A COMPILATION OF INFORMATION ON THE MAGNITUDE, NATURE AND IMPORTANCE OF COASTAL AQUIFERS IN SOUTHERN AFRICA

by

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EXECUTIVE SUMMARY

Coastal aquifers are geological formations adjacent to the coastline comprising sufficient water-saturated permeable material to produce significant volumes of water in boreholes and wells. The south coast of South Africa, in particular, has numerous coastal aquifers that are essentially of the same type. The perception appears to exist that these sources should be utilized because all the fresh water ultimately flows into the sea where it is considered lost to Man. Before this source can be managed, however, a better understanding of the nature and magnitude of coastal aquifers is required as well as a determination of what impact the removal of fresh water from the aquifer might have on associated ecosystems.

Before any investigations into ecosystem dependence on aquifer water can commence, an understanding of the geohydrology of aquifers is essential. This particular study was designed to be the first phase of an investigation into coastal ecosystems and aquifer water. The specific aims of the investigation were:

1) To collect and collate the available information on
   the nature and magnitude of coastal aquifers;
   the water quality; and
   the dependence of coastal ecosystems on aquifer water.

2) To compile a document containing the collated information listed above, including a detailed map of coastal aquifers in South Africa, and to lodge the relevant documents with the Department of Water Affairs (Directorate of Geohydrology).

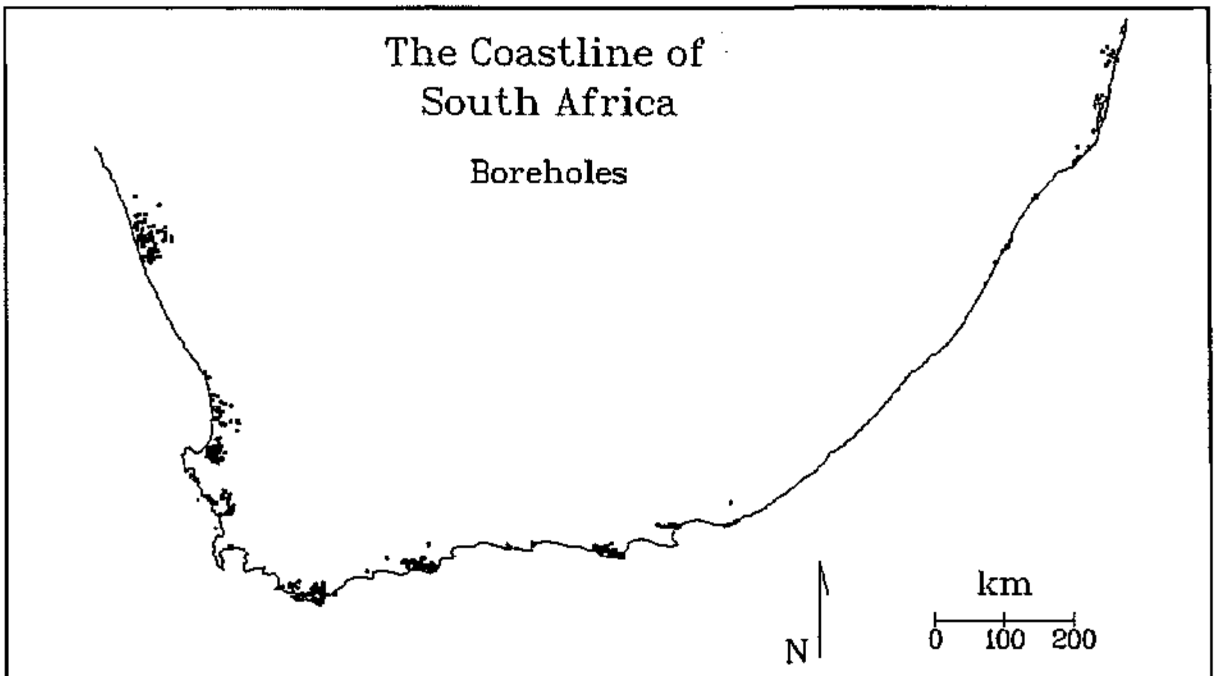
3) To present a list of research proposals based on available information, formulated at a workshop held specifically for this purpose.

For this study a coastal aquifer is defined as an unconfined aquifer (the upper boundary of the aquifer being the free water table under atmospheric pressure) that intersects the coastline.

To obtain as much of the available information on coastal aquifers as possible, several organizations and persons contributed reports on the geohydrology of coastal aquifers. A retrospective search of the literature was carried out on the CSIR WaterLit database. Use patterns of coastal aquifers were investigated by distributing questionnaires to all municipalities and Regional Services Councils along the coastline of South Africa.

