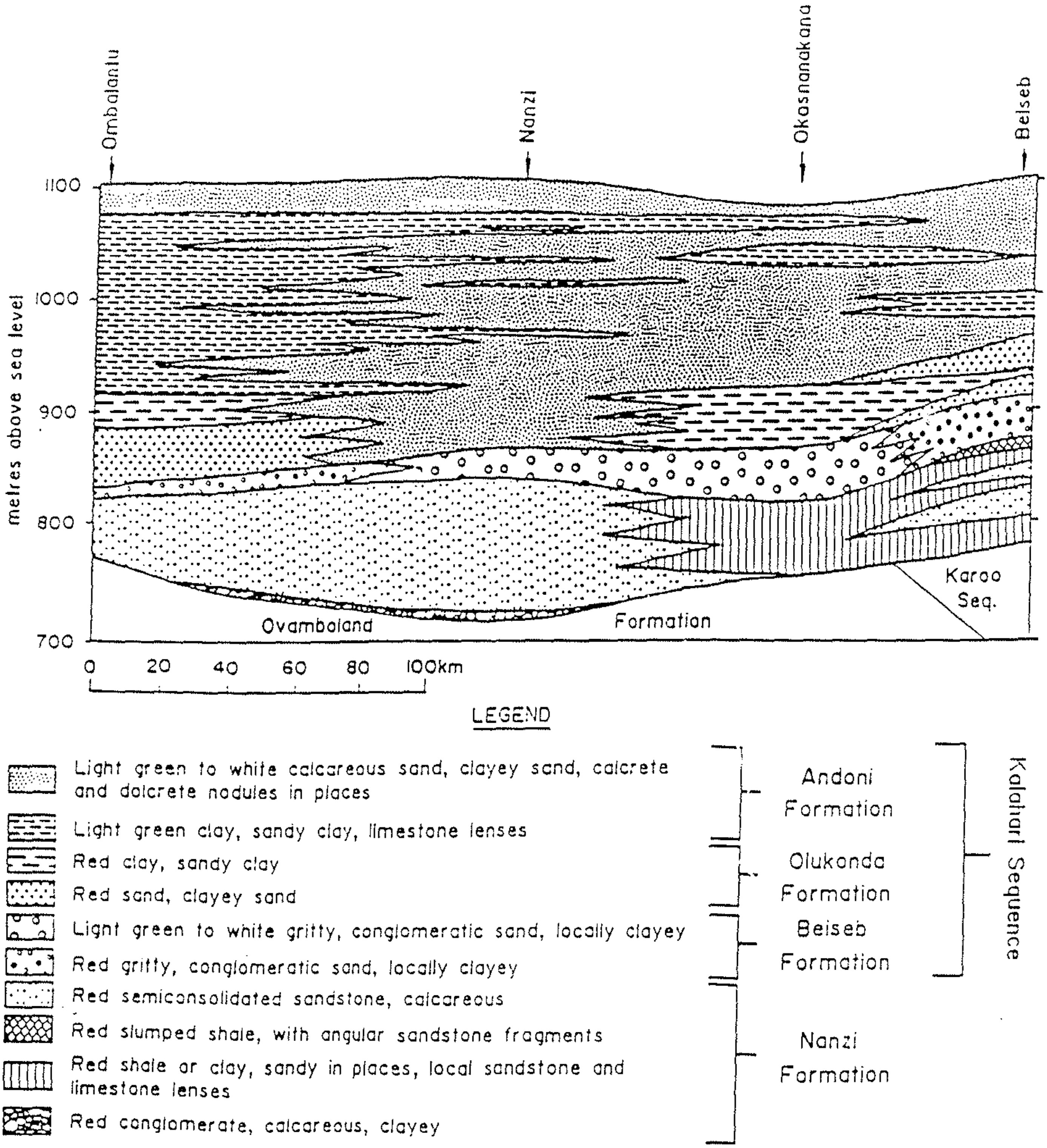



FIGURE 3. Geological cross section through the Mesozoic and Tertiary sediments in the Owambo Basin, showing the various lithological units of the area and their relationship with one another. ( After McG Miller ).

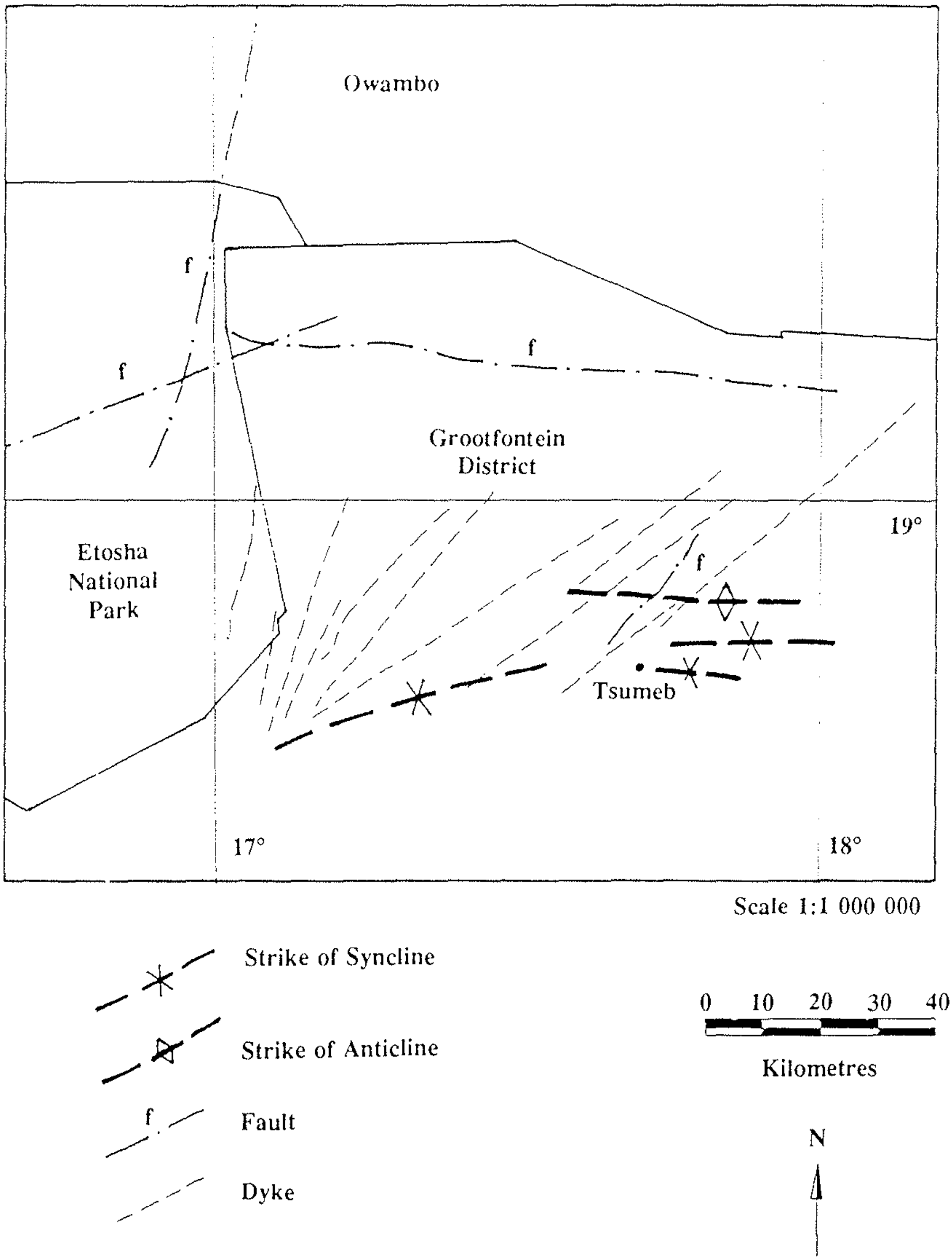



FIGURE 4. Map showing geological structure.

rainy season for the last 10 years ( Appendix 1 ). In the north of the area however, at Kakuse, the average is 468 mm over the last 10 years. It is recognized that rainfall increases to the north. However, the localised thunder storm nature of the rain which dominates in this area means that rainfall is variable over very short distances. This makes the interpolation of rainfall between stations difficult and liable to error. On a long term the overall trend of rainfall distribution is expected to average out, but in any one rainy season only a guide as to the amount of rainfall can be given. Rainfall variability has been measured at 35% around the mean. The last 10 years data has been selected for particular attention in this report as it is the most comprehensive. The intensity of rain is dominantly very high, but there are some lighter rain periods. Long term rainfall records in the Grootfontein District illustrate the cyclic variability of rainfall ( Figure 5 ). Cycles of 10 or 11 years duration are apparent since records began in 1910. These records also show there is no general change in the amount of rain over this period. The limited evidence available suggests that the mountains to the south of the investigation area have higher rainfall than anywhere else in the area ( up to 100 mm p.a. more ) ( Seeger ), but this has not been substantiated inside the study area.

Levels of potential evaporation are high, with values of the order of 2700 mm p.a. which far exceeds total rainfall. Only over very short periods ( measured in days ) does rainfall exceed potential evaporation, and then there is transpiration to contend with before infiltration could occur. The implication of this is that recharge is possibly an infrequent event which may not occur every year.

Humidity levels in the rainy season are in the range of 70% while in the dry season this drops to less than 30% ( van der Merwe ). The daily average number of hours of sunshine is 8.8 through the whole year, with the hours varying from the daily maximum amount of 10.3 hours in the dry season down to 6.6 hours in the wet season. The wet season is in the summer with longer daylight hours but cloud cover is common, so in winter in spite of the shorter days the sun shines all day and every day.

The temperature of the region is very variable from day to night and through the seasons ( van der Merwe ). The minimum temperature in the coldest part of the year ( July ) is 8°C., while the warmest month ( October ) records a maximum temperature of 34°C. Tsumeb records an average annual maximum temperature of 23°C. Daily diurnal variations of 13°C in the dry winter season and 20°C in the wet summer season are normal.

Winds are normally light, not exceeding 6.0 m/s, with still conditions for 25% of the time. For 25% of the time the wind blows from the north and north east which is associated with the wet summer season. The rest of the time throughout the dry season the wind blows from the south and west.

## 2.4 HYDROLOGY

Hydrology is of limited importance in this study area, because of the hot and dry climate and the soils which are unfavourable for runoff.

The only perennial surface water is restricted to sink holes in the dolomites. The sink holes reflect groundwater conditions as they are controlled by hydrogeological constraints rather than surface hydrological effects. These sink holes receive no surface runoff, only direct

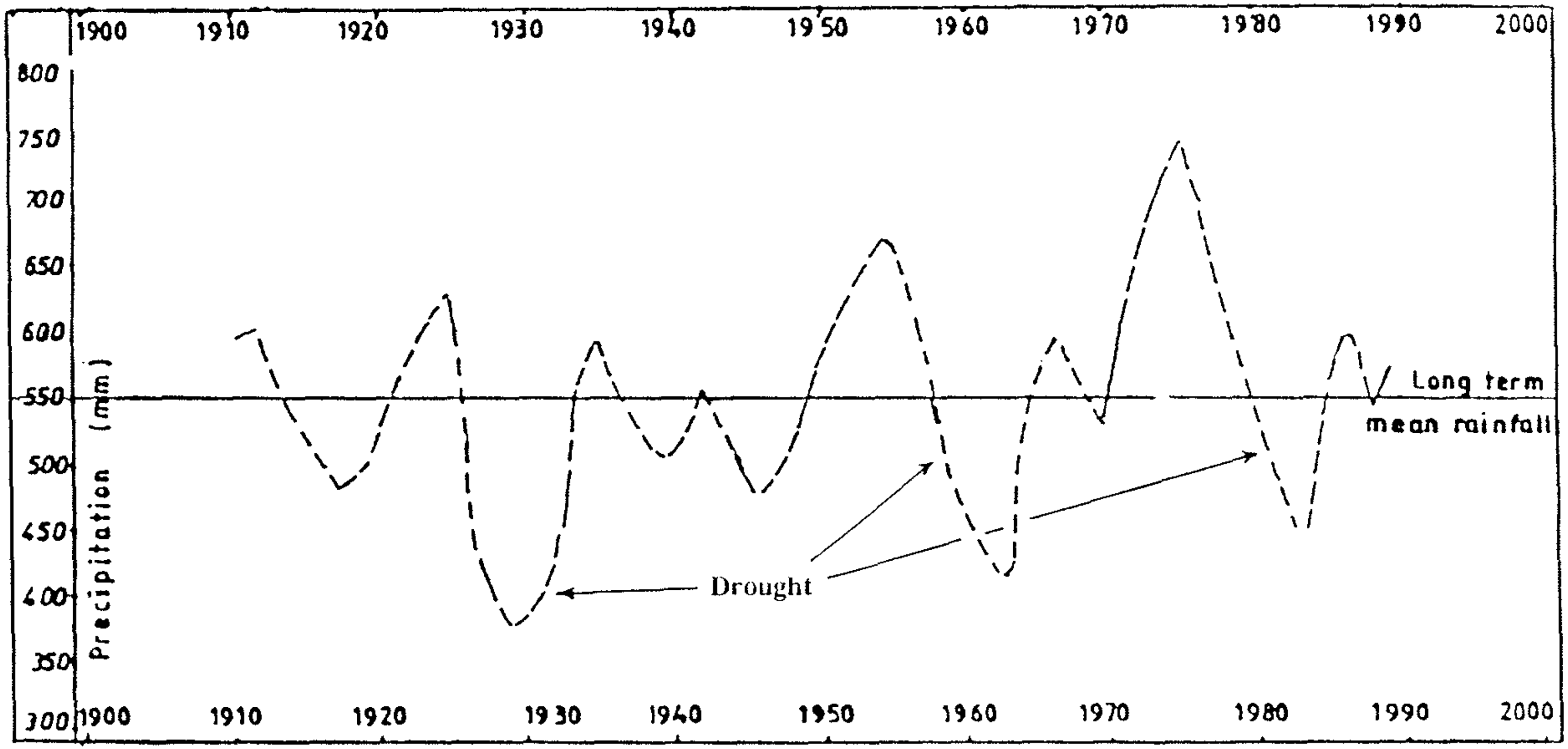



**FIGURE 5.** Long term averaged rainfall records starting in 1910 from the Grootfontein District illustrating the cyclic nature of rainfall ( After Seeger ).

rainfall, but are then subject to direct evaporation.

All rivers in this study area are ephemeral. Due to the low rainfall and nature of the soils and near surface lithology, runoff is very uncommon. Only in exceptional rainfall events is runoff caused by the saturation of the near surface environment. In most cases runoff is an extremely localised event caused by one storm. Only very rarely with widespread heavy rain do the ephemeral rivers flow to their discharge points. In the last 15 years the Omaramba Owambo has flowed to its discharge point twice. Other ephemeral rivers have flowed, but only locally, and usually in areas directly underlain by calcrete. All ephemeral rivers are perched up to 20 m above the water level, so any water infiltrating down from these perched rivers could reach groundwater after allowing for loss through evapotranspiration. Due to the difficulties in measuring flow in wide shallow river valleys and the exceptional nature of flood events, no specific data for surface water flow exist for this area.

## 2.5 TOPOGRAPHY

The area is bounded in the south by the Otavi Mountains which rise to an elevation of 1600 m a.m.s.l. These mountains drop rapidly away to a plain sloping gently to the north at elevations from 1200 m to 1100 m a.m.s.l. At the edge of the plain a few inselbergs occur. The mountains are composed of Damara Sequence units, dominantly dolomites ( Figure 6 ). Away from the mountains, the plains consist of Kalahari units. On the fringe of the plains and in the mountains many karst features are found, but only on the plains are large features found like sink holes ( Figure 7 ). Some of these have open water, while the rest are sediment filled. In the north east of the area occur longitudinal sand dunes rising up to 30 m above the plain. In the north west lies Etosha Pan, which is surrounded by featureless plains ( Figure 8 ).

Valleys in the mountains follow the regional strike of folding, which is east - west, but as the runoff is effectively zero due to the high levels of evapotranspiration and the surface nature of the catchment, they are all dry. In the Kalahari two types of valley are seen. Firstly there are valleys that appear to be structurally controlled by faulting and have a sinuous river course in a straight valley. The valley can be up to 20 m deep and 2000 m wide. Secondly, there are apparently random water courses up to 5 m deep and 100 m wide which form a dendritic pattern. This form of valley only appears on calcrete covered areas.

## 2.6 VEGETATION

The variability of vegetation indicates that no general crop coefficient can be determined, so vegetation cannot be realistically used to generate a figure for evapotranspiration. Because there is no figure for evapotranspiration, soil moisture deficit and water surplus cannot be calculated using the Grindley method. Each plant has its own water requirement, some taking water coming from the unsaturated zone and some from the saturated zone. Only with a monoculture or different plants with similar evapotranspiration rates can a value be established.

Detailed below are some of the complex vegetation changes both on a local and regional scale.

FIGURE 6. Karst landscape in the Otavi Mountains.

FIGURE 7. Typical sink hole in Damara carbonate rocks in the Otavi Mountains.

FIGURE 8. Kalahari Plains adjacent to the Etosha Pan.

The natural vegetation is broadly termed mountain savannah and karstfeld in the southern half of the area and forest savannah and woodland in the northern half ( van der Merwe ). However the exact nature of vegetation is determined by the soil and geology. In the Kalahari, trees grow preferentially on the longitudinal sand dunes while in the dune streets grass dominates. On the sandy plain tree savannah dominates.

The commonest trees that are found are Mopane ( Colophospermum Mopane ), Mongongo ( Ricinodendron rautanenii ) and Morula ( Sclerocarya caffra ) and Acacia species ( Palgrave ). Of these Mongongo is only found to grow on sand, while Morula will grow anywhere. Mopane tolerate all soils and will grow on calcrete.

Coarse and hard grasses such as Blackfoot Brachiaria ( Brachiaria nigropedata ), Wool Grass ( Anthephora pubescens ) and Kalahari Sand Quick ( Schmiditia pappophoroides ) grow in sandy areas while in the mountain regions bushes such as Leadwood ( Combretum imberbe ) grow with grasses like the Armgras species ( Brachiaria species ) ( Müller ).

Agriculture in the area has recently moved towards arabl: farming. This farming is localised and uncommon, but always expanding. Maize is the main crop, as dry land cropping dominates with minimal irrigation.

# 3. METHODS USED IN STUDY

## 3.1 USE OF HISTORICAL DATA

A mass of historical data is available in various places which can be of use in examining the groundwater potential of the area. The most useful sources are the Department of Water Affairs and the Geological Survey of Namibia, while mining houses can supply additional information.

The Department of Water Affairs maintains a data bank of many of the boreholes and wells in the study area. The records include water quality results, borehole design and construction details, geological logs, aquifer yields and water levels ( Appendices 2 and 3 ). However the data bank is not complete. As much data is sourced from outside the Department of Water Affairs, some of the data has to be treated cautiously. A general picture of an area can often be established by examining critically this information. A library of old reports and maps compliment the data bank which can deal with any groundwater related subject pertinent to that area, ranging from general investigation to hydrochemistry and geophysics. Any data which comes from a known reliable source, particularly internally sourced information, is considered to be of greater value than that from unverifiable sources.

The Geological Survey has a comprehensive collection of geological reports and maps. These have been prepared by their own staff or come in from outside professional sources. This provides a wider geological basis for any investigation. It is essential that the geological framework be well understood to make an intelligent assessment of the groundwater resources of the area.

Information coming from mining houses has provided limited and detailed information on a range of subjects, normally of peripheral use and take the form of geological borehole logs, geophysical results and geological maps.

In this report the majority of the hydrological data has not been used elsewhere.

## 3.2 APPLICATION OF REMOTE SENSING

Remote sensing is used to locate firstly aquifers and secondly drilling targets on an aquifer. Two forms of remote sensing have been applied to this area and they are aerial photography and satellite imagery. These two methods are considered here to be complimentary, as they work in different ways. Although much can be learnt from remote sensing, it is a remote reconnaissance tool, and anything that requires further work should be subject to field inspection.

Aerial photographs used in this area are on a scale of 1:50 000, provide stereo pairs of high definition and are black and white. The application of aerial photographs is particularly useful in carbonate areas, as the features causing possible karstification are usually very clear and sometimes can be seen through thin superficial cover. The 3D effect created through the use of stereo pairs is an additional valuable feature. Coverage of the area is complete with 66% overlap of photographs and 33% overlap between lines.

Although the area is vegetated, the density of the bush does not restrict the view of the ground. In fact vegetation is often seen to pick out fractures and contacts with larger trees growing on them. Often there is a subtle change in the type of vegetation caused by the geology, thus dolomites and sandstone can be separated and calcrete from sand dunes. Often the colour of the rocks and the landforms themselves can be diagnostic.

Satellite images with a scale of 1:250 000, have the advantage of seeing the area as a whole, so features can be seen in a regional context. It does not however form a stereo pair and has poorer definition than aerial photographs. Landsat images have been used here with false colours which show up the surface geology, particularly sand dunes and calcrete. Large scale structure like large faults can also be seen.

## 3.3 GEOPHYSICS

A wide range of geophysical surveys have been attempted in the area of investigation for aquifer delineation and the selection of drilling targets. The Department of Water Affairs first used geophysics here in the early 1970's when initial interest was shown in this area. Regional geophysical surveys had been undertaken on behalf of the government which had been intended to arise interest in the mineral potential of the area. Since 1989 the Department of Water Affairs has undertaken a considerable amount of further regional and local geophysical surveys.

The types of surface geophysics that have been attempted include resistivity, gravimetric, electro - magnetic and magnetic. Airborne geophysics in this area is limited to some magnetic surveys.

The object of these geophysical surveys has been to locate aquifers. Initially regional surveys have been undertaken to try to locate favourable areas which might prove to be an economically exploitable aquifer. Having outlined the regional location of the aquifer, local geophysical surveys are made to locate specific targets for drilling.

Geophysical surveys have been dominantly undertaken in carbonate areas, the object being to locate features such as fissures, geological faults and contacts which could be preferentially karstified. Although carbonate rocks are seen to outcrop in many areas, these rocks can be covered by Kalahari units which get progressively thicker towards the north. These Kalahari units mask the underlying geology, so geophysics is a useful tool to locate water bearing features. In addition to these buried features, geophysics is also used in areas with extensive outcrop, but slightly covered by a veneer of sand.

The type of geophysics used in this terrain is dependant on what sort of geological contrast is to be expected. In most of the carbonate areas the most useful tools were the resistivity and the electro - magnetic methods. Their success in this area is caused by the differential water content between the usually massive carbonate rock and the water filled fissures. The water filled fissures show up with higher conductivity or lower resistivity. These methods were used in both regional and local surveys.

The resistivity methods that have been widely applied in carbonate areas use a wide range of different types of array, spacing and measuring apparatus. The design of any survey is dependant on what is required from that survey and what groundwater conditions are expected. Vertical depth sounding was used to locate the water level and constant separation traversing ( CST ) has been used to locate geological contacts. CST was regularly used in series along profiles to create a resistivity cross section.

Electro - magnetic methods have been used in field investigations where the water levels were less than 30 m, a depth determined by the type of machine used ( EM 34/3 ). This method is most suitable in locating shallow buried fissures in dolomite.

Gravimetric surveys in theory should also prove useful, but when tried in 1989 the machines available were not robust enough and were not cost effective. In the early 1970's traverses were made across the regional geological strike ( i.e. in a north - south direction ), but these failed to show any anomalies except when by design they went over sink holes. These unfavourable results indicated that the method was only useful in small scale detailed surveys.

Magnetics could not be used to find fissures as this method relies on a magnetic contrast, which does not exist in a solely carbonate terrain. However, in an aeromagnetic survey which had been carried out on the behalf of the government, some concealed dykes, faults and basalts were revealed. It has been shown since 1989 that boreholes drilled into the hidden fault zones had an order of magnitude increase in yields over boreholes in the surrounding area. It was also initially considered that the dykes were also targets worth investigating. Magnetic surveys were justified to clarify the ground position of aeromagnetic anomalies.

On the Kalahari plains, geophysics has been attempted, but with much less success than on the carbonate units. The geology here is dominated by up to 200 m of the Kalahari Sequence and all surface geophysical techniques employed in this region have not penetrated through these sediments, thus only features in the Kalahari sediments can be observed. Although the Kalahari sediments are lithologically complex they have little or no contrast, so no geophysical method works. Because of this no anomalies have been seen in any of the surveys undertaken. Attempts with CST to locate a major fault thought to be oriented along the Omaramba Owambo and changes in the lithology drew a complete blank.

## 3.4 HYDROCHEMISTRY

Samples of groundwater have been taken from many boreholes in the investigation area. However, as the majority of these are from farm boreholes where the exact source of the water is often unknown, the result can frequently not be attributable to one aquifer. Because of this factor, data sourced from farm boreholes has to be treated with caution and should have a low reliability given to it, except where the borehole design is known and followed correctly and where the groundwater can only have come from one aquifer which is a response to the proven depth of the borehole. The most reliable boreholes for sampling are those drilled by the Department of Water Affairs, as the aquifer being sampled is always known.

All of the samples have been examined in accordance with widely accepted standards in the Department of Water Affairs laboratory in Windhoek. Samples have been taken mostly from production wells whilst pumping, very few from standing boreholes. Samples have been taken at all times of the year and when samples are compared from one aquifer taken at different times, no change of hydrochemistry is observed. In test pumping, the groundwater is periodically sampled. In every case no variation beyond normal sampling error has been reported.

Broadly the hydrochemistry of the area is determined by the host rock. The hydrochemistry of the groundwater that occurs in the Damara carbonate aquifer plots in the dolomite and recent recharge fields of the Piper Trilinear Diagram. Groundwater in the Kalahari units has a far more variable nature but the actual concentrations of $Ca^{2+}$ and $CO_3^-$ are less than in the carbonates. In the Piper Trilinear Diagram the hydrochemistry results of the unconfined Kalahari aquifer plot in the recent recharge field, while the results of the confined aquifer show mixing and ionic exchange.

The actual drinking water quality of the groundwater in most of the area is good, according to WHO standards. The groundwater is suitable for large scale demand, from towns down to farmsteads and normally requires no processing other than standard chlorination treatment for large towns.

The only place where groundwater quality is seen to get worse is in the west and north west of the area where the Kalahari aquifer occurs. Here the groundwater is reported to have elevated levels of sodium and chlorine. The cause of this is considered to be internal drainage which is situated to the immediate west of this area. The sediments may have a high sodium and chlorine content which dissolve into the groundwater. This internal drainage currently forms a saline pan called Etosha Pan.

# 4. DAMARA CARBONATE AQUIFERS

## 4.1 INTRODUCTION

The Damara Sequence carbonate rocks produce fissured aquifers which are caused by differences in the formation of karst features ( Figures 6, 9 and 10 ). These karst features determine groundwater occurrence. Intergranular effects are minimal and play no significant role here. The primary mechanisms for karstification seen here are changes in geology, the nature of the carbonate chemistry and tectonic events.

Contacts between the Otavi dolomites and the Mulden sandstones are considered important karstification zones ( Figure 2 ), especially in places subject to dilation caused by folding which enhances fissure formation.

The intrusive dykes which are found at various points are thought to have shattered the host rocks. When dolomite is the host rock, this forms a zone favourable for the development of karst features.

Limestone bands are occasionally found in the dominantly dolomite outcrop. These horizons can weather more readily in this terrain and in contact with dolomites can also form potential zones of karstification.

Tectonic activity after the formation of the Damara Sequence has resulted in folding and faulting. The faulting is readily seen and is an additional important control on karstification. Productive fissures and karstified zones in the Damara Sequence are however not ubiquitous.

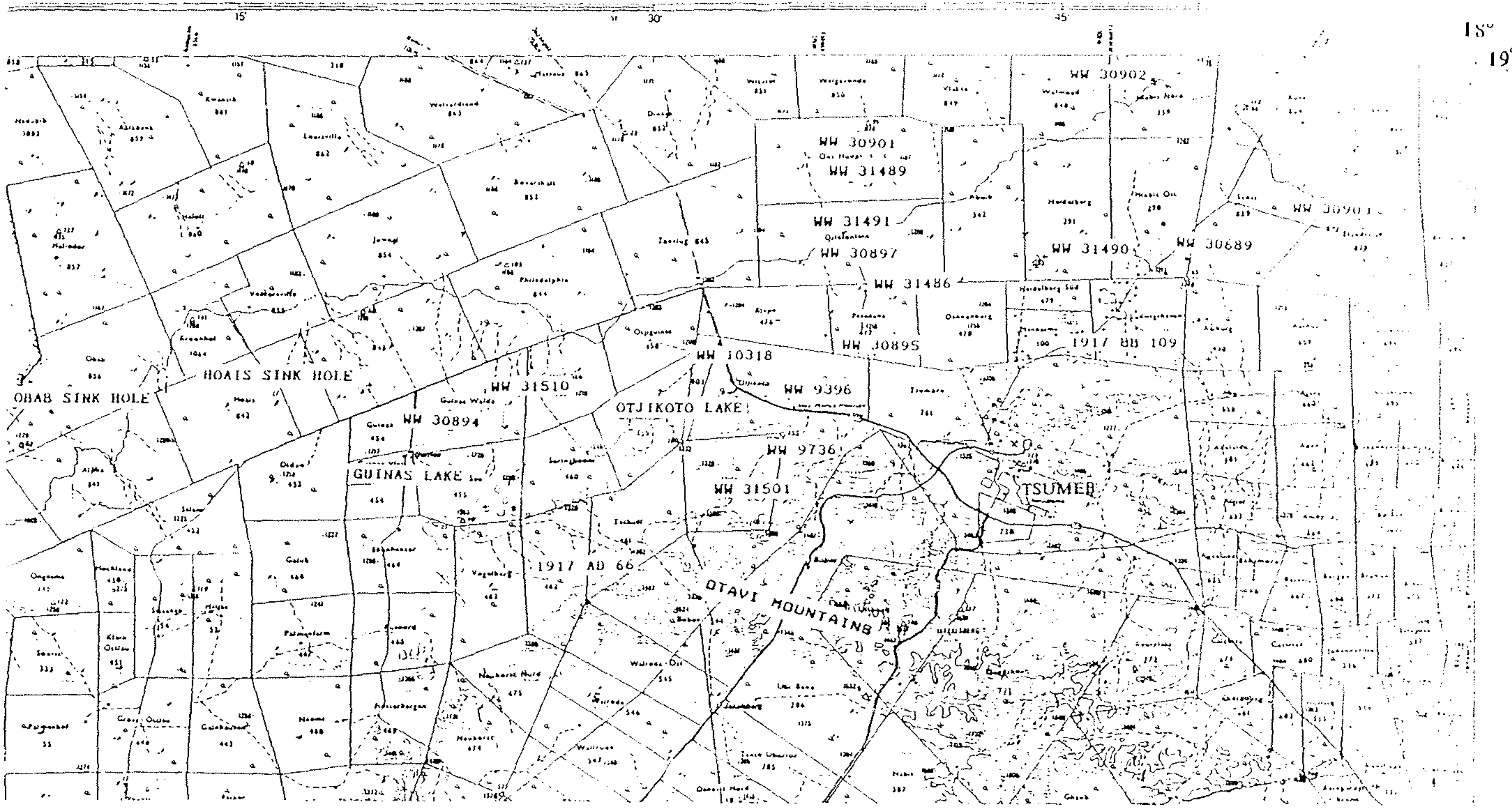
As the exploitable aquifers are discontinuous, boreholes are concentrated into favourable fissured areas. In general there is a trend for boreholes to be deeper in the mountains in the south, because of the regional groundwater piezometry of the unconfined dolomites ( Figure 11 ). A range of depths for the groundwater level of unconfined aquifers are seen in boreholes to a maximum depth of 100 m. However because of the discontinuous nature of the aquifer and the actual water strike depth, the actual depth of drilled borehole is variable, ranging from 30 m to 200 m. Borehole design is determined primarily by the encountered geology and hydrogeology.

The quality of the groundwater is good according to WHO standards and suitable for irrigation, with all results showing recent recharge.

Recharge estimates have been undertaken using the aquifer characteristics and hydrographs. Results indicate recharge to be dependent on rainfall and its intensity, with a maximum recharge of 30 mm p.a. or 3.6% of rainfall, but a more normal value is 10 mm or 2% of rainfall. In below average rainfall years there is often no recharge. Average recharge over the aquifer is considered to be $19*10^6$ $m^3$ p.a.

An analysis of long term hydrographs indicate discharge decreases as the groundwater level is lowered which would mean that fissuring decreases with depth.

The aquifers have been exploited by commercial farmers, with over 100 wells in the study area. The majority of these are low yielding as the primary requirement is stock watering, but



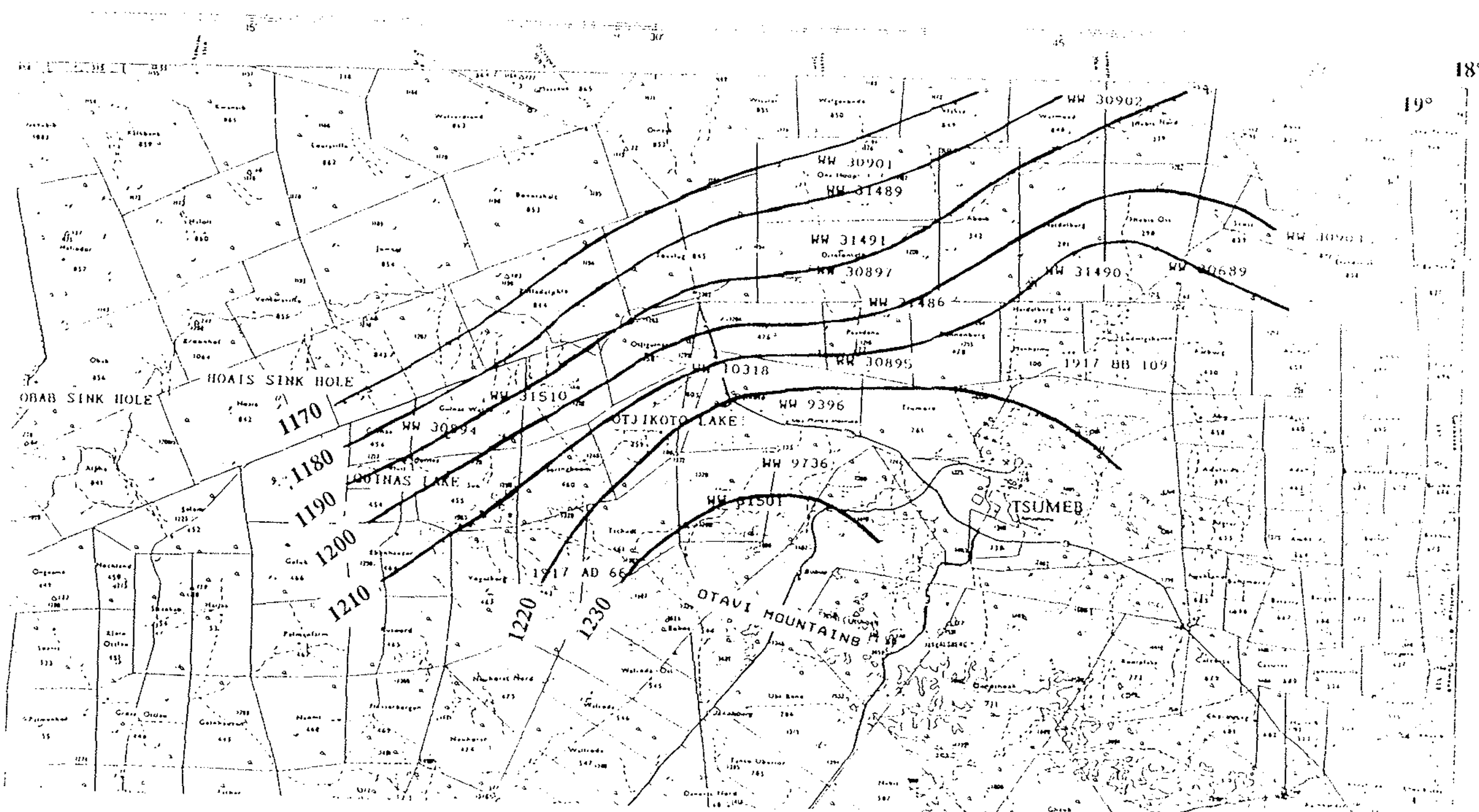

NORTH

0 5 10 15 20

Kilometres

SCALE 1 : 357 000

**FIGURE 9.** Borehole Location Map for the carbonate aquifer, showing places named in the text.




NORTH

0 5 10 15 20

Kilometres

SCALE 1:357 000

**FIGURE 10.** Piezometer contour map illustrating groundwater levels read on the 27-04-92. This represents the summer post rainy season situation. The end of the dry season situation differs little except for a general decrease in the piezometric levels, the greatest drop is seen in the Otavi Mountains represented here by boreholes 1917 AD 66 and WW 31501. Elevation of water level are in metres above m.s.l.

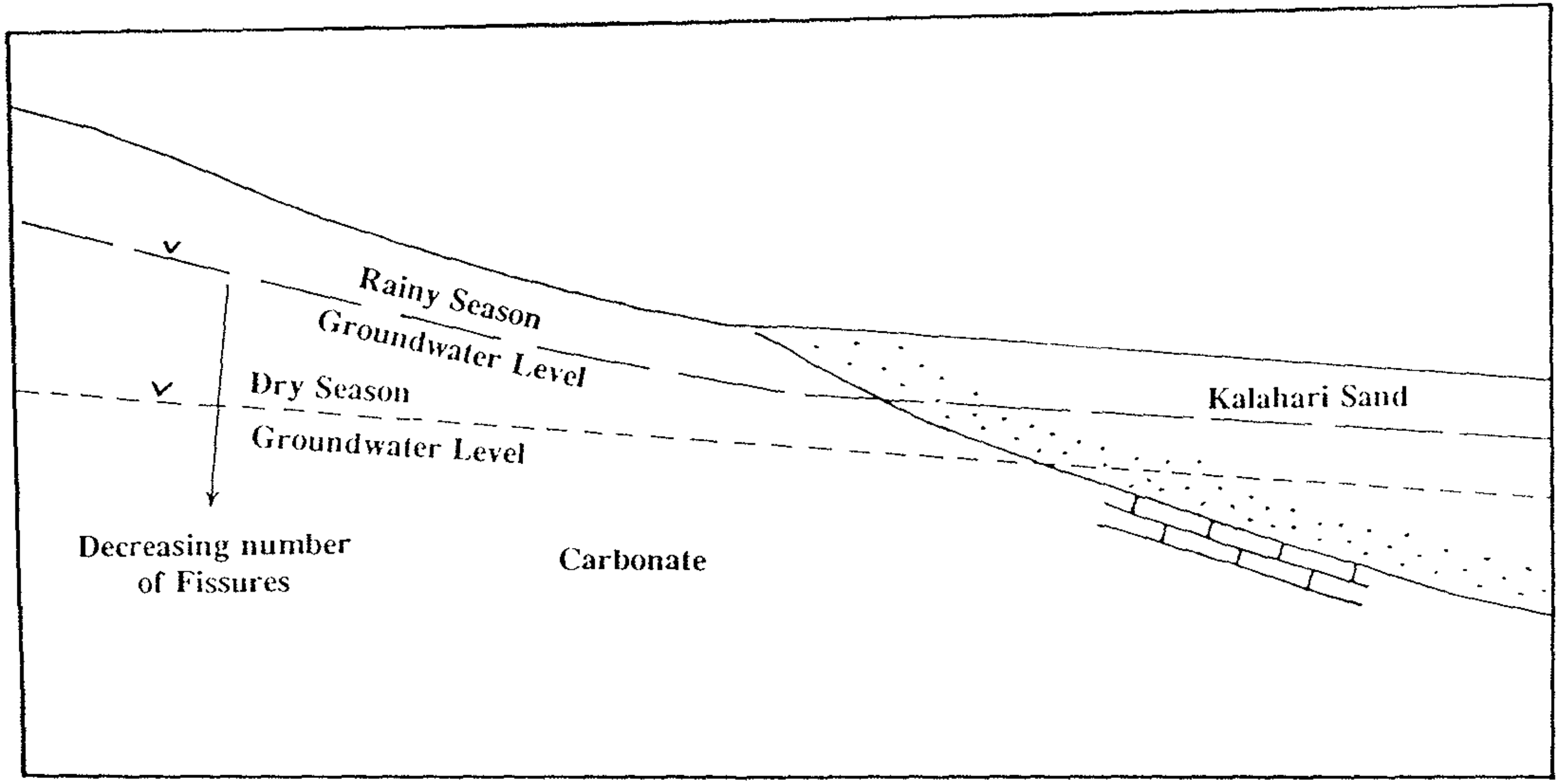



**FIGURE 11.** Diagramatic cross section to illustrate differences between rainy and dry season groundwater levels in Damara carbonate and Kalahari units.

there are some wells which are better yielding and these are used for irrigation. Large scale abstraction is concentrated in a few restricted localities and the potential effect of this on the groundwater levels should be monitored. Abstraction is considered currently to be $14.1*10^6$ $m^3$ p.a. On average, this would allow for a further $4.9*10^6 m^3$ p.a. to be abstracted.

The assessment of the groundwater resource by the Department of Water Affairs is restricted to two periods, once in the early 1970's when 10 boreholes were drilled and since 1989 with approximately 30 boreholes having been drilled to date.

## 4.2 AQUIFER CHARACTERISTICS

The object of the investigation into aquifer characteristics is to prove that these aquifers are fissured and can show a range of values of characteristics. A total of 7 boreholes have been test pumped.

The test pumping was spread out over the whole extent of the aquifer in a variety of karst structures. One of the tests was not successful due to the unavoidable recirculation of water.

The analysis of these tests assume standard Theis assumptions, including homogeneity, isotropy, that the aquifer has an infinite extent and uniform thickness. However, the nature of the karstified dolomitic aquifer is clearly not following these assumptions, so errors are bound to occur. In this assessment of the aquifer characteristics, each type of karst structure which has been test pumped is discussed separately. Test pumping in a fissured terrain is fraught with problems, for if the observation borehole is situated along the strike of the fracture the drawdown should follow the Gringarten - Witherspoon type curves as illustrated in Figure 12a ( Kruseman and de Ridder ). If the observation borehole is away from the fracture then the drawdown should follow a path on another set of Gringarten - Witherspoon type curves as shown in Figure 12b. Curve matching was done on the later data when the observed drawdown follows the Theis type curve. The drawdown data was processed using a computer programme called P Test.

### 4.2.1 Mulden - Otavi contact karstification overlain by Kalahari units.

The boreholes which were tested on the edge of the Kalahari plain to the north west of Tsumeb are WW 30897, 31486 and 31489. The intended target was the contact zone of the Otavi dolomites and the Mulden quartzites, but drilling showed the quartzites to be actually sandstone and fissuring on the contact was not as favourable as had initially been thought ( Figure 13 ). Because of the number of boreholes that had been drilled into this zone, those boreholes selected for testing were adequately served with observation boreholes. All these boreholes have up to 70 m of Kalahari sand above the Damara Sequence. All borehole drilling records indicate that a mixture of groundwaters is present from both the dolomite and Kalahari units, but the strongest groundwater occurs in dolomite ( over 90% ). Typical boreholes have the Kalahari units cased out because of the potential of the borehole to collapse.

The results are tabulated in Table 2. An examination of the drawdown data, plotted in Appendix 4, show that leaky conditions exist. The confining leaky layer is possibly the

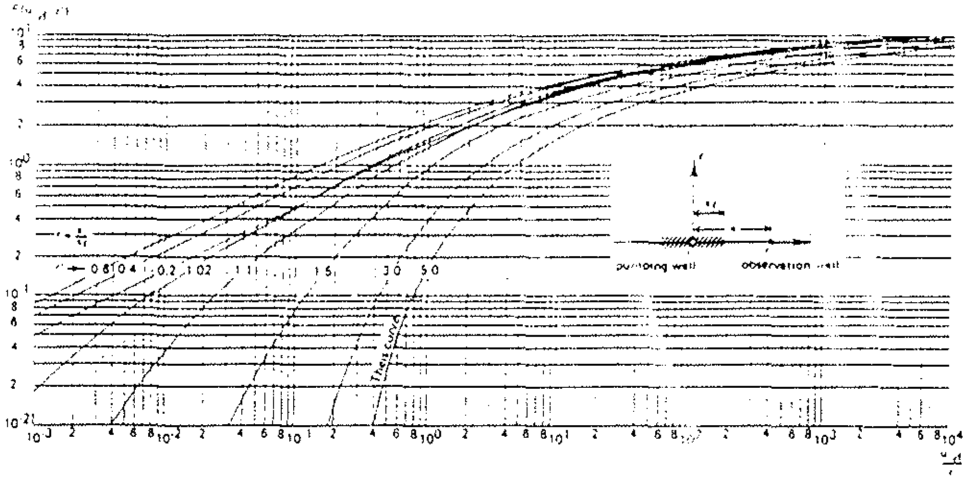


**FIGURE 12a.** Gringarten - Witherspoon type curves for a vertical Fracture with an observation borehole located along the x axis ( Kruseman and de Ridder ).

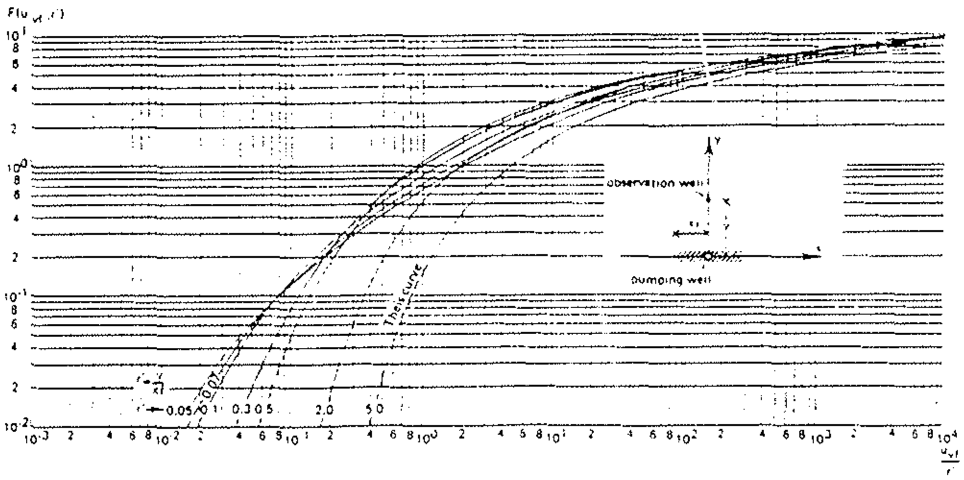


**FIGURE 12b.** Gringarten - Witherspoon type curves for a vertical fracture with an observation borehole located along the y axis ( Kruseman and de Ridder ).

