THE CAPE FLATS AQUIFER
CURRENT STATUS

March 1995

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Stellenbosch
March 1995

Report No	: 11/95
File No	: WF718/3
Project No	: WF718 6800 6860

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PREFACE

A great deal of energy has been expended on the Cape Flats aquifer over the past 30 years. Exploration was done, boreholes were drilled, experiments and tests were undertaken, groundwater modelling was attempted, evaluations were completed, reports were written, degrees were obtained and steering committees were established and disbanded. Yet today the development of this water resource remains little more than wishful thinking on the part of the hydrogeological community.

This report, which is a compilation of research findings from this period, attempts to define the relevance of the Cape Flats aquifer to the Cape Metropolitan Area. The current political changes and planning initiatives taking place at a regional level make this an appropriate time for a report of this nature.

In producing this document, extensive use was made of the Department of Water Affairs and Forestry discussion document produced by M A C Vandoolaeghe in 1990. A great many other, often very lengthy, reports were used and these are listed in the Bibliography. A quote given in the Vandoolaeghe document was found particularly relevant and worth repeating:

> *"Nothing will ever be attempted,*
> *if all possible objections*
> *must be first overcome"*
>
> SAMUEL JOHNSON

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1 INTRODUCTION

The Cape Metropolitan Area is experiencing significant urban growth, with a predicted population of 3,5 million by the turn of the century (Spies & Barriage, 1991). Many would, however, consider this to be a conservative estimate, considering the Olympic bid. This growth, coupled with current social upliftment programmes, has resulted in a dramatic increase in demand for potable water. Existing resources should continue to meet demands until the year 1998 (Ninham Shand, 1994), with the result that engineers are now having to look further afield to obtain additional surface water resources. Such water supply schemes would, however, incur substantial costs, both financial and environmental. The question has therefore arisen as to whether supplementary supplies of water could be obtained from underground sources.

The Cape Metropolitan Area contains both primary and secondary aquifers. Of these the Cape Flats has the greatest potential, yet remains the most underutilized. As an unconfined sandy aquifer it is ideally suited for conjunctive exploitation. Groundwater and artificially recharged stormwater and treated sewage effluents could provide a useful supplement to the existing surface water supplies.

As a primary sandy aquifer the Cape Flats has several distinct advantages:

a) The aquifer is recharged during the winter months and serves as a reliable resource during the long dry summer;
b) The aquifer is artificially recharged relatively easily and provides for additional treatment of wastewaters (both treated sewage effluent and urban stormwater);
c) Development and maintenance costs are low in comparison with surface water schemes;
d) The aquifer is centrally situated with regard to the urban area;
e) The supply of water from a groundwater scheme can be introduced or stopped instantly, providing maximum management flexibility.

With this in mind, the Cape Flats aquifer was explored and studied from several angles by a number of research organizations between 1966 and 1989. Most of this work was sponsored by the Water Research Commission (WRC) and the Department of Water Affairs and Forestry (DWA&F) under the guidance of a Working Group which included the Cape Town City Council (CCC) and Cape Provincial Administration (CPA). Three different teams - Henzen (1973), Gerber (1976) and Wessels & Greeff (1980) - explored different sections, i.e. western, central and eastern respectively, of the aquifer. With the exception of Gerber's (1976) work, exploration was primarily aimed at obtaining certain aquifer information to study the feasibility of reclamation, storage and abstraction of treated sewage effluent (Henzen, 1973) and surplus run-off from the Eerste River system (Wessels & Greeff, 1980). Little was done to delineate and describe the aquifer physically to arrive at an evaluation in terms of abstraction rates and aquifer potential. Two further studies were undertaken in order to bring the investigation to a logical conclusion. Gerber (1980) developed a simulation model capable of describing subsurface flow in the southern portion of the Cape Flats and Tredoux (1981) undertook a limited artificial recharge study using partially reclaimed stabilization pond effluent.

It was proposed by the Working Group that groundwater development of this aquifer begin in 1981. The CCC, the local authority responsible for the Metropolitan water supply, however, decided not to develop the Cape Flats aquifer. The resource was regarded as unproven, relatively small and of questionable quality. As a compromise, it was decided to undertake a pilot abstraction scheme in a section of the aquifer that would require a minimum of outlay expenditure. The water would be pumped to waste, as the local authority would not pay for feeding the groundwater production into the water supply network. This study was done by the DWA&F in the Mitchell's Plain area over a period of three years.

Today, some 30 years after the first geohydrological investigation began, the question whether the Cape Flats aquifer is viable is still being asked. The verdict was positive in 1981, but is this still true in 1995? What was a dune-scape invaded by rooikrans, is now urban sprawl in the form of Mitchell's Plain, Khayelitsha, Blue Downs, Dehlft, Mfuleni, just to mention a few suburbs. The recent Western Cape Systems Analysis (Ninham Shand, 1994) recommended the possible exploitation of the Cape Flats aquifer by 2005, should "experimentation prove this feasible". This report attempts to clarify this issue and represents a compilation of the earlier research efforts and subsequent appraisals by the DWA&F (Vandoolaeghe, 1990).

2 PHYSICAL CHARACTERISTICS

2.1 Topography

The Cape Flats represents a broad tombolo between the Cape Peninsula and mainland (Figure 1). The almost horizontal sandstones of Table Mountain were originally linked to the same formations capping the mountains on the eastern fringes of the Cape Flats. Post-Palaeozoic erosion has removed these sandstones between False Bay and Table Bay. Rivers have carved valleys to both False Bay and Table Bay, while surf-zone erosion during transgressions has formed marine platforms in the south-east corner of the Cape Flats. This fluvial and marine erosion has shaped the topography of deeply weathered Malmesbury Group and Cape Granite bedrock on the Cape Flats (Hartnady & Rogers, 1990).

2.2 Geology

The Cape Flats aquifer consists of Cenozoic deposits underlain by essentially impervious Malmesbury Shales or Cape Granite. The sands, which cover an area of some 630 km^2, extend in a northerly direction along the West Coast. Sedimentation initially occurred in a shallow marine environment, subsequently progressing to intermediate beach and wind-blown deposits, and finally to aeolian and marsh (peat)

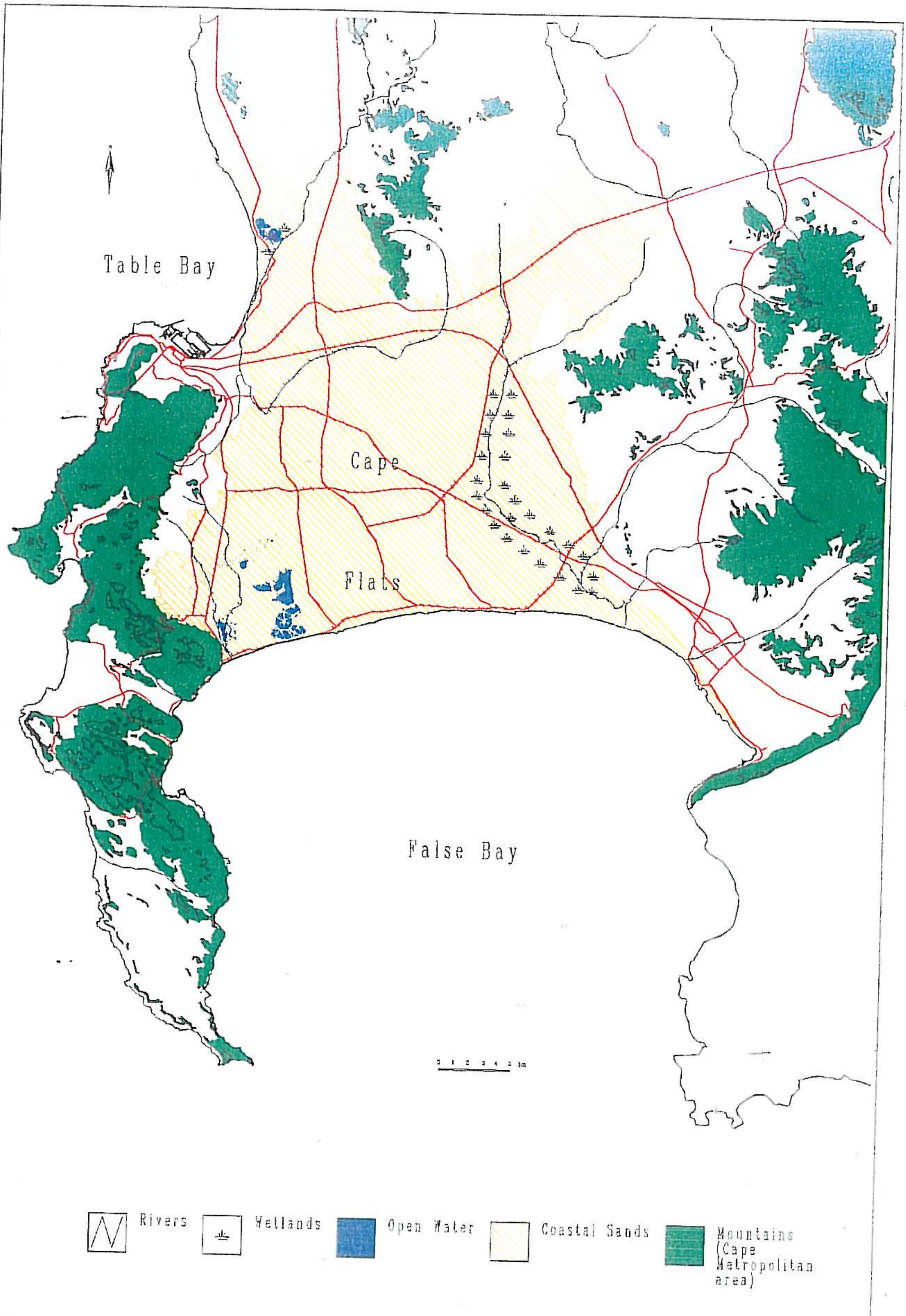


Fig 1 Location of the Cape Flats sand unit

conditions. A feature of the sediments is the presence of shelly material over most of the area. The sand body is generally stratified horizontally and several lithostratigraphic units can be recognized (Table 1). Portions of the area are covered by calcareous sands and surface limestone deposits (Figure 2), while silcrete, marine clays and bottom sediments of small inland water bodies also occur sporadically.