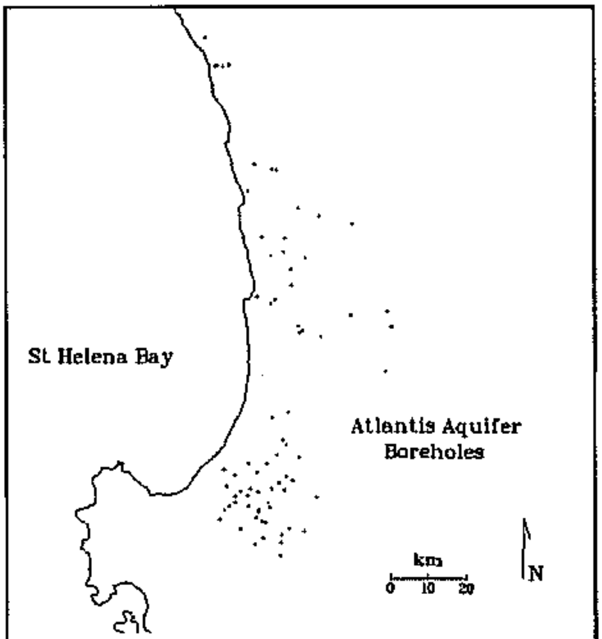
All the information available was used to compile this report but other information exists in confidential reports that could not be included. Hence the database is only as complete as the available information.

The information has been collated into the databases of MapInfo, dBase and AskSam. A total of 259 reports was collected from which the physical and chemical properties of the aquifers were extracted. Water quality data were entered into a geographic information system (MapInfo) from which maps can be generated depicting water quality for coastal aquifers in South Africa. Data presentation on a large scale is difficult. However, data can be viewed on MapInfo by scaling to suit the user's needs. This manipulation of the database can be demonstrated using an important water quality variable: total dissolved solids (TDS). When the whole coastline is viewed, it is very difficult to distinguish between individual data points.

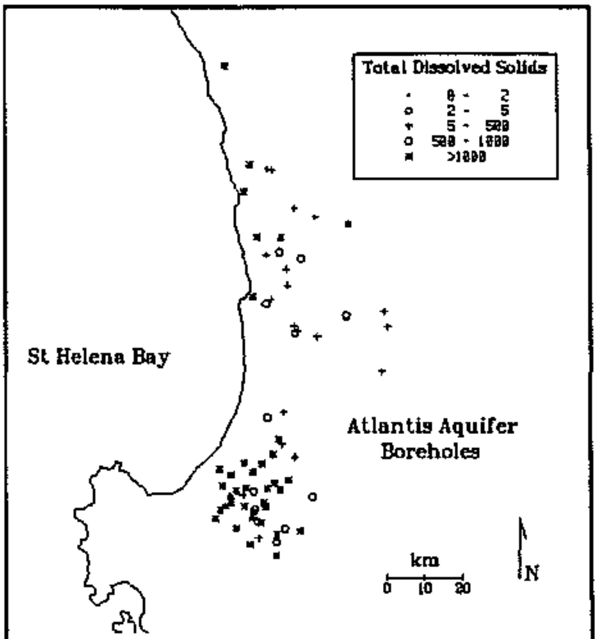


A map of the coastline of South Africa showing the location of the boreholes for which data are available.

The maps can be scaled and the data can be displayed thematically, showing frequency of values in predetermined categories.

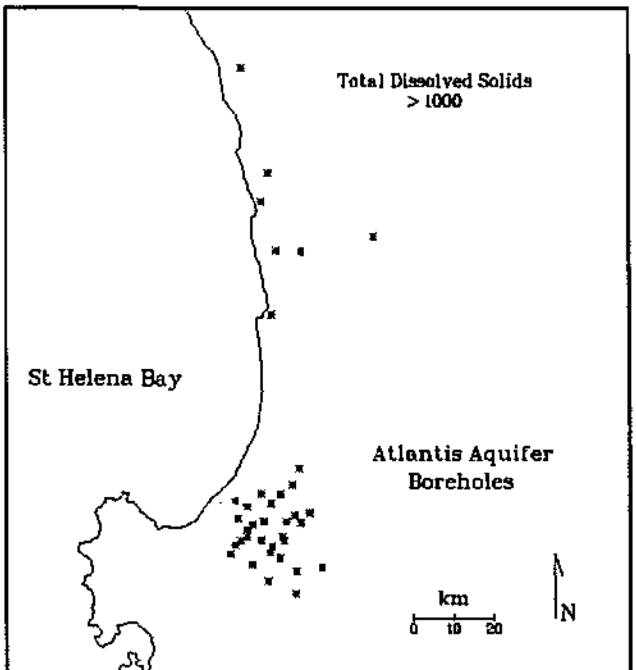


An example of an expanded section of the coastline to illustrate the degree of scaling possible.