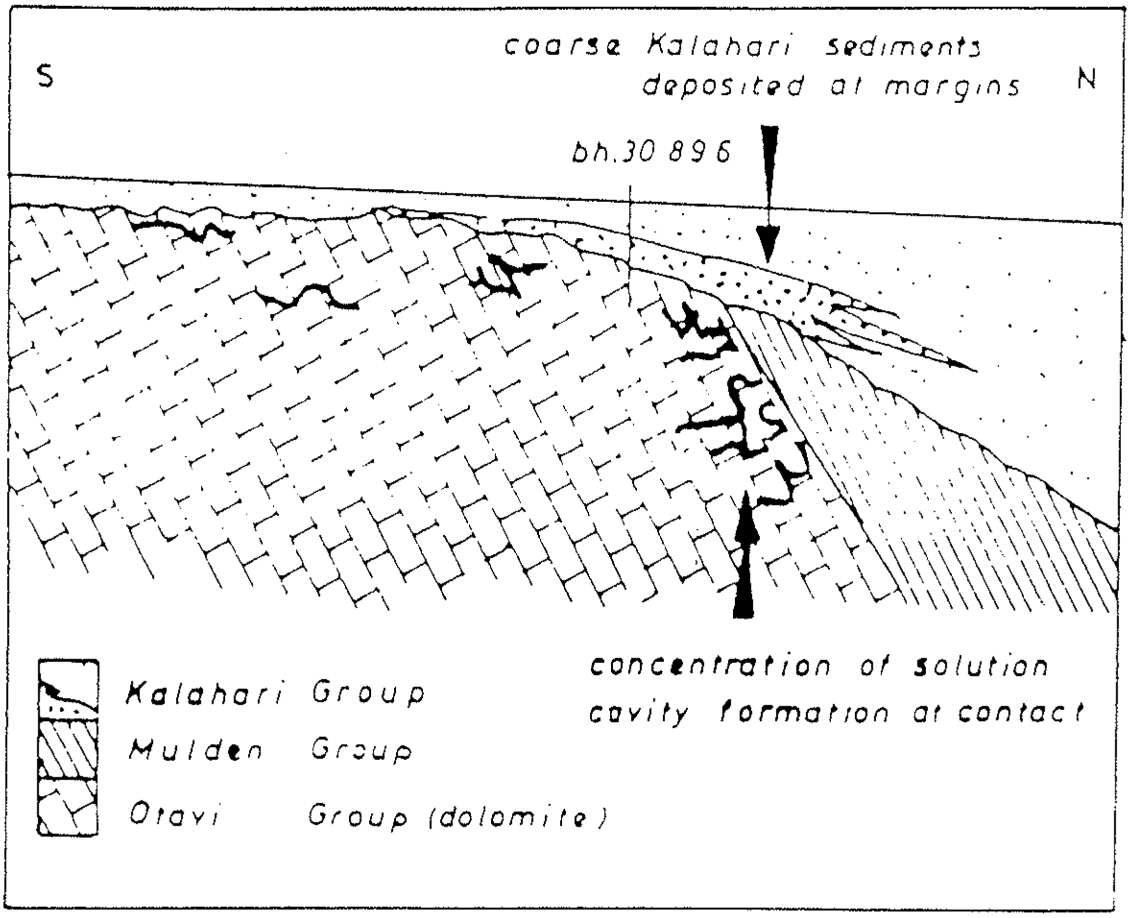



FIGURE 13. Diagramatic cross section through the southern margin of the Kalahari cover, illustrating the possibility for intense karstification on the contact of Otavi Group dolomites ( Poulter ).

overlying Kalahari sediments. Appendix 2 contains details of lithology and well design for the boreholes in this aquifer.

On borehole WW 30897 a longer 168 hour test pump was undertaken to dewater the leaky conditions. Experience has shown that false aquifer characteristics can be indicated from a short test pump. The leaky component can be dewatered in a longer test pump, radically effecting the assessment of the aquifer characteristics. In this case the aquifer was not dewatered.

A comparison of the results show that for WW 30897 and 31489, transmissivity is ~150 $m^2/d$. Storativity for all boreholes range from 0.06 to 0.002 typical of either unconfined or confined conditions. The test pumping of WW 31486 resulted in a low storativity value of ~0.002, which is typical of a confined aquifer. All other results show storativity values to be compatible with an unconfined aquifer. The very low transmissivity result from WW 31486 suggest that the aquifer is very poor there and possibly not fissured.

An examination of the drawdown graphs show that the fissured aquifer type curve devised by Gringarten - Witherspoon for observation and pumping boreholes along a common fissure ( Diagram 12a ) can be matched. This is particularly noticed in Appendix 4, Test Pumps 1, 2 and 3; that is between pumping borehole WW 30897 and observation boreholes WW 30896 and WW 30898.

| BOREHOLE | TRANSMISSIVITY ( $m^2/d$ ) | STORATIVITY | TEST DURATION ( HOURS ) | REMARKS |
|---|---|---|---|---|
| WW 30897 | 142 | 0.025 | 72 | From 30896 |
| WW 30897 | 156 | 0.01 | 72 | From 30898 |
| WW 30897 | 125 | 0.054 | 168 | From 30896 |
| WW 30897 | 110 | 0.023 | 168 | From 30898 |
| WW 31486 | 3.8 - 4.3 | - | 72 | Jacobs Approximation also used |
| WW 31489 | 121 | 0.002 | 72 | |

**TABLE 2.** Results of test pumping on the Otavi - Mulden contact. To determine these values leaky Theis was used.

The variability of the dolomite is underlined by these results, in that fissuring leads to a productive aquifer in some places and not in others. Additionally it is shown that the assumptions for the application of Theis do not hold, and in particular the aquifer is usually not isotropic, homogeneous or of uniform thickness.

### 4.2.2 Fissured Carbonate Aquifers as a result of Dyke Intrusion

The intrusion of dykes into carbonates was believed to fissure the host rock and form a potentially exploitable aquifer. Boreholes which were drilled into the dykes and subsequently test pumped are WW 30893 and 9396 ( Figure 9 ). Borehole WW 30893 has some suitable observation boreholes, while WW 9396 has no suitable observation wells. Drilling records show that WW 9396 is drilled only in dolomite, while WW 30893 has a 48 m thick layer of Kalahari sediments over it. However in the latter borehole, 90% of the groundwater comes from the dolomite. In both cases leaky conditions prevail. The Kalahari sediments possibly cause the leaky conditions in WW 30893, but there is no suggestion as to why WW 9396 should also be leaky. The results of the test pumping are summarised in Table 3 and are detailed in Appendix 4.

| BOREHOLE | TRANSMISSIVITY ( m ²/d ) | STORATIVITY | TEST DURATION ( HOURS ) | REMARKS |
|---|---|---|---|---|
| WW 9396 | 292 | - | 72 | - |
| WW 30893 | 190 | - | 72 | From pumping well under pumping |
| WW 30893 | 14 | - | 72 | From Obs. well 30894 under recovery |
| WW 30893 | 623 | 0.012 | 72 | Obs. well 30892 under pumping |
| WW 30893 | 10.5 | 0.0045 | 72 | Obs. well 30894 under pumping |
| WW 30893 | 11.5 | 0.0058 | 168 | Obs. well 30894 under pumping |
| WW 30893 | 943 | 0.025 | 168 | Obs. well 30892 under pumping |

**TABLE 3.** Results of the aquifer characteristics from the dykes.

The results show that the fissured aquifer has a transmissivity range from 10 to 900 m ²/d and storativity range from 0.004 to 0.025. Results from observation well WW 30894 indicate that transmissivity is significantly lower than that from other boreholes, possibly caused by the inhomogeneity of the fissured dolomite ( Figure 14 ). The drawdown response seen in Appendix 4, Test Pump 12 would suggest that the pumping borehole and the observation borehole lie in the same fracture system when compared with the Gringarten - Witherspoon type curves as illustrated in Figure 12a. Once again the results show that Theis's assumptions have not been fulfilled. The variability of these dyke structures can be underlined by borehole WW 31510, which was not test pumped. This borehole was drilled into a magnetic anomaly and confirmed with electrical geophysics, but the borehole was effectively dry.

Due to the leaky conditions borehole WW 30893 was test pumped for a longer period of time, 168 hours. The reasons for this have been discussed before. The attempt to dewater the leaky component of the aquifer failed, but the results did confirm the aquifer characteristics assessed on the first test pump.

An attempt to test pump borehole WW 31490 located on a fault failed because the pumped water could not be dumped sufficiently far removed from the test borehole and recirculation occurred.

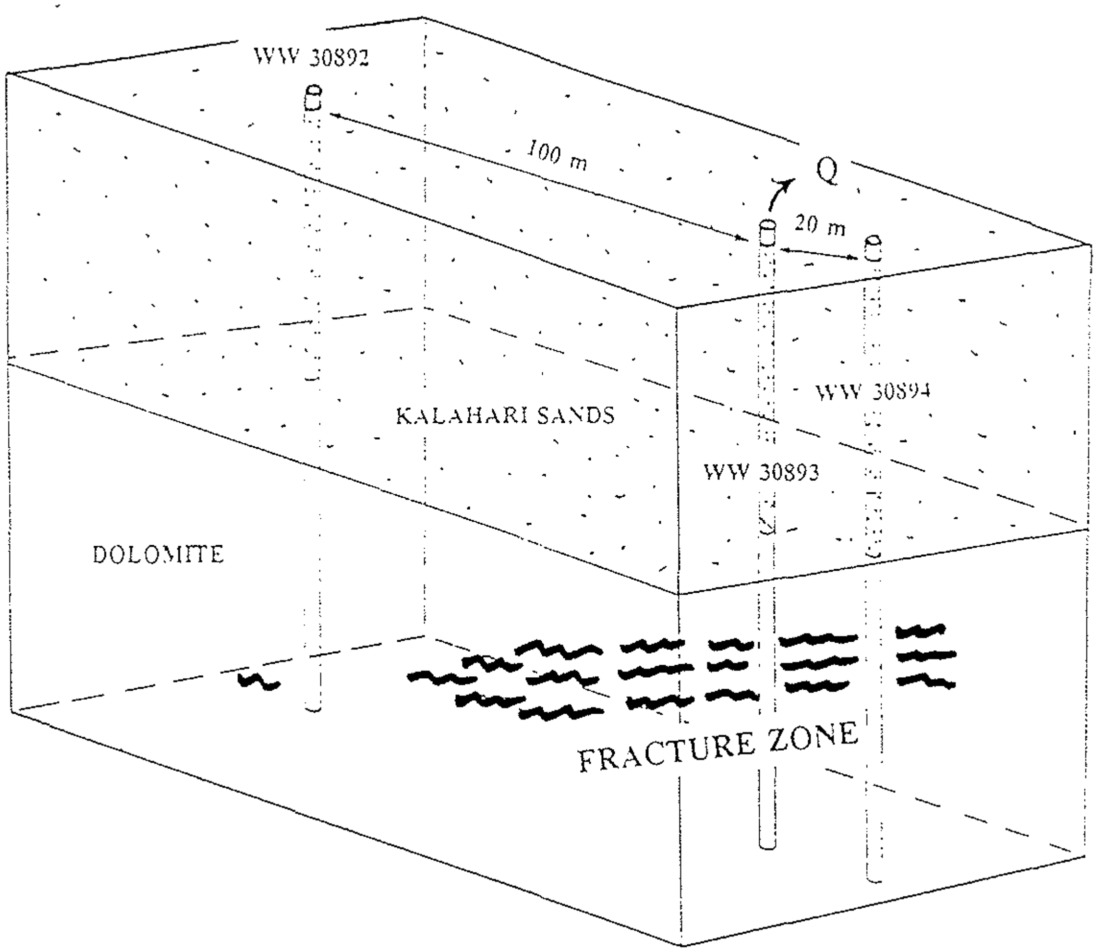



FIGURE 14. Diagramatic illustration of the interelationship between WW 30892, 30893 and 30894. The fracture system effects test pump results, with rapid and large drawdowns seen in observation borehole WW30894, but smaller drawdowns in observation borehole WW 30892.

### 4.2.3 Fissured Limestone Aquifers

The aquifer characteristics caused by karstification in limestones have been measured in borehole WW 9734, which has one observation well WW 9736. The limestone is seen to outcrop at surface. The conditions observed in the drawdown data indicate the aquifer is leaky ( Appendix 4, Test Pump 14 ). Again the fissured nature of the aquifer is apparent, as the good visual correlation between Figure 12a and drawdown graph of Test Pump 14. From this it would appear that the pumping borehole WW 9734 is in the same fracture as the observation borehole WW 9736. The results of this test are shown in Table 4. The results of this show that the transmissivity has a value of ~800 m $^2$/d and a storativity of ~0.0065.

| BOREHOLE | TRANSMISSIVITY ( m $^2$/d ) | STORATIVITY | TEST DURATION ( HOURS ) | REMARKS |
|---|---|---|---|---|
| WW 9734 | 779.5 | 0.0069 | 72 | Obs. well 9736 well under pumping |

**TABLE 4.** Aquifer characteristic results of test pumping Otavi Group limestones.

## 4.3 BOREHOLE DESIGN AND CONSTRUCTION

Boreholes in the carbonate aquifers are designed in response to the geology. In most cases where there is no Kalahari overburden, only a few metres of plain casing are installed at surface. Due to the problem of potential borehole collapse through the Kalahari sands, plain casing is inserted through these sands. In the exploration phase of this investigation, boreholes are often drilled to a diameter of 200 mm in the aquifer, but to do this it frequently means drilling to a larger diameter of 250 mm through the Kalahari to install temporary casing. A typical design for a borehole with no Kalahari overburden is illustrated in Figure 15.

Step tests have been undertaken to examine borehole efficiency, the data has been analysised from four boreholes and the results have been summarised in Table 5.

| BOREHOLE | B ( hr/m$^2$ ) | C ( hr$^2$/m$^5$ ) |
|---|---|---|
| WW 9396 | 0.012 | 0.000175 |
| WW 9734 | 0.047 | 0.0005 |
| WW 30893 | 0.01 | 0.018 |
| WW 30897 | 0.0357 | 0.00065 |

**TABLE 5.** Results of Step test analysis, where B represents laminar loss and C represents turbulent loss and are linked together in the formula s ( drawdown ) = B Q + C $Q^2$.

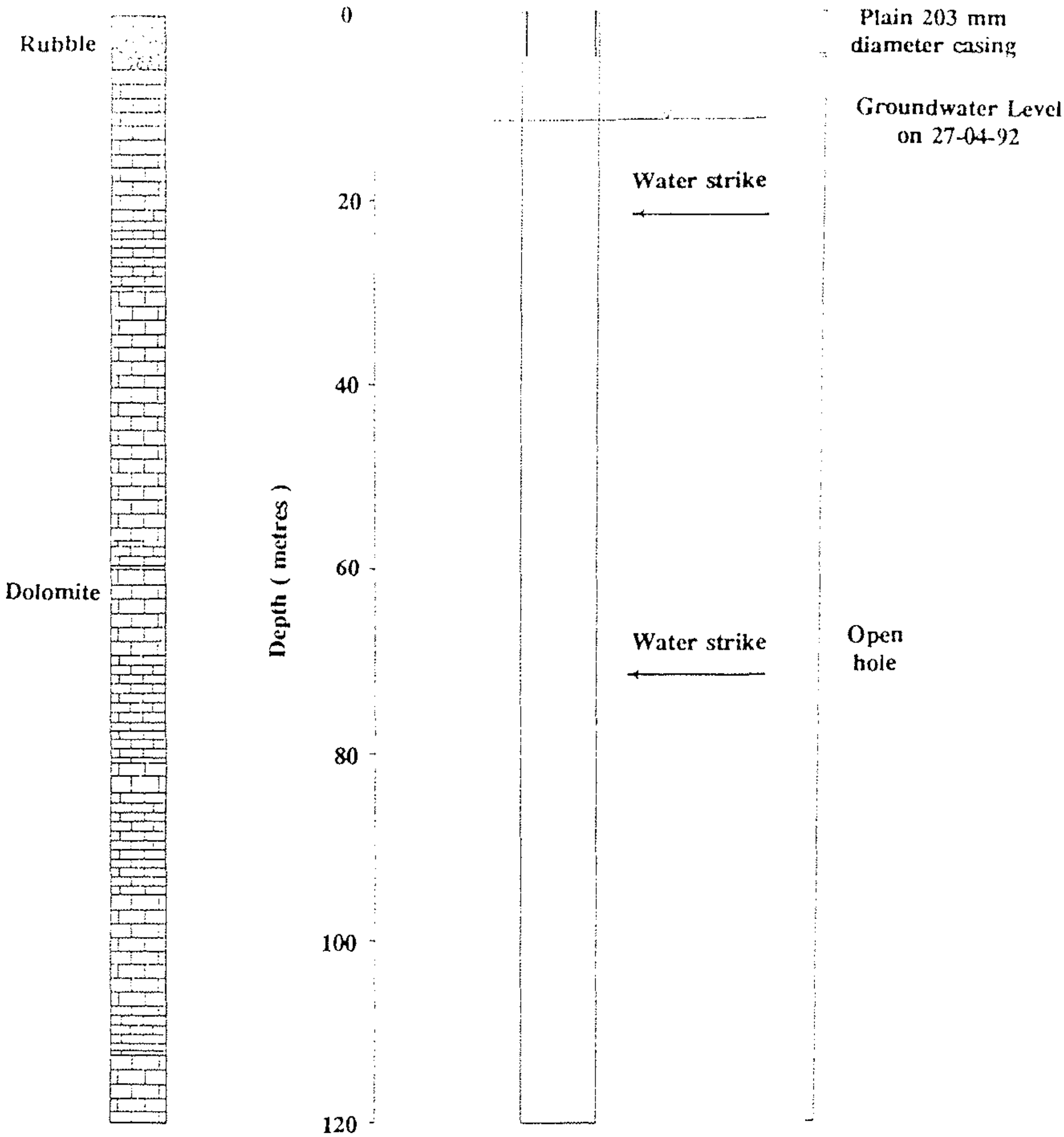



**FIGURE 15.** Diagramatic illustration of a typical borehole in the Damara carbonate aquifer. This particular example is modelled on WW 31488, drilled to a depth of 120 m with a 203 mm diameter ( See Appendix 2 for further detail ).

The data and graphs can be seen in Appendix 5. The analysis technique used in this case is to plot drawdown divided by discharge ( s/Q ) against discharge ( Q ) for each of the steps. The intersect of the straight line drawn through the plots with the y axis ( s/Q ) results in the value for the laminar loss ( B ). The gradient of the line is the turbulent loss ( C ). These values are linked together in the formula:

$$s = B\,Q + C\,Q^2$$

The results show a range of B values from 0.01 to 0.047, which is a fairly narrow range. Values of C show that all boreholes except WW 30893 have similar values, but the exception does show poor results.

## 4.4 HYDROCHEMISTRY

This aquifer shows relatively consistent chemistries which complement the nature of the aquifer. The most obvious control on the hydrochemistry is the effect of the dominant rock type, that is dolomite, which results in elevated concentrations of magnesium, calcium and bicarbonate. All other determinands have low levels of concentration. According to WHO standards, the groundwater in this aquifer is of the 'B' Standard. The cause of this is the elevated levels of magnesium and total hardness.

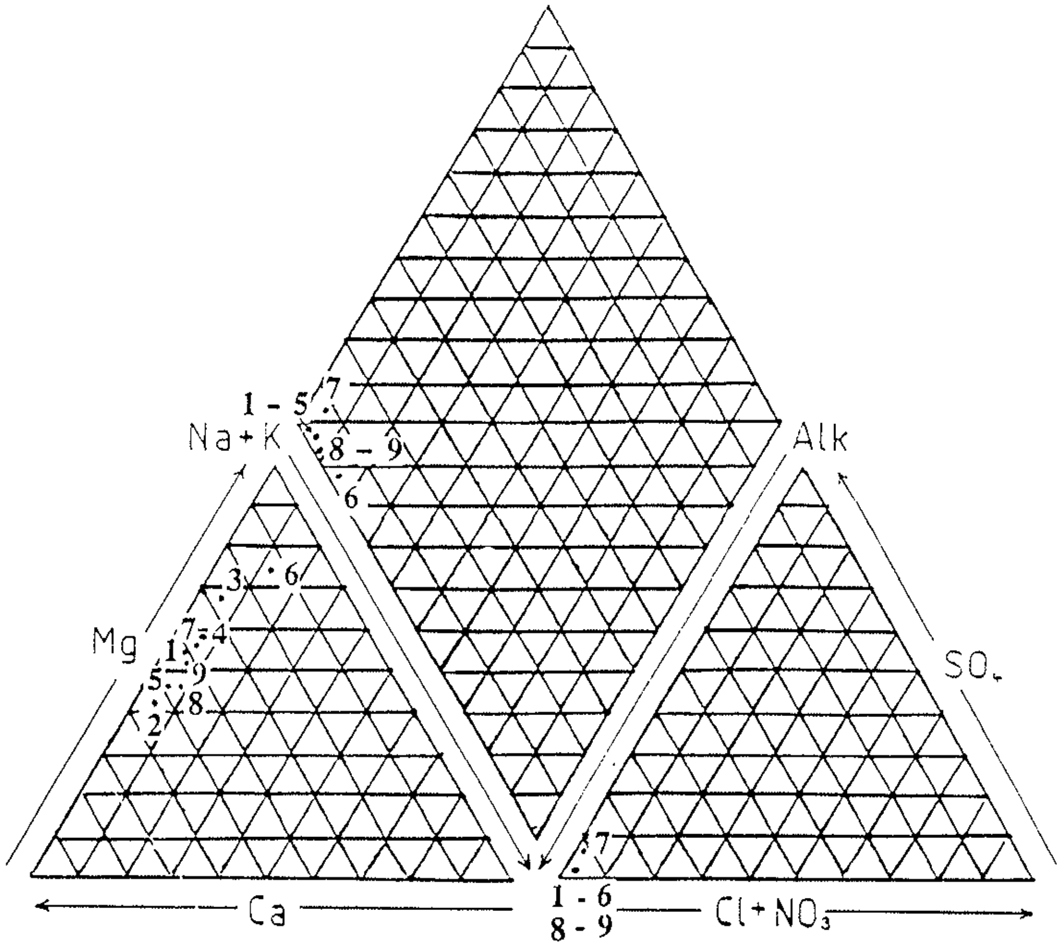
### 4.4.1 Irrigation Potential

The potential of this groundwater for use in irrigation is dependant on the type of crop grown. According to the USGS irrigation classification ( Appendix 6 ), the results range from C2 - S1 to C3 - S1, which means the groundwater has medium to high salinity so plants cultivated should have a moderate to good tolerance of salt but the soil must drain well. The low sodium content means that the groundwater is suitable for all soils and crops except those very sensitive to sodium.

The groundwater appears to be stable with a low Corrosivity Ratio of 0.1. The Langelier Saturation Index of 0.5 would suggest that scaling is possible. The Ryznar Index complements the previous comment, with a value of 6.3 which suggests a slight tendency for scaling. The cause of this scaling is attributed to the elevated concentrations of magnesium and calcium. An explanation of these factors is appended in Appendix 7.

### 4.4.2 Hydrochemical Analysis

The concentrations of determinands from selected boreholes are shown in Table 6. The range of magnesium and total hardness concentrations are 165 to 379 mg/l and 357 to 641 mg/l and illustrate the dominance of the dolomite in controlling the hydrochemistry of the groundwater. Concentrations of calcium are not so high, ranging from 103 to 300 mg/l. This reinforces the dolomitic nature of the aquifer, where the highest value seen comes from a sample taken from a borehole drilled into one of the limestone bands. All other determinands have low concentrations which are attributed to background levels where no trends can be seen. In Figure 16 the hydrochemistries are illustrated in the Piper Trilinear Diagram. Anionic




**Key**

| | TDS ( mg/l) | | TDS ( mg/l) |
|---|---|---|---|
| 1 - WW 9396 | 578 | 6 - WW 31488 | - |
| 2 - WW 9736 | 440 | 7 - WW 31490 | - |
| 3 - WW 30689 | 424 | 8 - WW 31495 | - |
| 4 - WW 30897 | 686 | 9 - WW 31497 | - |
| 5 - WW 31486 | - | | |

**FIGURE 16.** Piper Trilinear Diagram of selected groundwater samples. The results show that the plots lie in the recent recharge dolomitic field. Only four of these are detailed in Table 6 ( WW 9396, 9736, 30689 and 30897), the rest are only known in terms of percentage milliequivalents.

elements are not seen to vary, while the cationic determinands show variations only in the relative levels of magnesium. In general, magnesium is the dominant cation in this carbonate

| DETERMINAND | BOREHOLES | | | |
|---|---|---|---|---|
| | WW 9396 | WW 9736 | WW 30689 | WW 30897 |
| pH | 7.3 | 7.0 | 8.3 | 7.2 |
| TDS | 578 | 440 | 424 | 686 |
| Sulphate | 15 | 0 | 6 | 29 |
| Nitrate | 1.0 | Trace | 0.5 | <0.5 |
| Nitrite | <0.1 | 0 | 0 | <0.1 |
| Fluoride | 0.3 | 0.9 | 0.4 | 0.3 |
| Chloride | 6 | 5 | 7.0 | 10 |
| Tot. Alk. | 496 | 415 | 330.6 | 592 |
| Tot. Hard. | 522 | 415 | 357 | 614 |
| Sodium | 9 | 6 | 6 | 16 |
| Potassium | 3 | 1.6 | 2 | 3 |
| Calcium | 300 | 250 | 103 | 235 |
| Magnesium | 222 | 165 | 254 | 379 |
| Silicate | 19 | 10 | 29 | 30 |

TABLE 6. Hydrochemistry of the Otavi Group Aquifer. Results are arranged according to borehole number. Except for pH, all values are in mg/l. Calcium, Magnesium, Total Hardness and Total Alkalinity are expressed as $CaCO_3$. Silicate is expressed in terms of $SiO_2$. Nitrate and Nitrite are expressed in terms of N.

aquifer. The resultant plot shows the samples to lie in the recent recharge dolomitic field, which complements the known dolomitic background.

## 4.5 HISTORY OF GROUNDWATER LEVELS

The investigation area has had water levels monitored as part of a national survey from 1971, but only from two automatic water level recorders at Guinas Lake ( Figure 17 ) and Otjikoto Lake.

An expanding and continuing programme of groundwater level monitoring was set up at the start of the current investigation in 1989. The intention was to employ boreholes with an approximately 10 km spacing which would give useful information on groundwater gradients and the individual aquifer water level fluctuations ( Figure 10 ). The most important considerations in borehole selection for inclusion in the monitoring programme were hydrogeological. The drilling of monitoring boreholes was carried out in 1989 and quarterly

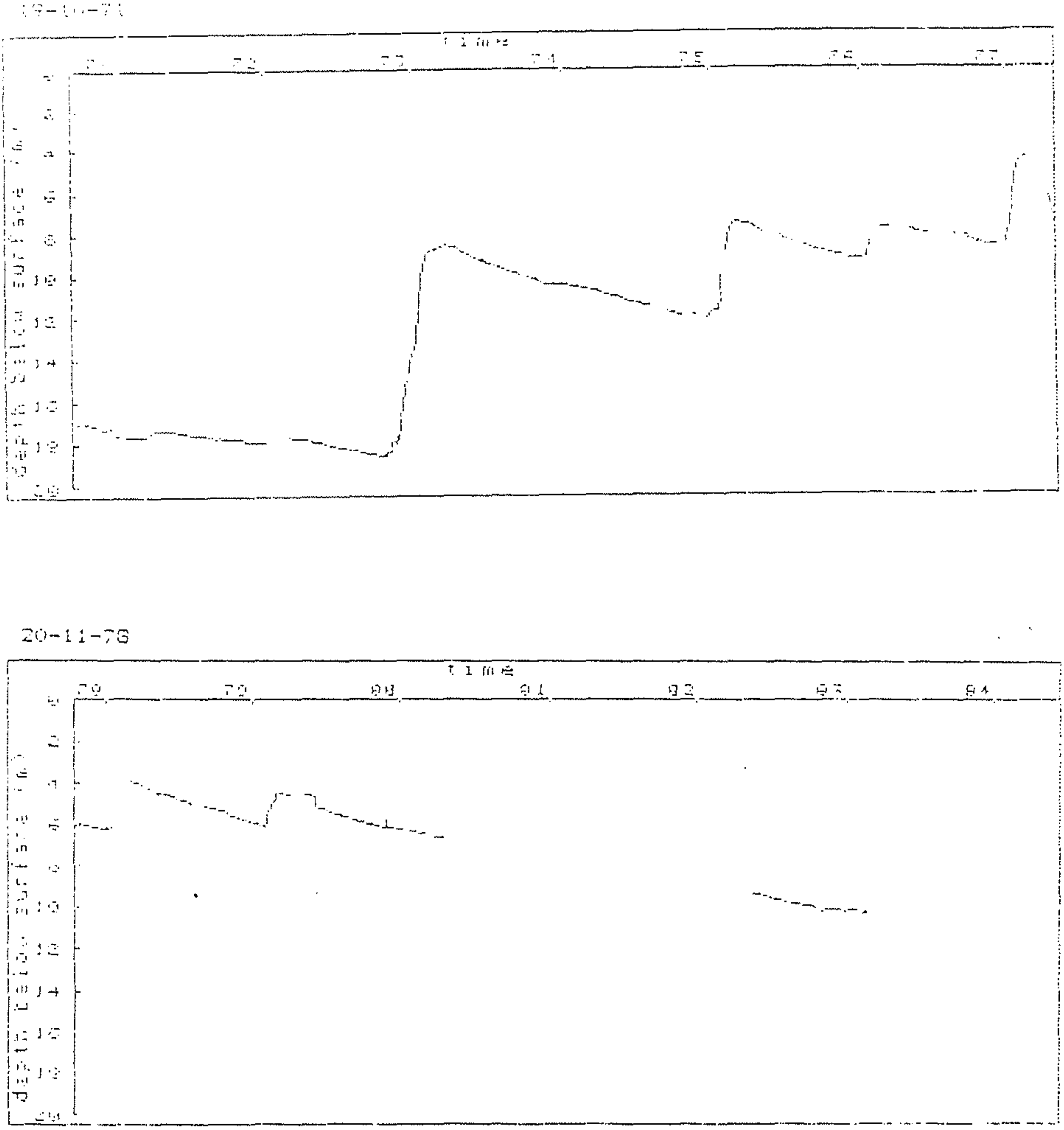
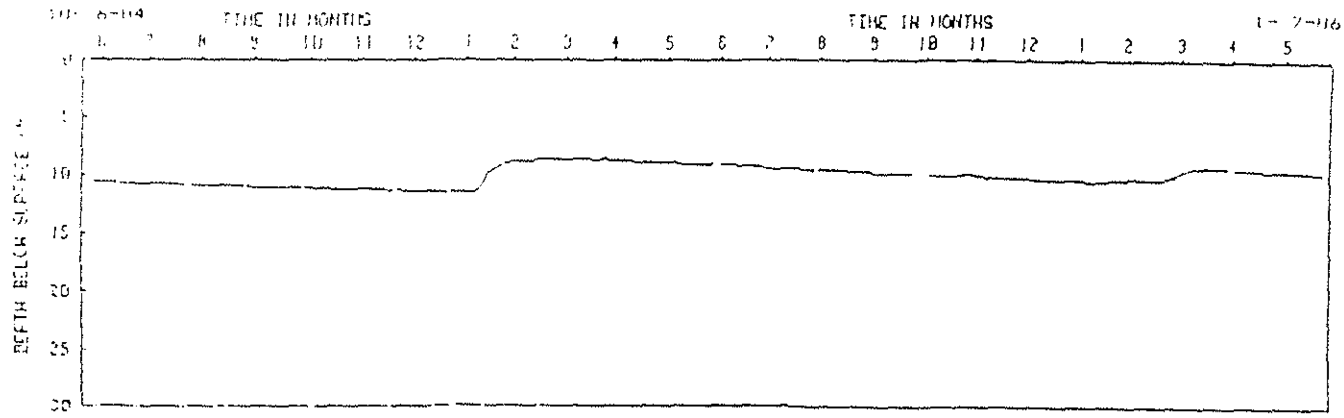
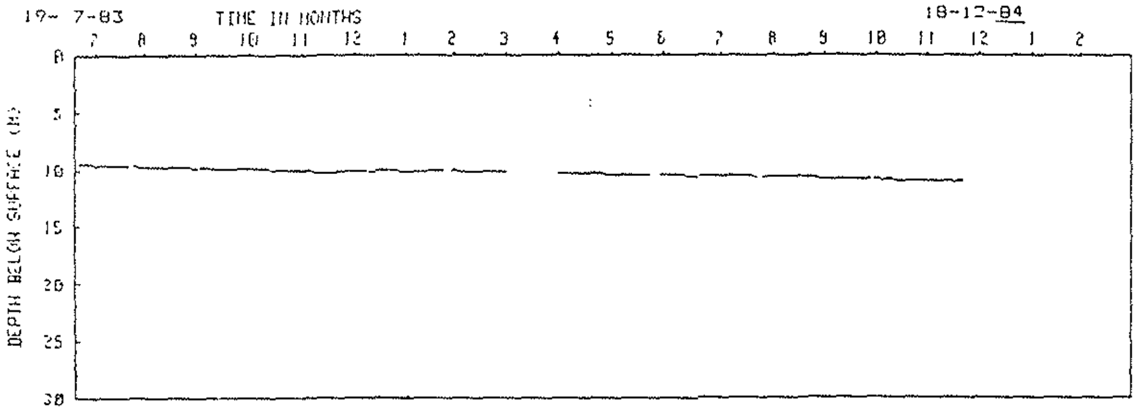
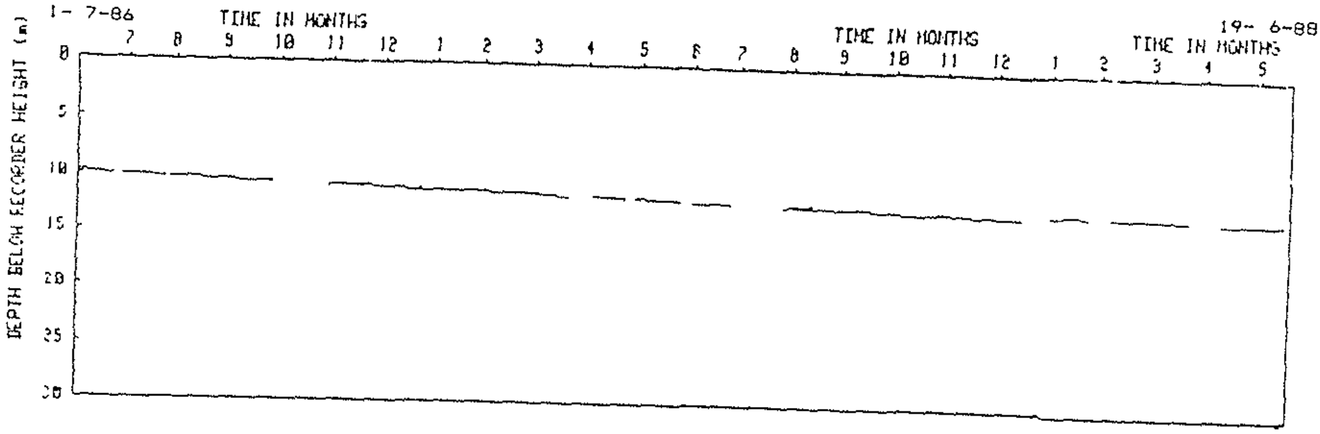
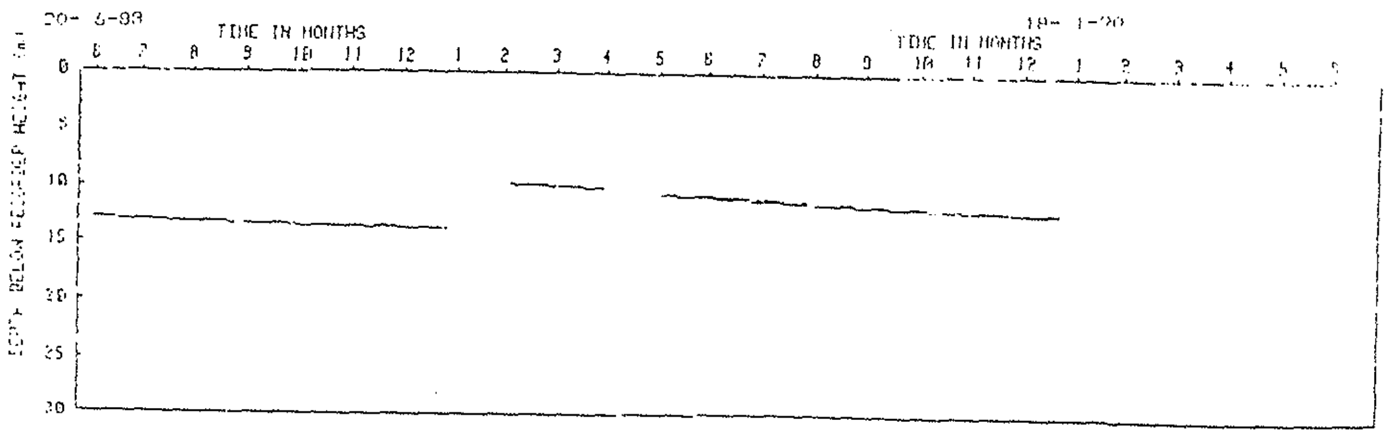



FIGURE 17. Guinas Lake hydrograph for the period 1971 to 1990. Rises in the hydrograph relate to above average rainy seasons. Compare this hydrograph to the hydrograph in Figure 19. Continued onto next page.


TIME IN MONTHS
TIME IN MONTHS
1- 7-86
DEPTH BELOW SURFACE


19- 7-83
TIME IN MONTHS
18-12-84
DEPTH BELOW SURFACE (M)


1- 7-86
TIME IN MONTHS
TIME IN MONTHS
19- 6-88
TIME IN MONTHS
DEPTH BELOW RECORDER HEIGHT (m)


20- 6-88
TIME IN MONTHS
TIME IN MONTHS

manually read water levels are available from January 1990. A complete record of all groundwater levels can be seen in Appendix 8. It is anticipated that the monitoring network will be increased with time.

### 4.5.1 Seasonal Fluctuations

In the dolomite region with generally shallower groundwater levels in unconfined carbonate aquifers, detailed groundwater records for the last 2.5 years exist. Broadly, the levels are seen to fluctuate according to the season, a rise in the wet and a fall in the dry. Thus in the 1990 dry season a fall of the order of 60 cm is followed by a rise through the 1990 - 1991 rainy season ranging from 20 to 110 cm, most of the increase being ~20 cm. Through the 1991 dry season a drop ranging from 50 to 500 cm is observed. Finally, the 1991 - 1992 rainy season shows a fall of 50 cm in some places and little change others.

The rainfall is partly responsible for the groundwater fluctuations in the dolomites where there are shallow water levels up to 10 m. Records indicate that Tsumeb ( Figure 18 ) received ~100 mm below average rainfall for 1990 - 1991, and even less in the 1991 - 1992 rainy season. These below average rainfall results can be, with the greatest of caution, extrapolated to the monitoring boreholes. Complete rainfall records are shown in Appendix 1. The problem is that as rainfall is so variable, recharge is variable and the recorded rainfall may not be the same event that caused recharge. In general, good rains bring a large rise in water levels and poor ones show no change while isolated high rises in water levels can be attributed to a single localised storm.

### 4.5.2 Longer Term Groundwater Fluctuations

The long term groundwater level records from the dolomite aquifer at Mannheim 100 ( Figure 19 ), Guinas Lake ( Figure 17 ) and Otjikoto Lake ( Appendix 9 ) indicate in some periods no recharge takes place, just a gradual lowering of groundwater levels. The groundwater levels can rise appreciably in one year with above average rainfall, to lower gradually once again. A cautious comparison of the Tsumeb rainfall records with these groundwater levels suggest that every average and above average rainy season provides for a rise in the groundwater levels of ~4 m, except when the aquifer had its groundwater at a high level then a rise of only ~2 m could be expected which would in turn drop quicker than normal. If the aquifer was at a low level, as seen in the early 1970's, the groundwater levels rose by 10 m the first year there was above average rainfall. Groundwater levels dropped slightly through the following dry season, to go up a further 5 m in the second and also above average rainy season.

Droughts show up with a constantly lowering hydrograph, for example in the Guinas Lake hydrograph ( Figure 17 ) there is virtually no recharge from 1971 to 1973 and 1980 to early 1989, except a 3.5 m increase in early 1985 and a 1.0 m increase in 1986. Over this latter time the groundwater level dropped from 9.0 m to 13.5 m, measured from a surface datum. By taking out recharge this suggests that in 9 years the level dropped by 9 m, or 1.0 m p.a. In the early 1970's the groundwater level dropped at a rate of 0.75 m p.a.. However, the groundwater level was then 18.0 m below surface datum. In 1979 the groundwater levels were high, only 4.0 m below surface datum but the rate of lowering was 2.5 m p.a. It is suggested

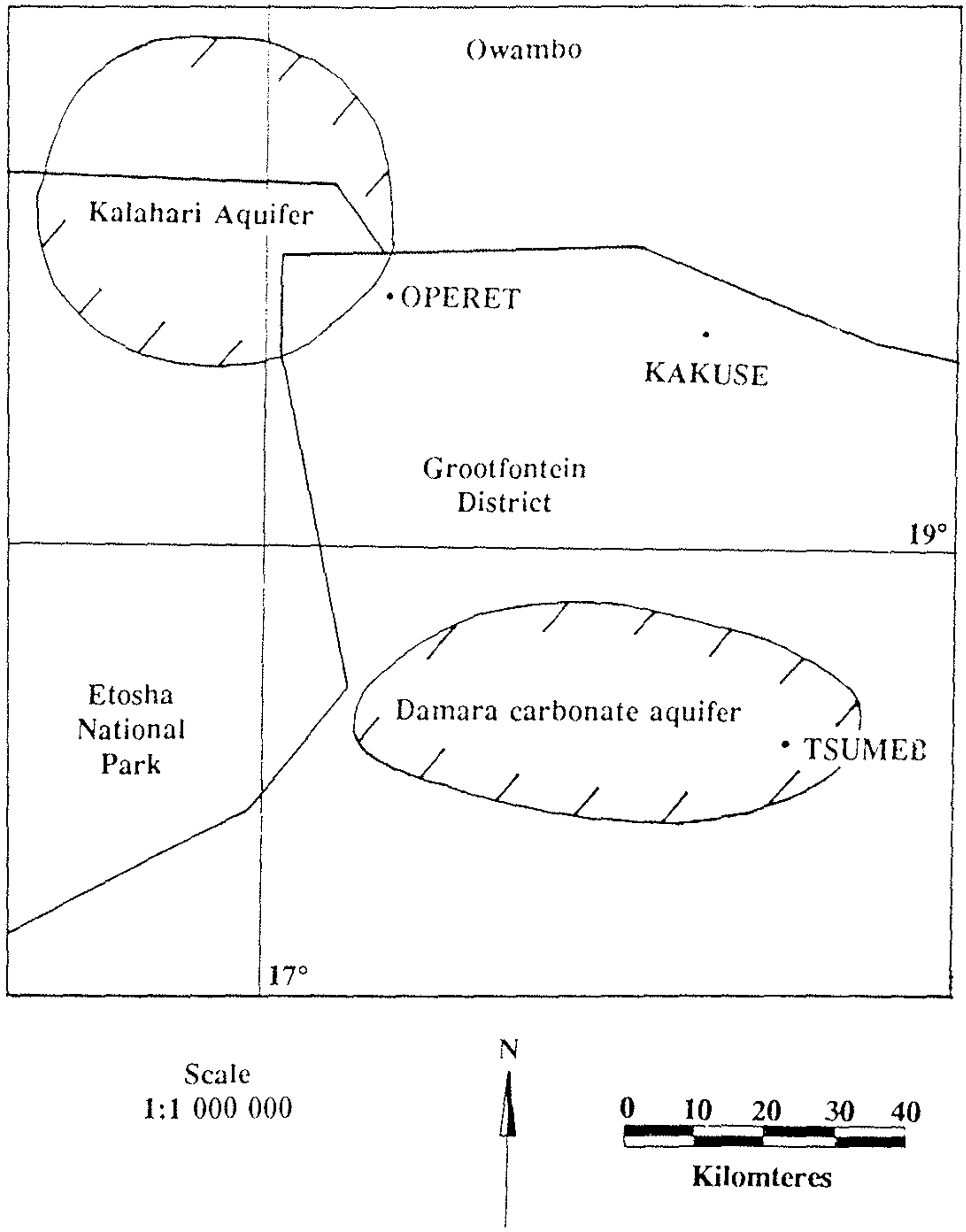



FIGURE 18. Rain gauge station locality map, the stations are in bold print and also shows position of aquifers.