TABLE 1: CAPE FLATS LITHOSTRATIGRAPHY

SANDVELD GROUP	Witzand Formation* Langebaan Formation Velddrif Formation Springfontyn Formation* Varswater Formation Elandsfontein Formation*	Recent Pleistocene Pleistocene Pleistocene Pliocene Miocene
FALSE BAY DOLERITES	(e.g. Logies Bay dyke)	Jur-Cretaceous
TABLE MOUNTAIN GROUP	Pakhuis Formation Peninsula Formation Graafwater Formation	Silurian Silurian Ordovician
	Cape Point Intrusive	Precamb-Cambrian
CAPE GRANITE SUITE	Cape Peninsula Batholith	Precamb-Cambrian
MALMESBURY GROUP	Sea Point Formation* Bloubergstrand Formation*	Late Proterozoic Late Proterozoic

* Not yet approved by SACS

[From: Hartnade & Rogers, 1990, p 4]

- The Witzand Formation consists of very fine to very coarse calcareous sands and has abundant small shells and shell fragments. These sands form an extensive system of parabolic, vegetation-bound coastal dunes;

- The Langebaan Formation, locally called the Wolfgat Formation, consists of calcrete and very fine to fine calcareous sands, which along the coast contain crossbedding. The calcretized upper surface of this unit forms the cliffs seen along the shoreline. Massive sandy surface limestone, which forms a hard irregular layer, covers much of the eastern Cape Flats. The degree of cementation, lime content and thickness of the unit vary considerably. The calcareous unit depicted in Figure 3 (east-west cross-sections) consists mainly of several hard, well-cemented layers which alternate with softer clayey or crumbly lime-rich zones. The lime-rich bed over the greater part of the area (Figure 3 north-south cross-section) is only a few metres thick and consists of an upper, hard, densely cemented zone of 250 to 350 mm, resting on soft, sandy yellow calcrete, which grades into calcareous sand, the lime content of which gradually decreases with depth. This represents the precipitation of secondary lime by groundwater action (Theron, 1984);

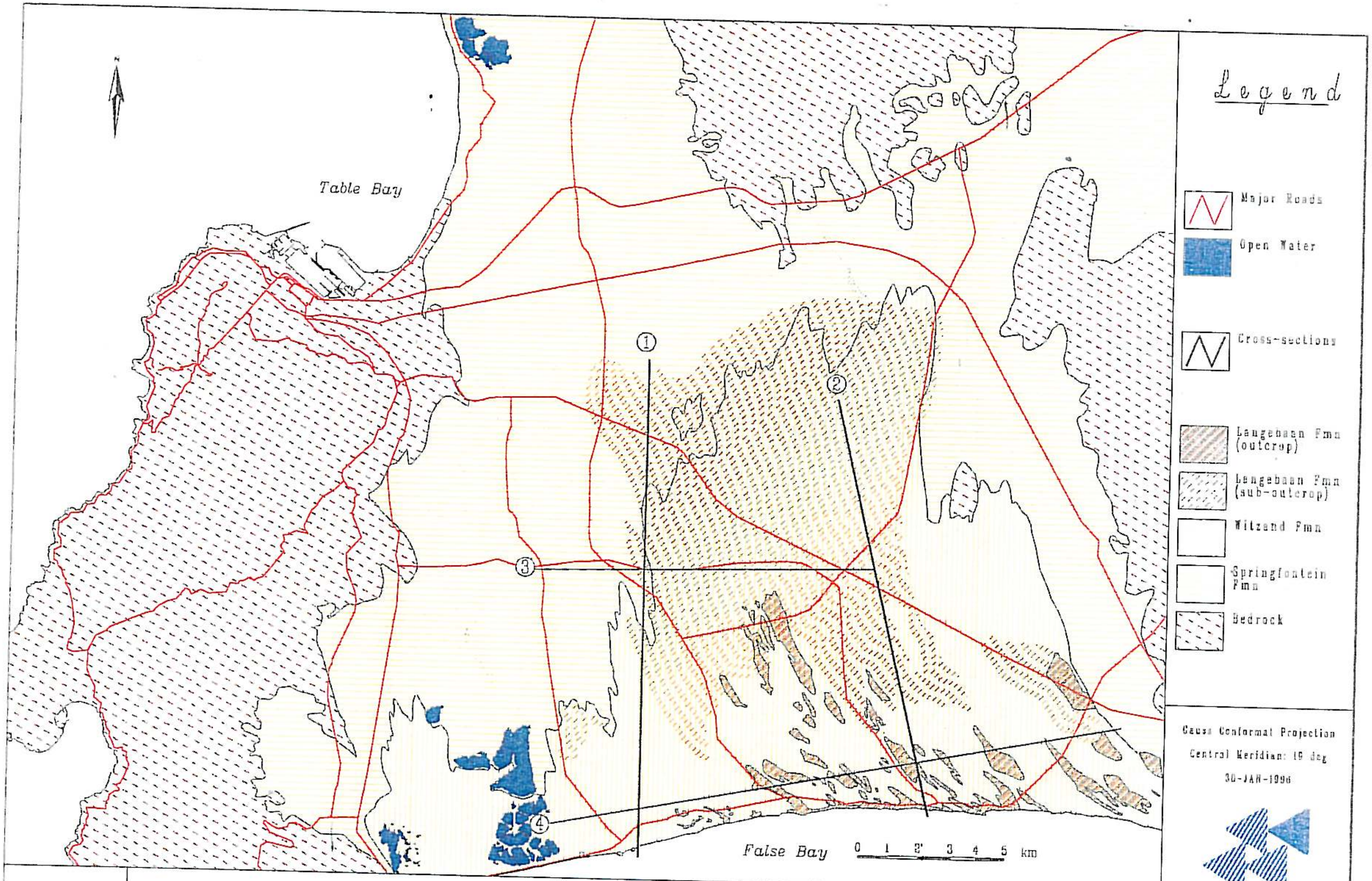


Fig. 2 Distribution of the major lithological units of the Sandveld Group within the Cape Flats