An example of the use of thematic data manipulation to differentiate between categories of a variable.

The data can also be displayed excluding either low or high values.



An example of the use of the data filter to eliminate selected categories of a variable.

Based on the Cenozoic deposits, 24 major coastal aquifers were recognized. The total area comprises approximately 29 600 km^2. There are two areas where no Cenozoic deposits, and presumably no primary aquifers, occur. These are the Tsitsikamma coast and the Transkei-Natal South coast region.

Reports were obtained giving data for boreholes in 13 of the 24 aquifers. Only 5 of these had been representatively sampled whereas the others had been sampled only in limited areas.

Ecologically, the most important water quality variables are nitrate and silicon. Nitrate in borehole water ranged from 0.1 to 1 000 mg l^{-1}, the west coast having high values. Silicon concentrations ranged from 0.1 to 33 mg l^{-1}, with particularly high values in the aquifers along the west coast, south of the Olifants River. TDS is the most commonly used measure of water suitability for human consumption. TDS ranged from 6 to 21 000 mg l^{-1}. The aquifers with high silicon concentrations had the highest TDS concentrations. These are also the aquifers with the highest rate of abstraction.

Four types of ecosystems are influenced by aquifer water: 1) dune vegetation with a phreatic component (plants which use ground water rather than upper soil water from rainfall; 2) marsh vegetation; 3) estuaries; and 4) surf-zones. For dune and marsh vegetation as well as surf-zone ecosystems, both the water quality as well as the water table depth appear to be important controls. However, in estuaries fresh water input appears to be the key factor. Whereas marsh vegetation has been studied extensively, the dependence of the phreatic component of dune vegetation, estuarine vegetation and surf microalgal communities on aquifer water has not.

The most important issue emanating from this study was that the data gathered from the questionnaire indicates that ground water users, i.e. municipalities and Regional Services Councils, do not understand the nature of aquifers, nor do they know how much water they are using. In general, it is evident that local authorities are largely uninformed on ground water management; some to a greater degree than others.

To formulate research proposals, a workshop was held to which specialists from various disciplines were invited. At the workshop all research ideas were tabled, classified and ranked in priority. Research proposals which covered the whole coastal region and which took the highest priority were identified as the following: 1) The geohydrological characterization of each coastal aquifer in South Africa, including the potential to provide potable water;

2) Quantification and characterization of inputs and outputs, both natural and artificial as well as transport processes in the aquifer. 3) The only other proposal which included the entire coastline was that comprising the dependence of ecosystems, both aquatic and terrestrial, on aquifer water. A list of regionally specific projects was also tabled.

1. INTRODUCTION

The increasing demand for water by many coastal resorts, along with water restrictions imposed due to drought conditions and rising costs of water supply, makes ground water in coastal dunes a very attractive and viable source of fresh water. Although the existence of this water has been known for a long time (for example, the Strandlopers made use of many springs and seepage points along the shoreline) the potential of dunes to deliver large quantities of fresh water has only recently been recognized by modern man. The increasing urbanization that is taking place along shorelines and estuaries is likely to have a large impact on the quality and quantity of aquifer water. Coastal aquifers are, however, not simply important socio-economic resources. They are also implicated in the functioning and maintenance of coastal ecosystems. The extent of the dependence of the biota on aquifer water or the nutrients it contains, is unknown. Marsh systems appear to require aquifer water for the maintenance of ecosystem diversity. But, whereas marshes have been well studied, little is known about the need for aquifer water by other ecosystems.

Unconfined aquifers are highly susceptible to pollution from human actions. They are composed of highly transmissive material with no impenetrable layer protecting the aquifer from above. Contaminants will penetrate the soil easily and move into the aquifer water. Unconfined coastal aquifers are not endless sources of water for human consumption. Over-use can result in salt water intrusion that will render the aquifer unsuitable for future use.

Little is known about the potential of coastal aquifers to provide water for human consumption. Even less is known about the dependence of different coastal ecosystems for fresh aquifer water. For this reason, before any study can be initiated into the role of ground water in coastal ecosystems, it is necessary to consolidate all available information into one document to develop a strategy for future research on coastal aquifers. A study was undertaken with the following specific aims:

1) To collect and collate all the available information on
   - the nature and magnitude of coastal aquifers;
   - the water quality and
   - the dependence of coastal ecosystems on aquifer water.
2) To compile a document containing the collated information listed above, including a

detailed map of coastal aquifers in South Africa, and to lodge the relevant documents with the Department of Water Affairs (Geohydrology).

3) To present a list of research proposals based on the available information formulated at a workshop held specifically for this purpose.

Much of the data obtained during this project have been entered into AskSam and MapInfo. The real value derived from the project will be generated by subsequent users extracting information from the computerized databases.