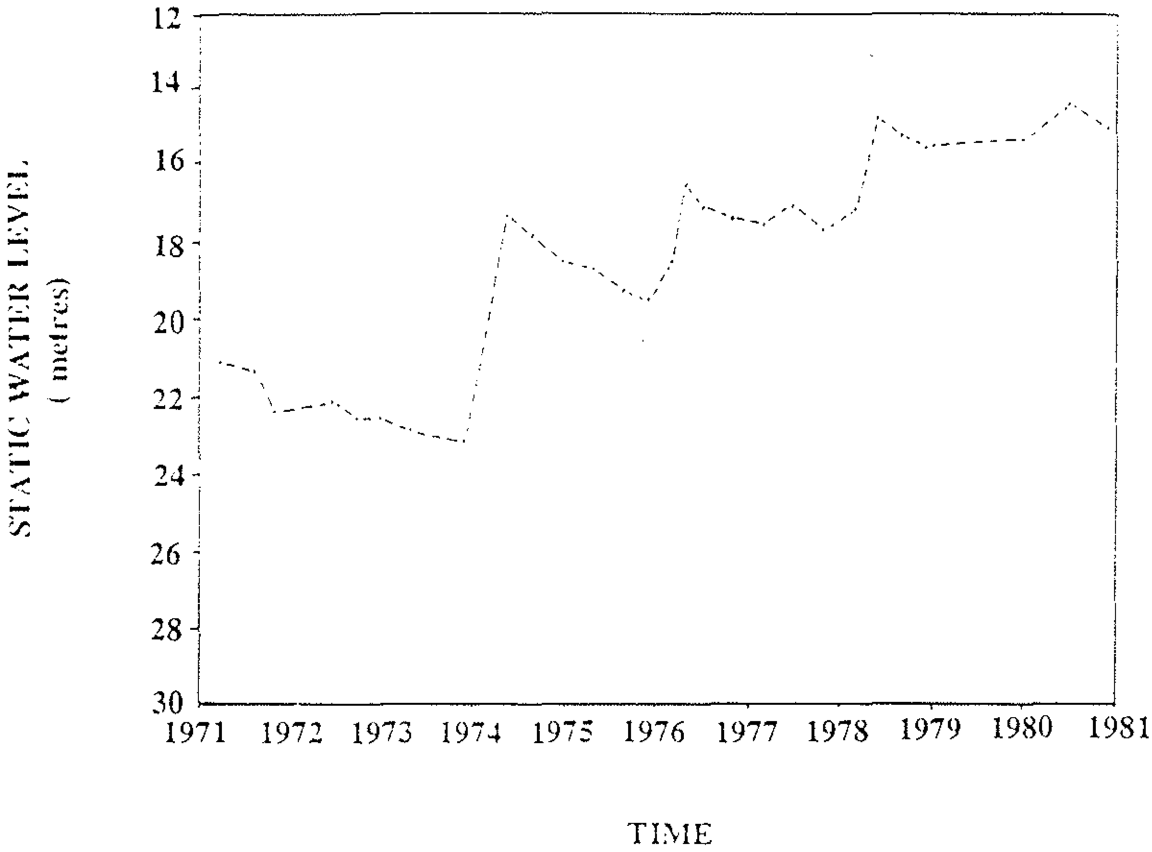



FIGURE 19. Borehole hydrograph from the farm Mannheim 100, for the period 1971 to 1981. The major rises in groundwater levels match above average summer rainfall events.

that the rate of loss of water is dependant on the groundwater level and the nature of the aquifer. This would mean that the aquifer has more fissures towards the surface. More groundwater is discharged when the groundwater level is high than when it is low. Discharge here includes evapotranspiration and the through - flow down the groundwater gradient. It has been noticed elsewhere in similar carbonate terrains that values of conductivity, specific yield and transmissivity are reduced at depth due to less karstification and this may be present here and be responsible for this.

### 4.5.3 Influence of Abstraction on Groundwater Levels

It is important to know what discharge is natural and what is artificial and whether artificial abstraction has influenced groundwater levels. Artificial discharge in this sense means any abstraction by man. Individual production wells can show a cone of dewatering whilst in use, but dewatering here is meant as the non transient lowering of groundwater levels in an aquifer by excessive pumping which may not rapidly recover.

Abstraction in this area has been going up over the years at an increasing rate, with the growth in population, the increasing expectations of the population, the mining industry and farming. Most of the abstraction is limited to a few places where relatively large volumes of groundwater are pumped out, while that groundwater abstracted over the region as a whole is minimal.

Pastoral farming aerially dominates the region and groundwater abstraction for this is limited. In a similar sized area to the immediate south west of this region it was estimated from field observation that $0.8*10^6$ $m^3$ p.a. was abstracted for this purpose ( Seeger ). It is considered that a similar quantity is being currently abstracted for the arable farming in the area of this study, or at least under $1.0*10^6$ $m^3$ p.a. It is questionable whether this low abstraction spread out over the area could definitely be seen and it is unlikely that it could be anyway reliably measured.

Irrigation is now more often undertaken, but aerially it is still limited to much less than 1% of the total area. However where it does occur, it is concentrated. The areas where significant irrigation are undertaken are Otjikoto and Guinas Lakes and the Ludwigshaven 480 and Mannheim 100 plots.

Tsumeb is a mining centre, which adversely effects the groundwater regime. Groundwater is required for the town and is also pumped out of the mine.

Major abstraction occurs at four places, that is Guinas and Otjikoto Lakes, Tsumeb and plots on the farms of Mannheim 100 and Ludwigshaven 480, but there is only one proven local cone of dewatering and this is at Tsumeb. Obviously each place does have an upper abstraction limit before unacceptable dewatering takes place. Except for Tsumeb, no area is definitely subject to a cone of dewatering yet. This means that regional groundwater level contouring can be undertaken over the area as a whole without fear of errors appearing caused by abstraction. The only place where caution should be exercised is around Tsumeb.

Current abstraction is not considered to exceed $14.1*10^6$ $m^3$ p.a.

## Otjikoto Lake

Otjikoto Lake is a collapsed sink hole in the middle Damara Sequence dolomites. It possibly has some structural control, as a magnetic anomaly passes adjacent to the lake ( Figures 2 and 10 ). The sink hole is partially filled with water, approximately 65 m deep from surface, with a diameter at surface of 100 m and has a bottle shaped cross section, so it opens out at depth. It has shear sides and an uneven bottom. At Otjikoto Lake the Government permitted maximum abstraction is $1.3*10^6$ $m^3$ p.a. but it is not necessarily what is in reality abstracted. The storage of the lake is of the order of $0.4*10^6$ $m^3$. As the quantity of recirculated groundwater through the irrigation process is unknown the real loss of groundwater from the aquifer has not been determined.

The maximum fluctuation of the lake water level is 19.0 m since the explorer Galton measured it in 1851 ( Brittan ). This can not be definitely attributed to abstraction, although the circumstantial evidence would indicate that. The groundwater level evidence is not matched to abstraction quantities and periods. Currently in the recent short term there is no evidence of a further substantial lowering of the lake water level ( Appendix 9 ).

The history of lake water levels and abstraction has not been fully recorded, but an indication of events can be pieced together. When the explorer Galton in 1851 reported the water level at 10 m from surface and the lake itself to be 55 m deep, but he did not indicate from where these measurements were taken. The 1851 levels were reported again in 1900, and abstraction started periodically from 1907. In 1910 water from Tsumeb mine was pumped back into the lake. Major road construction in 1968 led to the need to abstract water from Otjikoto Lake. As this water was transported away, it could not recirculate back to the lake. This abstraction is presumably the cause of the lowering of the lake water level to a reportedly all time low ( Brittan ). As soon as abstraction ceased the water levels recovered. In 1978 the lake level fluctuated from 11 m to 10 m ( Appendix 9 ), showing a complete recovery to the groundwater levels of 1851.

Groundwater levels monitored in boreholes WW 10318 and WW 9396 show no change which can be attributed to current abstraction from the lake ( Appendix 8 ). The fluctuations in these borehole groundwater levels are consistent with the regional groundwater level and are not in any cone of dewatering caused by abstraction from Otjikoto Lake. If there is currently any cone of dewatering it is smaller than 2100 m, assuming the aquifer is homogeneous. Any cone of dewatering would be fairly limited in its extent and over the region as a whole it would be very small.

## Guinas Lake

Guinas Lake is similar to Otjikoto Lake, being a collapsed sink hole in bedded dolomites with associated structural control and partially filled with water. Guinas Lake is larger than Otjikoto Lake, having a diameter of 150 m and a depth from surface of 100 m. The most recent available data from January 1990 shows the water level to be 12.4 m from surface datum. This would result in a volume of storage in the sink hole of $1.6*10^6$ $m^3$, or about four times that of Otjikoto Lake. Abstraction has not been so closely monitored for quantity and when it occurred as at Otjikoto Lake. Records of any sort do not go back as far as those for Otjikoto Lake. However it is known that water was only used for irrigation, so some circulation of the water is considered possible. A figure of abstraction similar to that of Otjikoto Lake of $1.3*10^6$ $m^3$ p.a. is considered likely, considering the type of crop, area of irrigation, number of crops p.a. and the nature of the soil.

A study of the lake water levels of Guinas Lake ( Figure 17 ) show that fluctuations in the level can be virtually all attributed to natural causes, and abstraction is thought to be minimal and can not be recognised in the hydrograph. Normally the effect of pumping on the hydrograph is seen as a slight increase in the lowering of the water level and that if pumping does start after the end of the rainy season the normal decay in water levels should be increased. This feature has not been recognised here.

It has yet to be proven whether there is a cone of dewatering centred around Guinas Lake. Groundwater level data around the lake is limited to one borehole which is 2000 m north of the lake. This borehole only shows regional fluctuations and nothing which can be attributed to abstraction from Guinas Lake.

Other Sink Holes

Abstraction at other collapsed sink holes as on the farms Hoais 842 and Obab 856 is minimal as this groundwater is used for a small amount of irrigation, stock watering and household supply.

Tsumeb

The Tsumeb area has undergone heavy groundwater abstraction since the commercial mining of copper started below the groundwater level in 1907 ( Brittan ). The abstraction of water is considered to have been greater when mining was in operation, in the periods 1907 to 1933, 1937 to 1940 and 1948 onward ( Lombaard et al. ). Since 1950 production has increased considerably, and it is suggested that increased groundwater abstraction follows copper production. Current abstraction from the mine itself is $7.0*10^6$ $m^3$ p.a. This mine water comes from workings up to 1300 m from surface.

In addition to this, internal Department of Water Affairs records report the town of Tsumeb abstracts a further $1.0*10^6$ m p.a. This water is derived from boreholes in the town, up to 3 km from the mine shaft. Recorded groundwater level data is minimal in the vicinity of Tsumeb. However the groundwater levels of most of the boreholes for town supply on their completion are at 100 to 120 m from surface, which is uncharacteristic of this area as a whole. To the immediate north of the mine, only 7.0 km away boreholes show that the groundwater levels are 10 - 20 m. The indication is that a cone of dewatering does exist with a radius of less than 7.0 km. The exact limits of the cone of dewatering are difficult to determine because there is a lack of suitable monitoring boreholes and the complexities of the groundwater regime caused by mine grouting. This latter problem results in some artificially perched groundwater. In terms of the area as whole this cone of dewatering occurs over a restricted area and so long as its presence is known, it can be ignored, except when considering the Tsumeb vicinity.

Ludwigshaven 480 and Mannheim 100 Farms

Situated between 10 and 15 km north of Tsumeb are two farms, Ludwigshaven 480 and Mannheim 100, which together have been divided up into a total of 47 plots since the 1950's. The farms were underlain by an extensive and high yielding aquifer which when combined with good soils made the area attractive for irrigation. Scattered over the 33.8 $km^2$ of plots are over 65 boreholes. The area of actual irrigation is constantly changing, but is much less than 33.8 $km^2$, possibly of the order of 2.0 $km^2$. The current maximum abstraction total for large scale irrigation is $2.0*10^6$ $m^3$ p.a. In addition there is small scale irrigation on a further 10 plots and this accounts for a further $0.2*10^6$ $m^3$ p.a. The maximum abstraction is therefore seen to be $2.2*10^6$ $m^3$ p.a. In practice it is unlikely that this figure is pumped out as the maximum abstraction values are not considered to be reached with normal farming practice. The actual loss of water from the hydrogeological system through evapotranspiration of the irrigated crops is less than the total water volume actually abstracted. As the groundwater level is shallow, ranging from 10 to 20 m and as the soils permit good drainage, recirculation of the groundwater is considered likely. The net result is that only a proportion of the $2.2*10^6$ $m^3$ p.a. maximum permitted abstraction is lost from the system. A suggestion is that only $1.0*10^6$ $m^3$ p.a. is actually lost.

Groundwater level evidence is restricted to records from one borehole on the farm Mannheim 100 ( Figure 19 ) for the period 1971 to 1981 and from one borehole on Ludwigshaven 480 from 1990 to 1992 ( See Appendix 8, 1917 BB -109 ). The hydrograph for the period 1971 - 1981 matches closely the hydrograph from Guinas Lake , which is 40 km away. It indicates similar fluctuations both in order of magnitude and the timing of them, albeit at Mannheim 100 the changes are not so great. An examination of the Mannheim 100 hydrograph shows no dewatering trend. Although recent data from Ludwigshaven 480 is of a very restricted time length, the fluctuations in the groundwater levels of the monitoring borehole are mirrored by the groundwater levels in the majority of other monitoring boreholes. Those levels which do not conform with this pattern are presumed to be subject to different rain storms and therefore different recharge events. In addition, the current regional groundwater levels in the area portray no anomalous cone of dewatering caused by abstraction.

## 4.6 RECHARGE

Recharge to the carbonate aquifers takes the form of diffuse recharge, leakage and through - flow. It has been shown in the Grootfontein area ( Seeger ) that diffuse recharge preferentially occurs in fractured and karstified areas, the more so when these rocks outcrop and when there is a shallow water level. Leakage is the result of saturated Kalahari sands draining into the carbonate aquifer. Through - flow is the movement of groundwater from areas of high head to low. The amount of recharge is variable according to the rainfall. It is considered that the more intense the rain is, the greater the proportion that contributes to recharge ( Seeger ). Recharge is considered to be $19*10^6$ $m^3$ p.a.

When recharge does occur it is controlled by evapotranspiration. As plants have different rates of evapotranspiration and different densities, the amount of water that is lost to evapotranspiration is virtually impossible to determine. In the very limited arable farming areas where only one type of plant is grown, it is theoretically possible to get a rate. However as this farming is so limited it would serve no point in getting a regional value.

The amount of recharge is variable, dependant on the quantity of rain. In this complex area, the most realistic approach to assess recharge is thought to be one of matching rainfall to the water levels. It should be remembered that any result will only hold good for the area immediately surrounding the monitoring borehole and should not be extrapolated ( Foster ). Additionally, the rainfall is known to be both seasonally and locally variable, so values from a far removed weather station may not be representative.

The problems with the variable nature of recharge in carbonate aquifers has been recognised in the Grootfontein area and this has only been resolved by having different abstraction policies between wet and dry periods ( Seeger ). In the Grootfontein area in dry periods there has to be a reduction of 50% from the wet period abstraction levels, and this is caused by the failure of the aquifer to be recharged.

Artificial recharge through very localised irrigation shows a groundwater " mound", particularly in the areas with more clay in the unsaturated zone. The water for irrigation is abstracted from groundwater. Due to the very localised area where it has been used, it is discarded from the regional investigation.

### 4.6.1 Diffuse Recharge

Diffuse recharge through fissures preferentially takes place in areas with fractured Damara Sequence rocks ( de Fries ). In areas of carbonate rocks of the Damara Sequence, the valleys are dry and no flow has been recorded even with the heaviest rainfalls. A delay of only a day or two is seen in the response of water levels in unconfined aquifers, depending on the width of the unsaturated zone.

An estimation of recharge has been made using specific yield and the increase of groundwater levels through the rainy season. Specific yield ( Sy ) has been assessed from test pumping results to be 0.01 and hydrographs provide groundwater level data. In 1976 an increase in groundwater levels of 3 m is observed. This would suggest recharge to be 30 mm. Over this time rainfall was 850 mm, so 30 mm recharge is 3.5% of rainfall. In average rainy seasons ( 500 mm ) the hydrograph is only seen to increase by 1 m or 2.0% of rainfall. Hydrographs show that when rainfall is below average there is no recharge. A problem with this estimation is that Sy probably gets smaller at depth because fissuring is less. This would result in greater changes in the groundwater level for the same amount of recharge. This is observed in 1974 data with large increases from very low groundwater levels. The Guinas Lake hydrograph ( Figure 17 ) records a 10 m increase and the Mannheim borehole hydrograph ( Figure 19 ) a 6 m increase. It is postulated that Sy could be ~0.003 at the base of the aquifer, while being ~0.01 at the top.

If recharge is 2% of the average rainfall of 0.5 m and considering the total area of the aquifers to be 40 km * 40 km or $1600*10^6$ $m^2$, recharge would be:

$$\text{Recharge Volume} = \text{Area} * \text{Rainfall} * \text{Recharge } \%$$

Substituting in values:

$$\text{Recharge Volume} = ( 1600*10^6 )( 0.5 )( 2\% )$$

$$= 16*10^6 \text{ m}^3 \text{ p.a.}$$

Areas where carbonate outcrop at surface rely on direct recharge and through - flow are seen to have an immediate lowering of groundwater levels in times of drought.

### 4.6.2 Leakage

In certain areas recharge is first to the Kalahari sands which then leak down into the carbonate aquifer. Attempts using 168 hour long test pumping to find out if the Kalahari sands could be dewatered failed, so assuming that leakage occurs over a large enough area and down to the fissured carbonate aquifer, recharge to the aquifer could be considered limitless so long as the Kalahari sands leak. This assumption is not correct as rainfall and hydrographs suggest a limit. Protracted droughts ( Figure 5 ) may result in the total dewatering of the Kalahari sands, caused by evapotranspiration upward and leakage downward. Groundwater levels would drop, possibly into the carbonate aquifers. Long term recharge is variable, being good in above average rainfall years and poor to non existent in times of drought.

### 4.6.3 Through - Flow Estimation and Discharge

In addition to direct diffuse recharge and leaking aquifers, there is an element of through - flow. Groundwater moves down the groundwater gradient from the Otavi Mountains in the south to the Kalahari plains in the north ( Figure 10 ) and as the carbonate aquifers are in the middle they will gain from the mountains and lose to the plains.

The quantity of through - flow can be estimated using Darcy's Law ( formula 1 ):

$$Q = A\ k\ i$$

where

Q = Through - Flow
A = Cross section area of aquifer
i = Gradient
k = Hydraulic conductivity

Area ( A ) is determined from the strike length of the aquifer ( 40 000 m ) multiplied by the aquifer thickness ( 30 m ), so A is $1.2*10^6$ m$^2$. Gradient i is derived from the piezometric map ( Figure 10 ) and equals 0.004. The assessment of a realistic value for hydraulic conductivity ( k ) requires three assumptions. The first assumption that only 10% of the average test pumping transmissivity ( T ) value be used. This is because test pumping T values are of a point, not the aquifer as a whole. Experience has shown that 10% of the test pumping value of T is a realistic for the aquifer. The second assumption is that T does not vary through the aquifer. The third assumption is that the aquifer thickness is constant, that there is no variation in groundwater levels. The last two assumptions are not strictly valid.

Hydraulic conductivity ( k ) is determined as follows in formula 2:

$$T/b = k$$

where

$b$ = Aquifer thickness
$T$ = Transmissivity
$k$ = Hydraulic conductivity

The aquifer thickness from borehole records is considered to be 30 m. Transmissivity from individual boreholes is ~500 $m^2/d$, so for the aquifer this represents 50 $m^2/d$. Substituting these values in formula 2 means that

$$k = 0.00002 \text{ m/sec}$$

Substituting A, k and i in formula 1:

$$Q = (1.2*10^{6})(2*10^{-5})(0.004)$$

$$Q = 0.096 \text{ m}^3\text{/sec}$$

$$\text{or } 3*10^{6}\text{m}^3 \text{ p.a.}$$

This result is a guide as to the order of magnitude of through - flow.

However in times of drought there is a general lowering of groundwater levels, but the drop is greater in the mountains ( Seeger ). This means the relative head difference is not so high, so the gradient ( i ) is less, therefore through - flow is less ( Figure 11 ). In addition, the carbonate aquifers have a lower conductivity at depth as there is less karstification, so there is a further drop in the amount of through - flow. It is further complicated as the through - flow out of the area may not be reduced by the same rate as the input, because the groundwater levels fall in the carbonate aquifers to the Kalahari sands at a similar rate. The Kalahari sands do not suffer a lowering of conductivity with depth, because the monotonous intergranular sands have the same conductivity at lower levels. As there is no change in head difference and conductivity, there is no reduction in flow, so the Kalahari aquifer is able to drain the carbonate aquifers at a constant rate irrespective of the groundwater level.

# 5. KALAHARI AQUIFER

## 5.1 INTRODUCTION

An extensive mostly confined and sometimes free flowing artesian aquifer dipping to the north west occurs in the north west corner of the Grootfontein District and into the Owambo Region and the Etosha National Park ( Figure 20 ). It consists of an ancient calcretized erosion surface which has become brecciated. Particularly north of Oshivelo, the calcrete material appears to have been reworked as borehole logs indicate the aquifer consists of a grit containing small pebbles of calcrete ( Figure 21 ). This unit is considered to be a palaeosol and is overlain by a usually green coloured laminated clay of variable thickness, which forms the aquitard ( Figure 22 ). The geological logs of all the boreholes show the same pattern throughout the aquifer and aquitard ( Appendix 3 ), that is, the clays are up to 12 m thick and the aquifer is up to 11 m thick. There is also evidence from logs that the aquitard and aquifer get thicker to the north and west. The partial free flowing conditions are a reflection of topography and the pressure head built up in the aquifer ( Figure 23 ).

The aquifer forms a remarkably planar form as it dips. This has been established after investigating all the aquifer intersections and expressing these intersections in heights a.m.s.l. ( Figure 20 ). The depth of the aquifer increases to the north west, increasing from ~35 m in WW 21625, to ~70 m in WW 16903 and up to 160 m in WW 2731. An examination of borehole drilling records shows that all one hour long blast tests produce similar yields with results of 50 $m^3$/hr. Because of the nature of the aquifer, it has relatively good aquifer characteristics and is a favourable target for exploitation.

A total of only 20 boreholes have been drilled into this aquifer since 1924. The reason for the limited development is a result of the problem of water quality and the cost of installing casing to seal off unconfined aquifers overlying the confined. Only 9 boreholes occur inside the potable zone and only 3 of these have been test pumped.

A saline zone in the aquifer occurs quite abruptly, to the west of the 17° E line of longitude. The cause of this salinity is an internal drainage basin which influences the groundwater quality in most of the Kalahari sediments, so the only potable portion of the Kalahari aquifer lies to the east of the 17° E line.

Transmissivity has been determined from test pumping and from this through - flow recharge has been estimated.

## 5.2 ASPECTS CONCERNING AQUIFER ORIENTATION

A contour map of the elevation of the aquifer ( Figure 20 ) shows that it forms an inclined plane which has been interpreted to represent a regional erosion surface. This map is made by plotting groundwater strike depths, the strike depths being derived from drilling records, on a topographic map.

The south easterly extent of this aquifer has not been yet established, although extrapolating the contour lines of the aquifer intersection depths back would indicate that the outcrop area is some 10 km south east of WW 21625. This would suggest that recharge for this aquifer

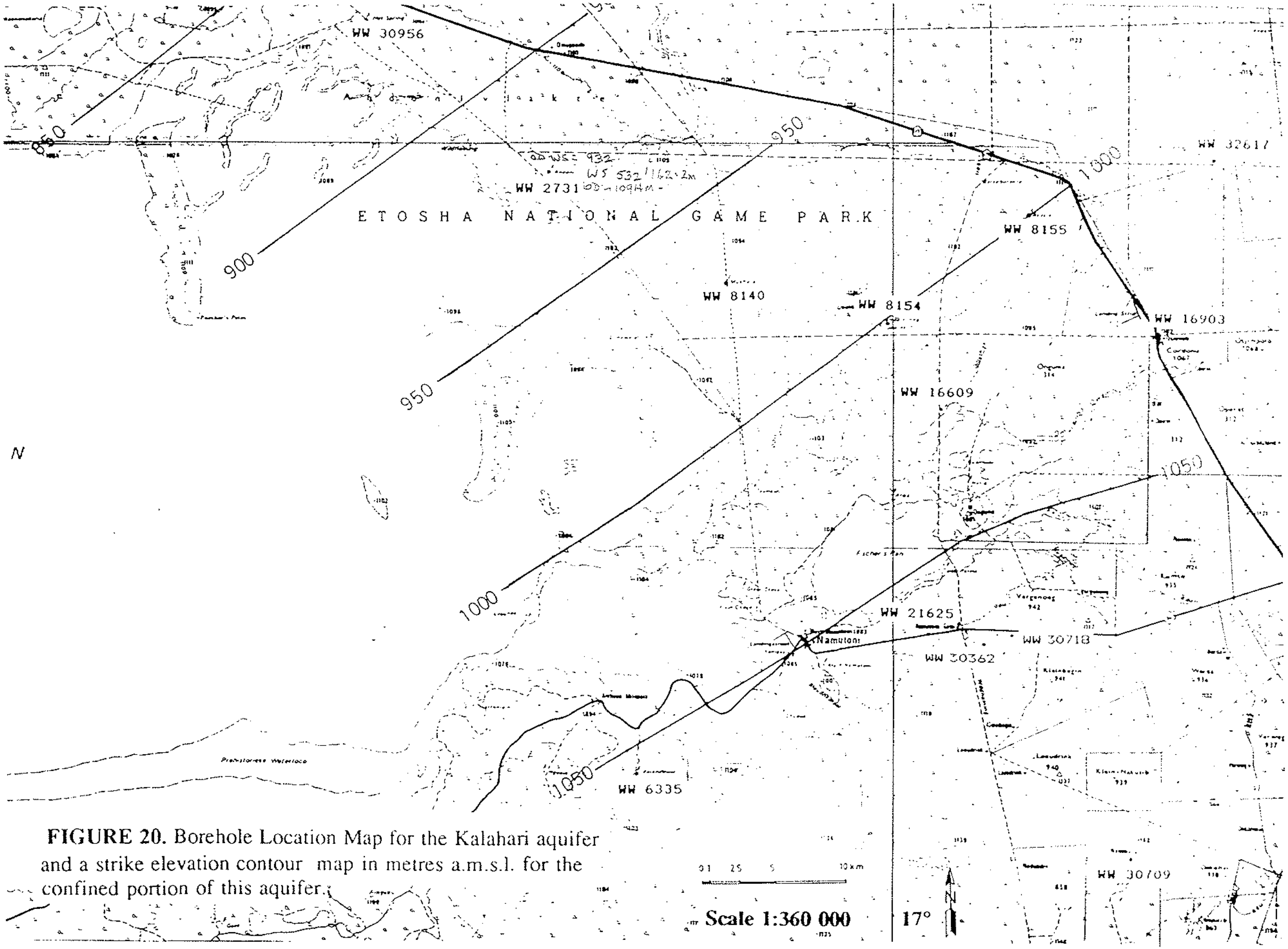



**FIGURE 20.** Borehole Location Map for the Kalahari aquifer and a strike elevation contour map in metres a.m.s.l. for the confined portion of this aquifer.

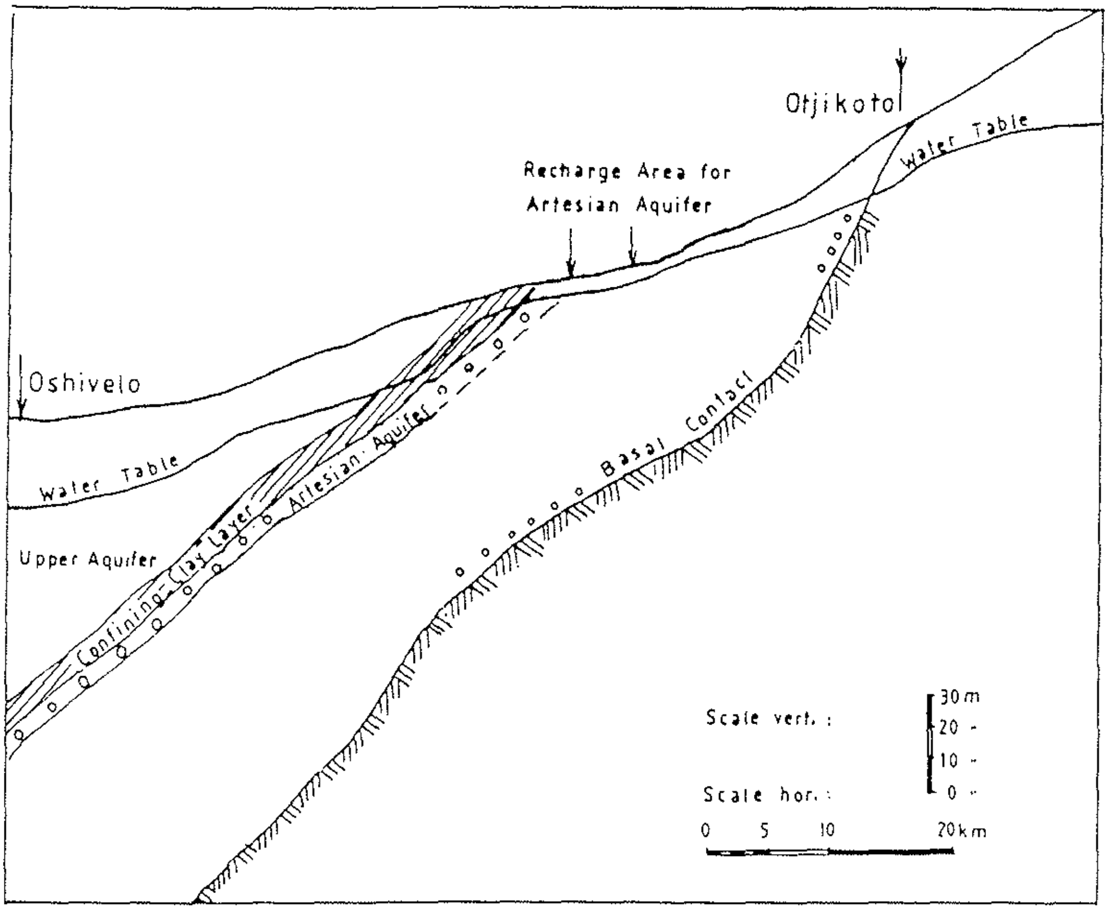



FIGURE 22. Cross section showing the Kalahari Aquifer between Oshivelo and Otjikoto Lake. The recharge area for this artesian aquifer is indicated.

FIGURE 23. Borehole WW 30956. Free flowing artesian well situated to the north of the Etosha Pan. See Figure 20 for location.

is directed through the unconfined portion of the aquifer ( Figure 22 ). Due to the complexities of resolving the original rock from its relatively recent calcretized form, the outcrop has not been found. The more recent calcretization may significantly change the hydrogeological characteristics of the aquifer, this being discussed in Aquifer Characteristics.

## 5.3 AQUIFER CHARACTERISTICS

### 5.3.1 Aquifer Characteristics in the Confined Portion

Pump testing confirms that the aquifer is confined and intergranular. The confined portion of the aquifer has a reputation as providing a reliable borehole yield and pump testing proves this, with transmissivity being ~400 $m^2/d$. This aspect has made it the aquifer for exploitation in the Namutoni area which requires relatively large volumes of water. Because it forms such a locally important aquifer, the nature of the aquifer and its characteristics must be ascertained to establish what are the constraints on the abstraction of groundwater.

Three test pump analyses have been assessed in this aquifer. In none of these tests were observation boreholes available, so no values for storativity can be determined. The tests were carried out on boreholes WW 16903, 30362 and 30718 ( Figure 20 ). The results of these test pump analyses are summarised in Table 7 and detailed in Appendix 10. The aquifer transmissivity varies over a restricted range between 300 and 500 $m^2/d$. This would suggest a certain uniformity for the aquifer, an interpretation which is supported by evidence from the geological borehole logs ( Appendix 3 ).

The test pump at Oshivelo on borehole WW 16903 was carried out when the borehole was completed in 1987. This borehole was initially blow tested for one hour and showed a rate of 50.0 $m^3/hr$. The main test pump was for 24 hours at a rate of 28.4 $m^3/hr$ and showed a transmissivity ( T ) of 300 - 400 $m^2/d$. An analysis of the recovery data showed similar results. The pumping data was measured over 1440 minutes, initially

| BOREHOLE | TRANSMISSIVITY ( $m^2/d$ ) | TEST DURATION ( HOURS ) | REMARKS |
|---|---|---|---|
| WW 16903 | 331 | 24 | |
| WW 30362 | 475 | 72 | |
| WW 30718 | 431 | 72 | |

**TABLE 7.** Summary of results of the aquifer characteristics of the confined Kalahari aquifer. Values of transmissivity were assessed using Jacobs Approximation, the drawdown data and graphs are in Appendix 10.

every minute with longer intervals later, while the recovery data records show that full recovery took 4 minutes with readings every minute. Although the test pump is not of sufficient duration, for it should have run for 72 hours, the indication of the transmissivity is consistent with subsequent test pumping.

The geology of WW 16903 comprises of a combination of light green coloured sandy clays and sands of the Andoni Formation down to a depth of 67 m when 0.5 m of clay is observed to overlie 6 m of the aquifer, that is from 67.5 - 73.5 m, which is possibly of the Olukonda Formation ( Appendix 3 ). In other boreholes, up to 1.0 km away from the tested borehole, the clay aquitard is recorded to be 1.0 m thick but with a blue colour and the palaeosol to range from 6.0 to 7.4 m thick. This results in an average thickness ( b ) for the aquifer of 6.8 m. Caution must be exercised in evaluating this data as although it is all derived from Department of Water Affairs, the data was not collected by a hydrogeologist. In spite of that the order of magnitude of the thicknesses of layers is considered correct. If a thickness of 6.8 m is assumed, the hydraulic conductivity ( k ) of the aquifer, given T/b = k, is 7*10 m/s. This places the aquifer in the range of clean sands to the lower end of gravels according to the classification of Freeze and Cherry p.29. This value is considered realistic given the lithological characteristics of the aquifer.

The test pumping of WW 30362 and 30718 confirm the short duration test pump result from WW 16903. Recovery in these two boreholes was too quick to be accurately measured by hand. The geology seen in these boreholes mirrors that observed in WW 16903, except that the overlying Andoni Formation is only ~35 m thick.

Given the similarities of the aquifer in terms of blast test yields and lithology, the haracteristics of the confined portion are thought to remain relatively constant.

### .3.2 Aquifer Characteristics in the Unconfined Portion

The aquifer characteristics of the unconfined portion of the aquifer should also be considered. o test pumping has been undertaken in the unconfined portion of the Kalahari aquifer where charge may take place. However, WW 31491 may give an indication as to these characteristics although this borehole lies outside the possible recharge area. The results are immarised in Table 8. Drilling records show that WW 31491 only records groundwater rikes in the Kalahari units. The results of WW 31491 are typical results for the unconfined Kalahari aquifer, being considerably less than the confined aquifer and the fissured dolomite uifer. These results compliment the drilling records.

| BOREHOLE | TRANSMISSIVITY ( $m^2/d$ ) | STORATIVITY | TEST DURATION ( Hours ) | REMARKS |
|---|---|---|---|---|
| WW 31491 | 23.5 | 0.0028 | 72 | |

**TABLE 8.** Summary of results from the unconfined portion of the aquifer.

A cautious comparison with the results from the confined portion suggests that there is an o er of magnitude reduction in transmissivity in the unconfined aquifer. This is accounted fc with the alteration of the geology by relatively recent calcretization in the unconfined aquifer.

magnesium. All other components have low concentrations.

### 5.5.1 Irrigation Potential

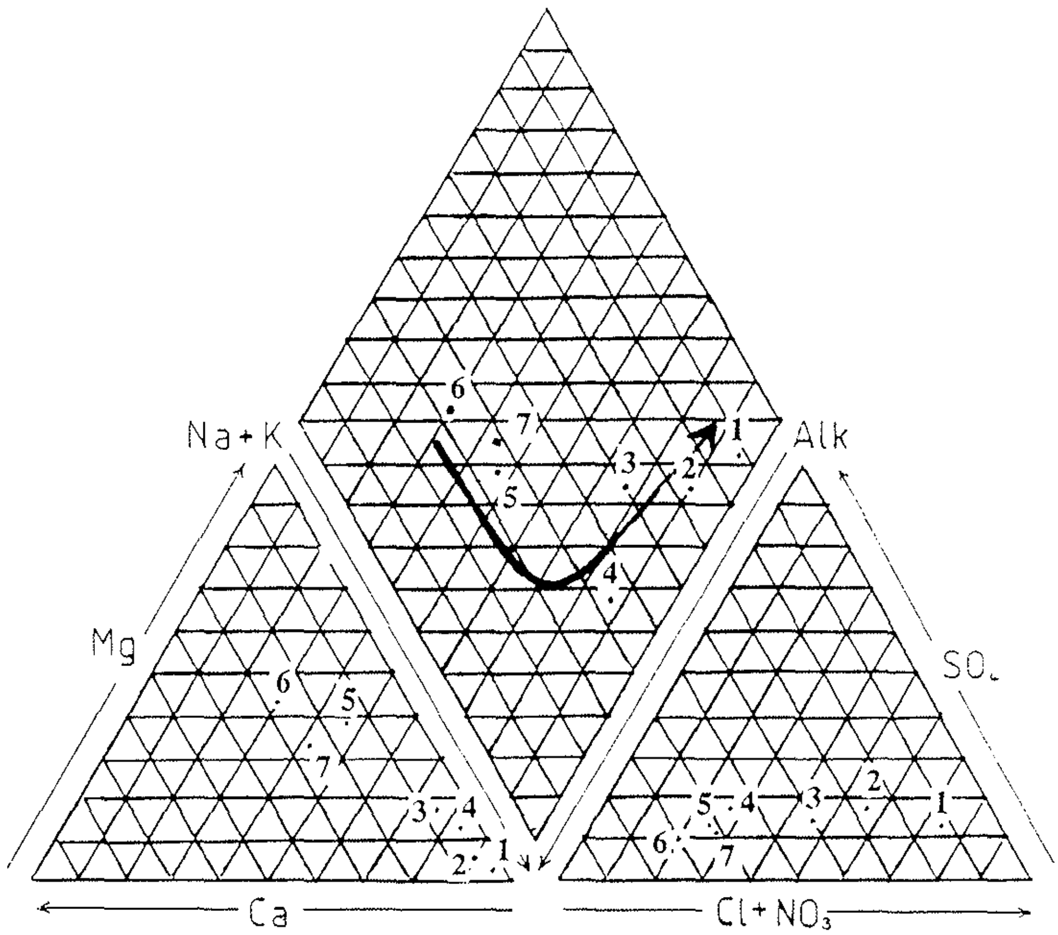
The potential of this groundwater for use in irrigation is mixed. The analyses of WW 21625 and WW 16903 show the irrigation classification of the USGS ( Appendix 6 ) to be C3 - S1, which means that although suitable for most plants on most soil types, due to the high sodium content a harmful concentration of sodium could occur in most soils. The groundwater from borehole WW 32617 is C3 - S3, which means that this water is only suitable for salt tolerant plants and can cause harmful sodium concentrations in most soil types. Special soil management should therefore be undertaken when using groundwater from any of these boreholes. To the west of the 17° E longitude line the groundwater gets more saline, so the problem seen in WW 32617 is exacerbated in the west, although flood irrigation has been attempted in southern Owambo. In addition, the stability of the groundwater is questionable for the groundwater in borehole WW 32617 has Corrosivity Ratio of 0.8 which means there is potential to corrode steel. This has implications in borehole design and in surface infrastructure. The Langelier Saturation Index of 0.4 would suggest scaling is also possible and the Ryznar Index value of 7.2 suggests that although stable, the groundwater might have corrosive tendencies. These stability assessments are valid here as the pH of the sample lies in the range of 7.0 to 8.0. An explanation of these factors is appended, in Appendix 7.

### 5.5.2 Hydrochemical Analysis

The concentrations of the determinands are shown in Table 10. The dominant control on the hydrochemistry from WW 21625 to WW 16903 and WW 32617 is cationic exchange. The result of this can be seen on the Piper Trilinear Diagram ( Figure 24 ). Calcium levels drop and sodium levels increase from WW 21625 in the south to WW 32617 in the north. At the same time chloride levels remain constant.

In borehole WW 32617 situated directly north of Oshivelo and still outside the influence of internal drainage, the sodium content of the groundwater is seen to more than double to ~310 mg/l in comparison to groundwater at Oshivelo in WW 16903 and Namutoni Gate in WW 21625. Concurrently, the calcium levels drop from ~150 mg/l in WW 16903 to ~50 mg/l in WW 32617. The conservative nature of the groundwater is seen in the fact that the chloride content remains constant at ~130 mg/l in all these places. Sulphate in the groundwater is seen to increase slowly northward through the area as the aquifer gets deeper, increasing from 84 mg/l at Namutoni Gate to 140 mg/l at borehole WW 32617.

More analyses are plotted on the Piper Trilinear Diagram than are shown in Table 10, as some analyses are only known in terms of percentage mille equivalents.




**Key**

| | TDS ( mg/l) | | TDS ( mg/l) |
|---|---|---|---|
| 1 - WW 2731 | 6712 | 5 - WW 16903 | 898 |
| 2 - WW 8140 | 2866 | 6 - WW 21625 | 975 |
| 3 - WW 16609 | 1645 | 7 - WW 30709 | 1125 |
| 4 - WW 32617 | 1110 | | |

**FIGURE 24.** Piper Trilinear Diagram of selected groundwater samples from the confined aquifer. The plots illustrate the base exchange and mixing of the groundwater. These samples are derived from Table 10. For comparison, a groundwater sample ( WW 30709 ) in the unconfined portion of the aquifer is also plotted.

| DETERMINAND | BOREHOLES | | | | | |
|---|---|---|---|---|---|---|
| | WW 2731 | WW 8140 | WW 16609 | WW 32617 | WW 16903 | WW 21625 |
| pH | 8.0 | 7.6 | 8.4 | 7.9 | 7.5 | 8.3 |
| TDS | 6712 | 2866 | 1645 | 1110 | 898 | 975 |
| Sulphate | 648 | 406 | 209 | 140 | 106 | 84 |
| Nitrate | 0 | 0 | 0 | 2.0 | 4.0 | 0 |
| Nitrite | 0 | 0 | 0 | 0.1 | 0 | 0 |
| Fluoride | 3.7 | 2.7 | 1.9 | 1.5 | 1.5 | 1.2 |
| Chloride | 3000 | 900 | 438 | 163 | 125 | 115 |
| Tot.Alk. | 750 | 680 | 560 | 496 | 496 | 596.2 |
| Tot. Hard. | 120 | 220 | 340 | 146 | 472 | 613 |
| Sodium | 2440 | 930 | 482 | 310 | 153 | 119 |
| Potassium | 50 | 21 | 18 | 15 | 5 | 3 |
| Calcium | 35 | 60 | 102 | 47 | 142.5 | 243 |
| Magnesium | 85 | 160 | 238 | 99 | 329 | 371 |
| Silicate | 32 | 48 | 25 | 22 | 40 | 32 |

**TABLE 10.** Hydrochemistry of the Confined Aquifer. Results are arranged according to the depth to the top of the aquifer, deepest on the left and the shallowest on the right. Except for pH, all values are in mg/l. Calcium, Magnesium, Total Hardness and Total Alkalinity are expressed as $CaCO_3$. Silicate is expressed in terms of $SiO_x$. Nitrate and Nitrite are expressed in terms of N.

Mixing is the dominant feature controlling hydrochemistry from WW 21625 to WW 2731 ( Figure 24 ). The effect of the internal drainage basin is noticeable immediately samples are examined to the west of the 17° longitude line. The chloride levels rapidly rise, going up from 150 mg/l at WW 21625 to over 450 mg/l in the groundwater in borehole WW 16609 which is 16 km to the west. A further 17 km to the west at borehole WW 8140 the chloride content of the groundwater is 900 mg/l and 14 km still further to the west the level reaches 3000 mg/l at borehole WW 2731. This conservative element is seen to increase due to the effect of salt trapped in the sediments dissolving into the groundwater. Concentration of sodium mirrors that of chloride, but not quite to the same proportions and sulphate even less so ( Table 10 ). Calcium and magnesium drop together to low concentrations to approximately one third of WW 21625 and WW 16903 values. This change in cations would indicate that ionic exchange is still taking place.

The hydrochemistry of the unconfined portion of the aquifer as seen in WW 30709 ( Figure 25 ) shows a degree of similarity with the closest confined aquifer borehole WW 21625. All the determinands between the two are of the same order of magnitude.

DEPARTMENT OF FISHERIES AND WATER
Private Bag 13193,Windhoek,9000,Namibia
REPORT ON ANALYSIS OF WATER

Sample number : CH56918
File number : B315
Sender : Drilling Section
Origin : FARM ( Control )
Sampling point : B315 NAKUSIB
Location description : Borehole : 30709

Date sample taken : 1990-07-04
Date sample received : 1990-07-18
Date sample analysed : 1990-08-01

Comments : Locality : 1 km south of house

| DETERMINANT: | | RESULT: | | DRINKING WATER GROUP: | |
|---|---|---|---|---|---|
| pH | : | 7.6 | | A | Excellent |
| Conductivity | : | 170.4 | mS/m | B | Good |
| Total Dissolved Solids (calculated from Conductivity) | : | 1125 | mg/l | | |
| Sulphate | as SO4: | 130 | mg/l | A | Excellent |
| Nitrate | as N: | <0.5 | mg/l | A | Excellent |
| Nitrite | as N: | <0.1 | mg/l | | |
| Fluoride | as F: | 1.2 | mg/l | A | Excellent |
| Chloride | as Cl: | 175 | mg/l | A | Excellent |
| Total Alkalinity | as CaCO3: | 566 | mg/l | | |
| Phenolphthalein Alkalinity | as CaCO3: | 0 | mg/l | | |
| Sodium | as Na: | 190 | mg/l | B | Good |
| Potassium | as K: | 5 | mg/l | A | Excellent |
| Calcium | as CaCO3: | 240 | mg/l | A | Excellent |
| Magnesium | as CaCO3: | 280 | mg/l | A | Excellent |
| Total Hardness | as CaCO3: | 520 | mg/l | B | Good |
| Silicate | as SiO2: | 39 | mg/l | | |

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER : B

STOCKWATERING : Suitable

IRRIGATION CLASSIFICATION : C3-S1
High salinity. Only suitable for plants with good salt tolerance and soils with very good drainage.
Low sodium content. Suitable for almost all soils and crops except those very sensitive to sodium.