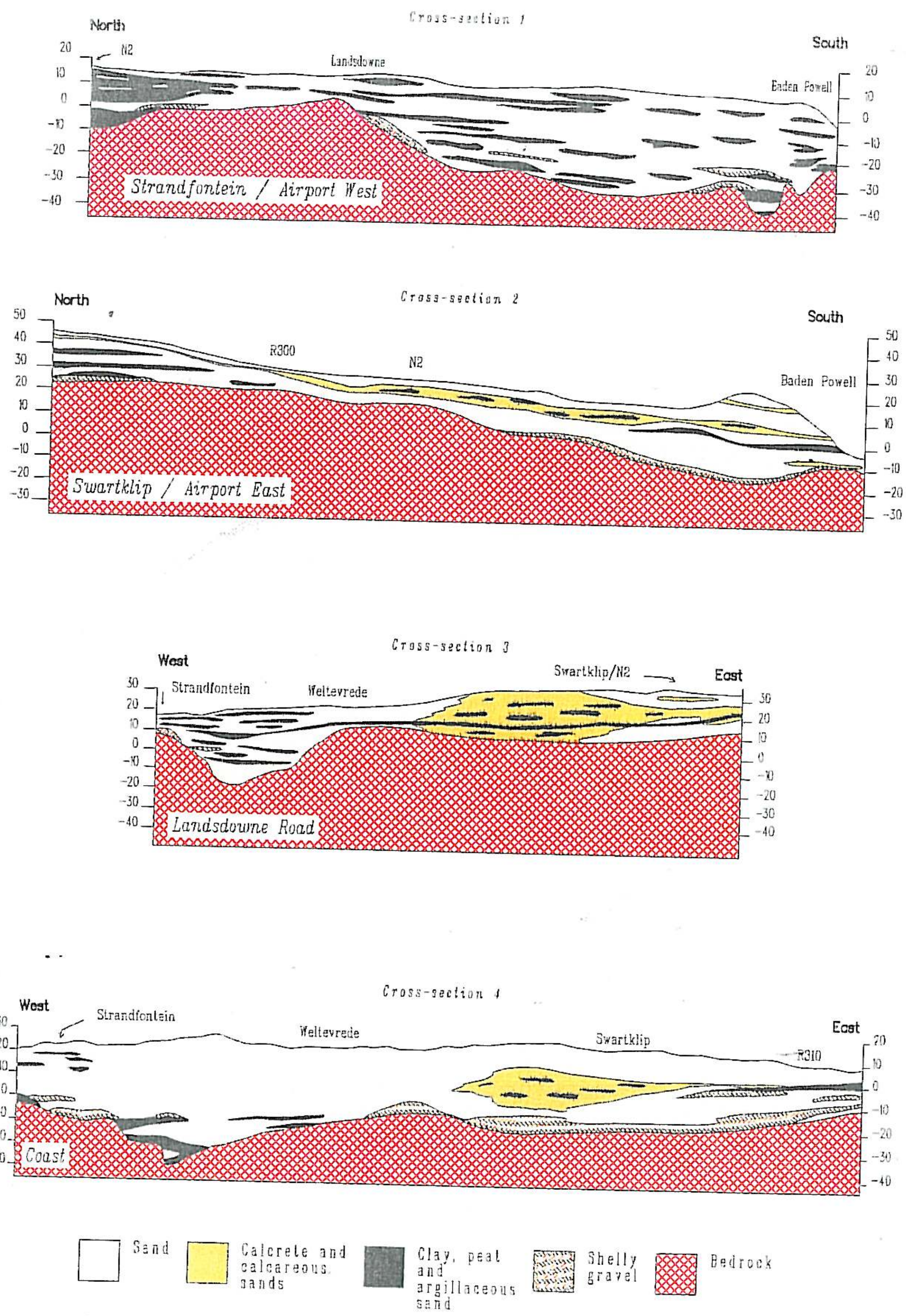


Fig 3 Selected geological cross-sections, as indicated on Figure 2

- The Velddrif Formation, which is best seen at the foot of the coastal cliffs, is a patchy deposit of poorly consolidated intertidal and estuarine sediments;

- The Springfontein Formation, which is aeolian in nature, consists of fine to medium quartzose sand. Grain size often increases with depth and thin calcareous clay and peat lenses may be present locally . The formation is relatively uniform and free of inclusions. In the vicinity of Philippi these sands attain an unusual degree of purity (99,5 % SiO_2) and have been mined for the manufacture of high-quality colourless glass. Vandoolaeghe (1989) suggests that this formation is nothing more than a decalcified facies of the Witzand Formation. Decalcification resulting from the action of groundwater where surface and subsurface permeabilities were relatively high and thus conducive to recharge and quick subsurface throughflow of young, aggressive groundwaters;

- The Varswater Formation is a marine deposit which consists of very fine to medium, often silty sand that contains abundant small shells and shell fragments, and a coarse shelly gravel;

- The Elandsfontyn Formation consists of angular, fine to coarse clayey sands. Peat and peaty clay layers are characteristic of this formation. The patchy, inland occurrence of these sediments suggests that the bulk of these terrestrial deposits may have been removed by subsequent marine transgressions.

The bedrock topography (Figure 4) shows that there is a Palaeo-valley reaching more than 40 m below mean sea level just to the east of Zeekoevlei. This runs northwards beneath the present-day Lotus River valley. This presumably represents a land surface related to a period of Late Tertiary low sea-level stand, perhaps even the major Oligocene regression, which reached down to about 400 m below present sea level (Hartnady & Rogers, 1990). The bedrock is predominantly argillaceous weathered Malmesbury shale, with minor weathered granite in places. The weathered zone of the bedrock is up to 44 metres thick. The bedrock gradient is from 80 m amsl at Bellville to -40 m at Zeekoevlei.

2.3 Geohydrology

The Sandveld Group deposits constitute what is known as the Cape Flats aquifer. The aquifer is regionally unconfined and internally is essentially free of lateral hydraulic or geological boundaries which may influence regional behaviour. The aquifer is not hydrogeologically linked to any other aquifer, except the talus/scree material along the foot of the mountains in the west. The aquifer pinches out against "impermeable" boundaries in the east, west and north, while the southern boundary is defined by the coastline extending along False Bay, between Muizenberg and Macassar. Figure 5 gives some indication of the average thickness of the sand unit. The aquifer itself is

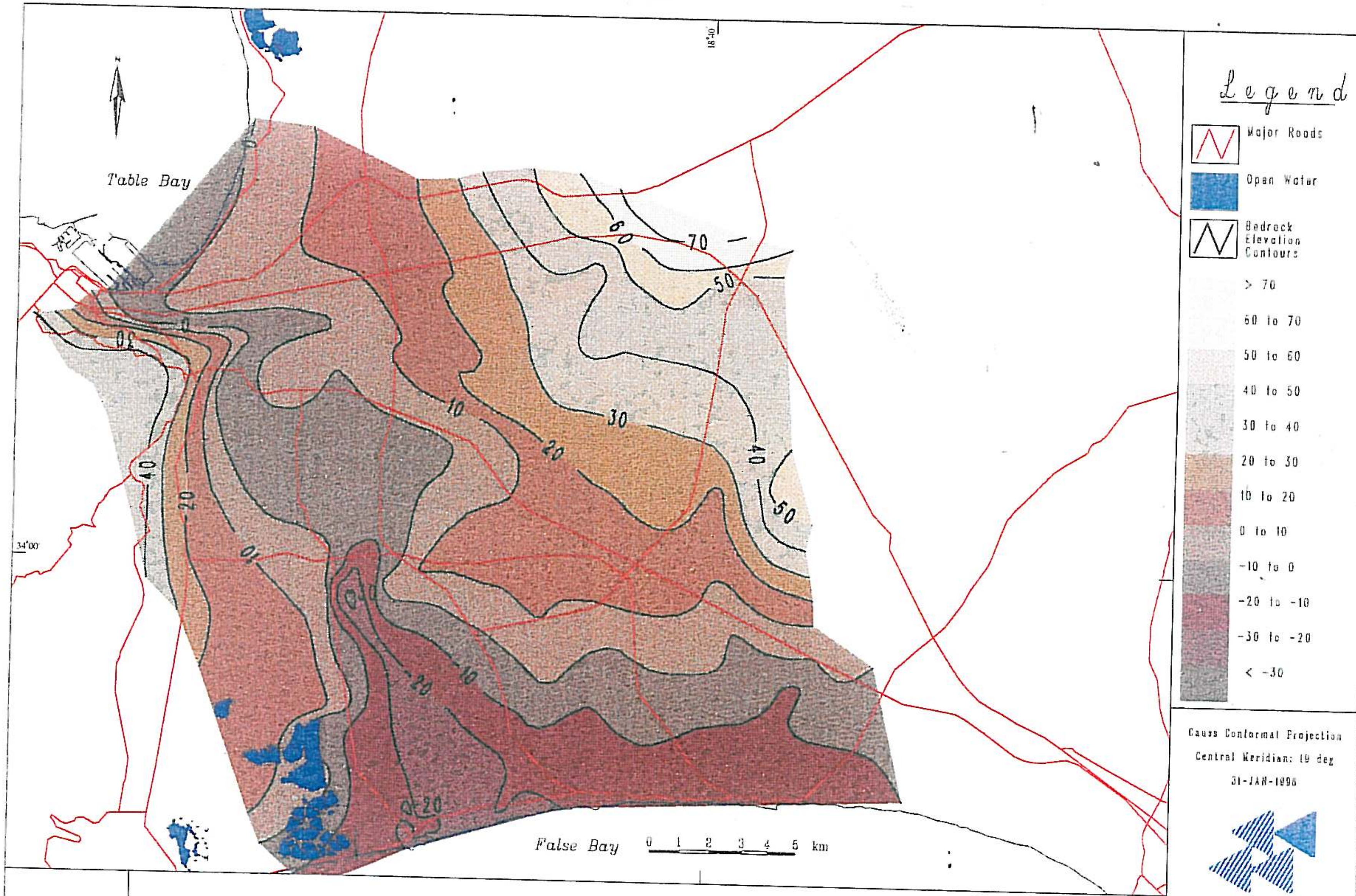


Fig. 4 Bedrock topography (mamsl) of the Cape Flats Aquifer

best depicted by the saturated sand isopleth map (Figure 6). The weathered bedrock has generally been considered as the impervious basement of the primary aquifer (Gerber, 1976; Wessels & Greeff, 1980).