This report comprises the following information: Firstly, a brief overview of the physical and chemical properties of coastal aquifers is aimed at providing the ecologist with a basic understanding of the terms and concepts used. This section includes a short overview of the literature on the use of coastal aquifers. Secondly, the available literature on the ecological requirements of coastal aquifers is reviewed. Thirdly, a synopsis of the data collated during the course of this study is presented in the form of examples of the output that can be obtained from the databases. Also included is a summary of responses from aquifer users or potential users regarding use patterns. The ecosystems associated with coastal aquifers in South Africa are identified as far as possible (section 4.2.3).

One of the aims of this project was to formulate research proposals based on the available information. Chapter 6 contains the results of a workshop held to identify areas of future research on coastal aquifers. During this workshop a large number of projects were discussed.

The appendices contain detailed references, data and questionnaire results.

2. PHYSICAL AND CHEMICAL PROPERTIES OF COASTAL AQUIFERS

2.1 Definition of a Coastal Aquifer

An aquifer is a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs (Driscoll, 1976). Present use of aquifer water in South Africa is confined to the supply of water for agriculture, scattered rural communities and small towns.

A coastal aquifer is defined as a water-bearing geological formation hydraulically connected to the sea (Johannes, 1980).

This study was limited to unconfined aquifers. An unconfined aquifer is a permeable bed partly filled with water and overlying a relatively impervious layer. The upper boundary of the aquifer is formed by a free water table under atmospheric pressure (Kruseman and De Ridder, 1970). These aquifers consist commonly of unconsolidated or semi-consolidated deposits of sand, gravel and pebbles in which the interstices are intact, the form not changed by subsequent compaction, recrystallization or cementation (DWA, 1986). These aquifers are found mainly in the geologically young strata of the Cretaceous, Tertiary and Quaternary age groups; for example, in the narrow strips of alluvium in and along surface water courses, in coastal sand deposits, as well as on clay and calcrete lenses (Vegter, 1987). Unconsolidated aquifers in the coastal zone of South Africa are capable of yielding from 5% to 30% of the gross volume of water stored in the aquifer (DWA, 1986). This water is easy to use as unconfined aquifers generally occur at shallower depths than confined aquifers. The supply of water, however, may be variable as the water table changes in response to any change in the amount of water stored within the aquifer and is also comparatively sensitive to drought periods.

Unconfined coastal aquifers form when permeable sediments, either unconsolidated dune sand, fluvial sand, estuarine sand, or a mixture of these, become deposited on an impermeable base landform (Rust, 1987). Deposition of these sediments has taken place as a result of sea level fluctuations during regression-transgression periods (Tinley, 1985) or as recent aqueous or aeolian deposition. The thickness of the deposits can vary from only a few metres to greater than 50 m (Rust, 1987). Downward movement of ground water is restricted by impermeable base rock.

Confined or semi-confined aquifers are completely saturated aquifers whose upper and lower boundaries are formed by aquicludes (Kruseman and De Ridder, 1970). They form as fractured and weathered parts of hard rock formations of igneous, metamorphic and sedimentary origin (DWA, 1986). The storage capacity of most confined aquifers is generally less than that of unconfined aquifers. Over 80% of South Africa's underground water supply comes from such confined aquifers.

2.2 Water Table

The water table is the surface between the zone of water saturation and the zone of aeration. It relates specifically to the water surface in unconfined aquifers (Bates and Jackson, 1984).

The depth of the water table from the soil surface depends largely on the porosity and permeability of the formation as well as on speed of recharge, or removal of water from the aquifer.

2.3 Flow

Differences in the height of the water table relative to a fixed subsurface point result in the development of an hydraulic gradient (Bates and Jackson, 1984). This results in a net flow of water from the region of elevated water table levels to regions of lower water table levels.

Movement of water in coastal aquifers is generally seawards due to a positive hydraulic gradient set up by the balance between recharge inland and discharge to the sea or estuary. If water losses through abstraction exceed recharge, the hydraulic gradient is reversed, resulting in sea water intrusion. Chemical gradients can also induce flow; for example, from regions of low salinity to regions of high salinity.

2.4 Recharge

Recharge, or ground water replenishment, can be either natural or artificial. Natural recharge includes direct recharge by precipitation, surface recharge through rivers and subsurface recharge from adjoining confined aquifers. Artificial recharge can be achieved by pumping water into the aquifer or by controlled seepage of effluent water and agricultural run-off.

Effluent water enters either through surface infiltration ponds or deep-well infiltration (DWA, 1986).