STABILITY OF WATER WITH RESPECT TO CaCO3 :
Langelier Index = 0.8 Scaling
Ryznar Index = 5.9 Scaling
CORROSION POTENTIAL OF WATER TOWARDS STEEL :
Corrosivity Ratio = 0.7 Corrosive

**FIGURE 25.** Hydrochemistry of WW 30709, a borehole in the unconfined portion of the Kalahari aquifer.

## 5.6 HISTORY OF WATER LEVELS

The confined aquifer shows a gradual constant increase in groundwater levels of 10 cm, followed by a drop of 2 cm through the eight months for which data is available. These changes are irrespective of rainy and dry seasons ( Table 11 ).

| Measurement Date | Static Water Level |
|---|---|
| 20-08-1991 | 11.88 |
| 22-10-1991 | 11.82 |
| 22-01-1992 | 11.78 |
| 23-04-1992 | 11.80 |

**Table 11.** Changes in static groundwater level in borehole WW 32617.

These results confirm that the portion of the Kalahari aquifer at WW 32617 is confined, as the rainy and dry seasons do not directly influence groundwater levels. Changes in the groundwater level only show the trend of change of head at that particular time.

## 5.7 RECHARGE AND DISCHARGE

It is considered that the confined portion of the Kalahari aquifer is recharged from the unconfined portion by through - flow. The unconfined aquifer is thought to be situated between Namutoni Gate and Otjikoto Lake ( Figure 22 ). If recharge to the confined portion of the aquifer is from the unconfined portion, so long as there is groundwater in the unconfined portion there will be recharge to the confined aquifer. One check on this hypothesis is to check on the groundwater levels in the confined aquifer. The 8 month long data set from WW 32617 shows that the groundwater level is changing irrespective of the onset of the dry season. This means that recharge to the confined portion is occurring. It would suggest that there is no direct diffusion recharge caused by rainfall, which confirms that the aquifer must be confined at WW 32617. The discharge mechanism is possibly through very slow leakage.

### 5.7.1 Recharge to the Unconfined Portion of the Aquifer

The problem is to know where the diffuse recharge area is. The hydrochemistry of the groundwater at WW 21625 suggests that this borehole is the closest confined aquifer borehole to the recharge area. The hydrochemistry does indicate that WW 21625 has a close similarity to the unconfined Kalahari aquifer as seen in WW 30709 ( Figure 20 ). The hydrochemistry of a groundwater sample from the unconfined aquifer from borehole WW 30709 has been plotted on the Piper Trilinear Diagram ( Figure 24 ). This sample is fairly representative of the hydrochemistry of the groundwater in what is considered the recharge area for the confined aquifer.

Recharge to the groundwater in the unconfined aquifer in this terrain is difficult to assess, except possibly on the large scale. Direct diffuse recharge is thought to be the dominant recharge mechanism with recharge from flood events in ephemeral streams playing a minor role.

One approach to measure the potential recharge of the confined portion is to assess recharge in the unconfined part of the aquifer. The aquifer recharge area is considered to be 20 km along strike and 10 km along dip. The distribution of boreholes in the confined aquifer determines the strike length. The dip length is computated from the gradient of the confined aquifer superimposed on the gradient of topography. The unconfined recharge area therefore covers an area of ~200 $km^2$. Assuming there is ~0.5 m rainfall and a suggested recharge rate of 2% of rainfall, gives a result for recharge of $2.0*10^6$ $m^3$/yr.

It is considered that in areas covered by thick ( +8 m ) layers of aeolian sand in the unsaturated zone there is little likelihood of direct diffusion recharge ( de Vries ).

The role of ephemeral streams in recharge has not been established. The flooding of ephemeral streams and subsequent infiltration to groundwater is so unpredictable that no quantity can be placed on the amount that goes to recharge. The quantity of water in the rivers is variable, as are the length of time the river flows, the depth of river water and the permeability of the river bed. To collect data on this is difficult, due to the periodic nature of a flood event,the usually localised flow and the short duration of a flood. In spite of all these problems and without much firm proof, most authors believe that flood events in ephemeral streams contribute to recharge in Kalahari areas.

In the Kalahari areas where there are only bedded units, diffuse flow is thought to be the mechanism for recharge. The effect on unconfined groundwater levels in the area is to see a rapid rise through the course of the rainy season and a drop through the dry.

### 5.7.2 Through - Flow Estimations

An estimate of theoretical through - flow can be made. It is unclear whether or not there is actual movement of groundwater through the aquifer, but based on test pump results and geological data an assessment of what could pass through can be made. To do this a number of assumptions have to be made. The first concerns the aquifer, that it is of uniform thickness and extends for a certain width, in this case 20 km, and that groundwater moves through all of the aquifer at equal rate. The second assumption is that the conductivity value derived from the test pump is correct. To assess through - flow the vertical cross section area of the aquifer perpendicular to the theoretical flow direction is needed, here called A. The width of the aquifer is 20 km multiplied by the thickness of 6.8 m equals the area ( A ), therefore A equals 136 000 $m^2$. Conductivity ( k ) is $7*10^{-4}$m/s and gradient ( i ) is the piezometric gradient, which is 0.0007. Through flow ( Q ) is given by the straight application of Darcy's Law, that is:

$$Q = k A i$$

Substituting, this results in:

$$Q = (7*10^{-4})(136\ 000)(0.0007)$$

$$Q = 0.07\ m^3/s$$
$$\text{or } 2.2*10^6\ m^3/yr$$

This value will increase if the 20 km width or the thickness increase.

The through - flow volume of $2.2*10^6$ $m^3$/yr can be spread over the recharge area, that is the ~200 $km^2$ area of the unconfined aquifer. This equals 11 mm of water over the whole area. The average rainfall from Operat ( Figure 18 ) is 500 mm, so 11 mm of recharge equals 2.2% of rainfall. The 2% of rainfall going to recharge suggested in paragraph 5.7.1 equates well with the 2.2% result derived from through - flow estimations.

The through - flow of $2.2*10^6$ $m^3$/yr is relatively close to that derived from the direct diffuse recharge quantity of $2.0*10^6$ $m^3$/yr. The correlation of these figures may suggest that recharge to this aquifer may be of this order of magnitude.

### 5.7.3 Discharge

No discharge point has been found for the aquifer. The possibility exists that the groundwater is lost through very slow leakage into the overlying sediments, as the confined groundwater is under pressure.

## 5.8 SUSTAINABLE YIELD

The sustainable yield is controlled by recharge in the unconfined portion of the aquifer and through - flow. The aquifer covers a large area, the vast majority of it is of no use to man due to its high salt content, but even so the potable portion covers at least 260 $km^2$ and could cover a great deal more towards the north. It is considered that there is a considerable stored volume of water in this aquifer, but without a figure for storativity this cannot be assessed.

There is no sign that the aquifer is under any stress with current abstraction.

Considering that recharge and through - flow calculations generate a similar result of ~$2.0*10^6$ $m^3$/yr, it is considered prudent to suggest that a total sustainable yield should be limited to ~$2.0*10^6$ $m^3$/yr. It may be better to start abstraction at a fairly conservative rate and measure the response. It would probably not be a good thing if the unconfined aquifer became dewatered caused by over abstraction in the confined aquifer. It would certainly have political consequences and probably hydrogeological ones as well.

## 5.9 ABSTRACTION

In only one place is the confined, partially free flowing artesian aquifer pumped to any degree. The Namutoni Camp in the Etosha National Park and a privately owned hotel complex both abstract groundwater from this aquifer at Namutoni Gate from boreholes WW 21625, WW 30362 and WW 30718. Current combined abstraction is estimated at $0.3*10^6$ $m^3$ p.a. with no evidence of the aquifer being stressed. Wells in the Etosha National Park are used for watering the game and the controlled pumping from these installations is minimal. In southern Owambo, some wells are used for stock watering. However most goes to waste, but the quantity is not known.

## 5.10 ASPECTS OF THE RELATIONSHIP BETWEEN AQUIFERS

The interaction of the confined aquifer found from Oshivelo to Namutoni and other unconfined aquifers should be clarified. Because of the need to try and find what relationship exists between them, it was conjectured that lithological differences and faulting occurred between the aquifers. A geophysical survey using a Constant Separation Traverse profile was laid out between these to test the theory, but nothing could be identified in the results. It is questionable whether this technique is applicable in this terrain, as it is unlikely to pick up lithological and structural differences as there is no contrast of resistivities. Geological faulting has been recognised in the area by the Geological Survey ( Figure 4 ) and the author from remote sensing and field investigation. It is also uncertain what, if any, role faults play in localising aquifers in this area. The complex lithology of the area is also unlikely to be resolved with resistivity.

# 6. AQUIFER COMPARISON AND DEVELOPMENT OPTIONS

## 6.1 AQUIFER COMPARISON

The Damara carbonate aquifers and the Kalahari aquifer differ in many aspects. The aquifers both show potential for development. The differences or similarities between these aquifers are of practical concern only when they effect water supply. Aspects which concern the development of these aquifers are sustainable yield, aquifer characteristics and water quality.

The Damara carbonate aquifer is unconfined or leaky, fissured with secondary porosity, discontinuous and recharge is linked closely to rainfall. The groundwater, however is of good quality, albeit slightly hard. Where suitable for exploitation, the Kalahari aquifer is confined, partially free flowing artesian, continuous and intergranular. Recharge of the confined portion of the aquifer is linked to recharge in the unconfined portion. The groundwater has variable quality.

These aquifers have in common the potential for large scale abstraction. In practice individual boreholes should have a sustainable yield potential of at least 30 $m^3$/hr for 10 hours a day, or not under 300 $m^3$/d. The sustainable yield is linked to the amount of recharge.

In terms of the use to which the groundwater is put, there appears to be little difference between the two of them as they are both of the WHO ' B ' standard. Therefore for use as drinking water there is no difference.

The irrigation potential of the Kalahari aquifer groundwater is not high, because the groundwater may prove corrosive and have an undesirable saline content. This may result in the shortening of the life of infrastructure and the build up of NaCl in the soil, while the type of crop grown must be tolerant of salt. The Damara carbonate aquifers do not suffer from these problems, but do introduce a problem of hardness. The elevated levels of this determinand will result in the scaling of infrastructure over time. Hardness does not effect the type of crop grown or concentrate in the soil, so long as there is good drainage.

The recharge to the confined portion of the Kalahari aquifer is determined by the amount of recharge in the unconfined portion of the aquifer. It has been estimated that recharge to this aquifer is ~ $2.0*10^6$ $m^3$/yr. It is considered prudent to restrict abstraction to this figure, at least at the beginning. Should more information become available a reassessment can then be made.

Recharge to the Damara carbonate aquifers is variable, depending on the amount and intensity of rain. It is considered that recharge can vary from 0% to 4% of rainfall. In periods of drought there may be no recharge while in above average rainfall recharge could be 4%. If an average of 2% is taken, then diffuse recharge of $4.0*10^6$ $m^3$/yr is possible. This does not take into account through - flow, which is difficult to assess. An estimate of through - flow is $3*10^6$ $m^3$/yr.

The aquifer characteristics of the confined portion of the Kalahari aquifer appear to be relatively constant which would indicate that the aquifer has a certain degree of uniformity. In practice this uniformity means that predictable performance of boreholes can be expected.

The Damara carbonate aquifers have been shown to be fissured and this inhomogeneity causes problems in the development of the aquifer. The success of a borehole depends on the intersection of water bearing fissures and this can lead to unsuccessful boreholes. The depth of intersection of a water bearing fissure is often unpredictable. A successful borehole will show favourable characteristics, with transmissivity ~500 $m^2/d$.

The design of a well field is determined according to whether the aquifer is confined or not. Well fields in confined aquifers should consist of one or two lines of boreholes drilled normal to the flow direction. In the case of the Kalahari aquifer,the lines should be oriented south west - north east. The unconfined and leaky Damara carbonate aquifer allows a scattering of boreholes over the extent of the aquifer.

The exploitation of either or both of these aquifers depend on the quantity of water required and purpose to which this groundwater will be put. The advantages and disadvantages of the development of these aquifers are however mentioned in Development Options.

## 6.2 DEVELOPMENT OPTIONS

The development of these aquifers can be summarised as follows:

Development of the Damara carbonate aquifers

Advantages

1. Good drinking water quality.
2. Suitable for irrigation.
3. Possibly has more groundwater available than the Kalahari aquifer.
4. Unconfined and leaky aquifer allows for a scattering of boreholes in well design.

Disadvantages

1. Abstraction quantities could be negatively influenced by drought.
2. Unpredictable depth of intersecting water bearing fissures makes budgeting of drilling costs difficult.
3. Risk of dry boreholes.
4. Pumping costs may be high, due to deep groundwater levels.

Development for the Kalahari aquifer

Advantages

1. Good drinking water quality.
2. Predictable depth of intersecting aquifer makes budgeting of drilling costs easy.

3. Pumping costs should be relatively low, caused by shallow groundwater levels.
4. Resource is more dependable than the Damara carbonate aquifer.

Disadvantages

1. Unsuitable for general irrigation.
2. Borehole design is costly.
3. Possibly has less sustainable yield than the Damara carbonate aquifer.
4. Well field limited in design.

## 7. CONCLUSIONS

In the area of this study there are two contrasting aquifers with potential for large scale abstraction. The groundwater is required to meet future demand, due to an expected growth in the population and possible increased irrigation.

The first aquifer is the Damara carbonate aquifer whose characteristics are variable, with transmissivity ranging from 10 $m^2/d$ to 900 $m^2/d$ and storativity ranging from 0.002 to 0.05. These results are typical of discontinuous, fissured and unconfined or leaky aquifers. Drawdown plots illustrate the fissured and sometimes leaky nature of the aquifer.

The hydrochemistry is typical of recent recharge dolomitic groundwater. The dominant cations are calcium and magnesium, and the dominant anion is bicarbonate. This hydrochemistry means that the groundwater is suitable for drinking water and is suitable to irrigate some crops.

Studies of hydrographs show that recharge is variable, periodic and infrequent. However, an attempt has been made to quantify recharge. The total potential recharge in favourable conditions is of the order of $19*10^6$ $m^3$ p.a. The current abstraction rate is considered to be $14.1*10^6$ $m^3$ p.a., thus a surplus apparently exists of $4.9*10^6$ $m^3$ p.a.

Caution should be exercised in using this surplus figure as it assumes recharge to be an annual event. If recharge does not take place, the aquifer is vulnerable to over exploitation if abstraction continued at $4.9*10^6$ $m^3$ p.a. This is of particular concern as the aquifer characteristics are not so favourable in the lower portions of the aquifer, where groundwater levels may fall on account of over abstraction. Initially, a more conservative abstraction regime is considered desirable. A figure of 50% of surplus is thought to be reasonable, thus giving a pumping rate of $2.5*10^6$ $m^3$ p a. Any abstraction programme should remain flexible.

The second aquifer is the Kalahari aquifer whose characteristics show the homogeneity of this aquifer, with the transmissivity falling inside a narrow range between 300 $m^2/d$ and 500 $m^2/d$. Hydrographs, borehole logs and drawdown graphs confirm the confined, intergranular and continuous nature of the aquifer.

The hydrochemistry of the groundwater shows signs of ionic exchange and mixing. Outside a saline zone, the groundwater is seen to have good quality. However the groundwater is unsuitable for irrigation because of the ionic exchange and mixing.

Recharge to the confined aquifer is dependable, because it relies on through - flow from its unconfined portion. Therefore recharge has been equated to sustainable yield. The sustainable yield of this aquifer is $\sim 2.0*10^6$ $m^3$ p.a. Current abstraction is limited to $\sim 0.3*10^6$ $m^3$ p.a., so there is a surplus of $1.7*10^6$ $m^3$ p.a. available for further abstraction. In practical terms abstraction could increase by $2*10^6$ $m^3$ p.a.

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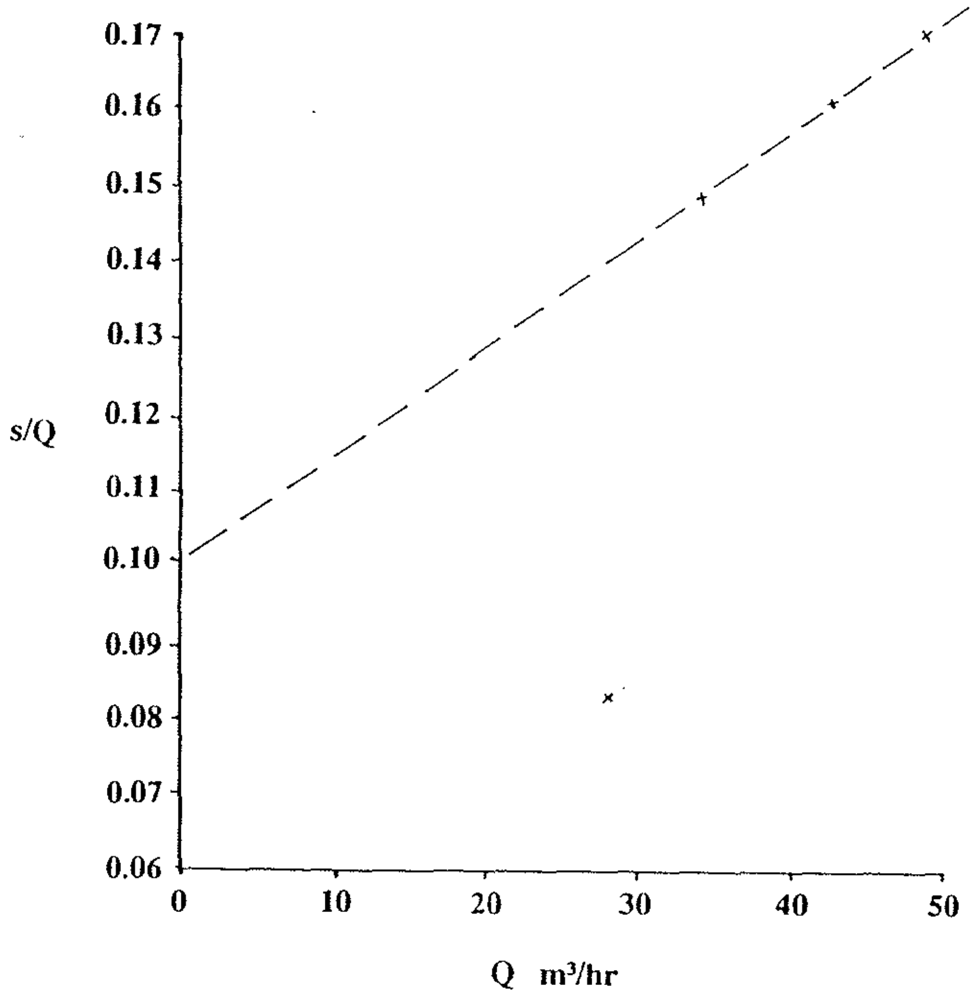


**STEP TEST**

**WW 30362**

s/Q against Q

| s/Q | Q |
|---|---|
| 0.083 | 27.9 |
| 0.148 | 33.8 |
| 0.161 | 42.5 |
| 0.170 | 48.6 |

s is in metres
Q is in $m^3/hr$

$$s = 0.1\ Q + 0.0015\ Q^2$$

# APPENDIX 1.

Monthly rainfall figures for three meteorological

stations in the study area.

STATION NAME : TSUMEB
STATION NUMBER : 1055/274
SUB-CATCHMENT : 2720
TYPE OF STATION : Rain

POSITION LATITUDE : 19.22 deg S
POSITION LONGITUDE : 17.72 deg E
DATE STATION OPENED : 1911-07-01

REPORT NAME : rainm

## MONTHLY RAINFALL SUMMARY

| SEASON | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1910/11 | ! | ! | ! | ! | ! | ! | ! | ! | ! | 8.1 | | | 8.1 ! |
| 1911/12 | 3.5 | 4.5 | 10.7 | 369.6 | 260.6 | 33.5 | 30.2 | .5 | 12.0 | | | [illegible] | [illegible] |
| 1912/13 | 4.2 | 21.6 | 153.9 | 33.1 | 58.7 | 75.4 | 142.7 | 8.1 | | | | [illegible] | [illegible] |
| 1913/14 | 5.6 | 66.0 | 79.5 | 33.0 | 111.8 | 68.2 | 50.5 | | | | .5 | | 475.2 |
| 1914/15 | 87.6 | 8.0 | 82.8 | 192.3 | 166.4 | 8.6 | 9.1 | .5 | | | | 16.2 | 510.5 |
| 1915/16 | | 40.1 | 181.1 | 75.4 | 43.9 | 143.3 | 7.1 | | | | | | [illegible] |
| 1916/17 | 15.2 | 102.1 | 159.5 | 49.8 | 200.4 | 42.2 | 29.5 | 35.2 | | | | [illegible] | 635.5 |
| 1917/18 | 4.2 | 37.3 | 91.4 | 141.0 | 36.3 | 186.2 | | | | .3 | | 3.3 | 501.1 |
| 1918/19 | 29.9 | 12.4 | [illegible] | 117.6 | 58.7 | 26.2 | 11.4 | | | | [illegible] | .3 | [illegible] |
| 1919/20 | 33.5 | 45.2 | 70.4 | 116.8 | 103.6 | 20.1 | 3.3 | 5.8 | | | | | 397.0 |
| 1920/21 | | 166.9 | 24.4 | 114.6 | 176.5 | 63.2 | 17.5 | 59.2 | | | | | [illegible] |
| 1921/22 | 9.7 | 73.7 | 33.5 | 40.1 | [illegible] | 49.0 | 1.0 | 3.0 | | | | | 271.2 |
| 1922/23 | 31.5 | 51.8 | 14.2 | 139.4 | 309.5 | 164.3 | 33.5 | 7.4 | | | | | 799.7 |
| 1923/24 | 12.4 | 24.6 | 45.0 | 52.6 | 92.2 | 141.5 | | | | | | .5 | 368.8 |
| 1924/25 | 33.5 | [illegible] | 117.3 | 198.6 | 143.3 | 183.4 | 169.2 | 33.5 | | | | | 955.1 |
| 1925/26 | | 56.6 | 44.7 | 136.7 | 36.1 | 63.5 | 92.6 | 3.6 | 7.1 | | | 2.5 | 433.4 |
| 1926/27 | 24.5 | 95.8 | 146.1 | 73.4 | 53.1 | 67.8 | 48.0 | | | | | | 512.7 |
| 1927/28 | 29.2 | 49.5 | 51.1 | 94.2 | 52.6 | 126.7 | 44.2 | | | | | 12.7 | 460.2 |
| 1928/29 | | 45.4 | 7.1 | 46.0 | 132.2 | 57.7 | 4.3 | | | | | | 291.3 |
| 1929/30 | 41.7 | 77.0 | 13.0 | 101.1 | 80.2 | 91.8 | 65.2 | | | | | | 461.2 |
| 1930/31 | 2.2 | 11.7 | 34.0 | 133.9 | 135.7 | 128.5 | 25.7 | .5 | | | | | 462.2 |
| 1931/32 | 19.2 | 111.8 | 94.2 | 28.4 | 75.7 | 50.5 | 5.1 | 2.5 | | | | | [illegible] |
| 1932/33 | 29.7 | 36.1 | 104.6 | 51.6 | 25.3 | 32.3 | 4.6 | | | | | | 284.2 |
| 1933/34 | 4.1 | 63.0 | 130.3 | 335.0 | 262.1 | 102.4 | 33.3 | .3 | | | | | 930.5 |
| 1934/35 | 10.2 | 25.9 | 145.0 | 129.8 | 65.5 | 45.5 | 22.6 | 5.0 | | | | | 451.5 |
| 1935/36 | 8.6 | 56.6 | 98.0 | 31.0 | 71.9 | 151.9 | 14.2 | 15.2 | | | | .5 | 497.9 |
| 1936/37 | 1.5 | 10.7 | 70.6 | 54.4 | 157.0 | 38.1 | 91.9 | 2.5 | | | | | 427.0 |
| 1937/38 | 29.5 | 73.9 | 133.9 | 204.0 | 198.6 | 17.2 | 45.3 | 11.7 | | | | | 717.7 |
| 1938/39 | 10.4 | 131.3 | 64.8 | 37.2 | [illegible] | 125.5 | 25.9 | 3.5 | | 2.0 | | | [illegible] |
| 1939/40 | 21.0 | 47.2 | 168.1 | 193.8 | 48.0 | 96.3 | 37.3 | | | | | | [illegible] |
| 1940/41 | 6.9 | 15.2 | 122.9 | [illegible] | 65.5 | 15.5 | 41.4 | | | | | .3 | 359.0 |
| 1941/42 | 33.8 | 7.1 | 29.0 | 103.9 | 141.5 | 213.4 | 25.4 | | | | | | 554.1 |
| 1942/43 | 53.4 | 11.9 | 119.6 | 30.7 | 24.1 | 84.1 | 56.4 | | | | | | 385.2 |
| 1943/44 | | 63.8 | 206.5 | 300.7 | 370.6 | 54.1 | 5.1 | | | | | | 1005.8 |
| 1944/45 | 25.4 | 30.2 | 63.8 | 45.5 | 44.7 | 61.0 | 18.8 | | | | | | 229.4 |
| 1945/46 | 11.9 | 130.6 | 50.0 | 61.5 | 44.7 | 26.2 | 6.6 | | | | | 4.1 | 335.6 |
| 1946/47 | 4.8 | 55.6 | 31.0 | 204.7 | 213.1 | 68.2 | 29.5 | | 2.2 | | | .5 | [illegible] |
| 1947/48 | 2.2 | 37.1 | 116.1 | 67.3 | [illegible] | 48.7 | 29.7 | 4.8 | | | | | [illegible] |
| 1948/49 | 21.1 | 74.2 | 1.8 | 54.6 | 33.1 | 124.2 | 5.1 | | | | | | [illegible] |
| 1949/50 | 1.0 | 79.2 | 46.3 | 171.2 | 223.0 | 127.3 | 185.7 | 34.0 | | | | | [illegible] |
| 1950/51 | | 77.2 | 117.6 | 24.2 | [illegible] | 91.0 | 63.2 | 44.5 | | | | | 515.7 |
| 1951/52 | 32.2 | 25.3 | 131.9 | 66.7 | 145.9 | 1.8 | 3.6 | | | | | | 426.0 |
| 1952/53 | 25.0 | 46.8 | 61.2 | [illegible] | 121.6 | 56.8 | 29.4 | 12.5 | | | | .5 | [illegible] |
| 1953/54 | [illegible] | 71.4 | 121.2 | 193.4 | 220.2 | 254.0 | 59.2 | | | | | 4.8 | [illegible] |
| 1954/55 | 7.9 | 22.2 | 98.9 | 149.9 | 93.7 | 45.4 | 55.6 | | | | | | 489.7 |

Quality of data : a = accumulated d = doubtful e = estimated ! = lost

STATION NAME : TSUMEB
STATION NUMBER : 1055/274
SUB-CATCHMENT : 2720
TYPE OF STATION : Rain

POSITION LATITUDE : 19.23 deg S
POSITION LONGITUDE : 17.72 deg E
DATE STATION OPENED : [illegible]

REPORT NAME : rainm

MONTHLY RAINFALL SUMMARY
======================

| SEASON | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1955/56 | 34.5 | 38.9 | 120.9 | 174.8 | 222.1 | 136.6 | 87.9 | 23.3 | | | | 20.3 | 859.2 |
| 1956/57 | 10.0 | 13.0 | 73.0 | 158.4 | 141.0 | 74.3 | 14.9 | 3.1 | | | | .3 | 493.5 |
| 1957/58 | 40.0 | 47.8 | 96.3 | 147.1 | 121.5 | 40.6 | 12.1 | | | | | 10.1 | 516.0 |
| 1958/59 | 6.1 | 76.3 | 36.7 | 52.3 | 139.2 | 48.4 | 102.3 | 8.3 | | | | | 500.7 |
| 1959/60 | 6.6 | 15.5 | 102.3 | 108.1 | 302.5 | 16.9 | 56.9 | 2.4 | | | | | 611.2 |
| 1960/61 | 47.1 | 65.9 | 67.2 | 74.3 | 134.7 | 133.3 | 31.6 | 20.2 | 5.3 | | | | 580.1 |
| 1961/62 | .5 | 118.7 | 65.9 | 61.8 | 180.2 | 29.1 | 17.5 | | | | 5.2 | | 479.1 |
| 1962/63 | 36.2 | 57.2 | 49.1 | 140.5 | 47.3 | 124.7 | 48.3 | | | | | | 503.3 |
| 1963/64 | 6.1 | 153.1 | 44.0 | 39.2 | 31.3 | 30.5 | 20.7 | | | | .2 | | 325.2 |
| 1964/65 | 5.6 | 8.3 | 52.2 | 80.6 | 37.1 | 97.3 | 54.4 | | .5 | | | 12.7 | 399.2 |
| 1965/66 | 3.5 | 74.4 | 62.2 | 241.0 | 65.7 | 78.6 | 37.3 | | | | | 25.5 | 587.2 |
| 1966/67 | .9 | 9.0 | 32.4 | 207.7 | 124.6 | 129.6 | 32.2 | | | | | 2.7 | 538.1 |
| 1967/68 | 14.9 | 184.9 | 122.0 | 202.0 | 46.1 | 151.0 | 18.4 | 31.3 | | | | | 770.5 |
| 1968/69 | 2.5 | 96.2 | 56.2 | l | 157.2 | 134.0 | 30.8 | | | | | | 477.5 l |
| 1969/70 | 20.1 | 98.3 | 9.4 | 129.3 | 74.2 | 13.3 | 22.8 | | | | | | 364.6 |
| 1970/71 | 8.3 | 16.1 | 117.5 | 220.1 | 193.1 | 19.1 | 12.1 | | | | | | 591.3 |
| 1971/72 | 30.0 | 32.1 | 9.6 | 125.6 | 38.2 | 179.0 | 10.5 | | | | | | 425.0 |
| 1972/73 | 67.9 | | 9.7 | 75.3 | 22.6 | 160.1 | 15.9 | | | | | | 352.0 |
| 1973/74 | l | l | l | l | 167.6 | 73.0 | 61.6 | | | | | | 302.2 l |
| 1974/75 | 29.4 | 55.5 | 23.0 | 158.0 | 62.3 | 160.5 | 50.5 | | | | | | 54[illegible] |
| 1975/76 | | 68.2 | l | l | l | l | l | l | l | l | l | l | 68.2 l |
| 1976/77 | l | l | l | l | l | 81.7 | 53.6 | | | | | 6.[illegible] | 31[illegible] |
| 1977/78 | | 33.1 | 73.2 | 288.5 | 225.5 | 66.0 | 26.0 | | | | 3.0 | | 824.2 |
| 1978/79 | 11.0 | 6.1 | 77.5 | 216.6 | 173.9 | 25.0 | 10.3 | 3.2 | | | 3.0 | | 535.5 |
| 1979/80 | 92.2 | 68.8 | 99.7 | 23.3 | 165.8 | 239.2 | 38.0 | | | | | 1.0 | 727.0 |
| 1980/81 | | 36.0 | 55.0 | 108.1 | 119.6 | 33.0 | 3.7 | | | | .5 | | 360.9 |
| 1981/82 | 11.5 | 44.0 | 70.5 | 118.3 | 131.0 | 102.5 | 34.2 | | | | | 3.5 | 521.0 |
| 1982/83 | 1.5 | 73.6 | 30.2 | 130.0 | 18.5 | 24.0 | 17.5 | | 25.0 | | | | 370.3 |
| 1983/84 | 7.0 | 108.5 | 166.5 | 41.7 | 45.0 | 40.5 | 47.0 | | | | | | 456.2 |
| 1984/85 | 14.5 | 37.0 | 26.5 | 99.0 | 183.5 | 50.5 | | | | | | | 466.0 |
| 1985/86 | 9.5 | 30.2 | 171.0 | l | 259.5 | l | l | l | l | l | l | l | 470.2 l |
| 1986/87 | l | l | l | 37.2 | 113.[illegible] | 11.0 | 30.0 | | | | | | 196.6 l |
| 1987/88 | 33.1 | 47.3 | 60.5 | 112.0 | 81.0 | 27.0 | 23.0 | | | | | | 373.2 |
| 1988/89 | 7.0 | 21.0 | 69.5 | 115.0 | 126.5 | 35.0 | 54.0 | | | | | | 427.0 |
| 1989/90 | 12.0 | 33.5 | 40.0 | 115.3 | 48.0 | 233.0 | 99.0 | | | | | | 561.0 |
| 1990/91 | 22.0 | 36.5 | 58.1 | 161.7 | 120.0 | 18.0 | | | | | | | 416.3 |
| 1991/92 | 38.1 | 29.0 | l | l | l | l | l | l | l | l | l | l | 67.1 l |

Quality of data : a = accumulated d = doubtful e = estimated l = lost

STATION NAME : KAKUSE
STATION NUMBER : 1102/104
SUB-CATCHMENT : 2720
TYPE OF STATION : Rain

POSITION LATITUDE : 18.78 deg S
POSITION LONGITUDE : 17.58 deg E
DATE STATION OPENED : 1982-10-01

REPORT NAME : rainm

## MONTHLY RAINFALL SUMMARY

| SEASON | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982/83 | 2.2 | 39.3 | 57.5 | 125.8 | 36.6 | 69.5 | 25.1 | 2.1 | 18.6 | | | .1 | 416.8 |
| 1983/84 | 4.5 | 64.4 | 101.9 | 35.7 | 63.4 | 83.9 | 27.4 | | 1.1 | | | | 382.3 |
| 1984/85 | 19.3 | 73.8 | 32.0 | 179.6 | 158.3 | 82.4 | | 2.6 | | | | | 549.0 |
| 1985/86 | 10.5 | 40.6 | 30.9 | 91.3 | 175.3 | 119.5 | 21.3 | | | | | 2.0 | 491.4 |
| 1986/87 | 29.1 | 29.5 | 43.2 | 64.4 | 129.3 | 44.2 | 14.2 | 2.0 | 5.5 | .5 | | | 363.0 |
| 1987/88 | 4.5 | 54.3 | 58.2 | 150.1 | 92.6 | 22.8 | 51.9 | | .7 | | | | 435.6 |
| 1988/89 | | 74.0 | 139.2 | 129.2 | 255.6 | 44.8 | 39.7 | .6 | | | | | 733.7 |
| 1989/90 | | 6.3 | 9.9 | 123.1 | 35.3 | 75.7 | 20.1 | | | | | | 275.9 |
| 1990/91 | 9.2 | 54.7 | 99.3 | 141.3 | 147.1 | 62.8 | | | | | | | 514.9 |
| 1991/92 | 41.1 | 62.3 | 120.5 | l | l | l | l | l | l | l | l | l | 223.3 l |

Quality of data : a = accumulated d = doubtful e = estimated l = lost

STATION NAME : OPERET
STATION NUMBER : 1102/338
SUB-CATCHMENT : 2720
TYPE OF STATION : Rain

POSITION LATITUDE : 18.63 deg S
POSITION LONGITUDE : 17.20 deg E
DATE STATION OPENED : 1984-12-01

REPORT NAME : raina

## MONTHLY RAINFALL SUMMARY

| SEASON | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1984/85 | l | l | 25.0 | 89.1 | 124.8 | 85.5 | 2.0 | | | | | | 326.4 l |
| 1985/86 | 16.0 | 26.0 | 86.0 | 61.5 | 140.5 | 116.5 | 17.0 | | | | | 7.5 | 471.0 |
| 1986/87 | 26.5 | 41.5 | 46.5 | 59.0 | 112.0 | 49.5 | 20.0 | 4.0 | | | | | 359.0 |
| 1987/88 | 25.5 | 29.0 | 100.0 | 172.5 | 134.0 | 14.0 | 56.5 | | | | | | 531.5 |
| 1988/89 | | 44.5 | 189.0 | 173.5 | 222.0 | 46.5 | 76.0 | 5.5 | | | | | 757.0 |
| 1989/90 | | 6.0 | 2.0 | 150.5 | 43.5 | 124.0 | 24.5 | | | | | | 350.5 |
| 1990/91 | 12.5 | 72.5 | 12.0 | l | l | l | l | l | l | l | l | l | 97.0 l |

# APPENDIX 2.

Borehole completion forms and Geological borehole logs for the Damara carbonate aquifer.

1917 BB - 115

**BOREHOLE LOG**

**WW 30689**

| | |
|---|---|
| 0 - 3 m | Black turf and calcrete. |
| 3 m - 7 m | Weathered light grey green dolomite. |
| 7 m - 9 m | Weathered medium grey green dolomite. |
| 9 m - 12 m | Oxidised weathered light grey dolomite. |
| 12 m - 15 m | Brown dusted weathered dolomite. |
| 15 m - 18 m | Oxidised weathered light grey dolomite. |
| 18 m - 21 m | Medium grey weathered dolomite. |
| 21 m - 24 m | Oxidised weathered medium grey dolomite. |
| 24 m - 27 m | Fresh medium grey dolomite. |
| 27 m - 32 m | Oxidised weathered medium grey dolomite. |
| 32 m - 33 m | Fresh medium grey dolomite. |
| 33 m - 57 m | Slightly weathered medium grey dolomite. |
| 57 m - 66 m | Light grey dolomite. |
| 66 m - 120 m | Fresh medium grey dolomite weathered at 72 m and 102 m - 111 m with calcite fragments. |

Water level on 4/10/89 was 7,67 m.

| | |
|---|---|
| 0 - 3 m | Surficial Cover. |
| 3 m - 120 m | Elandshoek Formation, Tsumeb Sub Group, Otavi Group. |

Borehole is on the farm Scott 839.

N. Hood 13/10/89.

1917 BB - 115

# BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)
# BOREHOLE COMPLETION REPORT (Private Contractor)

(Government Notice R. 74 of 14 January 1966, as amended)

Instruction: A separate report to be completed in respect of each borehole.

A. General

1. Full name of applicant: DEPT WATERWESE
2. Plaas / Farm: SCOT
3. Boring aanbeveel deur / Boring site selected by: GEOLOOG
4. District: [illegible]
5. No.
6. Geological site No.
7. Boorgat No. / Borehole No.: 30689
8. Poging / Attempt: 1 | 2 | 3 | 4
9. Date of commencement of work: 26-09-89
10. Date of completion of work: 26-09-89
11. Boring stopped at discretion of: Applicant / Geoloog
12. Give a short description of site of borehole (e.g. 100 metres north-west of dwelling house): 2 KM [illegible] 005 [illegible] 025 [illegible]

B. Geologiese Gesteentes

| Depth from surface (metres) | Strata | Dikte / Thickness (metres) |
|---|---|---|
| 0 - 12 | Klei met Kalkreet | 12 |
| 12 - 66 | Kalkreet Skalie | 54 |
| 66 - 120 | Skalie met Klei | 54 |

C.
1. 150 ... 120
3. Total depth from surface: 120

D. Water
1. Depth from surface at which water was struck: 8, 18, 25, 30, 65
2. Depth from surface to which water rose: 7
3. Yield per second: 24 m³/h
4. Apparent quality of water: Vars
5. Purpose for which water will be used: [illegible]

E. Pomptoets / Pumping test

BLANSTOETS

F. Boorgat voltooiing

Totale koste / Total cost

E.J. van Zyl
26-09-89
DWS 5045

[illegible]
28-09-89
Windhoek

1917 85 – 116

## BOREHOLE LOG

WW 31484

| | |
|---|---|
| 0 - 13 m | White powdery weathered dolomite. |
| 13 m - 18 m | Clean fresh hard white dolomite. |
| 18 m - 39 m | As above but contains many weathered fragments, also sheared with a brown colour. Moderately powderly. Particularly weathered at 30 m - 33 m. |
| 39 m - 42 m | Clean fresh hard white dolomite. |

Entire sequence is in Elandshoek formation, Tsumeb sub-group.

Water level on 13/9/89 was 5,63 m.

25-9-89

N Hood

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# BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)
# BOREHOLE COMPLETION REPORT (Private Contractor)

A. Algemeen/General

1. Volle naam van applikant / Full name of applicant: Dept van Waterwese
2. Plaas / Farm: Hidbis Ost
4. Distrik / District: Tsumeb
5. Boorterrein aangewys deur / Boring site selected by: Geoloog
7. Boorgat No. / Borehole No.: 31483 31484
9. Datum van begin van werk / Date of commencement of work: 4-09-89
10. Datum van voltooiing van werk / Date of completion of work: 6-09-89
11. Boorwerk gestaak na goeddunke van / Boring stopped at discretion of: Applikant / Applicant; Inspekteur / Inspector: X
12. Give a short description of site of borehole: ± 6 km Noord van Tsumeb – Tsintsabis Hoofpad

B. Geologie/Geology

| Diepte van oppervlakte (meter) / Depth from surface (metres) | Strata | Dikte / Thickness (metres) |
|---|---|---|
| 0-15 | Klei – Kalkreet | 15 |
| 15-42 | Dolomiet | 27 |

C.
1. 152 mm from surface to 42
3. Totale diepte van oppervlakte af / Total depth from surface: 42

D. Water
1. Depth from surface at which water was struck: 6 – 12 – 25
2. Depth from surface to which water rose: 4
3. Opbrengs per sekonde / Yield per second: ± 25 m³/h
4. Skynbare gehalte van water / Apparent quality of water: Vars
5. Purpose for which water will be used: Menslik + Suiping

E. Pompsiel/Pumping test

Blanco toets

I.
3. (a) Plain Length: 3 x 150 mm

TOTALE KOSTE / TOTAL COST

G. Verklaring deur boorkontrakteur en boorinspekteur / Declaration by boring contractor and boring inspector. I declare that the information supplied above is true and correct.

Handtekening van boorkontrakteur / Signature of boring contractor: E J van Zyl
Datum / Date: 6-09-89
Adres / Address: DWS 5045

Handtekening van booringspekteur / Signature of boring inspector: [signature]
Datum / Date: 22-09-89
Inspektoraat / Inspectorate: Windhoek

1917BA -77

BOREHOLE LOG

WW 31485

| | |
|---|---|
| 0 - 6 m | White coloured hard pan calcrete. |
| 6 m - 12 m | As above but powdery. |
| 12 m - 21 m | Light green coloured fine grained calcareous sediments. |
| 21 m - 45 m | Mixture of red, yellow and light green coloured fine grained sediments, including clay, in part hard. |
| 45 m - 57 m | As above but much coarser grained going to a conglomerate, but mixed, as it still has clay. |
| 57 m - 63 m | Still similar to above but higher clay content. Contains rare dolomite - sandstone fragments. |

Hole abandoned.

Entire sequence consists of kalahari material.

Water level on 13/9/89 was 5,23 m.

N. Lload 28.9.89

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1917 [illegible]

BOORGATVOLTOOIINGSVERSLAG (Private Kontrakteur)

BOREHOLE COMPLETION REPORT (Private Contractor)

A. Algemeen/General

1. Volle naam van applikant / Full name of applicant: Dept. Waterwese

2. Plaas / Farm: Driefontein

3. Distrik / District: Tsumeb

5. Boorplek aangewys deur / Boring site selected by: geoloog

7. Boorgat No. / Borehole No.: 31485

9. Datum van begin van werk / Date of commencement of work: 11/9/89

10. Datum van voltooiing van werk / Date of completion of work: 12/9/89

11. Boorwerk gestaak na goeddunke van / Boring stopped at discretion of: Applikant / Applicant: geoloog

12. Give a short description of site of borehole: 1 klik wes van Opstal

B. Geologiese inligting

| Depth from surface (metres) | Strata | Thickness |
|---|---|---|
| 0 - 20 | Kalkreet | 20 |
| 20 - 60 | Kalahari | 40 |
| | | 66 |

19" hole 15 m gerig; 15 m 4" × 1/16 plain

C. Total depth from surface: 66 / 66

D. Water

1. Depth from surface at which water was struck: 12

2. Depth from surface to which water rose: 10

3. Yield per second: 3 m³/h

4. Apparent quality of water: Vars

5. Purpose for which water will be used: Suiping

E. Pumping test: Geen toets

F. Boorkoste/Drilling costs

3. Casing left in borehole on completion: (a) Length 6 m × 200 ∅ AC

TOTALE KOSTE / TOTAL COST

G. Voering/Casing: Voering kom nie uit nie [illegible] word nie

H. Declaration by boring contractor and boring inspector

Signature of boring contractor: [signature] 

Datum / Date: 12/9/89

Address: Dept. Waterwese Windhoek DWS 5045

Signature of boring inspector: [signature]

Date: 13-9-89

Inspector: Windhoek

1917 6A - 99

## BOREHOLE LOG

**WW 31486**

| | |
|---|---|
| 0 - 6 m | Creamy white coloured calcrete - hard pan and powdery. |
| 6 m - 12 m | As above but very powdery. |
| 12 m - 15 m | Calcretised Kalahari fine grained sediments - cream coloured. Powdery. |
| 15 m - 30 m | Light grey fine grained Kalahari sediments. |
| 30 m - 120 m | Dark grey coloured weathered dolomite. Light grey clean dolomite at 45 m, 54 m, 72 m, 90 m, 93 m and 99 m. Very weathered sandy zones at 48 m, 60 m, 69 m, 96 m, 102 m. Evidence of slipage (shearing) all down the borehole. |

| | |
|---|---|
| 0 - 30 m | Kalahari sequence |
| 30 m - 120 m | Elandshoek formation, Tsumeb sub group |

Water level on 13/9/89 was 5,77 m.

N. Hood 28-9-89.

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BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)
BOREHOLE COMPLETION REPORT (Private Contractor)

Full name of applicant: DEPT van Waterwese
Farm: Driefontein
District: Tsumeb
Borehole site selected by: Geoloog
Borehole No.: 31486
Date of commencement of work: 6-9-89
Date of completion of work: 8-9-87
Give a short description of site of borehole: 3KIT Noordwes van Otavi

B. Geological log

| Depth from surface (metres) | Strata | Thickness (metres) |
|---|---|---|
| 0-30 | Kalkreet | 30 |
| 30-120 | Mikarkris-Dolomiet | 90 |

C. Diameter and depth of borehole: 150 mm from surface to 120 m
Total depth from surface: 120 m

D. Water
1. Depth from surface at which water was struck: 50-60-15
2. Depth from surface to which water rises: 15
3. Yield per second: 35 m³/h
4. Apparent quality of water: Vars.
5. Purpose for which water will be used: Mense en Diere

E. Pumping test: Blanko

F. Borehole costs
Casing: 7 x 150 mm

TOTALE KOSTE
TOTAL COST

E.J. van Zyl
8-07-89
DWS 5045

Windhoek
02-07-89

## BOREHOLE LOG

**WW 31488**

| | |
|---|---|
| 0 - 6 m | Weathered dolomite rubble. |
| 6 m - 21 m | Calcretised weathered dolomite. |
| 21 m - 30 m | Very weathered grey dolomite. |
| 30 m - 57 m | Weathered grey dolomite. |
| 57 m - 60 m | Medium grey dolomite. |
| 60 m - 69 m | Light grey dolomite. |
| 69 m - 81 m | Red brown dolomite, slightly weathered. |
| 81 m - 84 m | Light grey dolomite. |
| 84 m - 95 m | Medium grey dolomite. |
| 95 m - 105 m | Dark grey dolomite. |
| 105 m - 112 m | Rubbly weathered dolomite. |
| 112 m - 120 m | Medium grey dolomite. |

Entire sequence consists of Elandshoek Formation, Tsumeb Sub Group, Otavi Group.