Sands of the Witzand and Springfontein Formations constitute the major groundwater target. These sands range in size from fine to coarse and are generally well sorted and rounded. These characteristics ensure above-average hydraulic conductivity (30 - 40 m/d in the central area and 15 - 50 m/d in the eastern portion) for this component of the aquifer (Vandoolaeghe, 1989). These formations do, however, possess a degree of heterogeneity and anisotropy due to vertical and lateral grain size graduation and the occurrence of sandy clay and clayey sandy lenses. As a result, anisotropic groundwater flow conditions and/or a vertical flow component (leakage, delayed yield) occur to a more or lesser extent in most places where this formation is pumped.

The calcareous clay and calcrete layers of the Langebaan Formation, if present, act as a barrier and hinder the free flow of groundwater. This unit thus acts as an aquitard and results in a semi-confined aquifer. The Varswater Formation can also be classified as an aquitard when the Witzand and Springfontein Formations are present. The calcareous sands have relatively low hydraulic conductivities (1 - 10 m/d) and even the shelly gravel component has hydraulic conductivities between 6 and 23 m/d (Vandoolaeghe, 1989).

By virtue of the pelitic and extensively weathered nature of the Malmesbury metasediments, the bedrock is generally regarded as an impervious basement. The Malmesbury does, however, contain brittle sandstones and high yields have been obtained in these arenaceous units along the West Coast. Part of the groundwater abstracted in the Philippi agricultural area is derived from the bedrock. Wessels & Greeff (1980) also located a number of boreholes in the eastern Cape Flats producing good yields and qualities out of the Malmesbury rocks. The target zone is transmissive, brecciated zones associated with faults.

The aquifer is recharged principally from precipitation within the catchment. Average annual rainfall, which occurs mainly in winter and early spring, ranges from 500 to 800 mm across the Cape Flats. Gerber (1980) calculated that recharge from precipitation is in the order of 154 x 10^6 m^3 per annum. The Kuils River System, the most significant fluvial system in comparison, was estimated to contribute about 0,5 x 10^6 m^3 per annum. Similarly, recharge from surface water bodies in the west was considered insignificant. Analysis of groundwater levels in the Zeekoevlei area showed that this shallow pond is partly maintained by groundwater seepage, with the possible exception of short periods after heavy rains when the quasi-equilibrium system may be temporarily disturbed. In addition the base of the pond appeared sealed to a large extent as a result of mud and clay deposition. Similarly the municipal sewage treatment ponds were considered minor sources of recharge.