The main source of recharge to unconfined aquifers in South Africa is through direct rainfall infiltration and through infiltration of surface water. Recharge by rainfall infiltration comprises between 8% and 30% of the mean annual rainfall (data from Appendix 2). Recharge to unconfined aquifers is greater because of the sandy nature of the sediments as well as the relatively large surface area that is exposed to recharge (DWA, 1986).

2.5 Discharge

Natural discharge of water from an aquifer may be to rivers, lakes, lagoons, estuaries, the sea, or springs. The water table in the discharge area is close to the surface and can be recognized by marshy areas. Vegetation can also give an indication of ground water discharge by the presence of a high proportion of hydrophytes.

Discharge has been shown to be greatest near the shoreline, decreasing offshore. The rate of discharge is dependent on the slope of the water table above sea level (Bokuniewicz, 1980; Valiela *et al.*, 1980; Capone and Bautista, 1985; Harvey and Odum, 1990). Between 40% and 90% of the total flow usually occurs within 100 m of the shore (Bokuniewicz, 1980). Ground water discharge into estuaries typically takes place in a zone 30 to 100 m from the banks (Lee, 1977; Valiela *et al.*, 1980; Bokuniewicz, 1980; Capone and Bautista, 1985).

2.6 Chemistry

The natural chemistry of ground water varies with:

- recharge volume and rate;
- characteristics of the aquifer sediments;
- exchange of water between the bedrock and overlying deposits;
- residence time/response time (varies with saturated thickness, spatial extent, specific yield);
- depth of water table (aquifers with shallow water tables, <10 m, tend to have a close correlation between ground water quality and climate;
- abstraction; and

- pollution.

Classification criteria for natural ground water quality depend on the intended use: for drinking water, for industrial purposes or for irrigation. As water moves from the recharge area to the discharge area, the quality of the water is altered by various geochemical processes. When rain water enters the unsaturated zone it is pure (very low total dissolved solids content) and is slightly to moderately acidic. The water has a high carbon dioxide and oxygen content. Interactions of the water with mineral constituents and organic matter brings about active leaching and transport of dissolved salts. As ground water moves through the sand, plant root reactions decrease the oxygen and increase the carbon dioxide content. This results in the formation of carbonic acid, making the ground water more acidic. Furthermore, the total dissolved solids (TDS) content increases as water moves away from the recharge area.

Ground water salinity is affected by the following factors:

- evapotranspiration;
- sea water intrusion (either close to the sea as a natural condition , or farther inland through over-exploitation);
- salt leaching (most of the sediments of coastal aquifers are of marine origin and have both a high calcareous content and a high alkalinity. The calcareous component is derived mainly from shells and calcareous algal fragments. Leaching and dissolution of these compounds into ground water produces a high salt content; Rust, 1987);
- weathering and erosion of the parent material, for example, Bokkeveld Shales, have been shown to release large quantities of salts on leaching (Rust, 1987). Igneous rocks on the other hand produce little salt but commonly result in silicon enrichment (Todd, 1959);
- selective retention of salts by plants, for example, *Tamarisk* sp., concentrates the salts in leaves. When these leaves fall off annually, the salts leach out with the following rains causing a relocation of the salt in the soil profile;
- physical properties of the substratum; and
- retention time of water in the aquifer.

Ground water input into coastal waters has been shown to account for as much as 65% of the total fresh water inflow (Bokuniewicz, 1980). Alteration of this ground water flow through abstraction can result in salt water intrusion into wells, which also affects the salinity status of the whole aquifer system, and ultimately the ecological stability of the area.

Kohout and Kolipinski (1967) have suggested that a salinity gradient will exist along any shoreline where the fresh ground water reservoir is hydraulically connected to the sea through permeable bottom sediments. The closer the ground water to is to the sea, the higher the salinity of the aquifer water tends to be. This may be due to the deposition of salt by sea spray, which subsequently leaches into the water, or due to sea water intrusion into the ground water. Under natural conditions, the latter event must be very rare.

Ground water discharging at the shoreline may contain up to 2 000 mg salt l^{-1}. Certain plants and animals will tend to be found in zones in response to the salinity of the ground water. Brackish water species are usually found to be the most abundant near the shore, especially around springs, where salinity is lowest. Kohout and Kolipinski (1967) suggested that the most noticeable zonation is reflected in rooted plants and sessile animals. Studies that have investigated plant zonation with respect to interstitial salinity include those of Kohout and Kolipinski (1967; seagrass beds and fauna); Nestler (1977; rooted salt marshes); Smart and Barko (1978; rooted salt marshes) and Adams (1991; estuarine flora).

2.7 Use of Ground Water

2.7.1 Storage

The amount of water stored in an aquifer comprises the amount of water in the unsaturated zone as well as that below the water table. Water for human use is pumped from below the water table, but plants utilize water from the unsaturated zone. The maximum amount of water that can be abstracted without adversely affecting the aquifer, is known as the "safe yield". If the safe yield is exceeded flow into the borehole or well will be reduced or terminated. Over-extraction may lead to up-coning of poor quality water from base rock or sea water intrusion.