This borehole is on the farm Scott 839.

D. [illegible] 19-12-89

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Verwysing / Reference No. 12/4/2/...

# BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)
# BOREHOLE COMPLETION REPORT (Private Contractor)

Instruction: A separate report to be completed in respect of each borehole.

**A. Algemeen / General**

1. Volle naam van applikant / Full name of applicant: Dept. Waterwese
2. Plaas / Farm: Scott
3. No.:
4. Geologiese terrein No. / Geological site No.:
5. Boorgat No. / Borehole No.: 31488
6. Distrik / District: Tsumeb
7. Boorgatterrein aangewys deur / Boring site selected by: Geoloog
8. Poging / Attempt: 1 X | 2 | 3 | 4
9. Datum van begin van werk / Date of commencement of work: 24-10-89
10. Datum van voltooiing van werk / Date of completion of work: 30-10-89
11. Boring stopped at discretion of: Applikant / Applicant | Inspekteur / Inspector: Geoloog
12. Give a short description of site of borehole: ± 700 meter Suid van Opstal

**B. Geologie / Geology**

| Diepte van oppervlakte (meter) / Depth from surface (metres) | Strata | Dikte / Thickness (metres) |
|---|---|---|
| 0 – 1 | Rooi sand | 1 |
| 1 – 5 | Vaal Bank | 4 |
| 5 – 36 | Bruin Vaal Bank | 31 |
| 36 – 120 | Dolomiet | 84 |

**C. Diameter and depth of borehole**

1. 200 mm from surface to 120 m
2. mm from ... to ... m
3. Totale diepte van oppervlakte af / Total depth from surface: 120 m

**D. Water**

1. Depth from surface at which water was struck: 22 + 72 m
2. Depth from surface to which water rises: 10 m
3. Opbrengs per sekonde / Yield per second: ± 8 ... l
4. Skynbare gehalte van water / Apparent quality of water: Vars
5. Doel waarvoor die water gebruik sal word / Purpose for which water will be used: Mens en Dier

**E. Pomptoets / Pumping test**

1. Inside diameter of pump cylinder
2. Length of stroke
3. Number of strokes per minute
4. Depth to which pump cylinder was lowered
5. Commencement of test: Date
6. Completion of test: Date
7. Duration of test
8. Rest level / Non-flow test

Blaastoets

**F. Boorkoste / Drilling costs**

| | A | C |
|---|---|---|
| 1. ... drilled | | |
| 2. Testing of borehole | | |
| 3. Casing left in borehole on completion: Length 5 x 200 mm | | |
| Perforated: Length | | |
| TOTALE KOSTE / TOTAL COST | | |

**G. Casing**

G.P. Louw

J Brinkman 30-10-84

DWS 5051

[illegible] 10-11-89

Windhoek

1917AA - 98

## BOREHOLE LOG

**WW 31489**

| | |
|---|---|
| 0 - 9 m | Creamy coloured hard pan calcrete powdery nature. |
| 9 m - 15 m | As above but white coloured. |
| 15 m - 51 m | Mixture of red, yellow and light green fine grained calcareous sediments. |
| 51 m - 69 m | Conglomerate - quartz pebbles with some clay bands. |
| 69 m - 72 m | White clay. |
| 72 m - 120 m | Mulden sandstones in a dolomite breccia, with grey, black and light grey coloured fragments. Some graphitic limestone fragments. |

| | |
|---|---|
| 0 - 72 m | Kalahari sequence |
| 72 m - 120 m | Mulden formation, Otavi group |

[signature] 29.9.89

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BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)

BOREHOLE COMPLETION REPORT (Private Contractor)

Instruction: A separate report to be completed in respect of each borehole

**A. General**

1. Full name of applicant: DEPT WATERWESE
2. Farm: DRIEFONTEIN
3. No
4. District: TSUMEB
5. Boring site selected by: GEOLOOG
6. Geological site No
7. Borehole No: 31489
8. Attempt: 1 2 3 4
9. Date of commencement of work: 13-09-89
10. Date of completion of work: 14-09-89
11. Boring stopped at direction of: Applicant / Inspector: Geoloog
12. Give a short description of site of borehole: 1KM WES VAN OPSTAL [?]

**B. Geological Log**

| Depth from surface (metres) | Strata | Thickness (metres) |
|---|---|---|
| 0-6 | Klei met Kalkreet | 6 |
| 6-120 | Kalahari Silkreet | 114 |

**C. Diameter and depth of borehole**

1. 160 mm from surface to 120 m
2. mm from m to m
3. Total depth from surface: 120 m

**D. Water**

1. Depth from surface at which water was struck: 12, 24, 30, 45 m
2. Depth from surface to which water rises: 10 m
3. Yield per second: 24 m³/H [?]
4. Apparent quality of water: Vars
5. Purpose for which water will be used: Mens en Diere

**E. Pumping test**

1. Inside diameter of pump cylinder
2. Length of stroke
3. Number of strokes per minute
4. Depth to which pump cylinder was lowered
5. Commencement of test: Date
6. Completion of test: Date
7. Duration of test
8. After test

BLAASTOETS

**F. Borehole Drilling Costs**

| | A | B |
|---|---|---|
| Casing left in borehole on completion: Plain Length 6 x 180 mm [?] | | |
| Perforated Length | | |
| TOTAL COST | | |

[illegible]

14-09-89 [signature]

DWS 5045

[signature]

28-09-89

Windhoek

141768 - 118

# BOREHOLE LOG

## WW 31490

| | |
|---|---|
| 0 - 3 m | Light grey weathered hard dolomite. |
| 3 m - 12 m | Creamy white powdery weathered dolomite. |
| 12 m - 21 m | Light grey slightly weathered dolomite. |
| 21 m - 24 m | Light grey dolomite. |
| 24 m - 27 m | Medium grey slightly weathered dolomite. |
| 27 m - 39 m | Light grey slightly weathered and oxidised dolomite. |
| 39 m - 96 m | Light grey dolomite, slightly earthy at 60 m - 63 m and 66 m - 69 m. |

Entire sequence consists of Elandshoek Formation, Tsumeb Sub Group, Otavi Group.

Water level on 4.10.89 was 5,95 m.

This borehole is situated on the farm Heibis Ost 290.

N. Lloyd 23.10.89

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# BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)
# BOREHOLE COMPLETION REPORT (Private Contractor)

A. General

1. Full name of applicant: Dept. Waterwese
2. Farm: Hiebis Ost
3. Borehole site selected by: Geoloog
4. District: Tsumeb
7. Borehole No.: 31490
9. Date of commencement of work: 22-9-89
10. Date of completion of work: 25-9-89
11. Boring stopped at direction of: Geoloog
12. Short description of site of borehole: 1 km oos van opstal

B. Geological strata

| Depth from surface (metres) | Strata | Thickness (metres) |
|---|---|---|
| 0 - 12 | Klei, Kalkreet | 12 |
| 12 - 63 | Kalkreet, Dolomiet | 51 |
| 63 - 78 | Graniet | 15 |

C. Depth of borehole

1. 150 mm — 78
3. Total depth from surface: 78

D. Water

1. Depth from surface at which water was struck: 18, 30, 63
2. Depth from surface to which water rose: 10
3. Yield per second: 30 m³/h
4. Apparent quality of water: Vars
5. Purpose for which water will be used: Mens en Dier

E. Pumping test: Blaas toets

F. Casing left in borehole on completion: 18 x 150 mm

E.J. van Zyl
25-9-89
DEVS 5045

25-9-89
Windhoek

1717 BA - 113

# BOREHOLE LOG

## WW 31491

| | |
|---|---|
| 0 - 3 m | Grey powdery calcrete, hard pan variety. |
| 3 m - 6 m | White powdery hard pan calcrete. |
| 6 m - 30 m | Light grey green powdery calcretised fine grained sediments. |
| 30 m - 33 m | Light red grey green fine grained calcareous sediments. Sandy in part. |
| 33 m - 54 m | As above but shale, coloured light grey green. |
| 54 m - 81 m | Mixed Kalahari sediments, shales and sandstones, but fragments of dolomite with or without Hulden? on the fragments. More cherty at base. |
| 81 m - 93 m | Red coloured Hulden quartzites. Some chert fragments, and some white coloured shale. |

| | |
|---|---|
| 0 - 81 m | Kalahari Sequence. |
| 81 m - 93 m | Hulden. |

Water level on 4/10/89 was 9,09 m.

Borehole situated on farm Ons Hoop 847.

N. Hood 23.10.89

# BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)
# BOREHOLE COMPLETION REPORT (Private Contractor)

(Government Notice R. 34 of 14 January 1966 as amended)

Instruction: A separate report to be completed in respect of each borehole

**A Algemeen/General**

1. Volle naam van applikant / Full name of applicant: Dept. Waterwese
2. Plaas / Farm: Ons Hoop
3. No.
4. Distrik / District: Tsumeb
5. Boorplek gekies deur / Boring site selected by: Geoloog
6. Geologiese terrein No. / Geological site No.
7. Boorgat No. / Borehole No.: 31491
8. Poging / Attempt: 1 | 2 X | 3 | 4
9. Datum van begin van werk / Date of commencement of work: 18/9/89
10. Datum van voltooiing van werk / Date of completion of work: 21/9/89
11. Boorwerk gestaak na goedkeuring van / Boring stopped at discretion of: Applikant / Applicant: geoloog / Inspekteur / Inspector
12. Give a short description of site of borehole (e.g. 100 metres north-west of dwelling house): 1 Kilo wes van up stal

**B Geologiese/Geology**

| Diepte van oppervlakte (meter) / Depth from surface (metres) | Strata | Dikte / Thickness |
|---|---|---|
| 0 - 30 | Kalklaag met klip | 30 |
| 30 - 66 | Kalklaag los klip | 36 |
| 66 - 81 | Los Spoel Klip | 15 |
| 81 - 93 | Rooi Sand Steen hard | 12 |
| | | 93 |

Casing sketch annotations: 16 m Plain; 15 m 3 m PE; PL; PE; PL; 6 m PE; PL

**C**

1. 8" from surface to 81
2. 6" from 81 to 93

Total depth from surface: 93

**D Water**

1. Depth from surface at which water was struck: 18, 24, 80
2. Depth from surface to which water rose: 10
3. Opbrengs per sekonde / Yield per second: 3 Gell 24 K
4. Apparent quality of water: Vars
5. Purpose for which water will be used

**E Pomptoets/Pumping test**: Blaas toets

**F**

3. Casing left in borehole on completion: (a) Length 81 m 3200 m

TOTALE KOSTE / TOTAL COST

**G Voering/Casing**

If borehole is unsuccessful please state whether casing is recoverable or left in borehole at request of applicant: 81 m 8" Staal

Voering in gat gelaat.

**H Declaration by boring contractor and boring inspector**: I declare that the information supplied above is true and correct.

Handtekening van boorkontrakteur / Signature of boring contractor: [signature]

Datum / Date: 21/9/89

Adres / Address: Boorafdeling Waterwese. DWS 5045

Handtekening van boorinspekteur / Signature of boring inspector: [signature]

Datum / Date: 29-09-89

Inspektoraat / Inspectorate: Windhoek

## BOREHOLE LOG

WW 31501

| | |
|---|---|
| 0 - 12 m | Calcrete and weathered Mulden. |
| 12 m - 54 m | Mulden formation consisting of yellow brown sandstone and light grey hard quartzite. |
| 54 m - 90 m | Medium grey coloured dolomite. Dark coloured zone at 78 m. |
| 90 m - 110 m | Cavernous. No samples. |

This borehole is situated on the farm Uris 481 (commonly refered to as Tschudi)

Water level was 86,0 m.

20.03 '90

## BOORGATVOLTOOIINGSVERSLAG (Private Boorkontrakteur)
## BOREHOLE COMPLETION REPORT (Private Contractor)

Volle naam van applikant / Full name of applicant: Water Wese

Plaas / Farm: TSCHUDI

Datum van voltooiing van werk / Date of completion of work: 19-01-1990

| Depth from surface (metres) | Strata | |
|---|---|---|
| 0 – 60 | Los Kalmasie | 60 |
| 60 – 90 | Dolomiet | 30 |
| 90 – 110 | Geen boorsel nie | 20 |
| | | 110 |

B/GAT HET OP 86 m GROTE GEGEE WAARNA WATER WEG WAS. SODAT LEWERING NIE GEMEET KON WORD NIE.

Datum / Date: 20-01-1990

Verwysing No. / Reference No. 12/4/2/...

# BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)
# BOREHOLE COMPLETION REPORT (Private Contractor)

A. Algemeen/General

1. Volle naam van applikant / Full name of applicant: DEPT WATERWESE
2. Plaas / Farm: GRASVLAKTE — 3. No — 4. Distrik / District: TSUMEB
5. Boorplek aangewys deur / Boring site selected by: GEOLOOG — 6. Geologiese lêer No. / Geological file No. — 7. Boorgat No. / Borehole No.: 31510
8. Pogings / Attempts: 1 / 2 / 3 / 4 — 9. Datum van begin van werk / Date of commencement of work: 14-10-87
10. Datum van voltooiing van werk / Date of completion of work: 14-10-87 — 11. Boorwerk gestaak na goeddunke van / Boring stopped at discretion of: Applikant / Applicant: GEOLOOG; Inspekteur / Inspector
12. Give a short description of site of borehole: 1 KM WES VAN OPSTAL

B. Geologiese Gesteentes

| Diepte van oppervlakte (meter) / Depth from surface (metres) | Strata | Dikte / Thickness (metres) |
|---|---|---|
| 0 - 6 | KALKREET + KLEI | 6 |
| 6 - 54 | KALKREET | 48 |
| 54 - 90 | HARDE BANK | 36 |

C. Diameter en diepte van boorgat / Diameter and depth of borehole

1. 150 mm van oppervlakte af tot op / mm from surface to 90 m
2. mm van / mm from ... m af tot op / m to ... m
3. Totale diepte van oppervlakte af / Total depth from surface: 90 m

D. Water

1. Diepte van oppervlakte af waarop water getref is / Depth from surface at which water was struck: 54 m
2. Diepte van oppervlakte af tot waar water styg / Depth from surface to which water rises: m
3. Opbrengs per sekonde / Yield per second: ± 1 ... ℓ
4. Skynbare gehalte van water / Apparent quality of water: VARS
5. Doel waarvoor die water gebruik sal word / Purpose for which water will be used:

E. Pomptoets/Pumping test

1. Binnedeursnee van pompsilinder / Inside diameter of pump cylinder: mm
2. Lengte van slag / Length of stroke: mm
3. Getal slae per minuut / Number of strokes per minute
4. Diepte waarop pompsilinder geplaas was / Depth to which pump cylinder was inserted: m
5. Begin van toets / Commencement of test: Datum / Date; tyd / time
6. Voltooiing van toets / Completion of test: Datum / Date; tyd / time
7. Duur van toets / Duration of test: hours
8. Tenk gevul in / tank filled in

BLAAS TOETS

F. Boorkoste/Boring cost

| | R | c |
|---|---|---|
| 1. Boring per m | | |
| 2. Toets van boorgat / Testing of borehole | | |
| 3. Voering in boorgat gelaat na voltooiing / Casing left in borehole on completion: Lengte / Length 6 x 150 mm | | |
| TOTALE KOSTE / TOTAL COST | | |

G. Verklaring / Declaration

E.J. van Zyl — 14-10-87 — DWS 5045

[signature] — 23-10-84 — Windhoek

BOREHOLE LOG

WW 31510

| | |
|---|---|
| 0 - 6 m | Creamy coloured hard calcrete. |
| 6 m - 30 m | Fine grained kalahari sediments pale cream [illegible] colour. Powdery nature. |
| 30 m - 54 m | Assorted dolomite fragments in a red coloured [illegible] gritty to clay matrix. |
| 54 m - 90 m | Black clean massive dolomite. |

Water level unknown due to oil in hole.

This borehole is situated on the farm Grasvlakte 457.

N. Hood 12/10/87

# APPENDIX 3.

Borehole completion forms and Geological borehole logs for the Kalahari aquifer.

SWA 182
Boring 1

# SUIDWES-AFRIKA – SOUTH WEST AFRICA

AFDELING WATERWESE — WATER AFFAIRS BRANCH

MOET INGEDIEN WORD IN TRIPLIKAAT/TO BE RENDERED IN TRIPLICATE

Acacia BEISEB

* Eerste — First
* Tweede — Second
* Derde — Third

Seksie van en Watervoorraad uit Boorgat Nr / Section of and Water Supply from Borehole No. 8155

Plaas / Farm Etosha Panne Nr / No. Distrik / District Outjo.

Naam of beskrywing van Boorplek / Name or description of Site Stark se Vlakte

Datum van aanvang van werk / Date of commencement of work

Datum van voltooiing van werk / Date of completion of work 6/4/63

| Diepte vanaf Opperv. / Depth from Surface | Seksie / Section | Formasie / Strata |
|---|---|---|
| 10 | 10 | Opp. kalk met kwarts-gruis. |
| 20 | 10 | Bros grys tot ligbruin kalkgesementeerde sandsteen met enkele fyn digte gesilifiseerde sandsteen brokkies. |
| 30 | 10 | Ditto. |
| 40 | 10 | ditto, + Liggroen modderstseen. |
| 50 | 10 | ditto (kalkgesementeerde sandsteen neig na gruis. |
| 60 | 10 | Uitsluitlik bros lig-bruin kalkgesementeerde of gesilifiseerde sandsteen. |
| 75 | 15 | ditto. |
| 95 | 20 | Skynbaar sagte lig-kleurige sandsteen (Heel fyn gestamp) |
| 198 | 102 | Wit sagte sandsteen |
| 206 | 8 | Liggroen tot bruin moddersteen. |
| 250 | 44 | Bros liggroenblou moddersteen met heel-wat kwartsgruis |

DEURSNY EN DIEPTE VAN BOORGAT / DIAMETER AND DEPTH OF BOREHOLE

10, 8 duim vanaf oppervlakte tot / inches from surface to 130 – 133 voet / feet

6, 5 duim vanaf / inches from 133 / 238 voet tot / feet to 238 / 270 voet / feet

Totale diepte vanaf oppervlakte / Total depth from surface 270 voet / feet

POMPPROEFNEMING / PUMPING TEST

Met *Pomp *Bailer of *Suier / By *Pump *Bailer or *Syphon

Binnediameter van pompsilinder / Inside diameter of pump cylinder

Lengte van slag / Length of stroke

Aantal slae per minuut / Number of strokes per minute ARTESIES.

Diepte waarin pompsilinder geplaas was / Depth to which pump cylinder was inserted

Begin van proefneming: Datum uur / Commencement of test: Date hour

Voltooiing van proefneming: Datum uur / Completion of test: Date hour

Totale duur van proefneming / Total time testing ure / hours

Sout water gekry vanaf 45'–50' afgeseel op 133'

Diepte vanaf oppervlakte waar water getref was / depth from surface at which water was struck 270 voet / feet

Diepte vanaf oppervlakte waartoe water styg / Depth from surface to which water rises 1320 g.p.h.

Beraamde hoeveelheid per 24 uur / Estimated yield per 24 hours 320 vloei gelling / gallons

Is voorraad permanent of nie / Is yield considered permanent? Ja

Algemene kwaliteit van water / Apparent quality of water vars.

Doel waarvoor die water gebruik sal word / Purpose for which water will be used Wild.

VOERING NAGELAAT IN BOORGAT NA VOLTOOIING / CASING LEFT IN BOREHOLE ON COMPLETION

Gewoon / Plain — Lengte / Length 10, 8 — Deursny / Diameter 130, 133, 238 en 266.

Deurgeboorde / Perforated — Lengte / Length 6,5 — Deursny / Diameter

Boorterrein aangewys deur / Boring site selected by Geoloog.

Boordery gestaak na goeddunke (of op versoek) van / Boring stopped at discretion (or request) of Kitt

Voorman / Foreman G. M. Visser.

Boor Nr / Drill No. Datum / Date

Ek sertifiseer dat bovermelde besonderhede korrek is en dat die boorgat ooreenkomstig die Boorkontrak voltooi is
I certify that the above particulars are correct and that the Borehole has been completed in accordance with the Boring Contract

Datum / Date 6/4/63 — E. du Plessis — Boorinspekteur / Boring Inspector

*Skrap nie-toepaslike woorde — *Delete remarks inapplicable

SOB 135-8-61

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SWA 182
Boring 2

# SUIDWES-AFRIKA – SOUTH WEST AFRICA

AFDELING WATERWESE — WATER AFFAIRS BRANCH

MOET INGEDIEN WORD IN TRIPLIKAAT/TO BE RENDERED IN TRIPLICATE

* Eerste — First
* Tweede — Second
* Derde — Third

Seksie van en Watervoorraad uit Boorgat Nr / Section of and Water Supply from Borehole No. 8155

Plaas / Farm Etosha Panne Nr / No. Distrik / District Outjo.

Naam of beskrywing van Boorplek / Name or description of Site Stark se Vlakte

Datum van aanvang van werk / Date of commencement of work

Datum van voltooiing van werk / Date of completion of work 6/4/63.

| Diepte vanaf Opperv. / Depth from Surface | Seksie / Section | Formasie / Strata |
|---|---|---|
| 260 | 10 | Kalk en silikagesementeerde sandsteen |
| 274 | 14 | Bros ligbruin sanderige kalksteen. |
| | | S. A. de Waal. |
| | | 18/4/63. |

DEURSNY EN DIEPTE VAN BOORGAT / DIAMETER AND DEPTH OF BOREHOLE

duim vanaf oppervlakte tot / inches from surface to voet / feet

duim vanaf / inches from voet tot / feet to voet / feet

Totale diepte vanaf oppervlakte / Total depth from surface voet / feet duim / inches

POMPPROEFNEMING / PUMPING TEST

Met *Pomp *Bailer of *Suier / By *Pump *Bailer or *Syphon

Binnediameter van pompsilinder / Inside diameter of pump cylinder

Lengte van slag / Length of stroke

Aantal slae per minuut / Number of strokes per minute

Diepte waarin pompsilinder geplaas was / Depth to which pump cylinder was inserted

Begin van proefneming: Datum uur / Commencement of test: Date hour

Voltooiing van proefneming: Datum uur / Completion of test: Date hour

Totale duur van proefneming / Total time testing ure / hours

WATER

Diepte vanaf oppervlakte waar water getref was / depth from surface at which water was struck voet / feet

Diepte vanaf oppervlakte waartoe water styg / Depth from surface to which water rises voet / feet

Beraamde hoeveelheid per 24 uur / Estimated yield per 24 hours gellings / gallons

Is voorraad permanent of nie / Is yield considered permanent?

Algemene kwaliteit van water / Apparent quality of water

Doel waarvoor die water gebruik sal word / Purpose for which water will be used

VOERING NAGELAAT IN BOORGAT NA VOLTOOIING / CASING LEFT IN BOREHOLE ON COMPLETION

Gewoon / Plain — Lengte / Length — Deursny / Diameter

Deurgeboorde / Perforated — Lengte / Length — Deursny / Diameter

Boorterrein aangewys deur / Boring site selected by

Boordery gestaak na goeddunke (of op versoek) van / Boring stopped at discretion (or request) of

Voorman / Foreman

Boor Nr / Drill No. Datum / Date

Ek sertifiseer dat bovermelde besonderhede korrek is en dat die boorgat ooreenkomstig die Boorkontrak voltooi is
I certify that the above particulars are correct and that the Borehole has been completed in accordance with the Boring Contract

Datum / Date — Boorinspekteur / Boring Inspector

*Skrap nie-toepaslike woorde — *Delete remarks inapplicable

SOB 135-8-61

BOORGAT VOLTOOIINGSVERSLAG (Privaat Kontrakteur)
BOREHOLE COMPLETION REPORT (Private Contractor)

Instruksie: 'n Afsonderlike verslag moet vir elke boorgat voltooi word.
Instruction: A separate report to be completed in respect of each borehole.

A. Algemeen/General

1. Volle naam van applikant / Full name of applicant: S.W.A.R. Dept van Waterwese
2. Plaas / Farm: O'SHIVELO  3. No. ...  4. Distrik / District: [illegible]
5. Boorterrein aangewys deur / Boring site selected by ...  6. Geologiese terrein No. / Geological site No. ...  7. Boorgat No. / Borehole No.: 16003
8. Poging / Attempt*: 1 X | 2 | 3 | 4  9. Datum van begin van werk / Date of commencement of work: 26.4.76
10. Datum van voltooiing van werk / Date of completion of work: 7-9-76  11. Boorwerk gestaak na goeddunke van* / Boring stopped at discretion of: Applikant / Applicant: | Inspekteur / Inspector:
12. Gee 'n kort beskrywing van ligging van boorgat (bv. 100 meter noordwes van woonhuis) / Give a short description of site of borehole (e.g. 100 metre north-west of dwelling-house): 400 m N/O. van Pomphuis
* Merk toepaslike blok met 'n kruis/Mark applicable block with a cross.

B. Grondlae/Geology

| Diepte van oppervlakte af / Depth from surface | Seksie / Section | Strata |
|---|---|---|
| 0 - 42 | 42 | SAND |
| 42 - 50 | 8 | SKALIE |
| 50 - 67 | 17 | SAND |
| 67 - 67.50 | .50 | SKALIE |
| 67.50 - 73.50 | 6 | GRUISLAAG |

Geen verandering in W.R.L. gedurende toets

VOERING IN BOORGAT:

= 35 m X 300 mm
= 69 m X 250 mm
0 - 69 m X 200 mm
69 - 73 m X 200 mm FILTERS
73 - 73.50 m X 200 mm PLAIN

C. Deursnee en diepte van boorgat/Diameter and depth of borehole

1. 300 mm van oppervlakte af tot op / mm from surface to 73.50 m
2. ... mm van / mm from ... m af tot op / m to ... m
3. Totale diepte van oppervlakte af / Total depth from surface: 73.50 m

D. Water

1. Diepte van oppervlakte af waarop water gevind is / Depth from surface at which water was struck: 71 m
2. Diepte van oppervlakte af tot waar water styg / Depth from surface to which water rises: Artesies
3. Opbrengs per sekonde / Yield per second: ± 5000 Liter per uur
4. Skynbare gehalte van water / Apparent quality of water: Goed.
5. Doel waarvoor die water gebruik sal word / Purpose for which water will be used: Algemeen

E. Pomptoets/Pump test

1. Binnedeursnee van pompsilinder / Inside diameter of pump cylinder: 3¾" mm
2. Lengte van slag / Length of stroke: 7.5" mm
3. Getal slae per minuut / Number of strokes per minute: 35
4. Diepte waarop pompsilinder geplaas was / Depth to which pump cylinder was inserted: 60 m
5. Begin van toets / Commencement of test: Datum / Date 3.9.76 tyd / time 14h00
6. Voltooiing van toets / Completion of test: Datum / Date 3.9.76 tyd / time 17h00
7. Duur van toets / Duration of test: 3 uur / hours
8. Negeuur toets / Nine-hour test: liter tenk gevul in / litre tank filled in [illegible] min.

L.W. 'n Skepletoets is nie aanvaarbaar nie/N.B. A bailer test will not be acceptable

F. Boorkoste/Drilling costs

| | R | c |
|---|---|---|
| 1. m geboor @ ... per m / m drilled @ ... per m | | |
| 2. Toets van boorgat / Testing of borehole | | |
| 3. Voering in boorgat gelaat na voltooiing / Casing left in borehole on completion: (a) Gewoon / Plain: Lengte / Length ... m @ ... per m | | |
| (b) Geperforeer / Perforated: Lengte / Length ... m @ ... per m | | |
| TOTALE KOSTE / TOTAL COST | 6013 | 13 |

G. Voering/Casing

Indien boorgat onsuksesvol is, meld of voering nie herwin kan word nie of op versoek van applikant in boorgat gelaat is
If borehole is unsuccessful please state whether casing is irrecoverable or left in borehole at request of applicant

L.W. Voering wat in onsuksesvolle gate gelaat word is nie subsidieerbaar nie/N.B. Casing left in unsuccessful boreholes is not subsidisable.

H. Verklaring deur boorkontrakteur en boorinspekteur: Ek verklaar dat die inligting hierbo verstrek waar en juis is.
Declaration by boring contractor and boring inspector: I declare that the information supplied above is true and correct.

Handtekening van boorkontrakteur / Signature of boring contractor: [signature]
Datum / Date: 7/9/76
Adres / Address: P/S 13193 Windhoek.

Handtekening van boorinspekteur / Signature of boring inspector: [signature]
Datum / Date: 7-9-76
Inspektoraat / Inspectorate: Windhoek

L.W. Sien keersy vir verklaring en onderneming deur applikant/N.B. See reverse side for declaration and undertaking by applicant.

BOREHOLE LOG

WW 32617

| | | |
|---|---|---|
| 0 | – 5 m | Black turf |
| 5 m | – 36 m | Light green coloured gritty calcareous sandstone, soft and friable |
| 36 m | – 54 m | Greeny brown fine grained soft sandstone |
| 54 m | – 58 m | Green clay |
| 58 m | – 90 m | Light green fine grained sandstone |
| 90 m | – 96 m | Grey fine sandstone with calcrete grit fragments. |
| 96 m | – 108 m | Green clay with calcrete grit fragments |
| 108 m | – 120 m | Light greeny yellow small pebble conglomerate. Clasts of quartz, calcite and dolomite in a fine sand matrix. |
| 120 m | – 123 m | Brown sandstone |
| 123 m | – 126 m | Large pebble conglomerate. Clasts of quartz chert and dolomite |
| 126 m | – 144 m | Soft red brown sand. Some layers of a coarse quartz grit, some thin clay layers |
| 144 m | – 150 m | Very small pebble conglomerate and sandstones red brown and green coloured in a sandy matrix. |

This borehole is situated in Owambo, 13 kms north north east of Oshivelo.

The water was struck from 109 to 120 m.

Water level is approximately 10 m.

The aquifer is considered to be the Oshivelo Artesian Aquifer.

D. Umel
02.10.90

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BOORGATVOLTOOIINGSVERSLAG (Privaat Kontrakteur)
BOREHOLE COMPLETION REPORT (Private Contractor)

(Goewermentskennisgewing R. 74 van 14 Januarie 1966, soos gewysig)
(Government Notice R. 74 of 14 January 1966, as amended)

Instruksie: 'n Afsonderlike verslag moet vir elke boorgat voltooi word
Instruction: A separate report to be completed in respect of each borehole

A. Algemeen/General

1. Volle naam van applikant / Full name of applicant: Dept van Waterwese
2. Plaas / Farm: Oshivelo
3. No.: –
5. Boorgatterrein aangewys deur / Boring site selected by: Geoloog
6. Geologiese terrein No. / Geological site No.
7. Boorgat No. / Borehole No.: 32617
8. Poging / Attempt: 1 | 2 | 3 | 4
9. Datum van begin van werk / Date of commencement of work: 12/7/90
10. Datum van voltooiing van werk / Date of completion of work: 26/7/90
11. Boorwerk gestaak na goeddunke van / Boring stopped at discretion of: Applikant / Applicant | Kontrakteur / Contractor
12. Gee 'n kort beskrywing van ligging van boorgat (bv. 100 meter noordwes van woonhuis) / Give a short description of site of borehole (e.g. 100 metres north west of dwelling-house): 10 Km oos van Oshivelo; 12 Kilometer ... Strate
* Merk toepaslike blok met 'n kruis/Mark applicable block with a cross

B. Geologiese besonderhede

| Diepte van oppervlakte (meter) / Depth from surface (metres) | Strata | Dikte / Thickness (meter/metres) |
|---|---|---|
| 0 – 12 | Sand met Klei | 12 |
| 12 – 54 | Los laag ... sand | 42 |
| 54 – 60 | Kalkblok | 10 |
| 60 – 92 | Groen Klei | 32 |
| 92 – 150 | Sand met Klei | 58 |
| | | 150 |

C.
1. 20392
2. 264

Totale diepte van oppervlakte af / Total depth from surface

D. Water
1. Diepte van oppervlakte af waarop water aangetref is / Depth from surface at which water was struck
2. Diepte van oppervlakte af tot watervlak / Depth from surface to water level
3. Opbrengs per sekonde / Yield per second
4. Skynbare gehalte van water / Apparent quality of water
5. Doel waarvoor die water gebruik sal word / Purpose for which water will be used

E. Pomptoets/Pumping test
1. Binnedeursnee van pompsilinder / Inside diameter of pump cylinder
2. Lengte van slag / Length of stroke
3. Getal slae per minuut / Number of strokes per minute
4. Diepte waarop pompsilinder geplaas was / Depth to which pump cylinder was lowered
5. Begin van toets / Commencement of test: Datum / Date
6. Voltooiing van toets / Completion of test: Datum / Date
7. Duur van toets / Duration of test
8. Nege uur toets / Nine hour test

G. Voering/Casing

Indien boorgat onsuksesvol is, meld of voering uit herwin kan word en of op versoek van applikant in boorgat gelaat is
If borehole is unsuccessful please state whether casing is unrecoverable or left in borehole at request of applicant

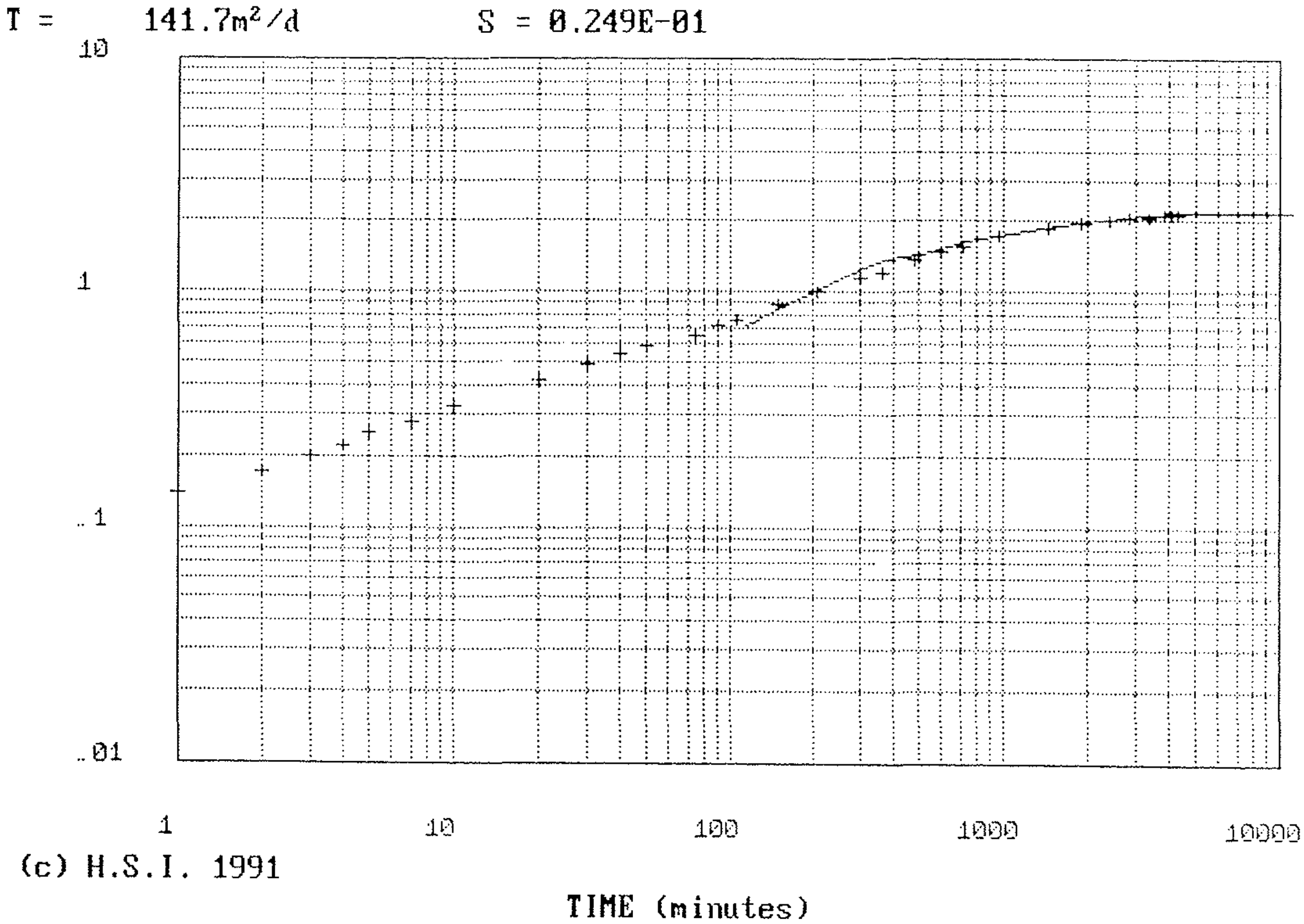
H. Verklaring deur boorkontrakteur en boorinspekteur / Declaration by boring contractor and boring inspector: Ek verklaar dat die inligting hierbo verstrek waar en juis is / I declare that the information supplied above is true and correct

Handtekening van boorkontrakteur / Signature of boring contractor:
Datum / Date: 26/7/90
Adres / Address: Dept van Waterwese DWS 5051

Handtekening van boorinspekteur / Signature of boring inspector:
Datum / Date:
Inspektoraat / Inspectorate:

# APPENDIX 4.

Test Pumping results from the Damara carbonate aquifer.



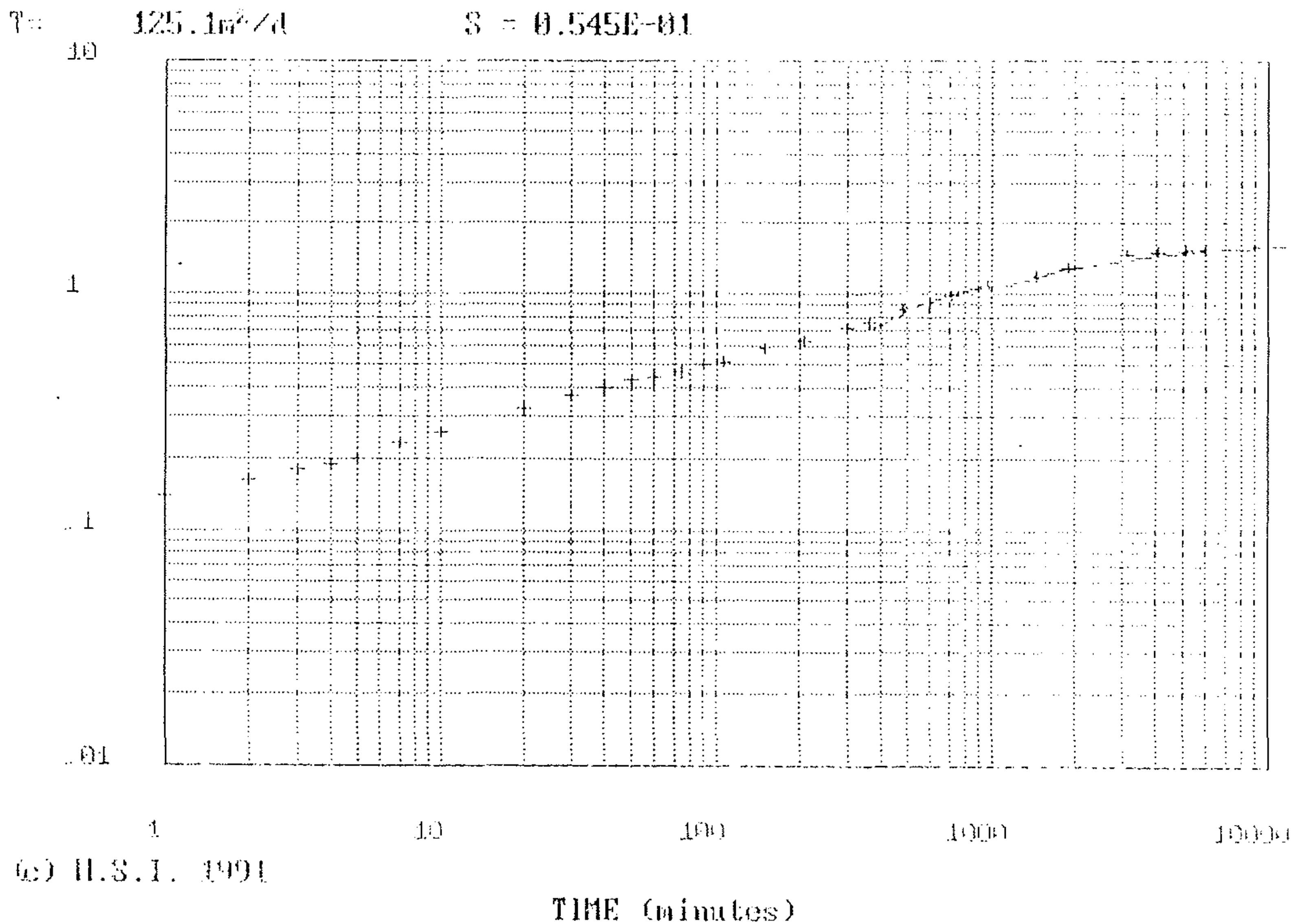

**Test Pump 1.** Test pump of WW 30897, as recorded in observation borehole WW 30896, situated 20 m away. Pumping rate 12.78 l/s. Test duration 72 hours.

| TEST PUMP OF WW 30897, AS RECORDED IN OBSERVATION BOREHOLE WW 30896, 20 m AWAY. PUMPING RATE 12.78 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 0.14 | 50 | 0.59 | 720 | 1.56 |
| 2 | 0.17 | 75 | 0.65 | 960 | 1.71 |
| 3 | 0.20 | 90 | 0.72 | 1440 | 1.86 |
| 4 | 0.22 | 105 | 0.76 | 1920 | 1.95 |
| 5 | 0.25 | 150 | 0.89 | 2400 | 2.02 |
| 7 | 0.28 | 210 | 1.00 | 2880 | 2.06 |
| 10 | 0.32 | 300 | 1.14 | 3360 | 2.08 |
| 20 | 0.42 | 360 | 1.21 | 3840 | 2.12 |
| 30 | 0.49 | 480 | 1.36 | 4080 | 2.13 |
| 40 | 0.54 | 600 | 1.47 | 4320 | 2.14 |

DATA SHEET TO ACCOMPANY TEST PUMP 1.

| TEST PUMP OF WW 30897, AS RECORDED IN OBSERVATION BOREHOLE WW 30898, 156 m AWAY. PUMPING RATE 12.78 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 120 | 0.01 | 960 | 0.27 | 3360 | 0.76 |
| 150 | 0.02 | 1200 | 0.35 | 3600 | 0.79 |
| 180 | 0.03 | 1440 | 0.40 | 3840 | 0.82 |
| 210 | 0.03 | 1680 | 0.46 | 4080 | 0.84 |
| 240 | 0.04 | 1920 | 0.51 | 4320 | 0.87 |
| 300 | 0.05 | 2160 | 0.56 | | |
| 360 | 0.06 | 2400 | 0.61 | | |
| 480 | 0.10 | 2640 | 0.65 | | |
| 600 | 0.14 | 2880 | 0.69 | | |
| 720 | 0.18 | 3120 | 0.72 | | |

DATA SHEET TO ACCOMPANY TEST PUMP 2.

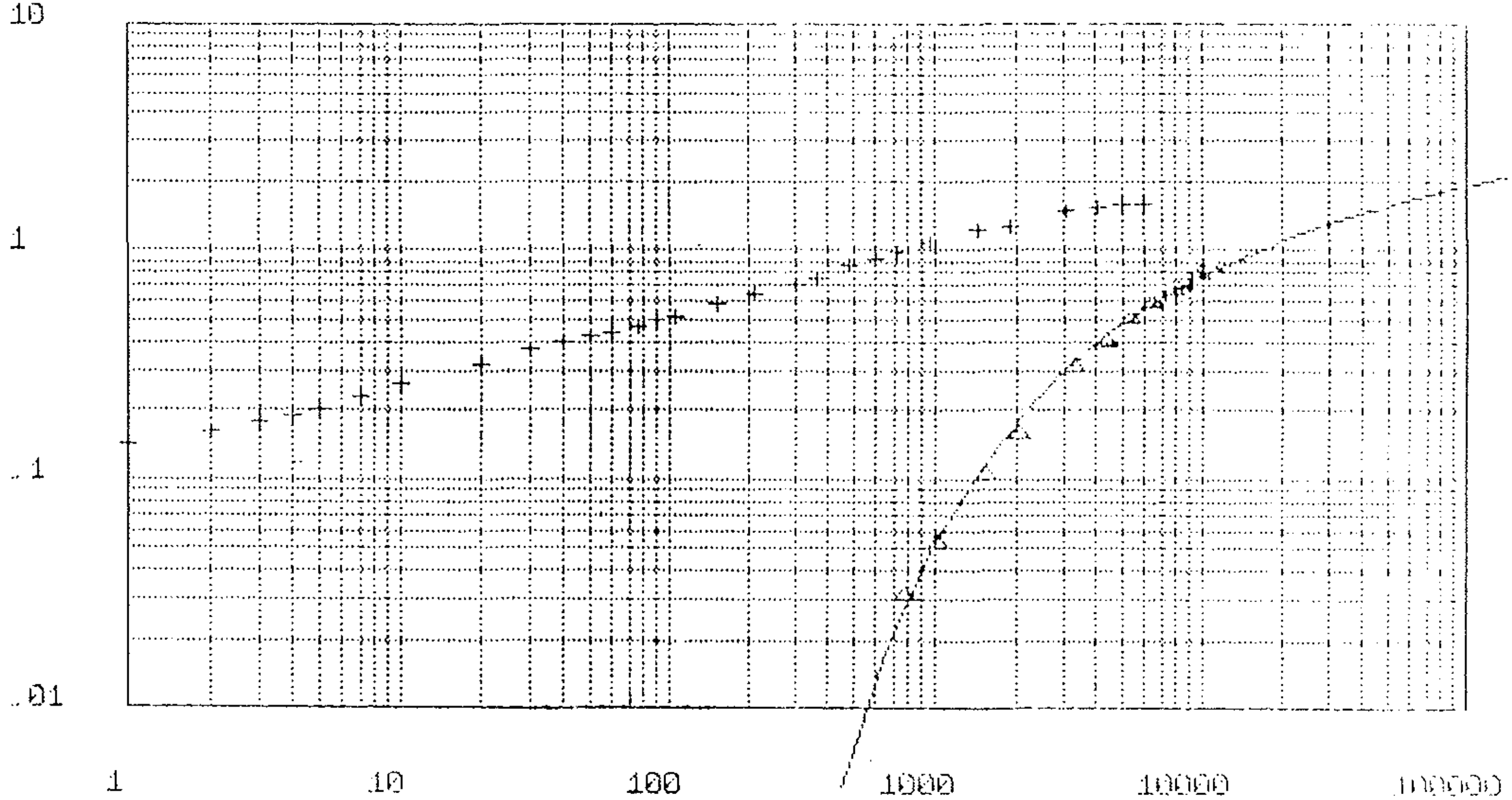



**Test Pump 3.** Test pump of WW 30897, as recorded in observation borehole WW 30896, situated 20 m away. Pumping rate 8.34 l/s. Test duration 168 hours.

| TEST PUMP OF WW 30897 AS RECORDED IN OBSERVATION BOREHOLE WW 30896, 20 m AWAY. PUMPING RATE 8.34 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 0.14 | 50 | 0.43 | 600 | 0.86 |
| 2 | 0.16 | 60 | 0.44 | 720 | 0.98 |
| 3 | 0.18 | 75 | 0.47 | 960 | 1.08 |
| 4 | 0.19 | 90 | 0.50 | 1440 | 1.22 |
| 5 | 0.20 | 105 | 0.52 | 1920 | 1.29 |
| 7 | 0.23 | 150 | 0.58 | 3120 | 1.47 |
| 10 | 0.26 | 210 | 0.64 | 4080 | 1.54 |
| 20 | 0.32 | 300 | 0.72 | 5040 | 1.57 |
| 30 | 0.37 | 360 | 0.76 | 6000 | 1.58 |
| 40 | 0.40 | 480 | 0.86 | | |

DATA SHEET TO ACCOMPANY TEST PUMP 3.