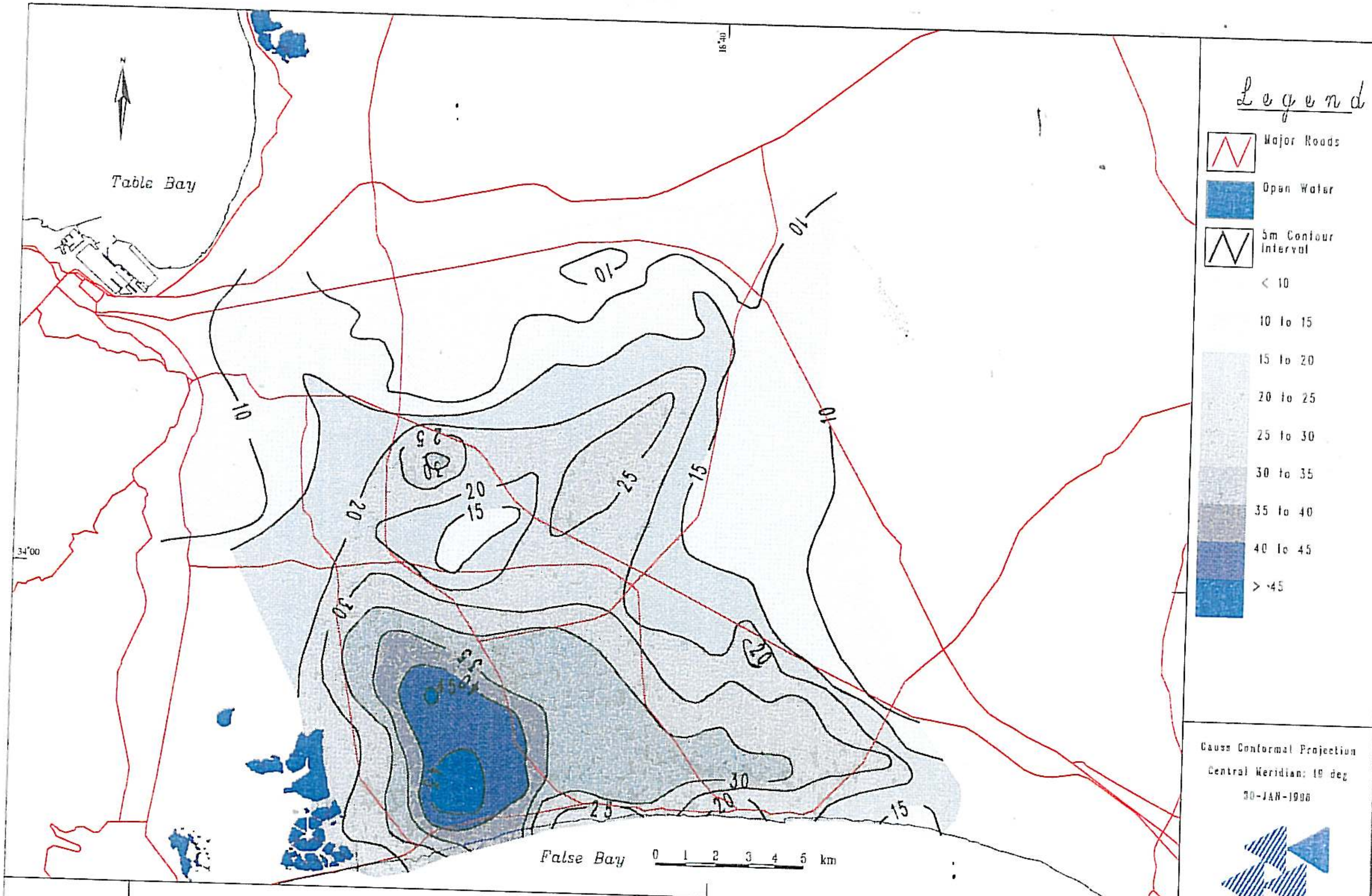


Fig. 5 Average thickness (m) of the sand unit on the Cape Flats

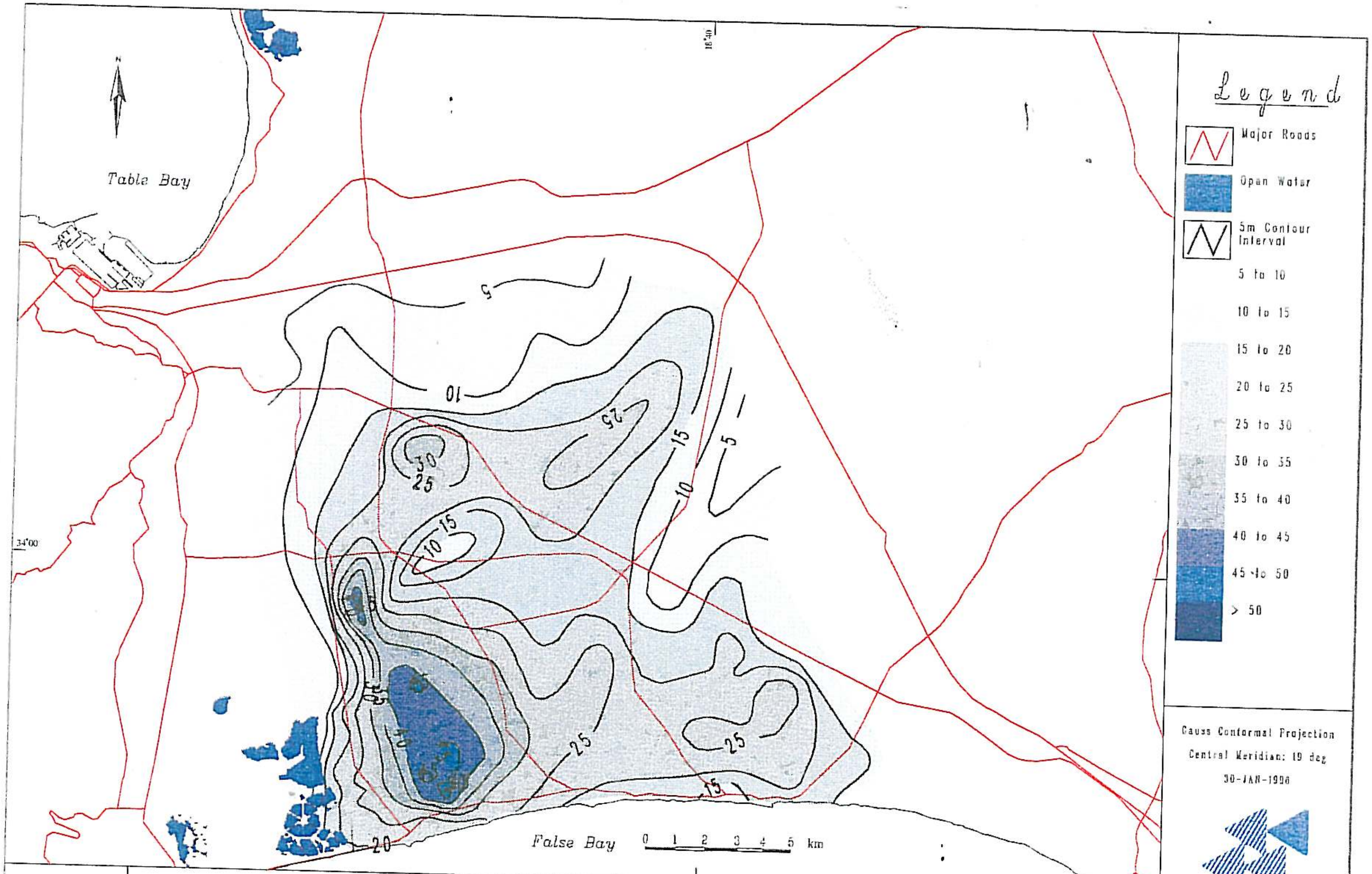


Fig. 6 Average thickness of saturated sands (m) - Cape Flats

Groundwater flow in the Cape Flats is either west to Table Bay or south to False Bay (Figure 7). In the main part of the aquifer (south of N2 highway) flow directions are either in a westerly direction towards Zeekoevlei or south towards Mnandi/Monwabisi. Water level contours also suggest a lower hydraulic conductivity along the coast than inland. Water loss is along the whole coastline and not along well-defined "channels". Seasonal water level fluctuations range up to 2 m in the north-east.

The investigations by Henzen (1973) and Gerber (1976) involved geophysical surveys, drilling, test pumping, sand analysis, experiments and laboratory tests, resulting in some idea of the hydraulic parameters of the aquifer. Transmissivity values ranged from 50 to 650 m^2/d, with typical values ranging between 200 and 350 m /d (Figure 8). The effective porosity was typically of the order of 0,10 to 0,12 but values of 0,25 were found over a large area. The vertical permeability was found to be smaller by a factor of 10 to 20 or even up to 100 when compared with the horizontal permeability. Replenishment of the aquifer due to precipitation was calculated at 36×10^6 m^3 per annum. The losses by evapotranspiration are extremely high and exceed 80 %. Average evapotranspiration rates at ground level were estimated at 2×10^{-8} m/s. This is especially true in the eastern portion where shallow calcrete units cause a perched water table. The annual seepage loss was calculated at 28×10^6 m^3.

Subsequent work by Vandoolaeghe (1989) confirmed that net groundwater recharge through sandy soils of the primary aquifers in the South-Western Cape varies between 15 % and 37 % of the annual precipitation. It also indicated that the transmissivity distribution (Figure 8), which formed a cornerstone of Gerber's 1980 modelling, was a gross generalization and was based on a very limited number of tests in a heterogeneous aquifer.

2.4 Groundwater quality

The chemical quality of the indigenous groundwater of the aquifer is summarized in Table 2. The water in the main part of the aquifer generally has a fairly low salinity and its outstanding characteristic is a relatively high temporary hardness. The maximum values recorded represent water drawn from isolated areas typified by a water table at or above ground level, resulting in extreme evaporation rates (Tredoux *et al.*, 1980). In addition, the occurrence of argillaceous "vlei" and marine deposits at different stratigraphic levels result in zones of saline water. The build-up of salts in these pockets is also ascribed to evaporation.

Figure 9 gives an idea of salinity over the entire aquifer. It shows that the more saline water generally occurs in the peripheral areas, for example, Pinelands and Parow. The Philippi area has by far the highest salt concentrations and Bertram (1989) showed that this was due to irrigation practices. High potassium and nitrate levels are a direct reflection of 400 odd tons of fertilizer applied annually. Figure 9 is based on Henzen's 1973 work and it is not clear whether this mineralized water body has subsequently moved further south towards False Bay. Vandoolaeghe (1990) believes this is unlikely considering the present degree and pattern of abstraction.

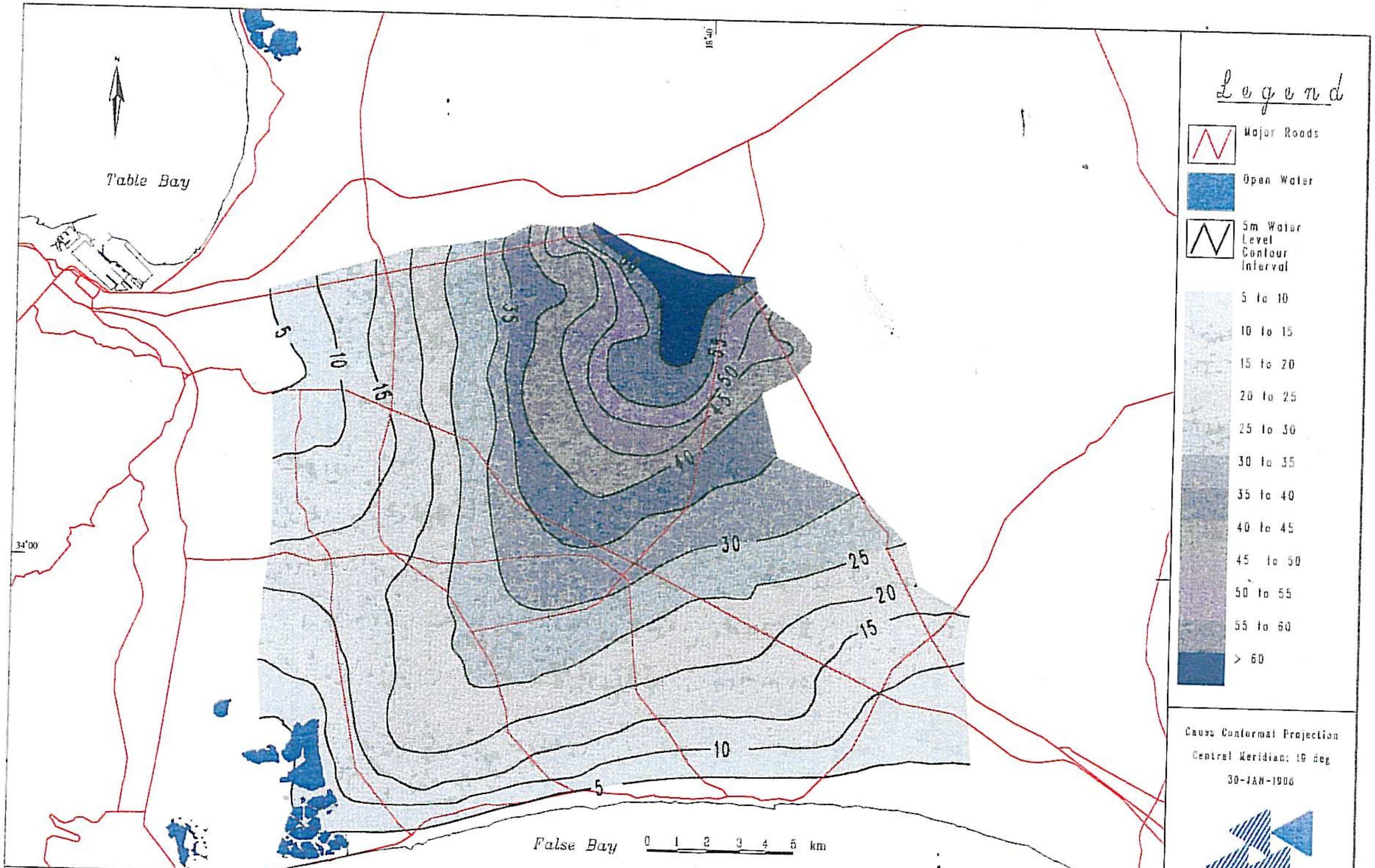


Fig. 7 Groundwater level contour plan - January 1977 (mamsl)