2.7.2 Contamination

For the purposes of this review, contamination is considered to be due to natural causes whereas pollution refers to human influences.

The following natural sources of contamination that may influence coastal aquifers were chosen by Wright (1991) from a list by Canter *et al.* (1987):

- Ground water/surface water interactions
- Natural leaching
- Saline intrusion
- Brackish water up-coning

These sources may be created and/or exacerbated by human activity.

The most economically important and immediately apparent source of contamination is that of saline intrusion. Salt water has slightly higher density than fresh water, so salty water always occurs below fresh water. The salt wedge along the coastlines, and in places along estuaries, prevents downward mixing of low salinity water, so that fresh ground water discharges closer to the shore.

Saline intrusion occurs when coastal aquifers are in direct contact with the sea and when over-pumping reverses the normal seaward flow of fresh water. The presence of a salt wedge has important implications since deepening wells for increased abstraction of water will increase the danger of intrusion by salt water.

2.7.3 Pollution

Pollution occurs as a result of deleterious substances and waste products produced by humans. Those which may adversely affect coastal aquifers (Canter *et al.*, 1987 in Wright, 1991) are:

1. Sources designed to discharge substances into the earth
   Wastewater treatment plants
   Septic tanks
2. Sources designed to store, treat and/or dispose of substances (discharge through unplanned release).
   Landfills and waste disposal sites
   Illegal dumping
   Graveyards
   Materials stockpiles
   Aboveground storage tanks
   Underground storage tanks

Stormwater detention basins

3. Sources designed to retain substances during transport or transmission

    Pipelines

    Materials transport operations

4. Sources discharging substances as a consequence of planned activities

    Animal wastes

    Irrigation

    Fertilizer application

    Urban runoff

    Percolation of atmospheric pollutants

5. Sources providing a conduit for, or inducing discharge through, altered flow patterns

    Boreholes and wells

    Construction excavation

2.7.4 Artificial Aquifer Manipulation

In Holland, an increase of water consumption in the late 1930's resulted in premature exhaustion of dune water resources, causing onset of sea water intrusion into production wells. In 1950 artificial recharge was implemented as a means of maintaining the fresh water:salt water balance in dunes (Piet and Zoeteman, 1980). Subsequently, dune infiltration has been practised widely as a means of storing and purifying surface water in order to meet public water demands. Problems are caused when artificial infiltration far exceeds the volume of natural recharge. This results in increasing the nutrient loads of potassium, nitrate and phosphate by factors of up to 100 (Van Dijk and De Groot, 1987). This increased nutrient load has influenced the vegetation for distances of hundreds of meters from the infiltration ponds (Van Dijk, 1985; Van Dijk and De Groot, 1987).

Artificial recharge is also practised in South Africa since the 1970's. The town of Atlantis has made use of the ground water supply from Cenozoic deposits. This supply has been augmented with recharge by stormwater and purified domestic and industrial effluent (Tredoux, 1987). Recharge by stormwater takes place by a series of detention ponds leading to a final infiltration pond in the recharge area. Domestic waste water used for artificial recharge first undergoes activated sewage sludge treatments that involve both nitrification and denitrification processes. The final effluent is fed to a maturation pond. Seepage from maturation ponds has been shown to cause a local increase in the water table height, bringing about marshy conditions and luxuriant growth around the ponds (Tredoux and Tworeck, 1984). Studies on the effect of these activities on ground water have shown that the water quality changes significantly after infiltration. For example, nitrate was found to decrease after infiltration but bicarbonate and calcium increased. The nitrate decrease is possibly due to bacterial denitrification causing an increase in nitrogen and carbon dioxide. The increase in carbon dioxide in turn results in dissolution of calcium carbonate, thereby increasing the alkalinity and calcium content of the water.

3. ECOLOGICAL REQUIREMENTS FOR COASTAL AQUIFER WATER

Many plants and animals depend on nutrients supplied by ground water flowing into the sea and estuaries. For example, fresh water naturally dilutes the salinity of the sea and its lower pH influences the solubility of several elements. Where pollution occurs in aquifers an increased and sometimes excessive nutrient load is passed on to adjacent ecosystems. If the aquifers have been pumped, or over-pumped, reduced fresh water and nutrient inputs can shift the ecological balance.