T = 110.7m²/d S = 0.227E-01



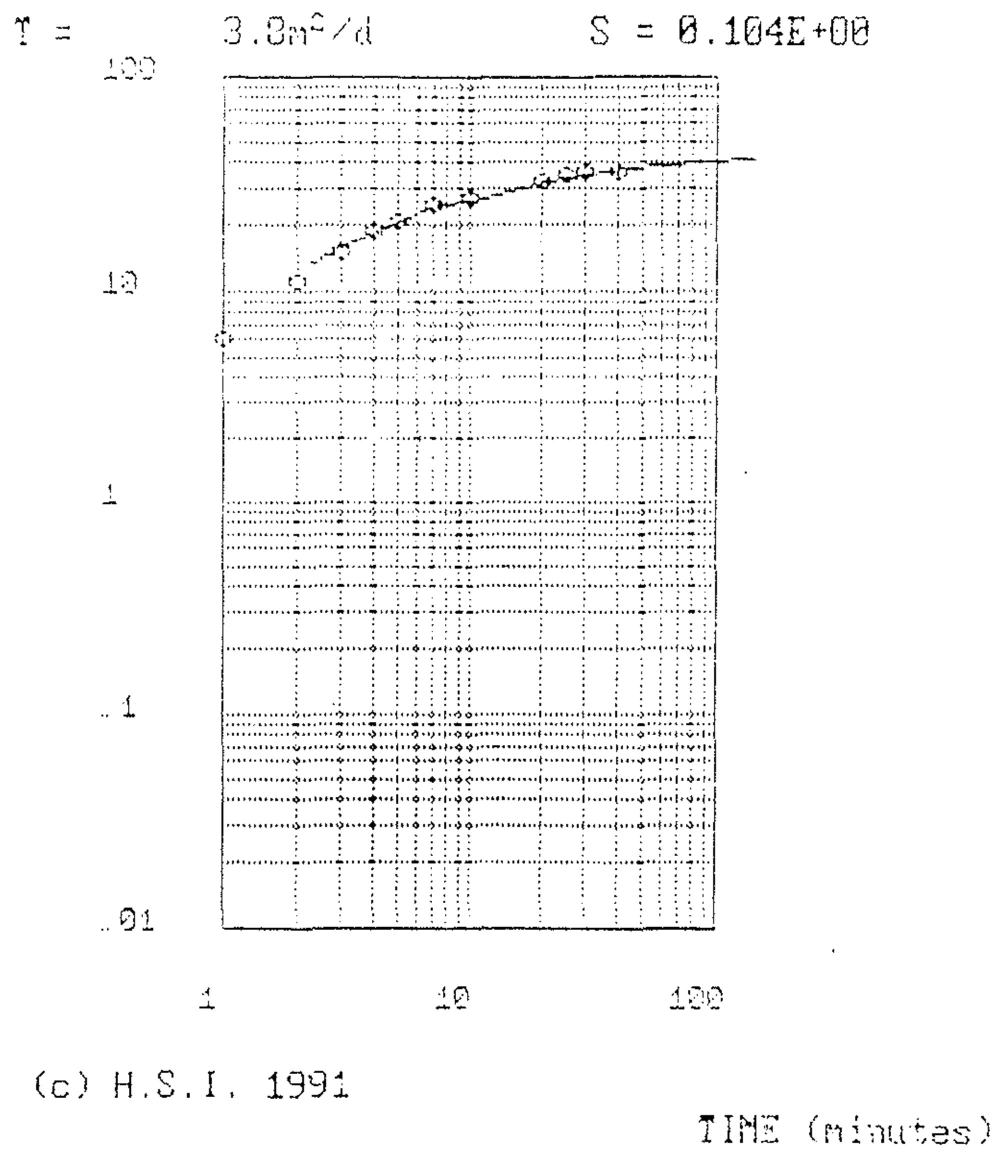

(c) H.S.I. 1991

TIME (minutes)

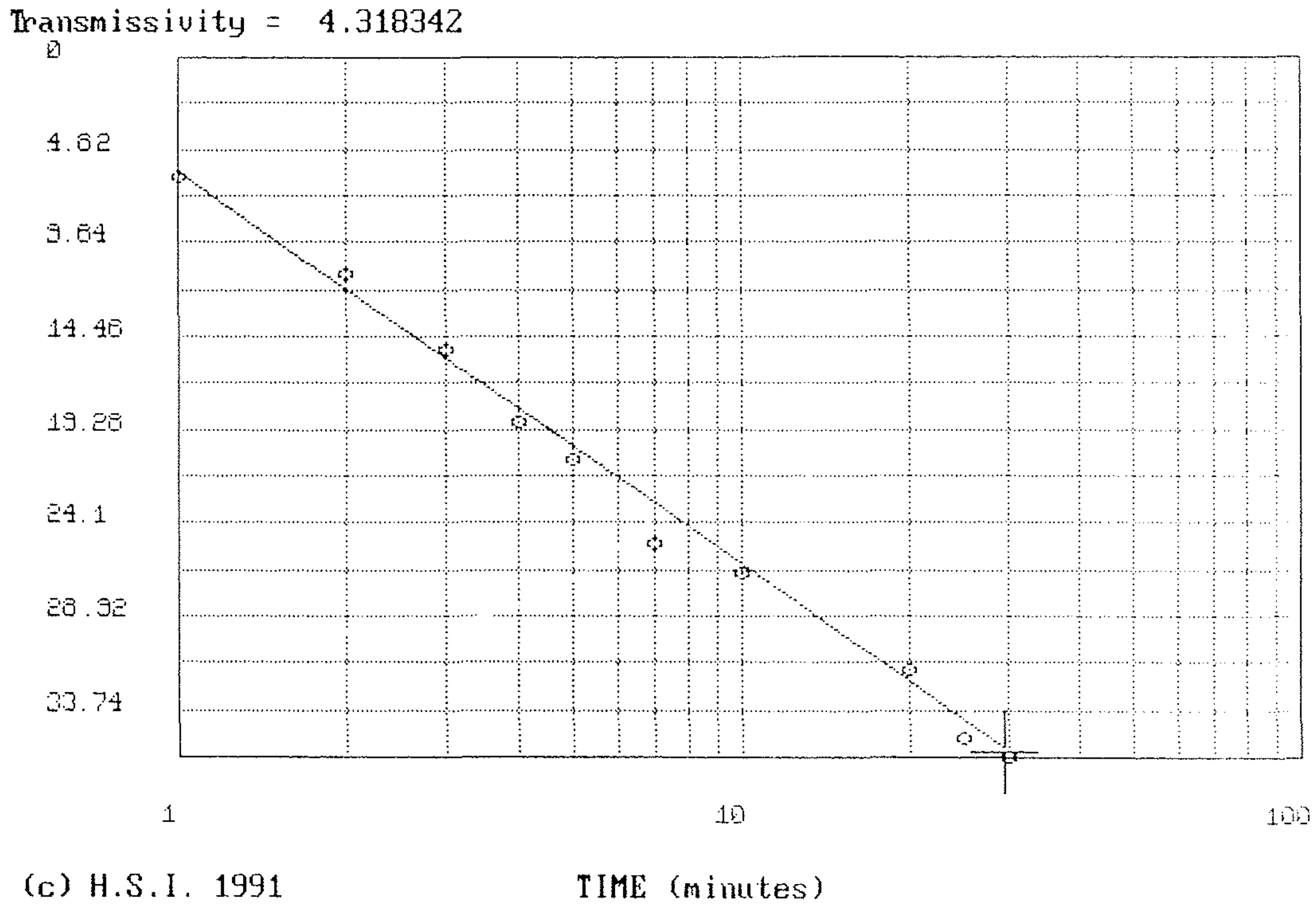
**Test Pump 4.** Test pump of WW 30897, as recorded in observation borehole WW 30898, situated 156 m away. Pumping rate 8.34 l/s. Test duration 168 hours.

| TEST PUMP OF WW 30897 AS RECORDED IN OBSERVATION BOREHOLE WW 30898, 156 m AWAY. PUMPING RATE 8.34 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 360 | 0.0 | 6000 | 0.57 | | |
| 480 | 0.01 | 7200 | 0.64 | | |
| 600 | 0.01 | 7920 | 0.69 | | |
| 720 | 0.03 | 9120 | 0.75 | | |
| 1440 | 0.10 | 10080 | 0.80 | | |
| 1680 | 0.12 | | | | |
| 1920 | 0.15 | | | | |
| 2880 | 0.27 | | | | |
| 3600 | 0.35 | | | | |
| 5040 | 0.49 | | | | |

DATA SHEET TO ACCOMPANY TEST PUMP 4.



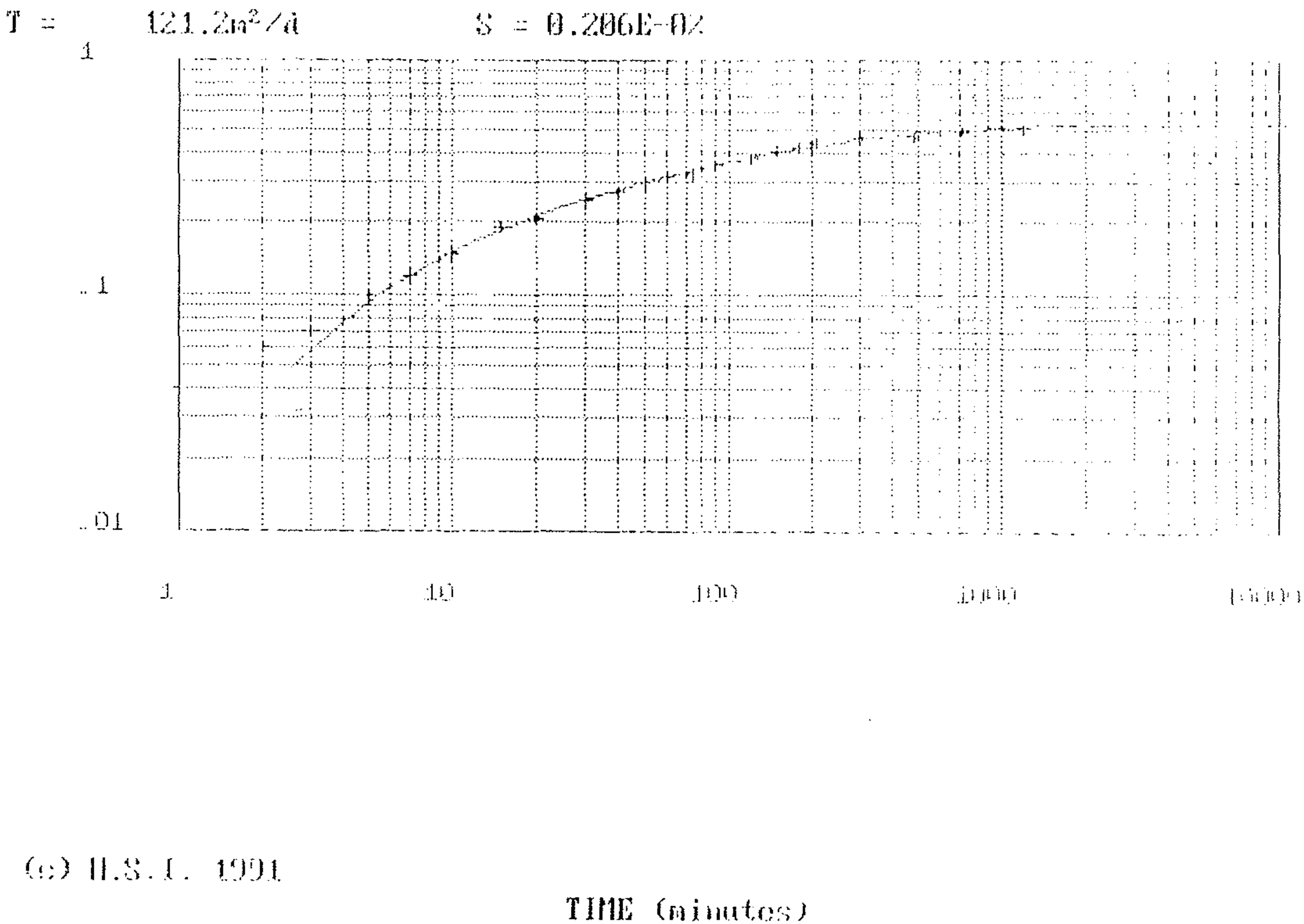

**Test Pump 5.** Test pump of WW 31486, as recorded in pumping well. Pumping rate 5.55 l/s. Test duration 72 hours.




**Test Pump 5.** Test pump of WW 31486, as recorded in pumping well. Pumping rate 5.55 l/s. Test duration 72 hours.

| TEST PUMP OF WW 31486, AS RECORDED IN PUMPING WELL. PUMPING RATE 5.55 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 6.19 | 40 | 36.15 | | |
| 2 | 11.24 | | | | |
| 3 | 15.21 | | | | |
| 4 | 18.88 | | | | |
| 5 | 20.88 | | | | |
| 7 | 25.12 | | | | |
| 10 | 26.72 | | | | |
| 20 | 31.65 | | | | |
| 25 | 35.13 | | | | |
| 30 | 36.10 | | | | |

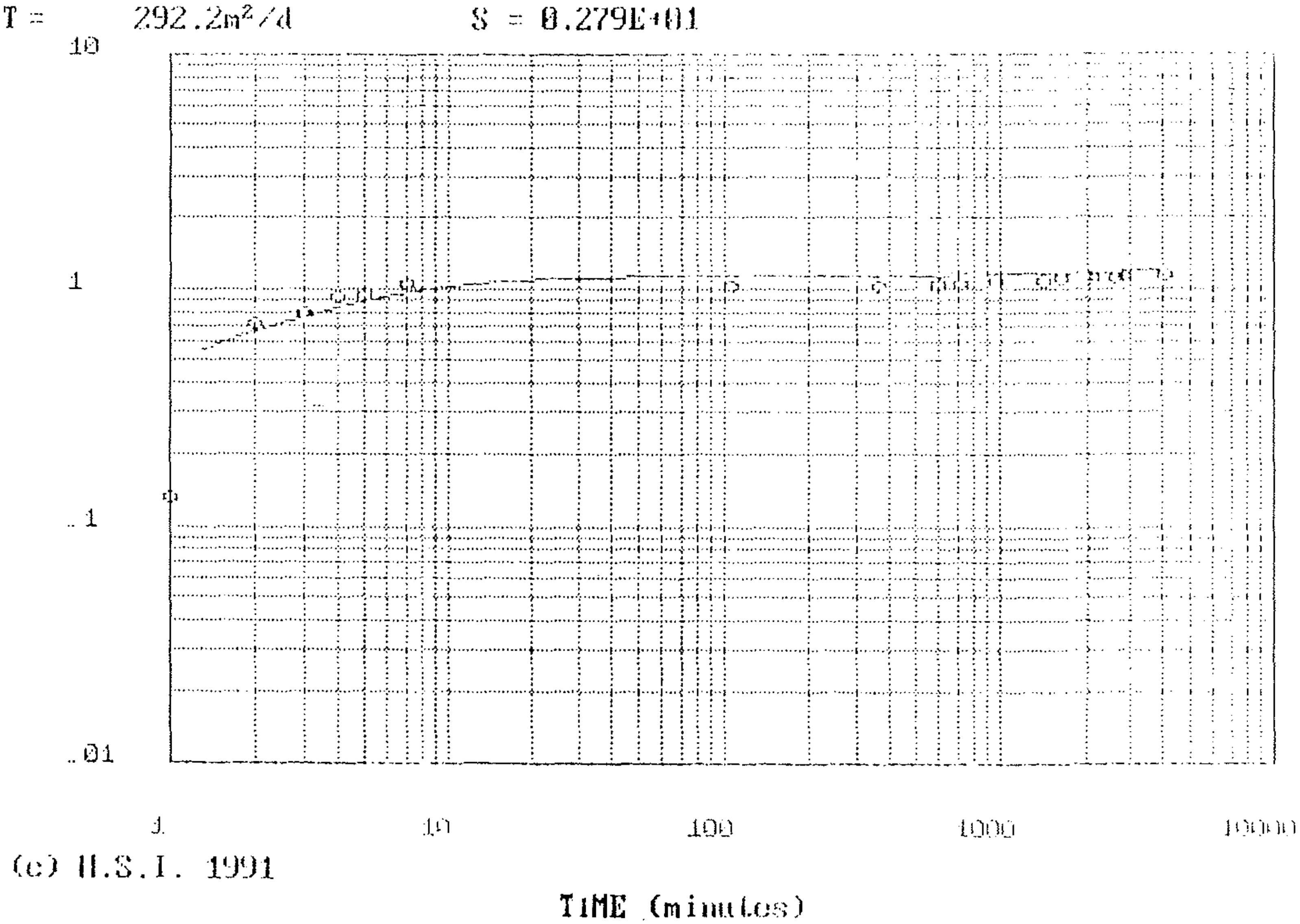
DATA SHEET TO ACCOMPANY TEST PUMP 5.




Test Pump 6. Test pump of WW 31489, as recorded in observation borehole WW 31485, situated 15.4 m away. Pumping rate 1.75 l/s. Test duration 72 hours.

| TEST PUMP OF WW 31489 AS RECORDED IN OBSERVATION BOREHOLE WW 31485, 15.4 m AWAY. PUMPING RATE 1.75 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 0.04 | 40 | 0.27 | 480 | 0.46 |
| 2 | 0.06 | 50 | 0.29 | 720 | 0.49 |
| 3 | 0.07 | 60 | 0.31 | 1200 | 0.50 |
| 4 | 0.08 | 75 | 0.32 | | |
| 5 | 0.10 | 90 | 0.35 | | |
| 7 | 0.12 | 120 | 0.38 | | |
| 10 | 0.15 | 150 | 0.41 | | |
| 15 | 0.19 | 180 | 0.42 | | |
| 20 | 0.21 | 210 | 0.44 | | |
| 30 | 0.25 | 300 | 0.46 | | |

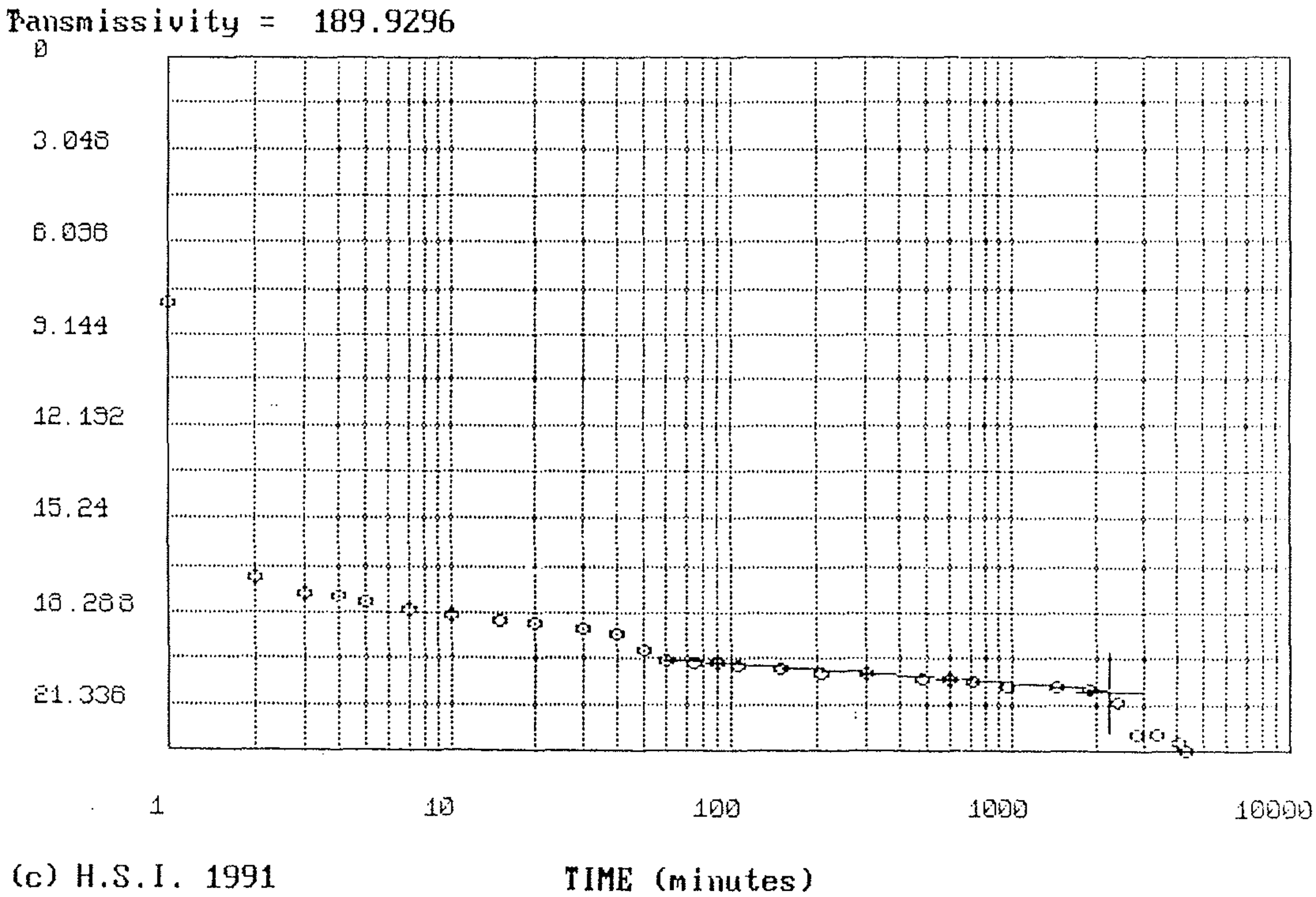
DATA SHEET TO ACCOMPANY TEST PUMP 6.




**Test Pump 7.** Test pump of WW 9396, as recorded in pumping well. Pumping rate 14.0 l/s. Test duration 72 hours. Storativity value is incorrect.

| TEST PUMP OF WW 9396, AS RECORDED IN PUMPING WELL. PUMPING RATE 14 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 0.13 | 960 | 1.08 | | |
| 2 | 0.72 | 1440 | 1.10 | | |
| 3 | 0.79 | 1680 | 1.11 | | |
| 4 | 0.94 | 2160 | 1.12 | | |
| 5 | 0.95 | 2640 | 1.13 | | |
| 7 | 1.05 | 2880 | 1.14 | | |
| 105 | 1.03 | 4080 | 1.15 | | |
| 360 | 1.04 | | | | |
| 600 | 1.06 | | | | |
| 720 | 1.07 | | | | |

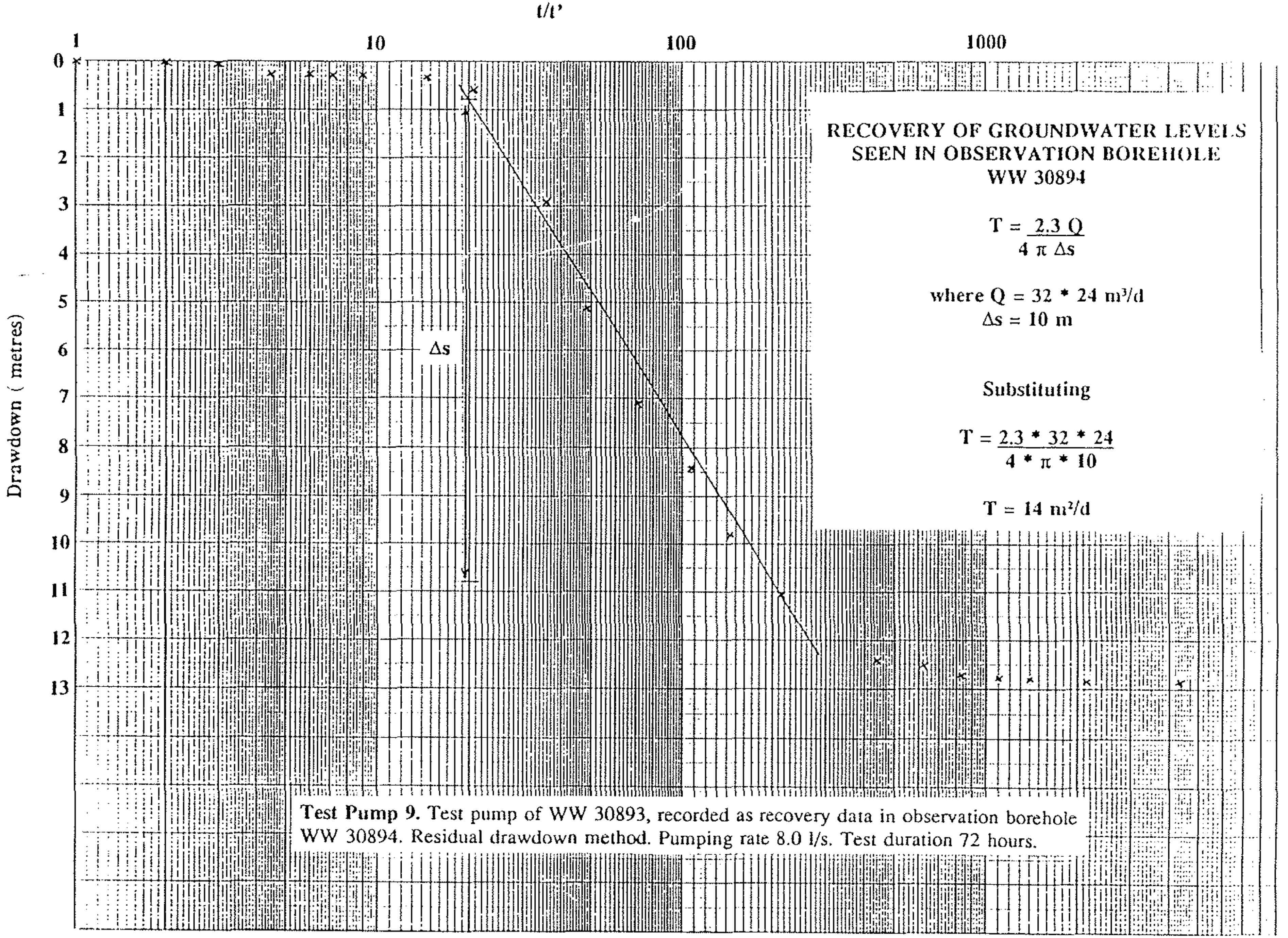
DATA SHEET TO ACCOMPANY TEST PUMP 7.




**Test Pump 8.**Test pump of WW 30893, as recorded in pumping well. Pumping rate 8.0 l/s. Test duration 72 hours.

| TEST PUMP OF WW 30893, AS RECORDED IN PUMPING WELL. PUMPING RATE 8 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 8.1 | 40 | 19.01 | 600 | 20.50 |
| 2 | 17.12 | 50 | 19.54 | 720 | 20.56 |
| 3 | 17.65 | 60 | 19.91 | 960 | 20.71 |
| 4 | 17.80 | 75 | 19.93 | 1440 | 20.77 |
| 5 | 17.97 | 90 | 19.99 | 1920 | 20.80 |
| 7 | 18.20 | 105 | 20.04 | 2400 | 21.30 |
| 10 | 18.35 | 150 | 20.14 | 2880 | 22.30 |
| 15 | 18.55 | 210 | 20.28 | 3360 | 22.33 |
| 20 | 18.63 | 300 | 20.30 | 4080 | 22.64 |
| 30 | 18.80 | 480 | 20.45 | 4320 | 22.86 |

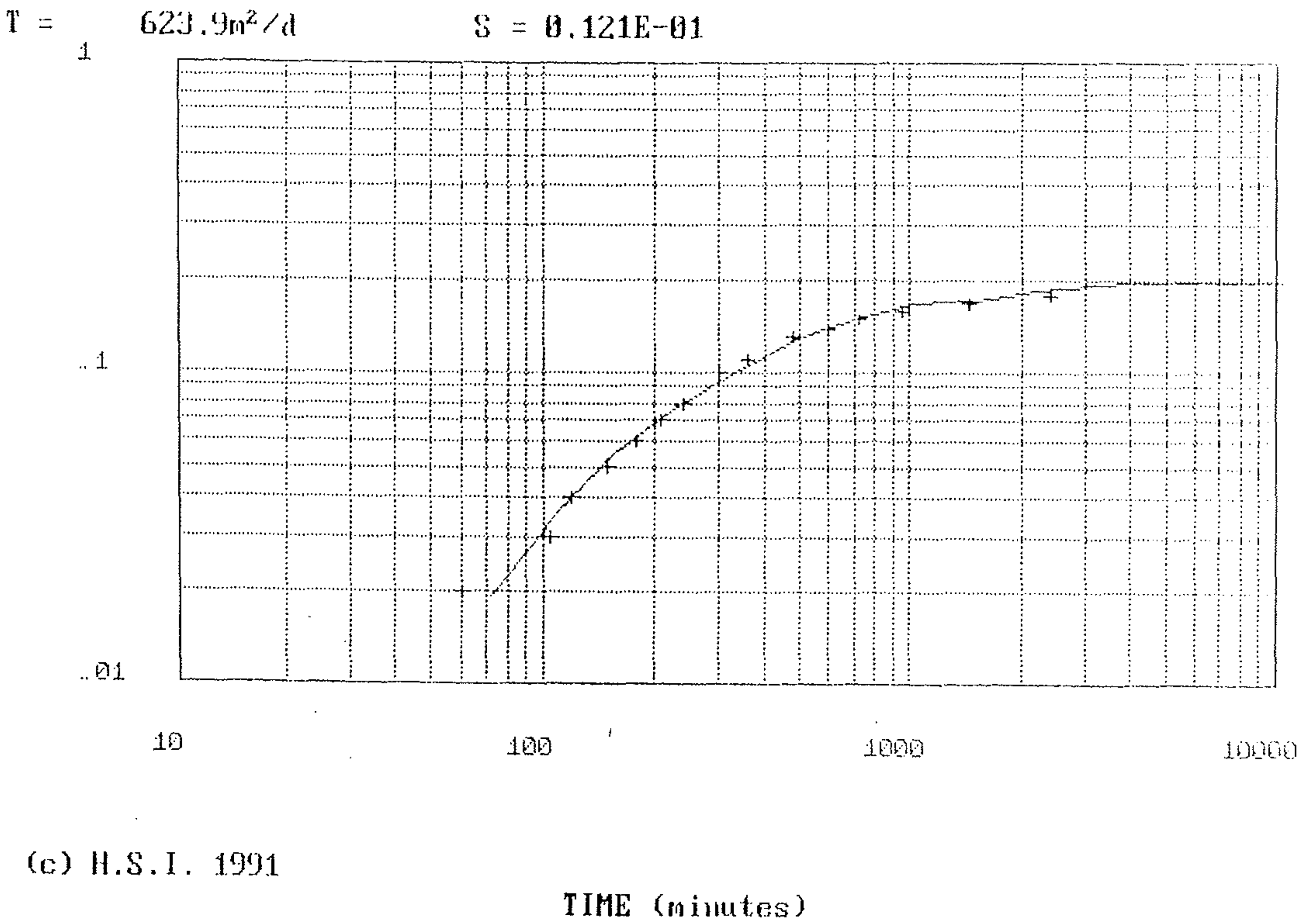
**DATA SHEET TO ACCOMPANY TEST PUMP 8.**




**Test Pump 9.** Test pump of WW 30893, recorded as recovery data in observation borehole WW 30894. Residual drawdown method. Pumping rate 8.0 l/s. Test duration 72 hours.

| PUMP TEST OF WW 30893, RECOVERY DATA OF OBSERVATION BOREHOLE WW 30894. PUMPING RATE 8 l/s. | | | | | |
|---|---|---|---|---|---|
| t/t' | RESIDUAL DRAW DOWN ( m ) | t/t' | RESIDUAL DRAW DOWN ( m ) | t/t' | RESIDUAL DRAW DOWN ( m ) |
| 4320 | 12.85 | 72 | 7.10 | 2.0 | 0.03 |
| 2160 | 12.85 | 48 | 5.12 | 1.0 | 0.0 |
| 1440 | 12.79 | 36 | 2.90 | | |
| 1080 | 12.78 | 20.5 | 0.60 | | |
| 824 | 12.69 | 14.4 | 0.33 | | |
| 617 | 12.49 | 9.0 | 0.24 | | |
| 432 | 12.40 | 7.2 | 0.23 | | |
| 216 | 11.05 | 6.0 | 0.23 | | |
| 144 | 9.80 | 4.5 | 0.22 | | |
| 108 | 8.40 | 3.0 | 0.04 | | |

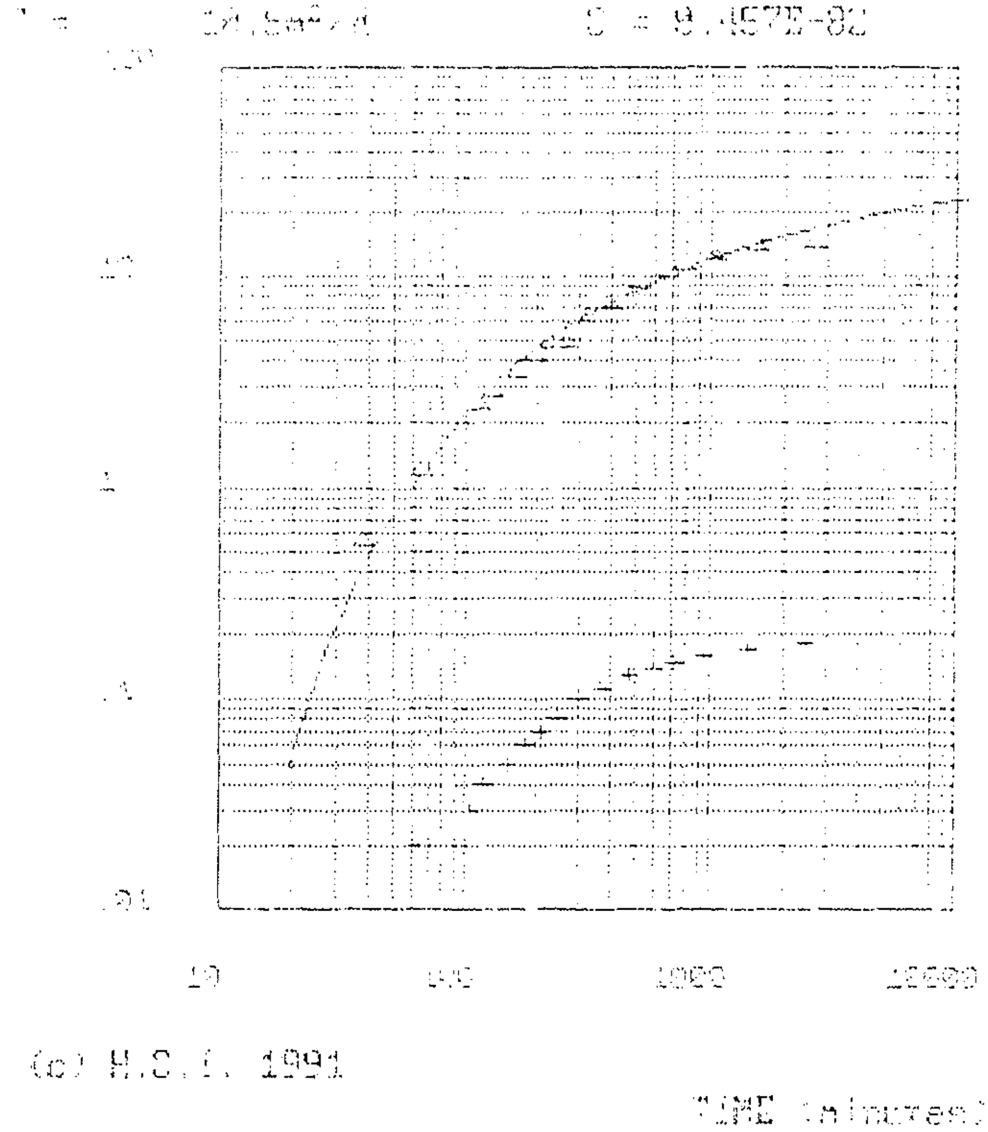
DATA SHEET TO ACCOMPANY TEST PUMP 9.




**Test Pump 10.** Test pump of WW 30893, as recorded in observation borehole WW 30892, situated 100 m away. Pumping rate 8 l/s. Test duration 72 hours.

| TEST PUMP OF WW 30893, AS RECORDED IN OBSERVATION BOREHOLE WW 30892, 100 m AWAY. PUMPING RATE 8 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 35 | 0.01 | 480 | 0.13 | 3840 | 0.22 |
| 60 | 0.02 | 600 | 0.14 | 4080 | 0.23 |
| 105 | 0.03 | 720 | 0.15 | 4320 | 0.24 |
| 120 | 0.04 | 960 | 0.16 | | |
| 150 | 0.05 | 1200 | 0.16 | | |
| 180 | 0.06 | 1440 | 0.17 | | |
| 210 | 0.07 | 2400 | 0.18 | | |
| 240 | 0.08 | 2640 | 0.19 | | |
| 300 | 0.10 | 3360 | 0.20 | | |
| 360 | 0.11 | 3600 | 0.21 | | |

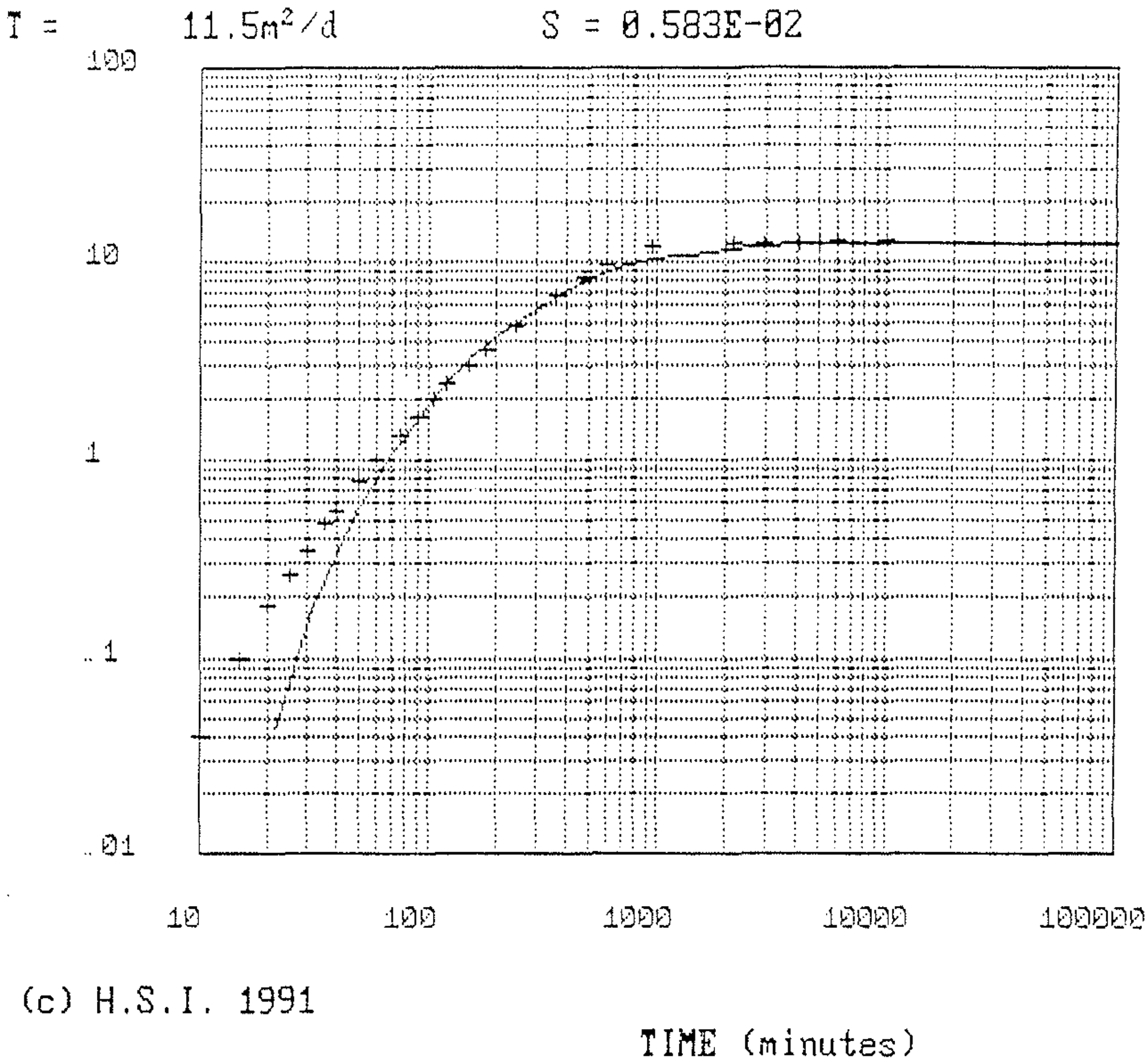
**DATA SHEET TO ACCOMPANY TEST PUMP 10.**




**Test Pump 11.** Test pump of WW 30893, as recorded in observation borehole WW 30894, situated 20 m away. Pumping rate 8.0 l/s. Test duration 72 hours.

| TEST PUMP OF WW 30893, AS RECORDED IN OBSERVATION BOREHOLE WW 30894, 20 m AWAY. PUMPING RATE 8 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 7 | 0.01 | 105 | 2.30 | 960 | 11.97 |
| 10 | 0.03 | 150 | 3.29 | 1440 | 13.05 |
| 15 | 0.10 | 180 | 3.93 | 2160 | 13.46 |
| 20 | 0.18 | 210 | 4.52 | 2400 | 13.52 |
| 30 | 0.39 | 240 | 4.63 | 2880 | 13.64 |
| 40 | 0.64 | 300 | 6.11 | 3600 | 13.69 |
| 50 | 0.89 | 360 | 7.07 | 4320 | 13.78 |
| 60 | 1.16 | 480 | 8.67 | | |
| 75 | 1.55 | 600 | 9.87 | | |
| 90 | 1.94 | 720 | 10.70 | | |

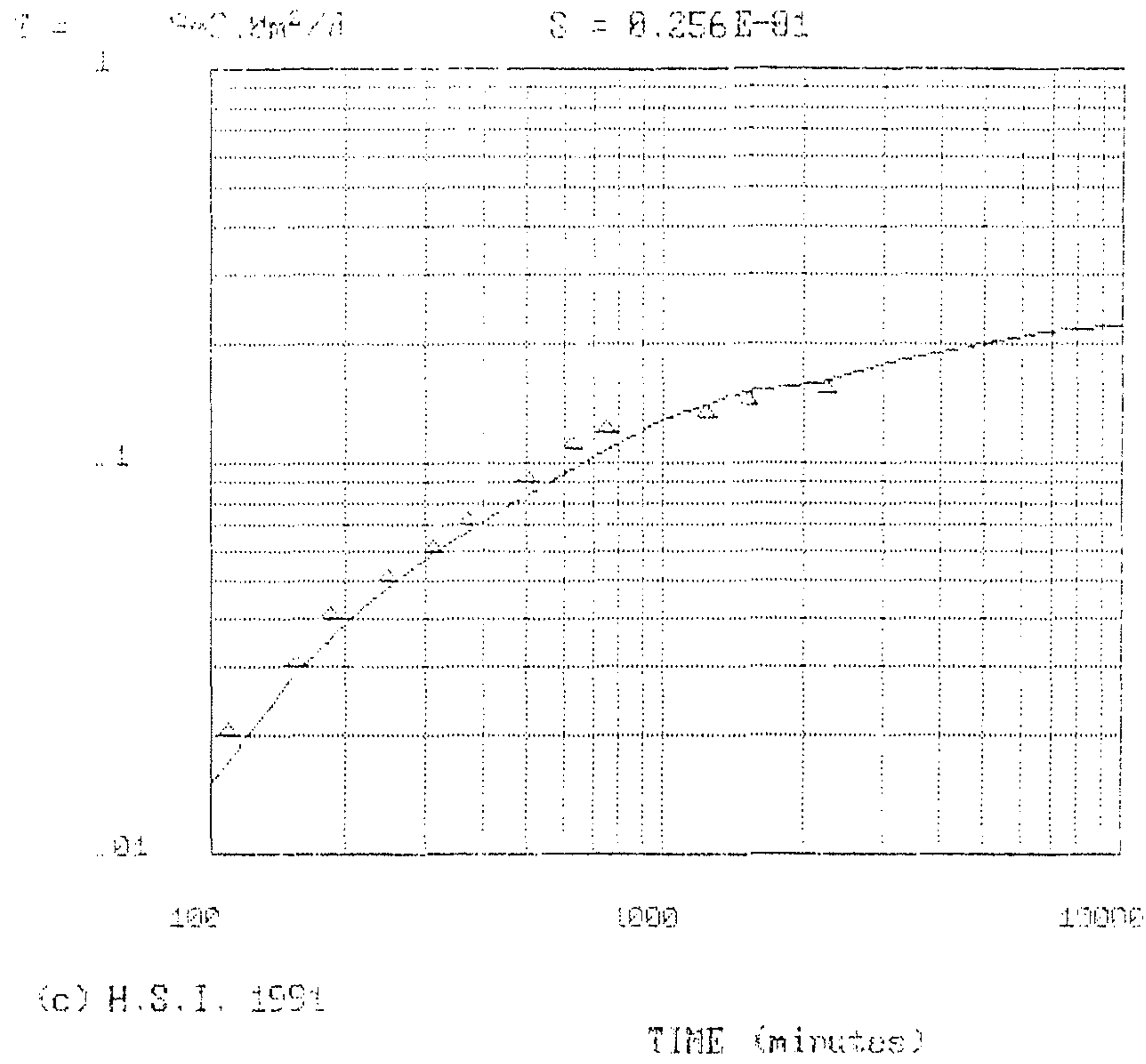
DATA SHEET TO ACCOMPANY TEST PUMP 11.