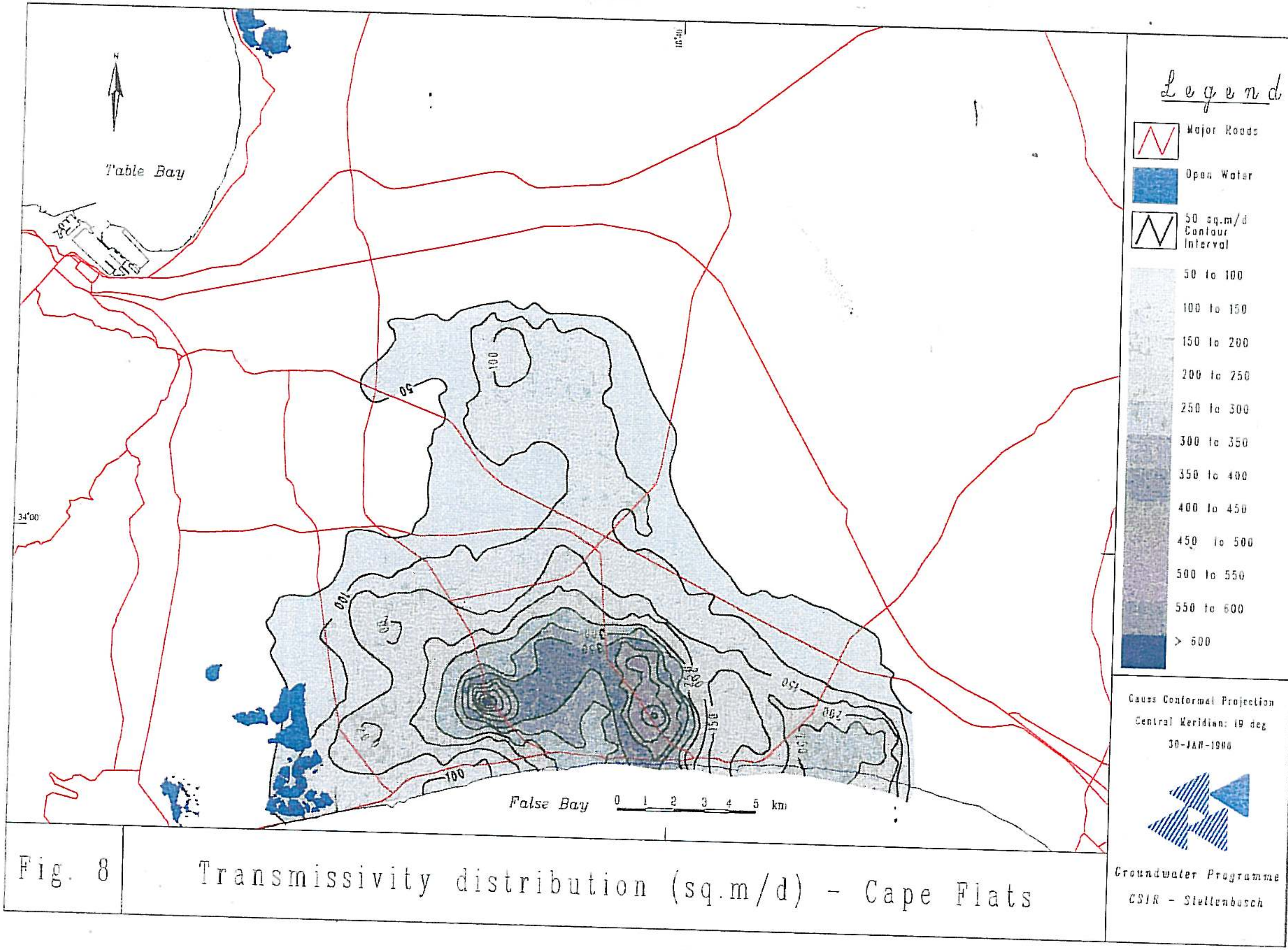


Fig. 8 Transmissivity distribution (sq.m/d) - Cape Flats

Fig. 9 Groundwater quality on the Cape Flats: represented as salinity (TDS) in mg/L

TABLE 2: INDIGENOUS GROUNDWATER QUALITY IN THE CAPE FLATS AQUIFER

CHEMICAL		CONCENTRATIONS		
		MEDIAN	MINIMUM	MAXIMUM
Sodium	mg/L	57	20	760
Potassium	mg/L	1,5	0,9	12,0
Calcium	mg/L	95	36	150
Magnesium	mg/L	11	3,9	93
Ammonia (as N)	mg/L	<0,5	<0,5	1,2
Sulphate	mg/L	30	4	166
Chloride	mg/L	99	35	1 317
Total Alkalinity (as $CaCO_3$)	mg/L	248	80	391
Nitrate (as N)	mg/L	<0,1	<0,1	2,6
Nitrite (as N)	mg/L	<0,05	<0,5	0,1
Total phosphate (as P)	mg/L	<0,1	<0,1	0,35
pH		7,7	7,0	8,2
Electrical conductivity	mS/m	78	43	499

[From: Tredoux *et al.*, 1980, p 80]

The abundance of shelly material throughout the aquifer results in a groundwater that is saturated with respect to calcium carbonate. Hence the occurrence of calcrete (calcareous horizons) near the water table.

The elevated H_2S concentrations commonly found in the Cape Flats are a result of sulphate reduction from natural bacteria and chemical processes. Although dissolved iron commonly occurs, the concentrations seldom exceed 1 mg/L. This is very much as a result of the high pH and calcium carbonate content. Iron could possibly be a problem with production boreholes and clogging of screens. Wright (1994) found that in the Swartklip/Khayelitsha area the water quality deteriorated with depth (Table 3). This contradicts the earlier findings of Henzen (1973). Although Henzen used 583 boreholes, only 111 of these were less than 15 m in depth and the majority of these were in the Philippi agricultural area.

3 RESOURCE POTENTIAL

The million-dollar question remains: How much water can be abstracted from the Cape Flats aquifer and where should the well field(s) be located?

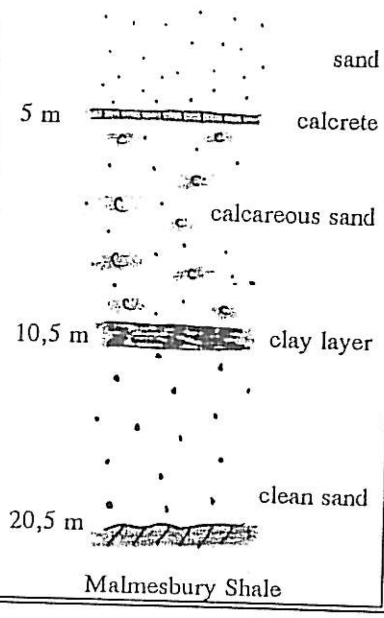
It was originally hoped that the Cape Flats Groundwater Development Pilot Abstraction Scheme undertaken by the DWA&F between 1983 and 1985 would provide an answer to this question. It was, however, found that it was not possible to extrapolate the results from this pilot study over the entire aquifer. This was largely due to the difference in scale, aquifer heterogeneity and lack of knowledge of the physical characteristics of the aquifer as a whole (Vandoolaeghe, 1989).

Several estimates have been made over the years, ranging from Henzen's (1973) estimate of 1 500 x 10^6 m^3 total storage capacity and 28 x 10^6 m^3 per annum safe yield to Ninham Shand's (1994) of 128 x 10^6 m^3 storage capacity and 18 x 10^6 m^3 per annum safe yield.

TABLE 3: KHAYELITSHA: GROUNDWATER QUALITY VARIATIONS WITH DEPTH

DETERMINANT		DEPTH (below surface)		
		4 m	9 m	18 m
K	mg/L	5,7	2,3	3,3
Na	mg/L	65	275	473
Ca	mg/L	150	124	201
Mg	mg/L	43,3	31,7	57,0
NH_4-N	mg/L	1,73	0,84	0,52
SO_4	mg/L	175	55	60
Cl^-	mg/L	96	338	845
Alk ($CaCO_3$)	mg/L	382	471	474
NO_x-N	mg/L	<0,1	<0,1	<0,1
P	mg/L	<0,1	<0,1	<0,1
DOC	mg/L	16,85	24	18,7
EC	mS/m	124	200	340
pH's (20°C)		6,9	6,9	6,7
TDS (calc)	mg/L	794	1280	2176
Hardness as $CaCO_3$	mg/L	554	441	738

LITHOLOGY



Several approaches have been taken when attempting to calculate the sustainable yield:

a) Gerber's 1980 simulation modelling can be used. As previously stated, this work was based largely on "the transmissivity" (Figure 8) and two rather impracticable well fields. A figure of 15 x 10^6 m^3 per annum was obtained using the more extensive (50 boreholes) of the two well field options. The value excludes the Philippi area and should be considered as a minimum value, since a very conservative approach had been used.

b) Vandoolaeghe (1990) used historical abstraction totals from the Philippi area and extrapolated these over that area of the aquifer with similar characteristics. This information, combined with that from the pilot abstraction study, gave a sustainable yield of about 20 x 10^6 m^3 per annum. Again, this excludes the Philippi agricultural area.

c) Abstraction should not exceed recharge. Although Henzen (1973) calculated a figure of 36 x 10^6 m^3 per annum for the entire aquifer, it is now considered more appropriate to use the more conservative "effective recharge" values calculated by Gerber (1976) - 12 x 10^6 m^3 per annum - and Vandoolaeghe (1989) - 14 x 10^6 m^3 per annum.

The best estimate for the safe yield of the Cape Flats aquifer, excluding current Philippi abstraction, is in the order of 15 to 20 x 10^6 m^3 per annum. The upper limit could probably be obtained for an initial number of years as a drawdown trough develops by drawing an available storage. Ultimately, however, the abstraction should not exceed average recharge. To this must be added the 13 x 10^6 m^3 per annum pumped in the Philippi agricultural area.