3.1 Dunes

3.1.1 Ground Water Level

The depth from the surface to the water table in dune sands may vary in response to a number of factors of which the most important are: permeability of the sand or gravel; thickness of the deposit; and the width of the dunefield. Where impermeable layers such as clay lenses occur, perched water tables may result and the water level may be closer to the surface than in other areas of the main aquifer. Dune width is linked to the depth of the water table in that the wider the dune, the higher the water table (Rawlins and Kelbe, 1988). Dune morphology is closely tied to ground water because wet sand is more stable and does not blow away as easily. A drop in the water table level could result in increased sand transport.

While the loss of water from coastal aquifers by evapotranspiration is known to account for large volumes of water, little effort has been made to quantify the actual amount of water taken up by natural vegetation. Phreatic plants use water from the unsaturated zone of the aquifer. Where high dunes occur and the water table lies many metres below the sand surface, it is unlikely that most plant root systems can reach the main water table; they will more likely use water held against gravitational forces. Theoretically, it is in the transition areas between the dunes, viz. the low-lying dune slacks, that the depth of the water table can become a limiting factor for the development of plant associations typical of these areas. The only studies in South Africa on phreatic dune plants have concentrated on the role of exotic plantations in influencing the ground water table (Lindley and Scott, 1987; Rawlins and Kelbe, 1988; Rawlins, 1991).

Fluctuations of ground water levels in unconfined aquifers may be brought about by evaporation and/or transpiration. This effect is observed as diurnal fluctuations in the level of the water table. The rate of evapotranspiration depends on factors such as temperature, season and type and age of the vegetation. Where ground water level fluctuations take place in response to abstraction and over-pumping, water levels may be lowered to such an extent that vegetation is adversely effected.

3.1.2 Ground Water Quality

Studies have shown that artificial dune infiltration causes an increased nutrient load that affects the vegetation. For example, Van Dijk (1985) and Vermeer (1987) reported that on the banks of infiltration ponds the vegetation had become dominated by nitrophilous grasses. Nitrophilous plants also dominate the margins of seepage pools, making it difficult to re-establish the original wet dune slack vegetation with its high diversity.

3.2. Marshes

3.2.1 Ground Water Level

The removal of water from marshes by over-pumping or drawdown of the aquifer results in plant succession that rapidly advances from a hydric state, where aquatic to semi-aquatic species dominate, to a more xeric state with a predominance of annual weeds.

The effects of lowering the water table include:

- changed soil-water conditions;
- reduced depth of standing water;
- reduced soil water content results in removal of anaerobic conditions;
- increase of redox potentials;
- rise of pH;
- increase of mineralization and nitrification;
- increase of nitrate concentrations;
- decrease of phosphate availability;
- increased soil temperature; and
- increased evaporation rates and rapid drying of the surface layers (Smith and Kadlec, 1983: Vermeer, 1987).

The seral plant species composition is determined by the altered nutrient regime (Vermeer, 1987); the seasonality of drawdown (Smith and Kadlec, 1983; Welling *et al.*, 1988; Merendino *et al.*, 1990); drought (Merendino *et al.*, 1990) and competition between the vegetation that developed during time of exposure. Most wetland plant species require bare mudflats for successive germination and establishment. The removal of water brings about more extreme temperatures and larger diurnal temperature fluctuations, thereby breaking wetland seed dormancy. In Texas, U.S.A., water tables are deliberately lowered with the intention of re-establishing emergent vegetation to provide nesting material and food for waterfowl.

3.2.2 Ground Water Quality

Natural ground water discharge can influence vegetation zonation and productivity through the diluting effect that fresh ground water has on the more saline coastal waters. The main function can be attributed to the dilution of interstitial water and near-shore sea water. Studies have shown correlations between the interstitial salinity and both seagrass beds (Kohout and Kolipinski, 1967) and mangroves (MacNae, 1968). There is, however, a dispute whether the growth of salt marsh species and community composition are governed by salinity (Chapman, 1976) or by nutrient status (Valiela and Teal, 1974; Nestler, 1977). For example, a reduction of interstitial salinity reduces osmotic stress and increases nutrient availability, thereby producing vigorous growth of some rooted aquatic species (MacNae, 1968). Interstitial salinity may be increased locally due to evaporation and transpiration. However, other authors believe that the distribution can be attributed rather to nutrients, so that the more vigorous growth of some of these rooted aquatic species at reduced interstitial salinities might be a consequence of elevated nutrient availability in some areas (MacNae, 1968).

Teal and Valiela (1978, as cited by Johannes, 1980) quantified the significance of ground water input to coastal ecosystems and calculated that ground water supplied 22% of the total nitrogen input to a salt marsh.

3.3 Surf-Zones

3.3.1 Ground Water Level

The absolute ground water level appears to be irrelevant to surf-zone ecosystems. However, the height of the ground water table above sea level has direct bearing on the amount of aquifer water that flows into the adjacent surf-zone. Regardless of the water quality, if little flow occurs, the influence of the aquifer on the surf-zone ecosystems will be negligible (Campbell and Bate, 1991).