**Test Pump 12.** Test pump of WW 30893, as recorded in observation borehole WW 30894, situated 20 m away. Pumping rate 9.34 l/s. Test duration 168 hours.

| 168 HOUR TEST PUMP OF WW 30893, AS RECORDED IN OBSERVATION BOREHOLE WW 30894, 20 m AWAY. PUMPING RATE 9.34 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 7 | 0.01 | 75 | 1.34 | 960 | 11.79 |
| 10 | 0.04 | 90 | 1.65 | 2160 | 12.42 |
| 15 | 0.10 | 105 | 2.03 | 2880 | 12.40 |
| 20 | 0.18 | 120 | 2.45 | 4080 | 12.40 |
| 25 | 0.26 | 150 | 3.04 | 5040 | 12.51 |
| 30 | 0.35 | 180 | 3.59 | 6000 | 12.65 |
| 35 | 0.47 | 240 | 4.79 | 10080 | 12.67 |
| 40 | 0.55 | 360 | 6.74 | | |
| 50 | 0.77 | 480 | 8.33 | | |
| 60 | 1.00 | 600 | 9.51 | | |

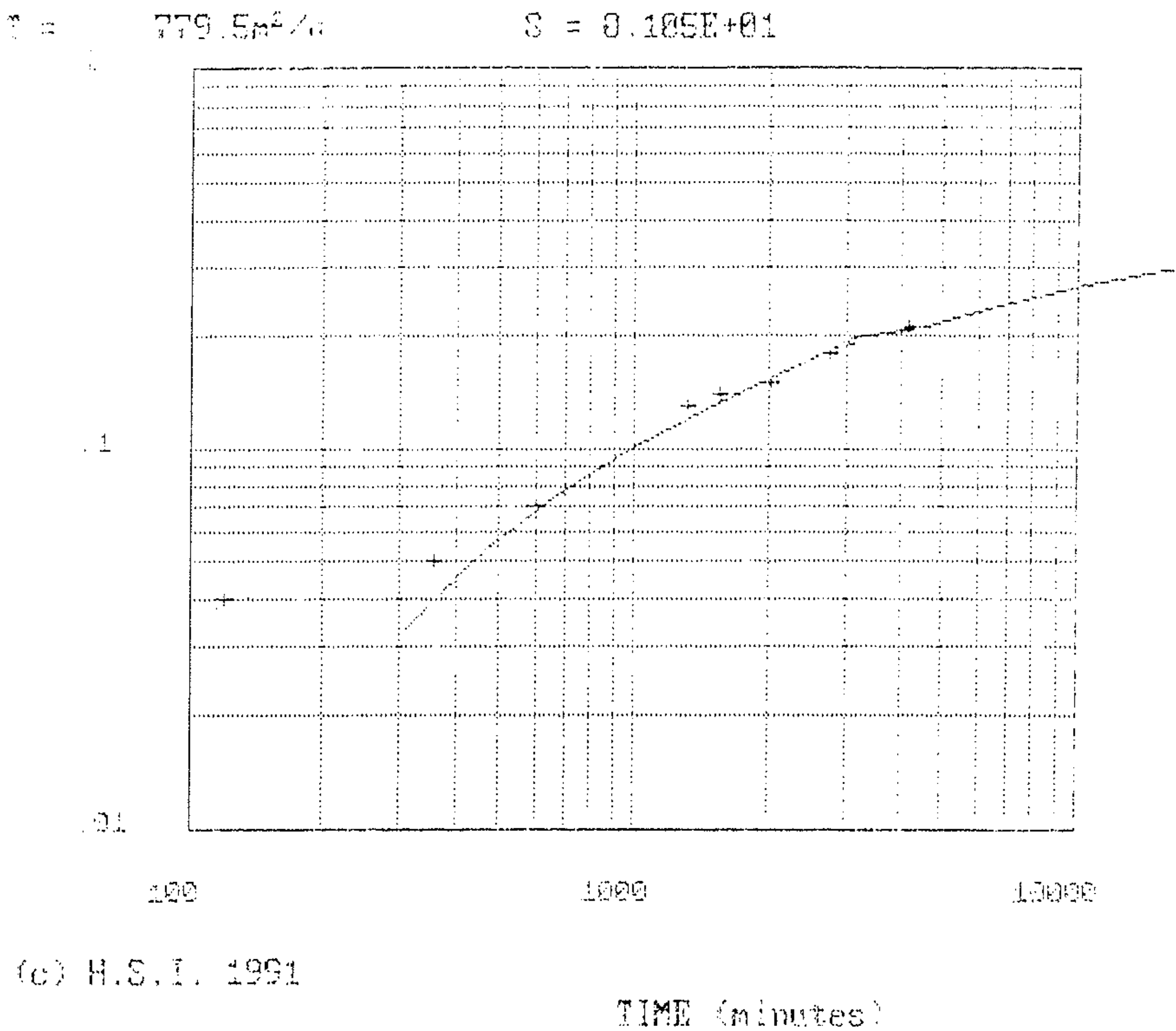
DATA SHEET TO ACCOMPANY TEST PUMP 12.




**Test Pump 13.** Test pump of WW 30893, as recorded in observation borehole WW 30892, situated 100 m away. Pumping rate 9.34 l/s. Test duration 168 hours.

| 168 HOUR TEST PUMP OF WW 30893, AS RECORDED IN OBSERVATION BOREHOLE WW 30892, 100 m AWAY. PUMPING RATE 9.34 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 7 | 0.01 | 720 | 0.12 | 8880 | 0.11 |
| 90 | 0.01 | 1200 | 0.13 | 9600 | 0.12 |
| 105 | 0.02 | 1440 | 0.14 | 10080 | 0.12 |
| 150 | 0.03 | 2160 | 0.15 | | |
| 180 | 0.04 | 3360 | 0.14 | | |
| 240 | 0.05 | 3840 | 0.13 | | |
| 300 | 0.06 | 4560 | 0.11 | | |
| 360 | 0.07 | 4800 | 0.12 | | |
| 480 | 0.09 | 5520 | 0.11 | | |
| 600 | 0.11 | 6480 | 0.12 | | |

**DATA SHEET TO ACCOMPANY TEST PUMP 13.**



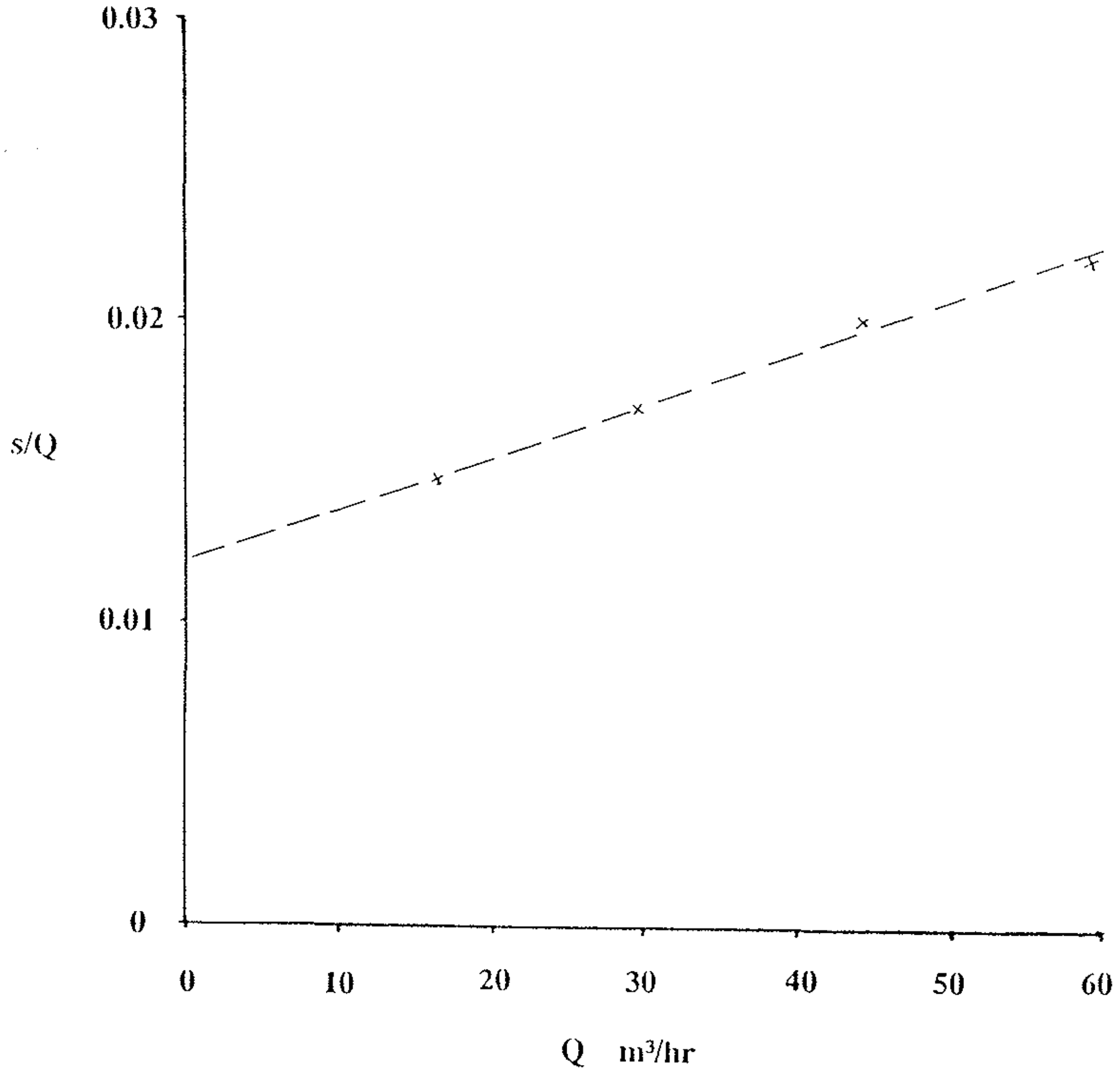

**Test Pump 14.** Test pump of WW 9734, as recorded in observation borehole WW 9736, situated 247 m away. Pumping rate 9.9 l/s. Test duration 72 hours.

| TEST PUMP OF WW 9734, AS RECORDED IN OBSERVATION BOREHOLE WW 9736, 247 m AWAY. PUMPING RATE 9.9 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 120 | 0.04 | | | | |
| 360 | 0.05 | | | | |
| 600 | 0.07 | | | | |
| 1320 | 0.13 | | | | |
| 1560 | 0.14 | | | | |
| 2040 | 0.15 | | | | |
| 2760 | 0.18 | | | | |
| 3000 | 0.19 | | | | |
| 3480 | 0.19 | | | | |
| 4200 | 0.21 | | | | |

**DATA SHEET TO ACCOMPANY TEST PUMP 14.**

# APPENDIX 5.

Step Test results from the Damara carbonate aquifer.




**STEP TEST**

WW 9396

s/Q against Q

| s/Q | Q |
|---|---|
| 0.0148 | 16.5 |
| 0.0173 | 30.0 |
| 0.02 | 44.5 |
| 0.0222 | 60.0 |

s is metres
Q is in $m^3/hr$

$$s = 0.012\,Q + 0.000175\,Q^2$$

# STEP TEST

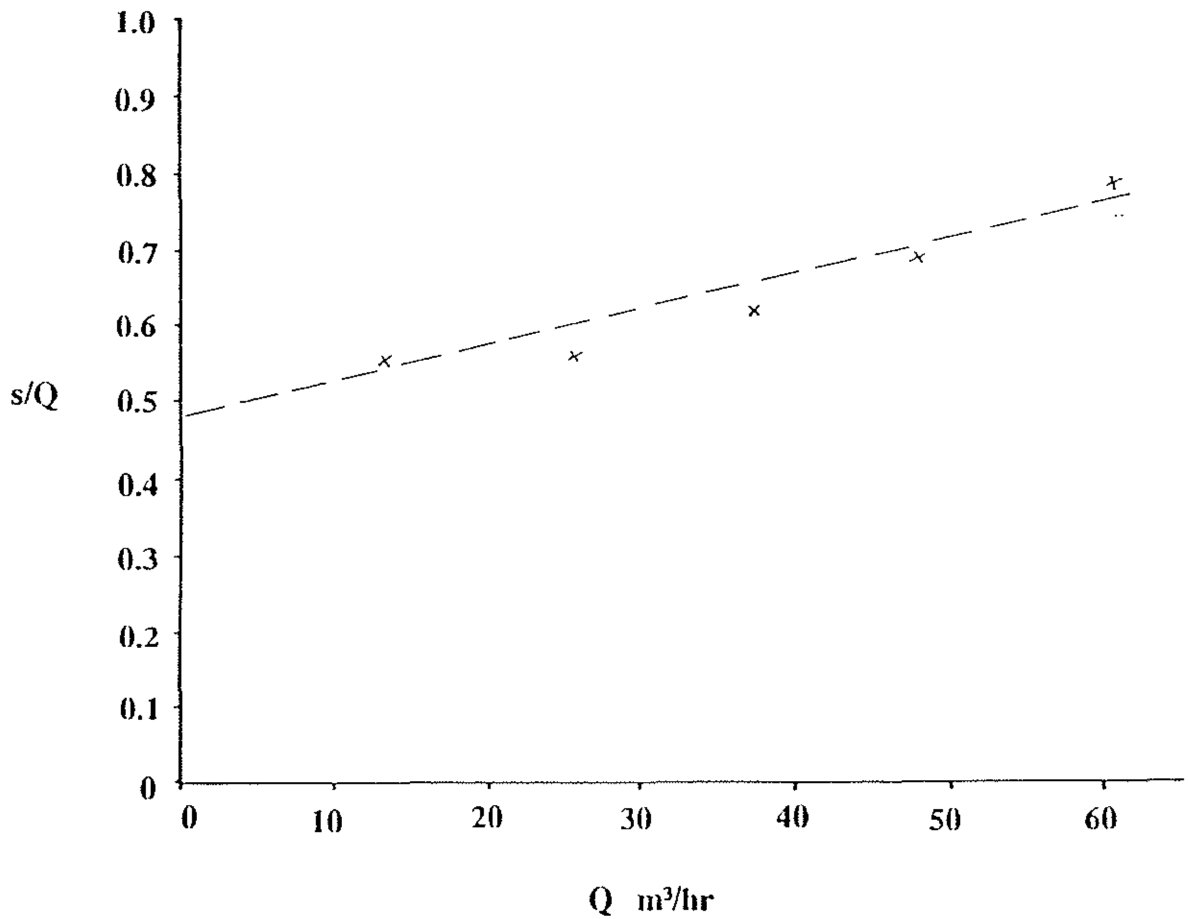
WW 9734

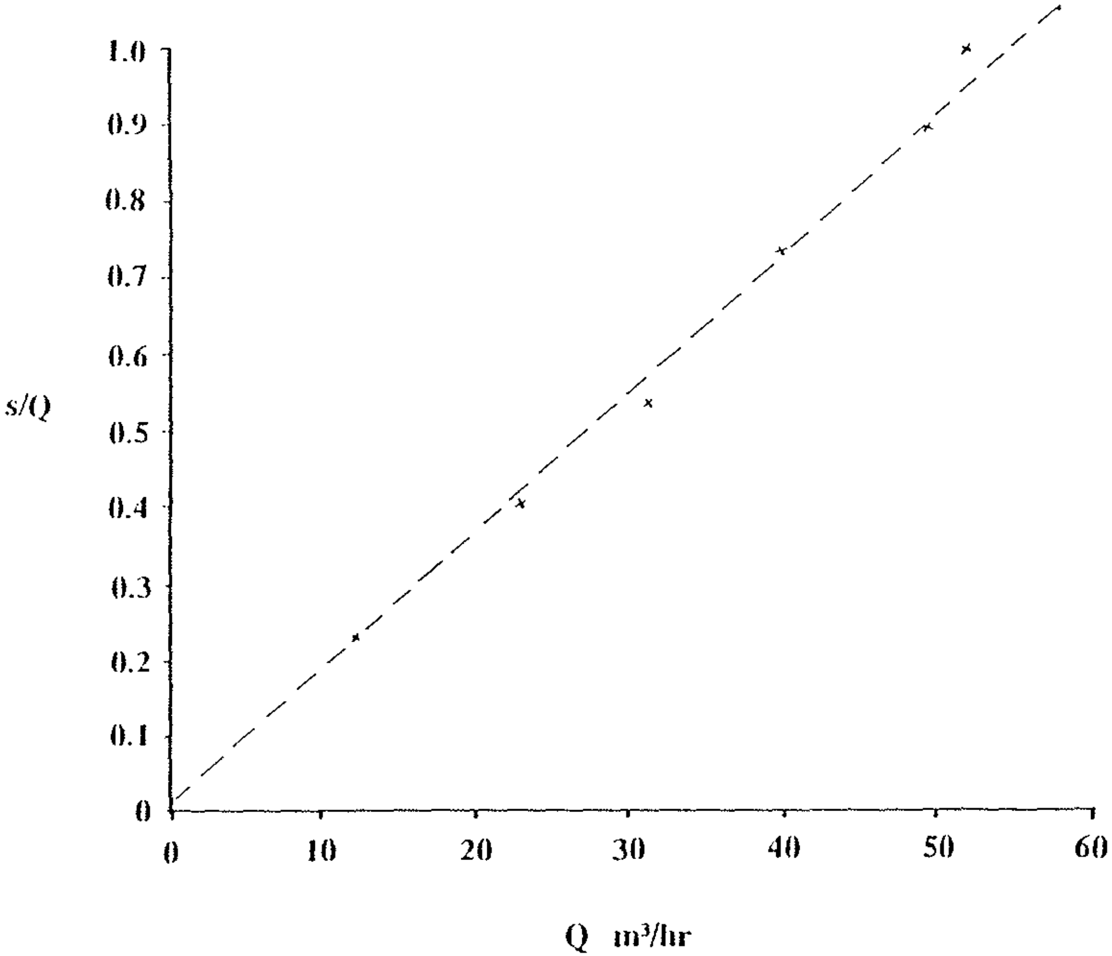
s/Q against Q

| s/Q | Q |
|---|---|
| 0.0550 | 13.0 |
| 0.0552 | 25.5 |
| 0.0618 | 37.5 |
| 0.0695 | 48.0 |
| 0.0786 | 61.0 |

s is in metres
Q is in m³/hr

$$s = 0.047\,Q + 0.0005\,Q^2$$






## STEP TEST

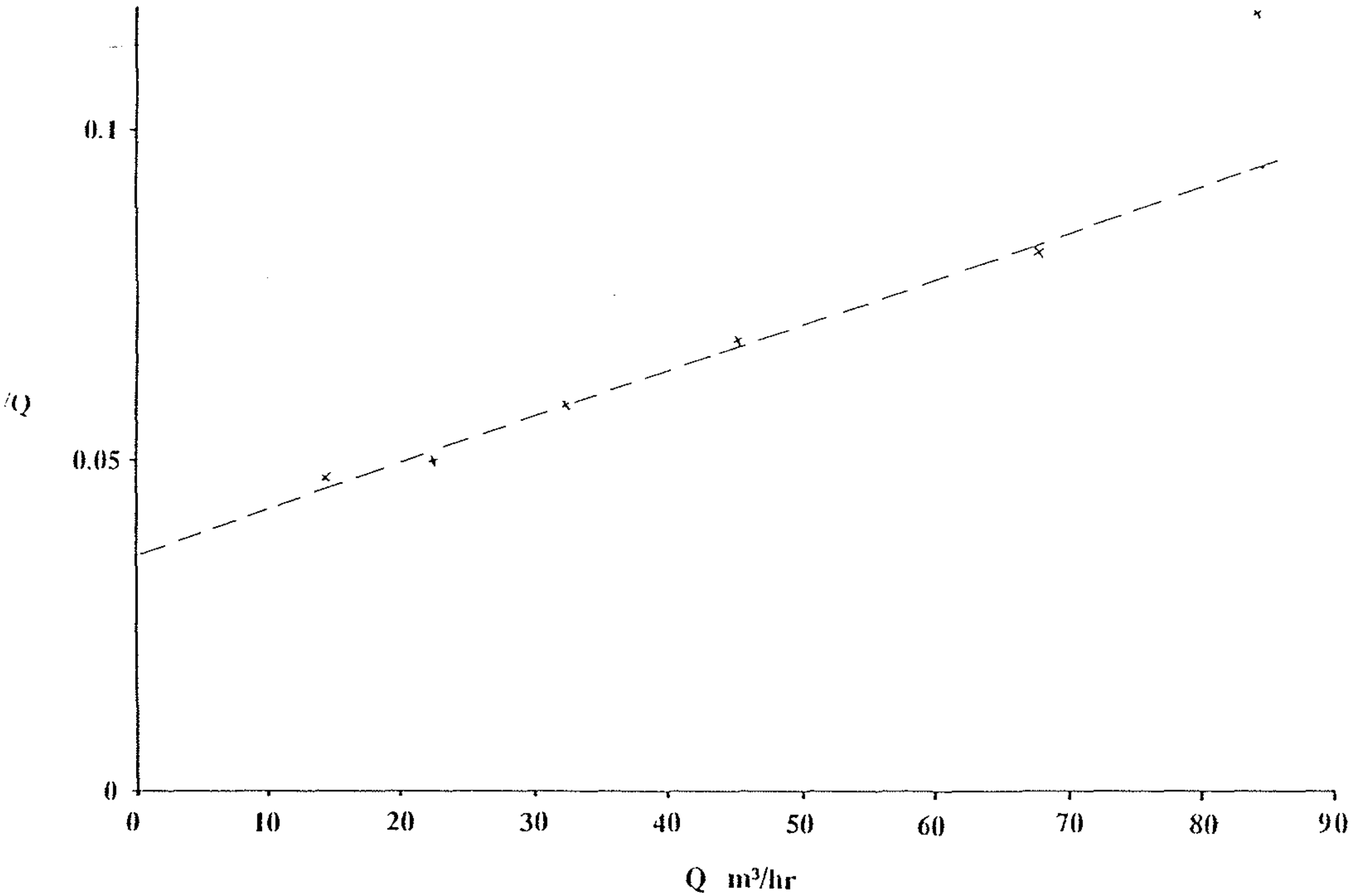
WW 30893

s/Q against Q

| s/Q | Q |
|---|---|
| 0.237 | 12.2 |
| 0.403 | 22.8 |
| 0.557 | 31.0 |
| 0.730 | 39.7 |
| 0.879 | 49.6 |
| 0.986 | 53.0 |

s is in metres
Q is in $m^3/hr$

$$s = 0.01\ Q + 0.018\ Q^2$$




**STEP TEST**

WW 30897

s/Q against Q

| s/Q | Q |
|---|---|
| 0.0479 | 14.5 |
| 0.0502 | 22.5 |
| 0.0590 | 32.5 |
| 0.0689 | 45.5 |
| 0.0825 | 68.0 |
| 0.1187 | 84.5 |

s is in metres
Q is in $m^3/hr$

$s = 0.0357\ Q + 0.00065\ Q^2$

## APPENDIX 6. USGS Classification for Irrigation Water.

LOW-SALINITY WATER (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

MEDIUM-SALINITY WATER (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

HIGH-SALINITY WATER(C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

VERY HIGH SALINITY WATER (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

SODIUM.

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitives plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

LOW-SODIUM WATER (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

MEDIUM-SODIUM WATER (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

HIGH-SODIUM WATER (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management - good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

VERY HIGH SODIUM WATER (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Sometimes the irrigation water may dissolve sufficient calcium from calcareous soils to decrease the sodium hazard appreciably, and this should be taken into account in the use of C1-S3 and C1-S4 waters. For calcareous soils with high pH values or for non-calcareous soils, the sodium status of waters in classes C1-S3, C1-S4 may be improved by the addition of gypsum to the water. Similarly, it may be beneficial to add gypsum to the soil periodically when C2-S3 and C3-S2 waters are used.

APPENDIX 7. Explanation of the Langelier saturation Index, Ryznar Index and Corrosivity Ratio.

Methods for determination of stability

Various methods are applied in practice for the determination and control of stability; for example the Langelier saturation index and the Ryznar stability index.

*Langelier saturation index*

The over- and undersaturation of water with respect to calcium carbonate may be indicated by the following saturation index:

Langelier saturation index = actual pH-pHs.

A positive value is indicative of scale-forming properties, while a negative index indicates that the water has corrosive properties and can dissolve calcium carbonate.

In practice, however, the index may be considered merely as an indication of a tendency, not of a capacity, to resist change. Water with high concentrations of calcium and carbonate ions has a better chance of resisting change in its composition than water containing low concentrations of these ions. This property is known as its buffer capacity. Soft water has a low buffer capacity and will consequently undergo change more readily than water with a high buffer capacity, although both may have the same saturation index.

*Ryznar stability index*

In order to exclude the possibility of interpreting a positive saturation index as indicating non-corrosive tendencies in cases where the water actually has corrosive properties, Ryznar proposed an empirical stability index:

Ryznar stability index = 2 pHs - pH.

This value is positive in all cases, and is interpreted as follows: between values of approximately 6,5 and 7,5 the water is fairly stable chemically with regard to $CaCO_3$. Values below 6,5 indicate scale-forming properties, while values above 7,5 are indicative of corrosive tendencies.

*Corrosivity ratio*

Even the stability index does not give the complete picture concerning deposition (scale formation) and corrosion, because other factors also influence the process. It is known that the release of air bubbles with rising temperature, as well as high concentrations of chloride and sulphate, causes corrosion. On the other hand bicarbonate (or alkalinity), even in the absence of calcium, will counteract corrosion of iron at pH values of about 7 to 8. These factors are used to determine the corrosivity ratio.

$$\text{Corrosivity ratio} = \frac{\text{mmol}/\ell\ Cl^- + 2(\text{mmol}/\ell\ SO_4^=)}{2\ (\text{mmol}/\ell \text{ alkalinity as } CaCO_3)}$$

The corrosivity ratio applies only to water in the pH range 7 to 8, which also contains dissolved oxygen. Values below 0,2 and in the presence of dissolved oxygen, indicate that the water does not have corrosive properties. Higher ratios are indicative of increasingly corrosive tendencies.

General rules which may be applied to establish the chemical stability of water as regards scale-forming or corrosive properties are set out in Table 16.

TABLE 16. Method of estimating the approximate chemical stability of water

| Ryznar index | Tendency for corrosivity or scale formation |
|---|---|
| >8,5 | highly corrosive |
| 7,5 to 8,5 | slightly corrosive |
| 6,5 to 7,5 | chemically stable |
| 5,5 to 6,5 | slightly depositing or scale-forming |
| <5,5 | highly depositing or scale-forming |

## Solving water conditioning problems using the modified Caldwell-Lawrence diagrams

The conditioning of water for domestic drinking and industrial purposes is usually concerned with adjusting pH and alkalinity, as well as the calcium and magnesium content of a water, to values which will minimize corrosion in mild steel and cast iron pipelines and aggression in cement-lined and asbestos-cement pipelines. It should also produce a water which is not too hard for domestic use and will not readily encrust warm water fittings. To achieve these 'conditioned' states, chemicals are added to the raw water to make it saturated or slightly oversaturated with respect to calcium carbonate. The MCL diagrams may be used to predict the chemical dosages required to obtain this condition.

Modified Caldwell-Lawrence diagrams graphically present equilibria interrelationships between alkalinity, acidity, pH and calcium in a plot with the parameters acidity and (Alk.-Ca) as co-ordinates. Acidity is defined as:

Acidity $= H^+ + HCO_3^- + H_2CO_3 - OH^-$; and alkalinity as

Alkalinity $= 2 \times CO_3^= + HCO_3^- + OH^- - H^+$.

# APPENDIX 8.

Groundwater levels for the Damara carbonate aquifer.

GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water le |
|---|---|---|---|---|
| 1917BA | 101 | WW9736 | 1990-01-18 | 36.48 |
| 1917BA | 101 | WW9736 | 1990-05-25 | 36.78 |
| 1917BA | 101 | WW9736 | 1990-07-23 | 36.90 |
| 1917BA | 101 | WW9736 | 1990-10-22 | 37.15 |
| 1917BA | 101 | WW9736 | 1991-01-21 | 37.40 |
| 1917BA | 101 | WW9736 | 1991-04-22 | 37.49 |
| 1917BA | 101 | WW9736 | 1991-07-22 | 37.67 |
| 1917BA | 101 | WW9736 | 1991-10-23 | 37.90 |
| 1917BA | 101 | WW9736 | 1992-01-22 | 38.14 |
| 1917BA | 101 | WN9736 | 1992-04-27 | 38.46 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water le |
|---|---|---|---|---|
| 1917BA | 104 | WW9396 | 1990-01-17 | 22.46 |
| 1917BA | 104 | WW9396 | 1990-05-24 | 22.60 |
| 1917BA | 104 | WW9396 | 1990-10-22 | 23.02 |
| 1917BA | 104 | WW9396 | 1991-01-21 | 23.20 |
| 1917BA | 104 | WW9396 | 1991-04-22 | 23.13 |
| 1917BA | 104 | WW9396 | 1991-07-23 | 23.25 |
| 1917BA | 104 | WW9396 | 1991-10-23 | 23.41 |
| 1917BA | 104 | WW9396 | 1992-01-22 | 23.57 |
| 1917BA | 104 | WN9396 | 1992-04-27 | 23.75 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Número | Well Number | Borehole No | Measurement Date | Underground water le |
|---|---|---|---|---|
| 1917BA | 108 | WW10318 | 1990-01-17 | 18.31 |
| 1917BA | 108 | WW10318 | 1990-05-24 | 18.18 |
| 1917BA | 108 | WW10318 | 1990-07-23 | |
| 1917BA | 108 | WW10318 | 1990-10-22 | 18.77 |
| 1917BA | 108 | WW10318 | 1991-01-21 | |
| 1917BA | 108 | WW10318 | 1991-04-22 | 18.79 |
| 1917BA | 108 | WW10318 | 1991-07-22 | 18.92 |
| 1917BA | 108 | WW10318 | 1991-10-23 | 19.11 |
| 1917BA | 108 | WW10318 | 1992-01-22 | 19.17 |
| 1917BA | 108 | WW10318 | 1992-04-27 | 19.39 |

GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water le |
|---|---|---|---|---|
| 1917BB | 115 | WW30689 | 1990-01-16 | 8.13 |
| 1917BB | 115 | WW30689 | 1990-05-24 | 8.22 |
| 17BB | 115 | WW30689 | 1990-07-23 | 8.54 |
| 1917BB | 115 | WW30689 | 1990-10-22 | |
| 1917BB | 115 | WW30689 | 1991-01-21 | 8.67 |
| 1917BB | 115 | WW30689 | 1991-07-22 | 8.46 |
| 1917BB | 115 | WW30689 | 1991-10-23 | 9.47 |
| 1917BB | 115 | WW30689 | 1992-01-22 | 9.71 |
| 1917BB | 115 | WW30689 | 1992-04-27 | Dry |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water le |
|---|---|---|---|---|
| 1917AB | 67 | WW30894 | 1990-01-17 | 39.21 |
| 1917AB | 67 | WW30894 | 1990-05-24 | 39.23 |
| 1917AB | 67 | WW30894 | 1990-07-23 | 39.62 |
| 1917AB | 67 | WW30894 | 1990-10-22 | 40.13 |
| 1917AB | 67 | WW30894 | 1991-01-21 | 40.47 |
| 1917AB | 67 | WW30894 | 1991-04-22 | 40.24 |
| 17AB | 67 | WW30894 | 1991-07-22 | 41.66 |
| 1917AB | 67 | WW30894 | 1991-10-23 | 41.08 |
| 1917AB | 67 | WW30894 | 1992-01-23 | 41.38 |
| 1917AB | 67 | WW30894 | 1992-04-27 | 41.78 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water lev |
|---|---|---|---|---|
| 1917BA | 66 | WW30895 | 1990-01-17 | 14.17 |
| 1917BA | 66 | WW30895 | 1990-07-23 | 14.54 |
| 1917BA | 66 | WW30895 | 1990-10-22 | 14.76 |
| 1917BA | 66 | WW30895 | 1991-01-21 | 14.93 |
| 1917BA | 66 | WW30895 | 1991-04-22 | 14.70 |
| 1917BA | 66 | WW30895 | 1991-07-22 | 14.92 |
| 1917BA | 66 | WW30895 | 1991-10-23 | 15.08 |
| 1917BA | 66 | WW30895 | 1992-01-22 | 15.22 |
| 1917BA | 66 | WW30895 | 1992-04-27 | 15.43 |

GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water lev |
|---|---|---|---|---|
| 1917BA | 68 | WW30897 | 1989-02-23 | 2.50 |
| 1917BA | 68 | WW30897 | 1990-07-23 | 5.65 |
| 1917BA | 68 | WW30897 | 1990-10-22 | 5.75 |
| 1917BA | 68 | WW30897 | 1991-01-21 | 5.79 |
| 1917BA | 68 | WW30897 | 1991-04-22 | 5.58 |
| 1917BA | 68 | WW30897 | 1991-07-22 | 5.87 |
| 1917BA | 68 | WW30897 | 1991-10-23 | 6.00 |
| 1917BA | 68 | WW30897 | 1992-01-22 | 6.07 |
| 1917BA | 68 | WW30897 | 1992-04-27 | 6.33 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BA | 70 | WW30901 | 1990-01-17 | 10.22 |
| 1917BA | 70 | WW30901 | 1990-05-25 | 10.48 |
| 1917BA | 70 | WW30901 | 1990-07-23 | 10.80 |
| 1917BA | 70 | WW30901 | 1990-10-22 | 10.76 |
| 1917BA | 70 | WW30901 | 1991-01-21 | 10.71 |
| 1917BA | 70 | WW30901 | 1991-04-22 | 10.31 |
| 1917BA | 70 | WW30901 | 1991-07-22 | 10.76 |
| 1917BA | 70 | WW30901 | 1991-10-23 | 10.89 |
| 1917BA | 70 | WW30901 | 1992-01-22 | 10.82 |
| 1917BA | 70 | WW30901 | 1992-04-27 | 11.22 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BB | 121 | WW30902 | 1990-01-17 | 4.22 |
| 1917BB | 121 | WW30902 | 1990-05-25 | 4.23 |
| 1917BB | 121 | WW30902 | 1990-07-23 | |
| 1917BB | 121 | WW30902 | 1990-10-22 | 4.51 |
| 1917BB | 121 | WW30902 | 1991-01-21 | 4.60 |
| 1917BB | 121 | WW30902 | 1991-04-22 | 4.04 |
| 1917BB | 121 | WW30902 | 1991-07-22 | 4.48 |
| 1917BB | 121 | WW30902 | 1991-10-23 | 4.54 |
| 1917BB | 121 | WW30902 | 1992-01-22 | 4.61 |
| 1917BB | 121 | WW30902 | 1992-04-27 | 4.88 |

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BB | 114 | WW30903 | 1990-01-16 | 7.07 |
| 1917BB | 114 | WW30903 | 1990-05-24 | 7.14 |
| 1917BB | 114 | WW30903 | 1990-07-23 | 7.47 |
| 1917BB | 114 | WW30903 | 1990-10-22 | 7.68 |
| 1917BB | 114 | WW30903 | 1991-01-21 | 7.47 |
| 1917BB | 114 | WW30903 | 1991-04-22 | 6.80 |
| 1917BB | 114 | WW30903 | 1991-07-22 | 7.39 |
| 1917BB | 114 | WW30903 | 1991-10-23 | 7.77 |
| 1917BB | 114 | WW30903 | 1992-01-22 | 7.83 |
| 1917BB | 114 | WW30903 | 1992-04-27 | 8.15 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BA | 97 | WW31485 | 1990-01-17 | 6.08 |
| 1917BA | 97 | WW31485 | 1990-05-25 | 6.15 |
| 1917BA | 97 | WW31485 | 1990-07-23 | 6.45 |
| 1917BA | 97 | WW31485 | 1990-10-22 | 6.54 |
| 1917BA | 97 | WW31485 | 1991-01-21 | 6.49 |
| 1917BA | 97 | WW31485 | 1991-04-22 | 6.35 |
| 1917BA | 97 | WW31485 | 1991-07-22 | 6.61 |
| 1917BA | 97 | WW31485 | 1991-10-23 | 6.70 |
| 1917BA | 97 | WW31485 | 1992-01-22 | 6.66 |
| 1917BA | 97 | WW31485 | 1992-04-27 | 6.98 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BA | 99 | WW31486 | 1990-01-17 | 6.19 |
| 1917BA | 99 | WW31486 | 1990-05-25 | 6.31 |
| 1917BA | 99 | WW31486 | 1990-07-23 | |
| 1917BA | 99 | WW31486 | 1990-10-22 | 6.96 |
| 1917BA | 99 | WW31486 | 1991-01-21 | 6.75 |
| 1917BA | 99 | WW31486 | 1991-04-22 | 6.46 |
| 1917BA | 99 | WW31486 | 1991-07-22 | 6.79 |
| 1917BA | 99 | WW31486 | 1991-10-23 | 6.92 |
| 1917BA | 99 | WW31486 | 1992-01-22 | 6.99 |
| 1917BA | 99 | WW31486 | 1992-04-27 | 7.20 |

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BB | 117 | WW31487 | 1990-01-16 | 12.22 |
| 17BB | 117 | WW31487 | 1990-07-23 | 10.24 |
| 1917BB | 117 | WW31487 | 1990-10-22 | |
| 1917BB | 117 | WW31487 | 1991-01-21 | 10.45 |
| 1917BB | 117 | WW31487 | 1991-04-22 | |
| 1917BB | 117 | WW31487 | 1991-07-22 | 10.15 |
| 1917BB | 117 | WW31487 | 1991-10-23 | 10.58 |
| 1917BB | 117 | WW31487 | 1992-01-22 | 10.64 |
| 1917BB | 119 | WW31487 | 1992-04-27 | 10.99 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water lev |
|---|---|---|---|---|
| 1917BB | 119 | WW31488 | 1989-10-31 | 10.00 |
| 1917BB | 119 | WW31488 | 1990-05-24 | 10.62 |
| 1917BB | 119 | WW31488 | 1990-07-23 | 10.93 |
| 1917BB | 119 | WW31488 | 1990-10-22 | |
| 1917BB | 119 | WW31488 | 1991-01-21 | 11.11 |
| 1917BB | 119 | WW31488 | 1991-07-22 | 10.87 |
| 1917BB | 119 | WW31488 | 1991-10-23 | 11.16 |
| 1917BB | 119 | WW31488 | 1992-01-22 | 11.32 |
| 1917BB | 119 | WW31488 | 1992-04-27 | 11.65 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BB | 118 | WW31490 | 1989-09-22 | 10.00 |
| 1917BB | 118 | WW31490 | 1991-01-21 | 7.06 |
| 1917BB | 118 | WW31490 | 1991-07-22 | 6.74 |
| 1917BB | 118 | WW31490 | 1991-10-23 | 7.11 |
| 1917BB | 1 8 | WW31490 | 1991-04-27 | 7.49 |

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BC | 73 | WW31501 | 1990-01-19 | 86.00 |
| 1917BC | 73 | WW31501 | 1990-05-24 | 79.69 |
| 1917BC | 73 | WW31501 | 1990-07-23 | 79.84 |
| 1917BC | 73 | WW31501 | 1990-10-22 | 80.11 |
| 1917BC | 73 | WW31501 | 1991-01-21 | 80.36 |
| 1917BC | 73 | WW31501 | 1991-04-22 | 80.43 |
| 1917BC | 73 | WW31501 | 1991-07-22 | 80.67 |
| 1917BC | 73 | WW31501 | 1991-10-23 | 80.91 |
| 1917BC | 73 | WW31501 | 1992-01-22 | 81.20 |
| 1917BC | 73 | WW31501 | 1992-04-27 | 81.57 |

23/04/1992

GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917BB | 109 | | 1990-05-24 | 13.97 |
| 1917BB | 109 | | 1990-07-23 | 14.32 |
| 1917BB | 109 | | 1990-10-22 | 14.67 |
| 1917BB | 109 | | 1991-01-21 | 14.62 |
| 1917BB | 109 | | 1991-04-22 | 13.60 |
| 1917BB | 109 | | 1991-07-22 | 14.17 |
| 1917BB | 109 | | 1991-10-23 | 14.78 |
| 1917BB | 109 | | 1992-01-22 | 14.71 |
| 1917BB | 109 | WW N/N | 1992-04-27 | 15.13 |

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GROUND WATER INFORMATION SYSTEM

WATER LEVELS

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water leve |
|---|---|---|---|---|
| 1917AD | 66 | | 1990-07-23 | 88.50 |
| 1917AD | 66 | | 1990-10-22 | 81.10 |
| 1917AD | 66 | | 1991-01-21 | 78.98 |
| 1917AD | 66 | | 1991-04-22 | 82.63 |
| 1917AD | 66 | | 1991-07-23 | 86.94 |
| 1917AD | 66 | | 1991-10-23 | 77.48 |
| 1917AD | 66 | | 1992-01-22 | 77.37 |
| 1917AD | 66 | WW N/N | 1992-04-27 | 77.38 |

## APPENDIX 9.

Static groundwater levels for Otjikoto Lake for the period 1971 to 1992.