The available yield as discussed above does not take the artificial recharge of treated wastewaters or urban stormwater runoff into consideration. Much of the earlier research dealt with this aspect. Tredoux (1981) showed that in the Strandfontein area purified effluent could be infiltrated by means of surface spreading (basins) at rates between 3,5 and 15 m/day, provided effluent turbidity remained below 2 NTU. Using a conservative rate of 7 m/day translates into a recharge potential of 70 000 kL/day for a basin with a 1 ha bottom surface. An operating efficiency of 60 % would achieve an annual recharge of more than 15 000 ML per 1 ha basin. The Wessels & Greeff (1980) study also proved the validity of artificially recharging the aquifer in the eastern portion of the Cape Flats. By making use of the natural "vleis" in the area an additional 27 x 10^6 m^3 of surplus surface water from the Kuils and Eerste Rivers could be recharged at minimal cost. The water could then be recouped through a system of interdunal basins and 212 production boreholes covering an area of 11,4 km^2 in what is today Khayelitsha.

Subsequent to these studies much of the aquifer has been covered by urban development and the validity of the results today needs to be re-evaluated. There is no doubt about the value of artificial recharge for both augmenting the natural recharge and thus permitting increased abstraction, and preventing more saline water from entering the well field. The only issue is whether there is still sufficient undeveloped land on which a recharge basin could be constructed. These would obviously have to be directly related to the well field locations. The possibility of using injection wells has as yet not been locally researched.

Having the water in the ground is one thing, being able to abstract it is a different story. Water is currently being abstracted in bulk in two areas. The Philippi agricultural area (15 km^2) is responsible for pumping in excess of 13 x 10^6 m^3, while the Cape Town Municipality pumps more than 5 x 10^6 m^3 for irrigation purposes at Mitchell's Plain and Strandfontein. Several other smaller schemes were established to serve local irrigation needs, but are currently not in operation.

Of the earlier researchers it was only Gerber (1980) who outlined possible well fields. Two well field options were considered, one of 27 boreholes, extending from Weltevreden Road to Swartklip Road, and a second of 50 boreholes, which extended across the entire southern portion of the aquifer from Strandfontein Road to the Kuils River marshes (Figure 10). These would yield 10 x 10^6 m^3 per annum and 18 x 10^6 m^3 per annum respectively and produce a drawdown of 5 m in the Philippi farming area and 12,5 m in the centre of the field. The layout of these well fields appears to be based largely on the transmissivity data presented in Figure 8 and, although acceptable for modelling purposes, is not very practical with regard to implementation.

Vandoolaeghe (1990), employing a more practical approach, proposed two well fields concentrated in the areas of greatest transmissivity (Figure 10). The western well field is located around the Mitchell's Plain Waste Water Treatment Works in the vicinity of Weltevreden Road. The eastern well field is centered on Swartklip Road south of the solid waste disposal site. These two fields, although smaller in area than those of Gerber, would have higher yielding boreholes (10 - 30 L/s as against 5 - 12 L/s) and yield 10 to 12,5 x 10^6 m^3 per annum and 5 to 7,5 x 10^6 m^3 per annum respectively.

By means of GIS the existing data was used to define areas of greatest potential with regard to abstraction (Figure 11). The aquifer characteristics used included transmissivity, saturated thickness and water quality. It must be noted that the final categorization had been fairly subjective, as much of this information is of a more regional/general scale and based on a limited number of field tests. The Vandoolaeghe proposal has the greatest merit, as this not only takes the aquifer characteristics into account but also attempts to address the practical constraints. Figure 12 illustrates the current status of urban development, much of which has taken place since the initial research was done. Points that have to be taken into consideration include:

- land availability;
- possible sources of pollution;
- whether it is possible to include some form of artificial recharge, and
- whether the water is for local use or to be fed into the general metropolitan supply.

4 EXPLOITATION POTENTIAL

It is clear that geohydrologically the Cape Flats aquifer represents an important resource which can be exploited as a municipal water supply. The main question is how and when this should be done.

The Atlantis Water Resource Management Scheme, which exploits a similar but lesser resource within the Cape Metropolitan Area, serves as an excellent example of how it should be done. Abstraction is concentrated in optimally placed well fields, with artificially recharged wastewater both supplementing natural recharge and hence increasing available yield, and forming a hydrological barrier against contamination from adjacent pollution sources. Concentrated abstraction results in a local cone of depression, which when correctly managed, allows the maximum volume of water to be abstracted without any long-term detrimental impact on the resource.

Unfortunately in the case of the Cape Flats aquifer, it is slightly more difficult to fully exploit the resource, as urban planners totally ignored the aquifer when developing the Cape Flats. Figure 12 illustrates how the urban planners have managed to locate a solid waste disposal site and wastewater treatment works directly above the most productive part of the aquifer. Besides these, the main portion of the aquifer contains

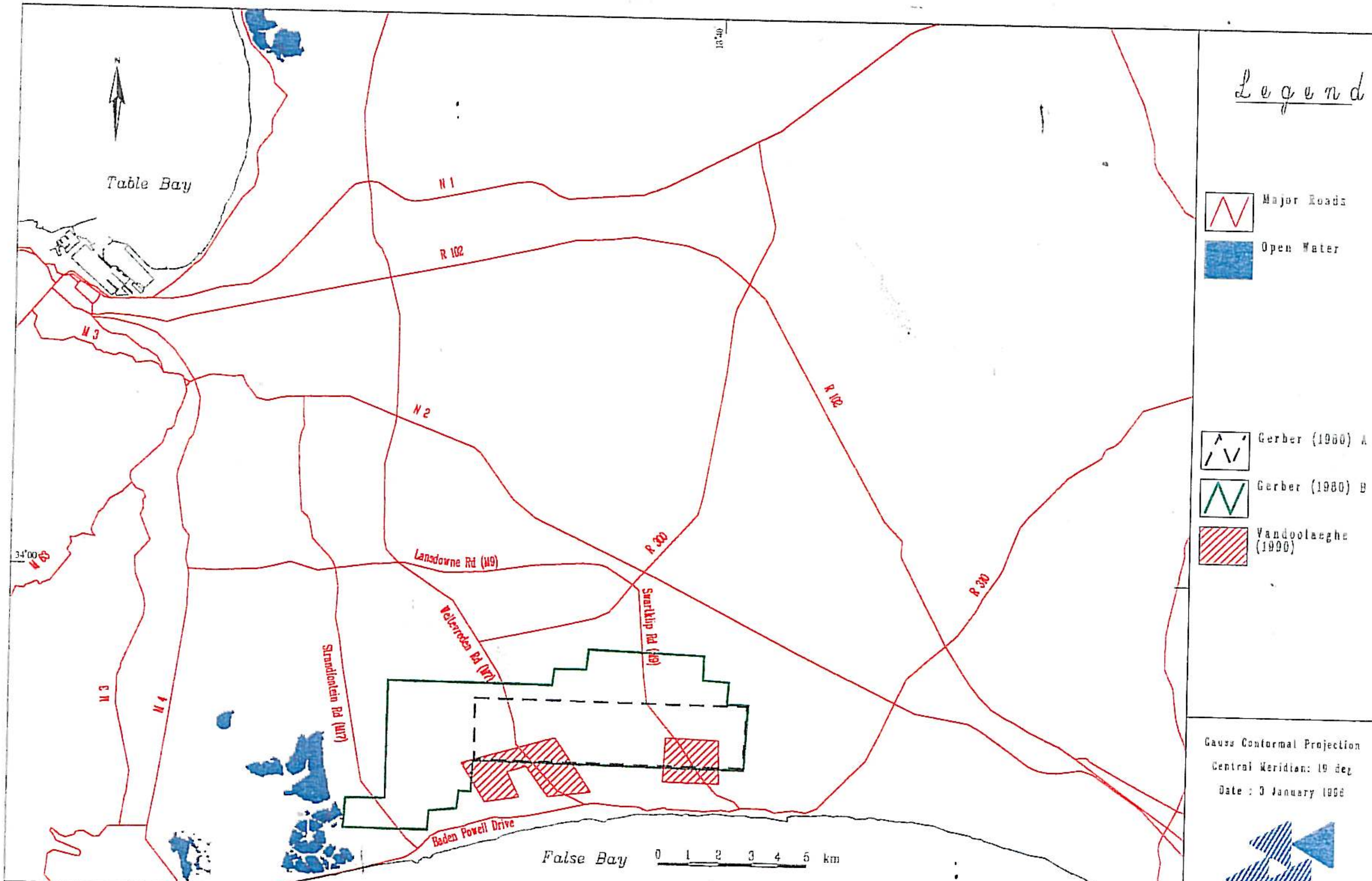


Fig.10 Proposed well field sites

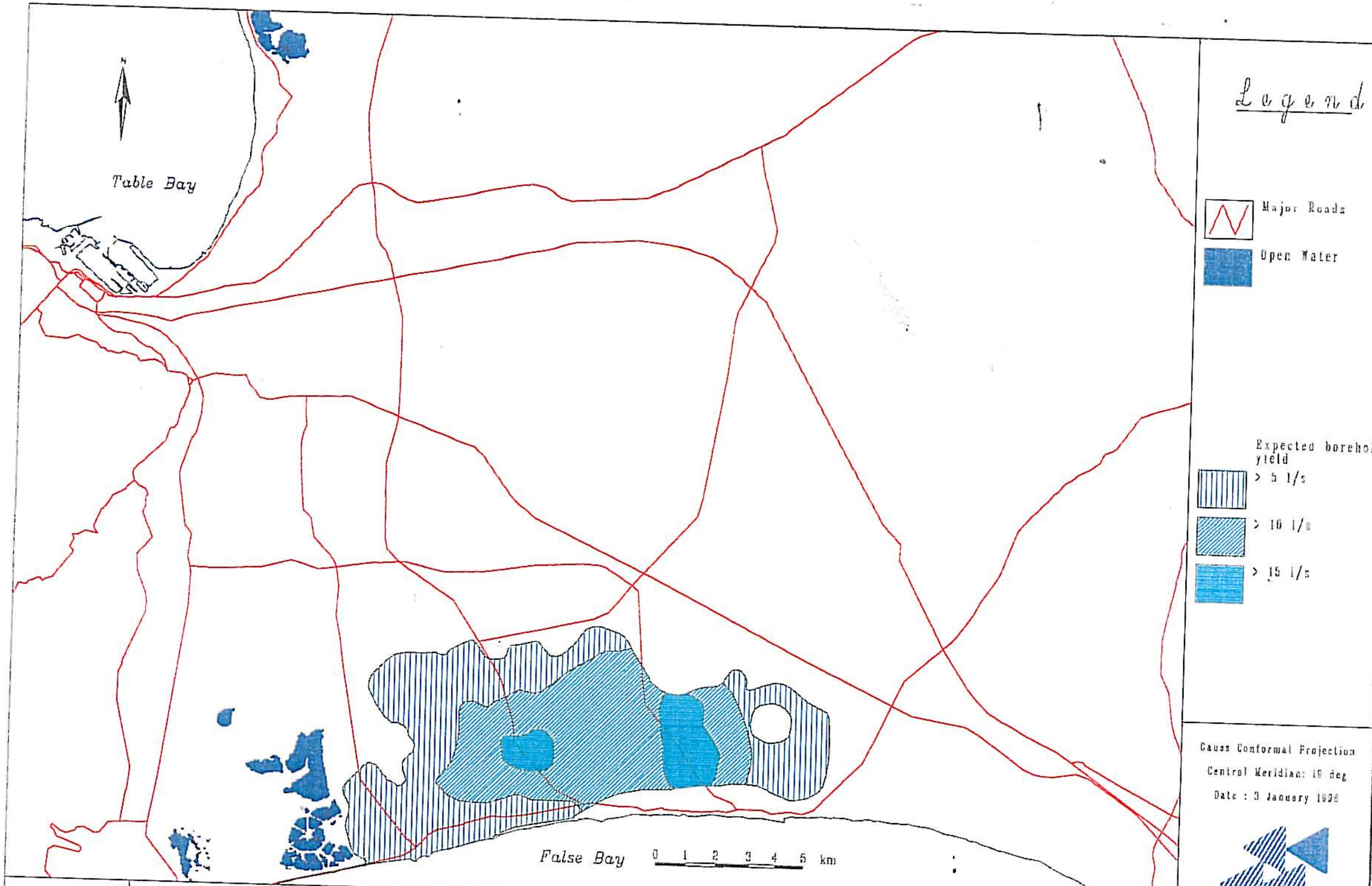


Fig.11 Plan indicating the areas most suitable for groundwater abstraction

Fig.12 Current land use plan indicating potential pollution sources

a multitude of other potential pollution sources. The high-risk sources include wastewater treatment works, waste disposal sites, a power station, industry, commerce and intensive agriculture. Probably the most important of the low to medium-risk sources are the lower-income residential townships, which often contain large squatter communities. The many potential pollution sources are of concern, as the sandy, unconfined nature of the aquifer makes it particularly vulnerable to pollution. In many places the groundwater level is close to the surface, which adds to the aquifer's susceptibility to pollution. The aquifer is already locally contaminated or even polluted (Vandoolaeghe, 1990).

Tredoux (1984) provided evidence of groundwater pollution by leachate from both the Mitchell's Plain Waste Water Treatment Works and Swartklip solid waste disposal site. Water level and water quality monitoring during the Pilot Abstraction Test also irrefutably proved that the wastewater treatment plant maturation ponds were causing groundwater pollution. Studies have also indicated that the diffuse pollution sources are impacting on the groundwater. Bertram (1989) showed that much of the Philippi area is contaminated as a result of the agricultural practices. The occurrence and degree of pesticides contamination in this area remain to be investigated. Current studies in the informal settlements and lower-income townships have also indicated that contamination of the upper part of the aquifer occurs in the immediate vicinity of the shacks. The contaminated water does not, however, appear to penetrate below the calcrete and clay horizons (Wright, 1994). There is, however, a strong possibility that the contaminated water would be drawn down into the main aquifer should any large-scale abstraction take place.

The current groundwater pollution problems are not insurmountable, but do necessitate the need for artificial recharge. The pollution threat can be effectively counted through the correct positioning of recharge facilities. This, however, raises the question of land availability. Recharge by surface spreading requires fairly large tracts of land which are generally not readily available in urban areas. Any recharge facility would have to be confined to the coastal zone and the vicinity of Strandfontein and Swartklip Roads. It will, however, require innovative engineering to position recharge facilities in these localities in order to counter pollution sources such as the Philippi agricultural area and Swartklip waste disposal site. The recharge facilities would also have to be located and managed in such a way that the result and groundwater mound do not affect neighbouring residential areas which already experience problems with a high groundwater table.

The fact that much of the area has already been developed as an urban area does not pose a major obstacle to well field development. Much of the Pilot Abstraction Scheme for example was sited on municipal land in an already built-up area, with boreholes sunk in parks, in playing fields and on street corners. This approach would be followed when designing a production well field, irrespective of whether the water is used locally or pumped into the main Metropolitan supply. Figure 13 provides a conceptual idea of the suggested recharge and abstraction zones. The Pilot Abstraction Scheme site should be used as the starting point, with progressive exploration and development across the area. This phased, site-specific approach has proved highly successful in the Atlantis aquifer.

Fig.13 Conceptual Plan Showing Proposed Recharge & Abstraction Zones

Ninham Shand (1994) attempted to put preliminary cost estimates to a groundwater supply scheme. This was based very much on the Vandoolaeghe (1990) well field design and excluded any recharge facilities. The primary economic considerations included the cost of wells, pumps, disinfection works and power, as well as the cost of interconnecting pipelines and storage reservoirs. The cost, however, excludes the final connection to the main Cape Metropolitan supply system. This financial exercise produced a unit cost of water value of between R0,20/m^3 and R0,22/m^3. This assumed a repayment period of 25 years at an interest rate of 16 %. This estimate compares favourably with that of the Atlantis Water Resource Management Scheme (R0,20/m^3). Table 4 provides a comparison with some of the alternative surface water supply schemes considered by the Western Cape System Analysis.

TABLE 4: ALTERNATIVE WATER SUPPLY SCHEMES FOR THE CAPE METROPOLITAN AREA

SCHEME	YIELD (10^6 m^3 per annum)	UNIT COST OF WATER
Palmiet 1	31	1,0
Eerste River Diversion	19	1,5
Voëlvlei/Lorelei 1	15	1,6
Cape Flats aquifer	18	2,2
Skuifraam Dam	72	2,4
Misverstand raising	70	5,3
Sewage effluent exchange	20	6,3
Diep River	12	7,9
Sewage direct re-use	36	10,6
Seawater desalination	100	20

[From: Ninham Shand, 1994]

5 CONCLUSIONS AND RECOMMENDATIONS

The Cape Flats aquifer remains a viable resource, notwithstanding urbanization and the resultant groundwater pollution. In the order of 15 to 20 x 10^6 m^3 could be abstracted annually and fed into the Metropolitan water supply system at a unit cost of R0,22/m^3. This could be increased by means of artificial recharge of treated wastewater and stormwater runoff. The water quality would be such that minimal treatment would be necessary.

The size of the resource and unit cost should be considered in the light of groundwater serving as:

- a peak Metropolitan Supply;
- a local urban supply, and
- an emergency (drought) supply.

It is unlikely that any further major studies on a regional scale will significantly improve on the currently available knowledge. It is, however, recommended that the CSIR revisit the initial data and model the aquifer with currently available software in order better to define the transmissivity and groundwater flow patterns. Efforts should then be made progressively to develop a groundwater supply scheme around the initial Pilot Abstraction Scheme. The water should initially be used as a local urban supply. It is crucial that, in order to finally succeed with this scheme, the engineer, geohydrologist and urban authority work as a team. The Atlantis Water Resource Management Scheme serves as a fine example of how this can be done.

The current escalation in urban development within the Metropolitan area makes it imperative that a "core" project team be established as soon as possible. It is important that the initial planning begin now in order to have the scheme fully operational by the year 2005, as proposed by the Western Cape System Analysis.

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