[illegible]

[illegible]

| Todo Number | Well Number | Borehole No | Measurement Date | Underground water |
|---|---|---|---|---|
| 1917BA | 116 | | 1971-05-11 | 16.80 |
| 1917BA | 116 | | 1971-05-21 | 16.80 |
| 1917BA | 116 | | 1971-05-24 | 16.56 |
| 1917BA | 116 | | 1971-05-28 | 16.59 |
| 1917BA | 116 | | 1971-06-01 | 16.58 |
| 1917BA | 116 | | 1971-06-13 | 17.30 |
| 1917BA | 116 | | 1971-06-22 | 17.31 |
| 1917BA | 116 | | 1971-06-25 | 18.00 |
| 1917BA | 116 | | 1971-06-28 | 17.60 |
| 1917BA | 116 | | 1971-07-02 | 18.24 |
| 1917BA | 116 | | 1971-07-05 | 17.72 |
| 1917BA | 116 | | 1971-07-07 | 18.06 |
| 1917BA | 116 | | 1971-07-10 | 19.08 |
| 1917BA | 116 | | 1971-07-12 | 18.20 |
| 1917BA | 116 | | 1971-07-17 | 18.86 |
| 1917BA | 116 | | 1971-07-19 | 18.30 |
| 1917BA | 116 | | 1971-07-24 | 19.00 |
| 1917BA | 116 | | 1971-07-26 | 18.86 |
| 1917BA | 116 | | 1971-07-31 | 19.04 |
| 1917BA | 116 | | 1971-08-02 | 18.88 |
| 1917BA | 116 | | 1971-08-05 | 19.08 |
| 1917BA | 116 | | 1971-08-09 | 18.54 |
| 1917BA | 116 | | 1971-08-12 | 19.30 |
| 1917BA | 116 | | 1971-08-16 | 18.90 |
| 1917BA | 116 | | 1971-08-21 | 19.46 |
| 1917BA | 116 | | 1971-08-23 | 18.71 |
| 1917BA | 116 | | 1971-08-28 | 19.24 |
| 1917BA | 116 | | 1971-08-30 | 18.40 |
| 1917BA | 116 | | 1971-09-04 | 19.10 |
| 1917BA | 116 | | 1971-09-06 | 18.30 |
| 1917BA | 116 | | 1971-09-11 | 19.28 |
| 1917BA | 116 | | 1971-09-13 | 18.38 |
| 1917BA | 116 | | 1971-09-17 | 19.34 |
| 1917BA | 116 | | 1971-09-20 | 18.88 |
| 1917BA | 116 | | 1971-09-24 | 19.46 |
| 1917BA | 116 | | 1971-09-27 | 18.82 |
| 1917BA | 116 | | 1971-10-02 | 19.64 |
| 1917BA | 116 | | 1971-10-04 | 18.53 |
| 1917BA | 116 | | 1971-10-09 | 19.88 |
| 1917BA | 116 | | 1971-10-11 | 18.78 |
| 1917BA | 116 | | 1971-10-14 | 19.06 |
| 1917BA | 116 | | 1971-10-19 | 19.10 |
| 1917BA | 116 | | 1971-11-06 | 19.31 |
| 1917BA | 116 | | 1971-11-08 | 18.72 |
| 1917BA | 116 | | 1971-11-15 | 19.52 |
| 1917BA | 116 | | 1971-11-22 | 19.02 |
| 1917BA | 116 | | 1971-11-24 | 19.44 |
| 1917BA | 116 | | 1971-11-25 | 19.60 |
| 1917BA | 116 | | 1971-12-06 | 19.02 |
| 1917BA | 116 | | 1971-12-16 | 19.98 |
| 1917BA | 116 | | 1972-01-04 | 19.10 |
| 1917BA | 116 | | 1972-01-12 | 18.50 |
| 1917BA | 116 | | 1972-01-[illegible] | 18.25 |

[illegible]

[illegible] PAGE: [illegible]

| Topo Number | Well Number | Borehole No | Measurement Date | Underground water [illegible] |
|---|---|---|---|---|
| 1917BA | 116 | | 1972-01-27 | 18.44 |
| 1917BA | 116 | | 1972-01-31 | 19.10 |
| 1917BA | 116 | | 1972-02-15 | 18.84 |
| 1917BA | 116 | | 1972-02-23 | 20.00 |
| 1917BA | 116 | | 1972-03-08 | 19.34 |
| 1917BA | 116 | | 1972-03-15 | 19.78 |
| 1917BA | 116 | | 1972-04-14 | 19.66 |
| 1917BA | 116 | | 1972-05-10 | 17.80 |
| 1917BA | 116 | | 1972-05-15 | 18.94 |
| 1917BA | 116 | | 1972-05-23 | 18.10 |
| 1917BA | 116 | | 1972-06-15 | 17.54 |
| 1917BA | 116 | | 1972-07-15 | 17.02 |
| 1917BA | 116 | | 1972-08-15 | 16.94 |
| 1917BA | 116 | | 1972-09-15 | 16.40 |
| 1917BA | 116 | | 1972-10-16 | 16.16 |
| 1917BA | 116 | | 1972-11-15 | 16.00 |
| 1917BA | 116 | | 1972-12-14 | 16.16 |
| 1917BA | 116 | | 1972-12-15 | 19.62 |
| 1917BA | 116 | | 1973-01-15 | 20.40 |
| 1917BA | 116 | | 1973-03-07 | 18.82 |
| 1917BA | 116 | | 1973-04-06 | 19.47 |
| 1917BA | 116 | | 1973-04-10 | 19.47 |
| 1917BA | 116 | | 1973-05-05 | 18.80 |
| 1917BA | 116 | | 1973-06-06 | 18.84 |
| 1917BA | 116 | | 1973-07-01 | 18.88 |
| 1917BA | 116 | | 1973-07-29 | 19.42 |
| 1917BA | 116 | | 1973-08-04 | 19.77 |
| 1917BA | 116 | | 1973-09-04 | 19.22 |
| 1917BA | 116 | | 1973-10-04 | 19.62 |
| 1917BA | 116 | | 1973-11-02 | 20.64 |
| 1917BA | 116 | | 1973-11-29 | 20.46 |
| 1917BA | 116 | | 1974-01-03 | 19.03 |
| 1917BA | 116 | | 1974-02-01 | 18.08 |
| 1917BA | 116 | | 1974-02-24 | 17.88 |
| 1917BA | 116 | | 1974-03-02 | 17.02 |
| 1917BA | 116 | | 1974-03-27 | 16.80 |
| 1917BA | 116 | | 1974-04-27 | 16.37 |
| 1917BA | 116 | | 1974-05-23 | 16.57 |
| 1917BA | 116 | | 1974-06-27 | 16.50 |
| 1917BA | 116 | | 1974-07-05 | 16.40 |
| 1917BA | 116 | | 1974-07-23 | 16.33 |
| 1917BA | 116 | | 1974-08-25 | 16.18 |
| 1917BA | 116 | | 1974-09-25 | 16.17 |
| 1917BA | 116 | | 1974-10-25 | 16.14 |
| 1917BA | 116 | | 1974-11-27 | 15.94 |
| 1917BA | 116 | | 1974-12-05 | 15.96 |
| 1917BA | 116 | | 1974-12-07 | 16.35 |
| 1917BA | 116 | | 1974-12-12 | 16.74 |
| 1917BA | 116 | | 1974-12-17 | 18.84 |
| 1917BA | 116 | | 1974-12-21 | 16.52 |
| 1917BA | 116 | | 1974-12-30 | 18.11 |
| 1917BA | 116 | | 1975-01-05 | 16.14 |
| 1917BA | 116 | | 1975-01-08 | 18.22 |

[illegible]

WATER LEVELS [illegible]

| Toco Number | Well Number | Borehole No | Measurement Date | Underground water [illegible] |
|---|---|---|---|---|
| 1917BA | 116 | | 1975-01-12 | 16.34 |
| 1917BA | 116 | | 1975-01-17 | 16.00 |
| 1917BA | 116 | | 1975-01-20 | 16.39 |
| 1917BA | 116 | | 1975-01-29 | 16.36 |
| 1917BA | 116 | | 1975-02-09 | 15.72 |
| 1917BA | 116 | | 1975-02-13 | 16.73 |
| 1917BA | 116 | | 1975-03-02 | 16.20 |
| 1917BA | 116 | | 1975-03-13 | 15.44 |
| 1917BA | 116 | | 1975-03-24 | 16.24 |
| 1917BA | 116 | | 1975-03-31 | 16.42 |
| 1917BA | 116 | | 1975-04-11 | 16.04 |
| 1917BA | 116 | | 1975-04-13 | 15.39 |
| 1917BA | 116 | | 1975-05-01 | 16.30 |
| 1917BA | 116 | | 1975-05-15 | 16.26 |
| 1917BA | 116 | | 1975-06-05 | 16.13 |
| 1917BA | 116 | | 1975-07-09 | 15.70 |
| 1917BA | 116 | | 1975-08-07 | 15.67 |
| 1917BA | 116 | | 1975-09-09 | 15.72 |
| 1917BA | 116 | | 1975-10-11 | 15.70 |
| 1917BA | 116 | | 1975-10-19 | 15.86 |
| 1917BA | 116 | | 1975-10-31 | 16.51 |
| 1917BA | 116 | | 1975-11-10 | 16.04 |
| 1917BA | 116 | | 1975-12-09 | 16.76 |
| 1917BA | 116 | | 1976-01-16 | 15.16 |
| 1917BA | 116 | | 1976-02-10 | 15.30 |
| 1917BA | 116 | | 1976-03-13 | 16.20 |
| 1917BA | 116 | | 1976-04-10 | 16.92 |
| 1917BA | 116 | | 1976-06-10 | 16.56 |
| 1917BA | 116 | | 1976-07-17 | 16.73 |
| 1917BA | 116 | | 1976-08-13 | 16.04 |
| 1917BA | 116 | | 1976-09-12 | 16.10 |
| 1917BA | 116 | | 1976-10-11 | 15.84 |
| 1917BA | 116 | | 1976-11-21 | 13.97 |
| 1917BA | 116 | | 1977-02-10 | 12.43 |
| 1917BA | 116 | | 1977-03-09 | 12.66 |
| 1917BA | 116 | | 1977-04-10 | 12.58 |
| 1917BA | 116 | | 1977-05-08 | 12.54 |
| 1917BA | 116 | | 1977-05-30 | 12.53 |
| 1917BA | 116 | | 1977-06-05 | 12.73 |
| 1917BA | 116 | | 1977-07-03 | 12.60 |
| 1917BA | 116 | | 1977-07-31 | 12.38 |
| 1917BA | 116 | | 1977-08-01 | 12.84 |
| 1917BA | 116 | | 1977-10-04 | 12.72 |
| 1917BA | 116 | | 1977-11-05 | 13.00 |
| 1917BA | 116 | | 1977-12-06 | 13.01 |
| 1917BA | 116 | | 1978-01-29 | 12.44 |
| 1917BA | 116 | | 1978-02-09 | 11.76 |
| 1917BA | 116 | | 1978-02-21 | 10.50 |
| 1917BA | 116 | | 1978-03-16 | 10.12 |
| 1917BA | 116 | | 1978-04-16 | 10.06 |
| 1917BA | 116 | | 1978-05-21 | 10.16 |
| 1917BA | 116 | | 1978-07-24 | 10.24 |
| 1917BA | 116 | | 1978-08-13 | 10.34 |

[illegible]

# [illegible]

WATER LEVELS PAGE :

| Tdd Number | Well Number | Borehole No | Measurement Date | Underground water |
|---|---|---|---|---|
| 1917BA | 116 | | 1978-07-12 | 10.26 |
| 1917BA | 116 | | 1978-08-16 | 10.64 |
| 1917BA | 116 | | 1978-08-22 | 10.45 |
| 1917BA | 116 | | 1978-09-21 | 10.45 |
| 1917BA | 116 | | 1978-10-23 | 10.21 |
| 1917BA | 116 | | 1978-11-20 | 10.48 |
| 1917BA | 116 | | 1978-12-19 | 10.56 |
| 1917BA | 116 | | 1979-01-18 | 10.50 |
| 1917BA | 116 | | 1979-03-26 | 9.98 |
| 1917BA | 116 | | 1979-05-19 | 10.19 |
| 1917BA | 116 | | 1979-06-21 | 10.19 |
| 1917BA | 116 | | 1979-07-20 | 9.88 |
| 1917BA | 116 | | 1979-09-02 | 10.46 |
| 1917BA | 116 | | 1979-09-19 | 10.13 |
| 1917BA | 116 | | 1979-10-23 | 10.21 |
| 1917BA | 116 | | 1979-11-22 | 10.14 |
| 1917BA | 116 | | 1979-12-23 | 10.48 |
| 1917BA | 116 | | 1980-01-21 | 10.13 |
| 1917BA | 116 | | 1980-02-26 | 10.15 |
| 1917BA | 116 | | 1980-04-05 | 8.55 |
| 1917BA | 116 | | 1980-06-11 | 8.46 |
| 1917BA | 116 | | 1980-07-12 | 8.45 |
| 1917BA | 116 | | 1980-08-12 | 8.92 |
| 1917BA | 116 | | 1980-09-16 | 9.45 |
| 1917BA | 116 | | 1980-10-21 | 9.40 |
| 1917BA | 116 | | 1980-11-21 | 9.43 |
| 1917BA | 116 | | 1980-12-24 | 9.62 |
| 1917BA | 116 | | 1981-01-29 | 9.13 |
| 1917BA | 116 | | 1981-04-28 | 9.83 |
| 1917BA | 116 | | 1981-09-21 | 9.19 |
| 1917BA | 116 | | 1983-06-14 | 11.23 |
| 1917BA | 116 | | 1983-07-20 | 11.53 |
| 1917BA | 116 | | 1983-08-20 | 11.20 |
| 1917BA | 116 | | 1983-09-25 | 11.37 |
| 1917BA | 116 | | 1983-10-22 | 12.24 |
| 1917BA | 116 | | 1983-11-24 | 12.70 |
| 1917BA | 116 | | 1983-11-29 | 11.64 |
| 1917BA | 116 | | 1983-12-19 | 11.44 |
| 1917BA | 116 | | 1984-01-09 | 11.38 |
| 1917BA | 116 | | 1984-01-19 | 12.53 |
| 1917BA | 116 | | 1984-02-15 | 11.60 |
| 1917BA | 116 | | 1984-03-21 | 12.24 |
| 1917BA | 116 | | 1984-04-24 | 12.55 |
| 1917BA | 116 | | 1984-05-21 | 12.16 |
| 1917BA | 116 | | 1984-06-25 | 13.03 |
| 1917BA | 116 | | 1984-07-19 | 12.35 |
| 1917BA | 116 | | 1984-08-21 | 12.50 |
| 1917BA | 116 | | 1984-09-24 | 13.40 |
| 1917BA | 116 | | 1984-10-29 | 12.78 |
| 1917BA | 116 | | 1984-11-11 | 12.27 |
| 1917BA | 116 | | 1984-11-26 | 13.32 |
| 1917BA | 116 | | 1984-12-13 | 12.33 |
| 1917BA | 116 | | 1984-12-29 | 13.44 |

[illegible]

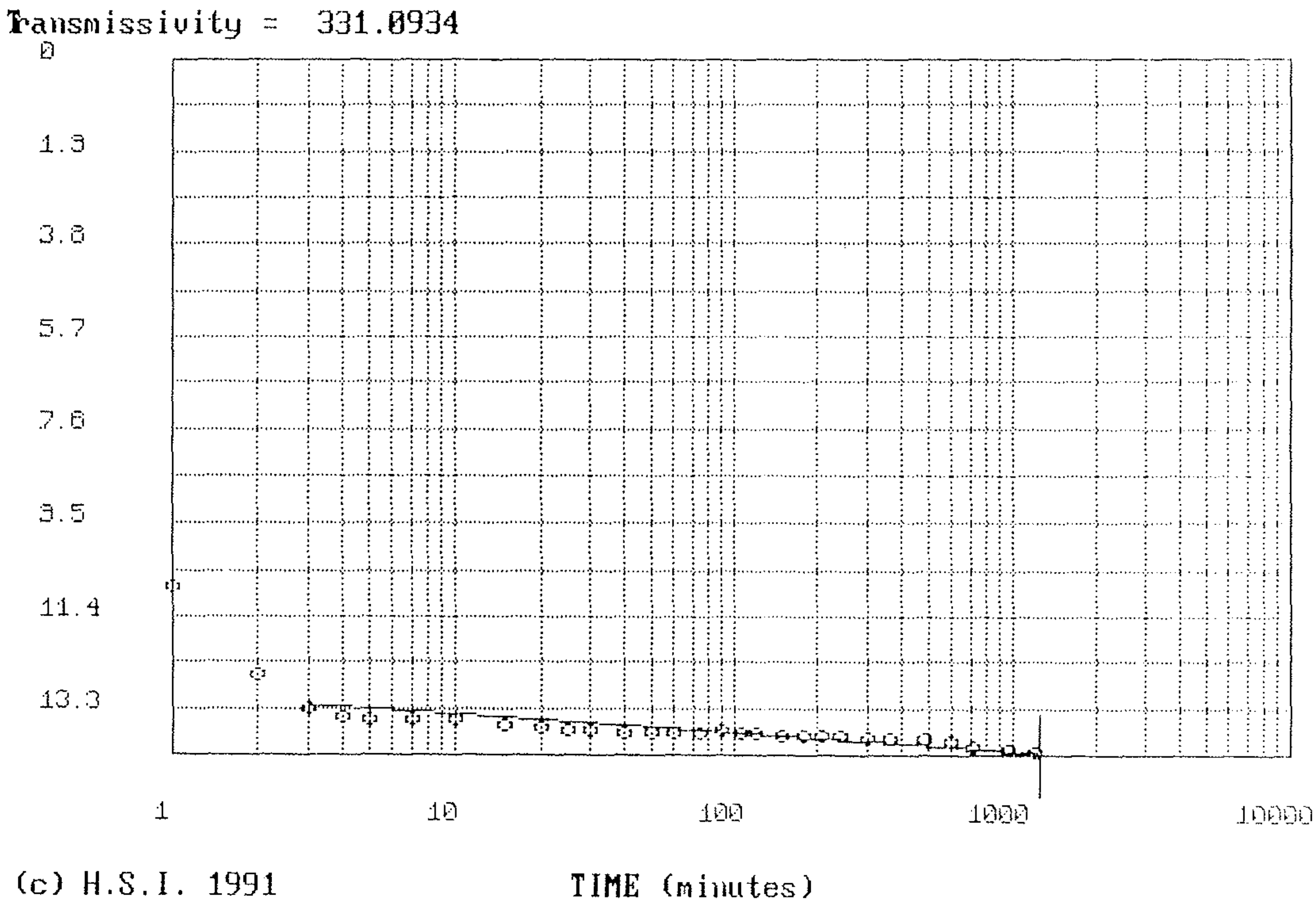
WATER LEVELS 

| Tod Number | Well Number | Borehole No | Measurement Date | Underground water |
|---|---|---|---|---|
| 1917BA | 116 | | 1985-01-14 | 12.80 |
| 1917BA | 116 | | 1985-01-19 | 13.49 |
| 1917BA | 116 | | 1985-02-15 | 10.82 |
| 1917BA | 116 | | 1985-03-14 | 10.46 |
| 1917BA | 116 | | 1985-03-18 | 11.79 |
| 1917BA | 116 | | 1985-04-29 | 11.11 |
| 1917BA | 116 | | 1985-05-23 | 11.07 |
| 1917BA | 116 | | 1985-06-26 | 11.55 |
| 1917BA | 116 | | 1985-07-25 | 11.65 |
| 1917BA | 116 | | 1985-08-26 | 11.55 |
| 1917BA | 116 | | 1985-09-20 | 12.44 |
| 1917BA | 116 | | 1985-10-28 | 12.40 |
| 1917BA | 116 | | 1985-11-18 | 11.88 |
| 1917BA | 116 | | 1985-11-25 | 12.35 |
| 1917BA | 116 | | 1985-12-17 | 11.08 |
| 1917BA | 116 | | 1985-12-20 | 11.47 |
| 1917BA | 116 | | 1986-01-25 | 12.13 |
| 1917BA | 116 | | 1986-02-10 | 11.29 |
| 1917BA | 116 | | 1986-02-24 | 11.33 |
| 1917BA | 116 | | 1986-03-24 | 11.36 |
| 1917BA | 116 | | 1986-04-25 | 12.21 |
| 1917BA | 116 | | 1986-05-01 | 11.71 |
| 1917BA | 116 | | 1986-05-19 | 12.06 |
| 1917BA | 116 | | 1986-05-22 | 12.56 |
| 1917BA | 116 | | 1986-06-27 | 12.38 |
| 1917BA | 116 | | 1986-06-30 | 11.96 |
| 1917BA | 116 | | 1986-07-23 | 12.54 |
| 1917BA | 116 | | 1986-08-12 | 12.19 |
| 1917BA | 116 | | 1986-08-23 | 13.23 |
| 1917BA | 116 | | 1986-08-29 | 12.27 |
| 1917BA | 116 | | 1986-09-22 | 12.51 |
| 1917BA | 116 | | 1986-10-04 | 12.39 |
| 1917BA | 116 | | 1986-10-22 | 13.13 |
| 1917BA | 116 | | 1986-11-21 | 12.12 |
| 1917BA | 116 | | 1986-12-19 | 13.44 |
| 1917BA | 116 | | 1987-01-23 | 12.80 |
| 1917BA | 116 | | 1987-02-20 | 12.31 |
| 1917BA | 116 | | 1987-03-21 | 13.21 |
| 1917BA | 116 | | 1987-04-27 | 12.79 |
| 1917BA | 116 | | 1987-05-22 | 13.74 |
| 1917BA | 116 | | 1987-06-26 | 13.86 |
| 1917BA | 116 | | 1987-07-24 | 13.12 |
| 1917BA | 116 | | 1987-08-26 | 13.96 |
| 1917BA | 116 | | 1987-09-24 | 14.26 |
| 1917BA | 116 | | 1987-10-21 | 14.22 |
| 1917BA | 116 | | 1987-11-21 | 13.50 |
| 1917BA | 116 | | 1987-12-15 | 14.17 |
| 1917BA | 116 | | 1988-01-22 | 13.10 |
| 1917BA | 116 | | 1988-02-19 | 13.10 |
| 1917BA | 116 | | 1988-03-19 | 13.71 |
| 1917BA | 116 | | 1988-04-25 | 13.32 |
| 1917BA | 116 | | 1988-0[illegible] | 13.3[illegible] |
| [illegible] | 116 | | 1988-06-27 | 14.1[illegible] |

| Plot Number | Well Number | Borehole No | Measurement Date | Underground Water |
|---|---|---|---|---|
| 1917BA | 116 | | 1988-07-19 | 14.53 |
| 1917BA | 116 | | 1988-08-22 | 14.24 |
| 1917BA | 116 | | 1988-09-24 | 14.98 |
| 1917BA | 116 | | 1988-10-24 | 14.61 |
| 1917BA | 116 | | 1988-11-22 | 14.41 |
| 1917BA | 116 | | 1988-12-19 | 14.10 |
| 1917BA | 116 | | 1989-01-23 | 14.21 |
| 1917BA | 116 | | 1989-02-27 | 13.40 |
| 1917BA | 116 | | 1989-03-27 | 13.80 |
| 1917BA | 116 | | 1989-04-24 | 13.85 |
| 1917BA | 116 | | 1989-05-26 | 14.01 |
| 1917BA | 116 | | 1989-06-26 | 14.04 |
| 1917BA | 116 | | 1989-07-24 | 13.20 |
| 1917BA | 116 | | 1989-08-26 | 13.90 |
| 1917BA | 116 | | 1989-09-25 | 14.37 |
| 1917BA | 116 | | 1989-10-23 | 14.74 |
| 1917BA | 116 | | 1989-11-29 | 14.53 |
| 1917BA | 116 | | 1989-12-19 | 13.33 |
| 1917BA | 116 | | 1990-01-26 | 14.00 |
| 1917BA | 116 | | 1990-02-24 | 13.82 |
| 1917BA | 116 | | 1990-03-17 | 13.87 |
| 1917BA | 116 | | 1990-04-24 | 14.10 |
| 1917BA | 116 | | 1990-05-26 | 14.51 |
| 1917BA | 116 | | 1990-06-23 | 14.75 |
| 1917BA | 116 | | 1990-07-23 | 14.79 |
| 1917BA | 116 | | 1990-08-23 | 15.31 |
| 1917BA | 116 | | 1990-09-22 | 15.37 |
| 1917BA | 116 | | 1990-10-22 | 15.31 |
| 1917BA | 116 | | 1990-11-20 | 15.14 |
| 1917BA | 116 | | 1990-12-19 | 14.37 |
| 1917BA | 116 | | 1991-02-22 | 14.30 |
| 1917BA | 116 | | 1991-02-25 | 14.37 |
| 1917BA | 116 | | 1991-03-25 | 14.88 |
| 1917BA | 116 | | 1991-04-22 | 13.52 |
| 1917BA | 116 | | 1991-05-16 | |
| 1917BA | 116 | | 1991-05-20 | 14.87 |
| 1917BA | 116 | | 1991-06-24 | 14.81 |
| 1917BA | 116 | | 1991-07-23 | 14.59 |
| 1917BA | 116 | | 1991-08-20 | 15.17 |
| 1917BA | 116 | | 1991-09-26 | 15.34 |
| 1917BA | 116 | | 1991-10-24 | 15.41 |
| 1917BA | 116 | | 1991-11-25 | 15.11 |
| 1917BA | 116 | | 1991-12-17 | 15.20 |
| 1917BA | 116 | | 1992-02-24 | 15.15 |
| 1917BA | 116 | | 1992-03-29 | 15.04 |
| 1917BA | 116 | | 1992-04-27 | 15.47 |
| 1917BA | 116 | | 1992-05-25 | 15.88 |

# APPENDIX 10.

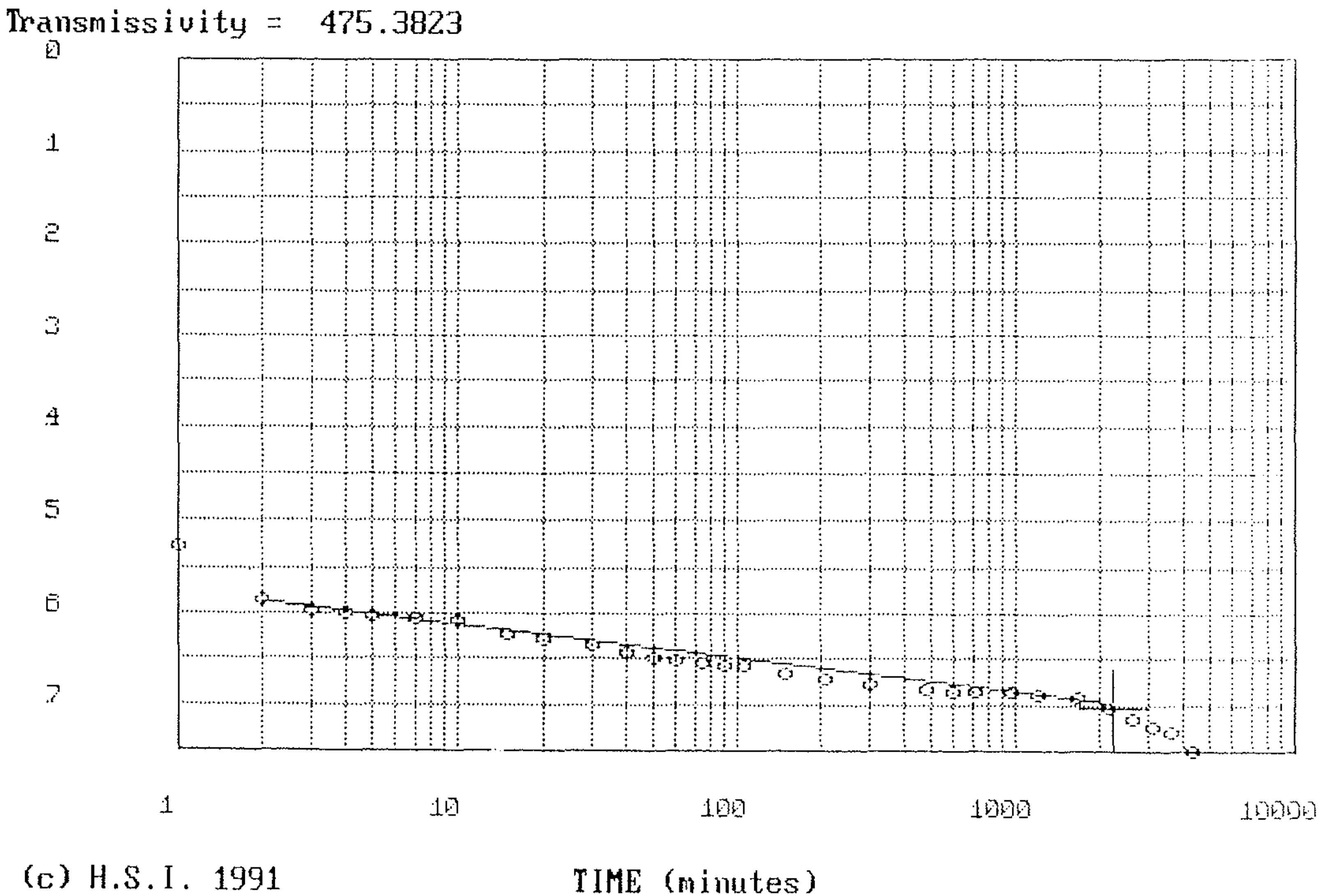
Test Pumping results from the Kalahari aquifer.




**Test Pump 1.** Test pump of WW 16903, as recorded in pumping well. Pumping rate 7.92 l/s. Test duration 24 hours.

| TEST PUMP OF WW 16903, AS RECORDED IN PUMPING WELL. PUMPING RATE 7.92 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 10.81 | 30 | 13.75 | 210 | 13.88 |
| 2 | 12.59 | 40 | 13.79 | 240 | 13.88 |
| 3 | 13.32 | 50 | 13.80 | 300 | 13.92 |
| 4 | 13.49 | 60 | 13.81 | 360 | 13.92 |
| 5 | 13.52 | 75 | 13.82 | 480 | 13.93 |
| 7 | 13.52 | 90 | 13.78 | 600 | 13.99 |
| 10 | 13.54 | 105 | 13.80 | 720 | 14.07 |
| 15 | 13.66 | 120 | 13.82 | 960 | 14.15 |
| 20 | 13.70 | 150 | 13.84 | 1200 | 14.19 |
| 25 | 13.74 | 180 | 13.87 | 1440 | 14.25 |

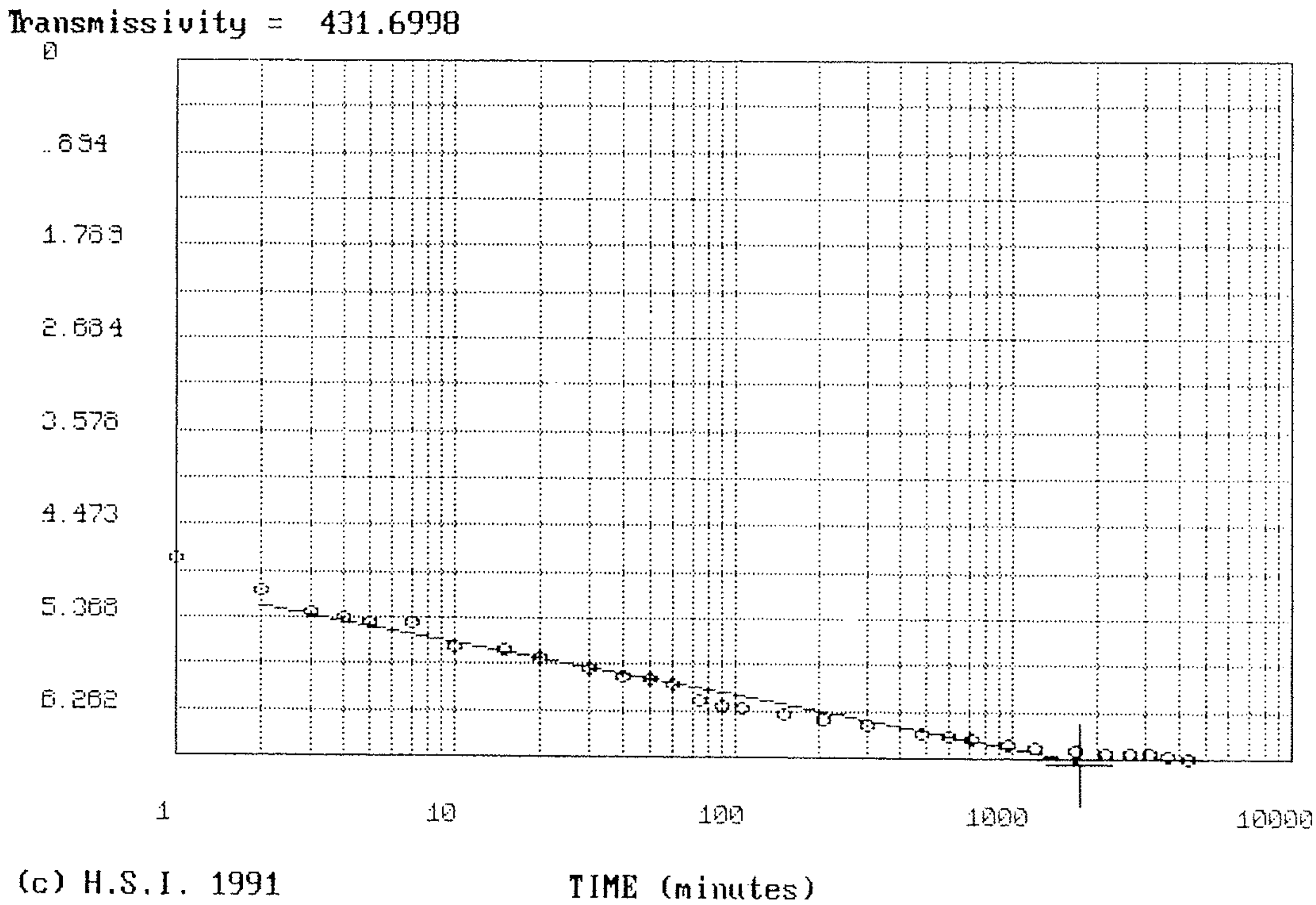
**DATA SHEET TO ACCOMPANY TEST PUMP 1.**




Test **Pump 2.** Test pump of WW 30362, as recorded in pumping well. Pumping rate 11.41 l/s. Test duration 72 hours. WW 30362 is located 500 m south east of WW 21625.

| TEST PUMP OF WW 30362, AS RECORDED IN PUMPING BOREHOLE. PUMPING RATE 11.41 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 5.27 | 40 | 6.43 | 600 | 6.86 |
| 2 | 5.86 | 50 | 6.48 | 720 | 6.86 |
| 3 | 5.97 | 60 | 6.53 | 960 | 6.87 |
| 4 | 5.99 | 75 | 6.54 | 1200 | 6.88 |
| 5 | 6.03 | 90 | 6.57 | 1680 | 6.93 |
| 7 | 6.07 | 105 | 6.59 | 2160 | 7.03 |
| 10 | 6.10 | 150 | 6.65 | 2640 | 7.15 |
| 15 | 6.23 | 210 | 6.71 | 3120 | 7.23 |
| 20 | 6.28 | 300 | 6.77 | 3600 | 7.30 |
| 30 | 6.34 | 480 | 6.85 | 4320 | 7.50 |

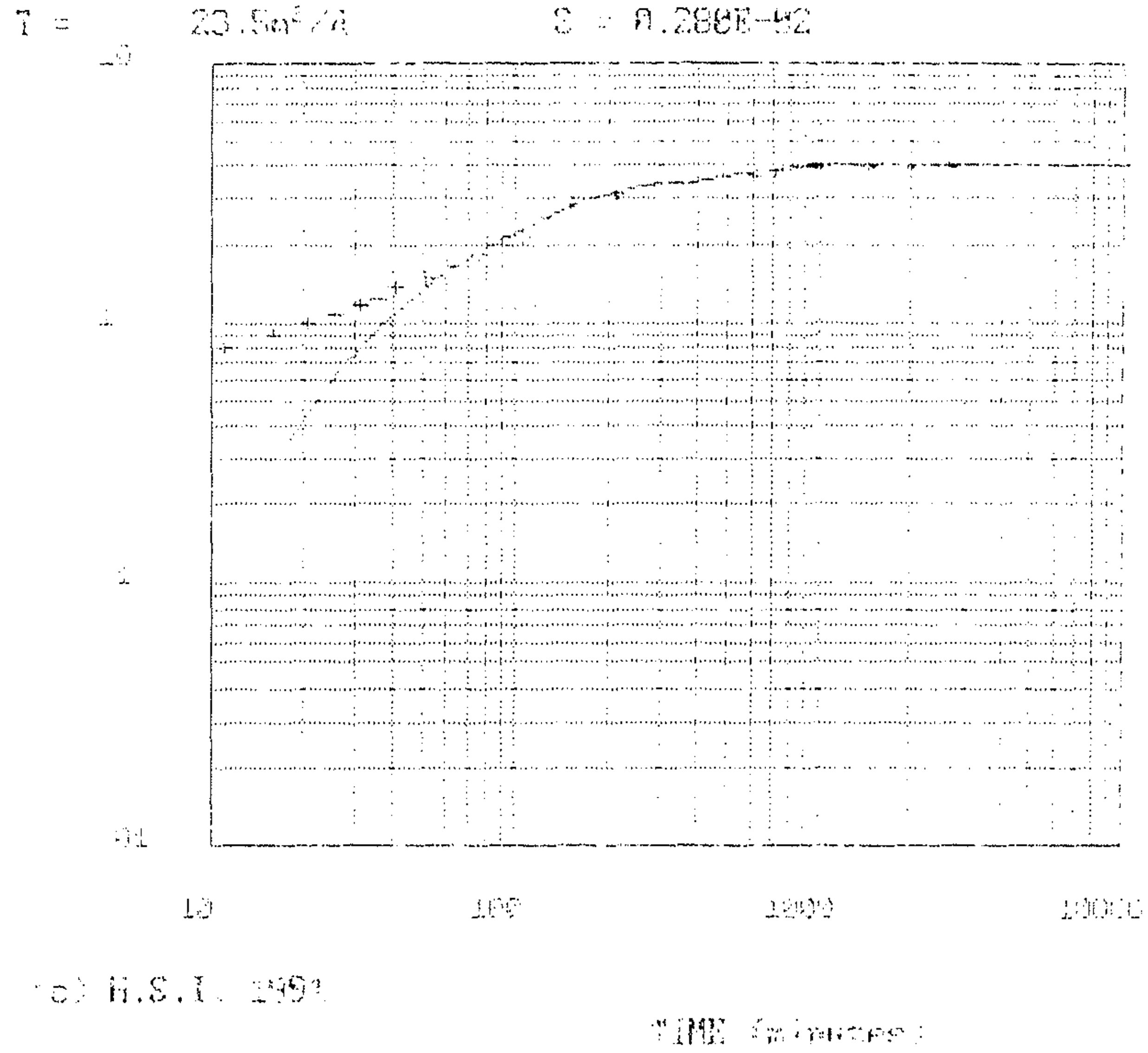
**DATA SHEET TO ACCOMPANY TEST PUMP 2.**




**Test Pump 3.** Test pump of WW 30718, as recorded in pumping well. Pumping rate 13.88 l/s. Test duration 72 hours. WW 30718 is located 2000 m east of WW 21625.

| TEST PUMP OF WW 30718, AS RECORDED IN PUMPING WELL. PUMPING RATE 13.88 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 1 | 4.81 | 40 | 5.94 | 600 | 6.51 |
| 2 | 5.11 | 50 | 5.97 | 720 | 6.54 |
| 3 | 5.32 | 60 | 6.01 | 960 | 6.57 |
| 4 | 5.38 | 75 | 6.16 | 1200 | 6.60 |
| 5 | 5.41 | 90 | 6.21 | 1680 | 6.64 |
| 7 | 5.42 | 105 | 6.25 | 2160 | 6.65 |
| 10 | 5.64 | 150 | 6.30 | 2640 | 6.66 |
| 15 | 5.67 | 210 | 6.34 | 3120 | 6.67 |
| 20 | 5.76 | 300 | 6.40 | 3600 | 6.69 |
| 30 | 5.85 | 480 | 6.47 | 4320 | 6.71 |

**DATA SHEET TO ACCOMPANY TEST PUMP 3.**




**Test Pump 4.** Test pump of WW 31491, as recorded in observation borehole WW 30901, situated 21 m away. Pumping rate 6.25 l/s. Test duration 72 hours.

| TEST PUMP OF WW 31491 AS RECORDED IN OBSERVATION BOREHOLE WW 30901, 21 m AWAY. PUMPING RATE 6.25 l/s. | | | | | |
|---|---|---|---|---|---|
| TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) | TIME ( Mins ) | DRAW DOWN ( m ) |
| 11 | 0.67 | 91 | 1.83 | 1441 | 3.94 |
| 16 | 0.80 | 106 | 1.97 | 1921 | 3.97 |
| 21 | 0.90 | 121 | 2.14 | 2641 | 3.98 |
| 26 | 0.99 | 151 | 2.50 | 3121 | 3.98 |
| 31 | 1.07 | 211 | 2.87 | | |
| 36 | 1.17 | 301 | 3.14 | | |
| 41 | 1.22 | 481 | 3.45 | | |
| 51 | 1.35 | 602 | 3.60 | | |
| 61 | 1.47 | 721 | 3.68 | | |
| 76 | 1.65 | 961 | 3.82 | | |

DATA SHEET TO ACCOMPANY PUMP TEST 4.

# APPENDIX 11.

Step Test results from the Kalahari aquifer.

## STEP TEST

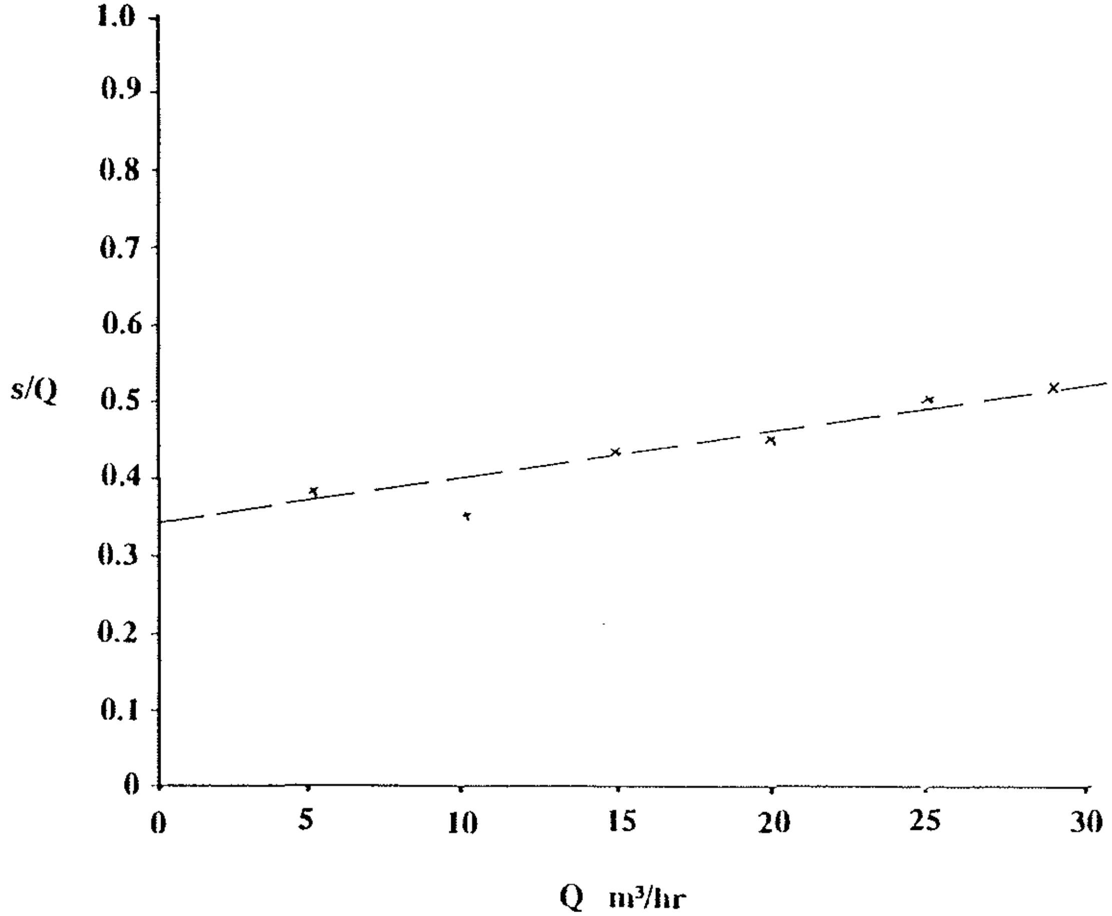
**WW 16903**

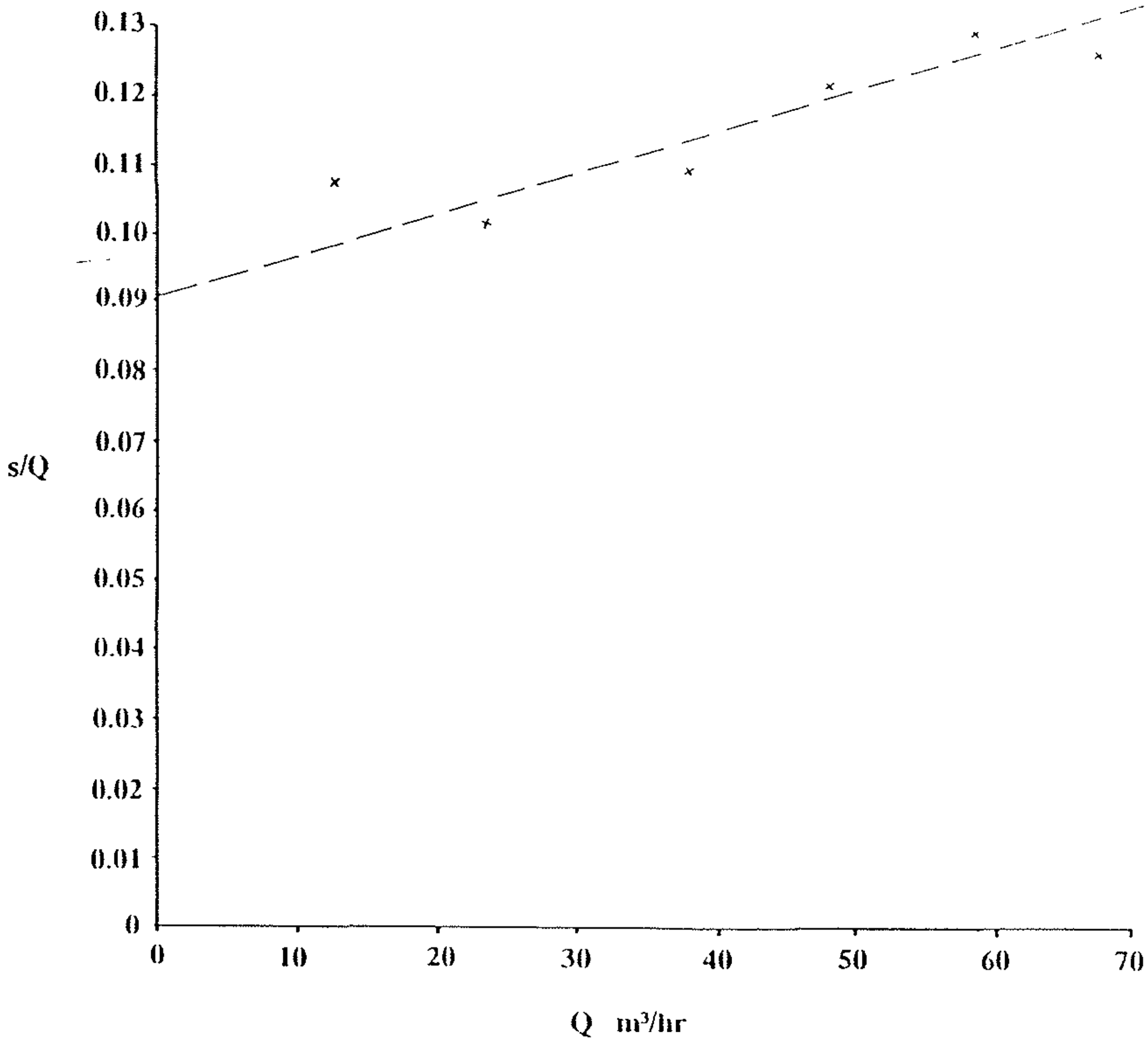
s/Q against Q

| s/Q | Q |
|---|---|
| 0.38 | 5.0 |
| 0.35 | 10.0 |
| 0.43 | 15.0 |
| 0.50 | 20.0 |
| 0.51 | 25.0 |

s is in metres
Q is in $m^3/hr$

$$s = 0.34\,Q + 0.0055\,Q^2$$






**STEP TEST**

**WW 30718**

s/Q against Q

| s/Q | Q |
|---|---|
| 0.108 | 13.1 |
| 0.102 | 24.0 |
| 0.109 | 38.3 |
| 0.121 | 48.6 |
| 0.129 | 59.0 |
| 0.126 | 68.0 |

s is in metres
Q is in $m^3/hr$

$s = 0.091\,Q + 0.0006\,Q^2$