3.3.2 Ground Water Quality

Ground water discharge into surf-zones can be affected by human activity in two ways. Over-pumping of ground water resources reduces the ground water discharge thereby reducing the nutrient input to the sea. A further problem in the case of urbanization is the effect that pollution has on aquatic ecosystems. Elevated nutrient loads may result in algal blooms in the adjacent marine environment.

The importance of ground water discharge to nutrient budgets of coastal waters depends on factors that control the degree of nutrient enrichment of the ground water as well as hydrological factors that influence ground water discharge rate (Capone and Bautista, 1985; Lapointe *et al.*, 1990).

Nitrogen has generally been found to be the nutrient in shortest supply in coastal waters (Ryther and Dunstan, 1971; Valiela *et al.*, 1978). Even if the rate of ground water discharge into the sea is less than that of surface runoff, it is nevertheless more important in terms of nitrate inputs. These high nitrate inflows to surf-zones are large enough to bring about algal blooms and increased productivity.

Bokuniewicz (1980) has shown that subsurface discharge in Great South Bay, New York, may account for 10-20% of the fresh water input and 75% of the nitrogen entering the system (Bokuniewicz, 1980; Capone and Bautista, 1985). Furthermore, ground water carries about 20 times more nutrients than does rain water (Valiela *et al.*, 1990). Similarly, Johannes (1980) found that 50% of the nitrogen input into the coastal area of Perth was due to ground water discharge. Studies by McLachlan and Illenberger (1986) and Campbell and Bate (1991) have shown the importance of nutrients derived from ground water emanating from the Alexandria dune field, South Africa, for the productivity of phytoplankton in the adjacent surf-zone. The nitrate concentration of aquifer water was almost 10 times higher than that of sea water. Soluble reactive phosphorus and ammonia were present in concentrations similar to that of sea water.

Surf-zone primary productivity was estimated to be 120 kg C per running metre of beach per year (Campbell and Bate, 1988), the nitrogen requirements of the surf phytoplankton being 10.1 kg N per running metre of beach per year (Campbell and Bate, 1991). The nitrogen entering the surf-zone from the adjacent aquifer more than adequately made up for losses of both organic and inorganic nitrogen (Campbell and Bate, 1988) from the system.

Productivity studies along the South African coastline by Campbell and Bate (1990a,b,c) have shown productivity to decrease from west to east (Table 1). The nutrient content of all aquifer water was much higher than that of river or sea water. On the west coast, phytoplankton productivity is supported by nutrient upwelling of the Benguela Current. Along the east coast, although aquifer discharge rates are often substantial, most of the nutrients supporting surf-zone productivity were land-derived. It is the correlation between high phytoplankton productivity and high nutrient input along the south coast that led investigators to question the importance of aquifer-derived nutrients for surf-zone primary productivity. The high nutrient load (nitrate and silicon) caused by aquifer discharge into surf-zones has been shown to result in diatom blooms and accumulations, as seen at False Bay, South Africa. It is necessary to emphasise the importance of aquifer water quality in the functioning of ecosystems, particularly if the water is nutrient-rich or contains phytotoxins.

3.4 Estuaries

3.4.1 Ground Water Level

Ground water often contributes to the flow of streams and estuaries, particularly in sandy bed estuaries. If the ground water level drops far below the estuarine bed, aquifer water will have no impact on the estuarine ecosystems.

3.4.2 Ground Water Quality

Enhanced nutrient loading by ground water can have serious consequences in estuaries. Ground water does not enter rivers or estuaries as point sources, but over the entire estuary bed. Although the input of contaminants into the sea is diluted by wave action, input into estuaries greatly magnifies adverse effects of severely polluted ground water.

TABLE 1. Nutrient concentrations of ground water from around the South African coastline in relationship to the productivity of these areas (Campbell and Bate, 1990a,b,c).

	NH_4 µmol l^{-1}			NO_3 µmol l^{-1}			Si µmol l^{-1}			PO_4 µmol l^{-1}			Prod. kgC m^{-1} yr^{-1}
	River	Sea	Ground	River	Sea	Ground	River	Sea	Ground	River	Sea	Ground	
Port Nolloth	1	1	2	3	4	30	21	21	144				12050 (100 avg)
Muizenberg	<50	180	<50	<10	130	120-300	10	35	130	46	70	32	2400
Macassar	<50	<12	<50	<10	140	53	10	100	20	<2	<3	0.5-7	550
Walker Bay	<50	<12	<50	<10	<10	53		<20	50	<2	<3	7	2100
Struisbaai	<50	<12	<50	<10	<10	120-300	10	<20	70	<2	<3	0.5-7	550
De Hoop	<50	<12	<50	<10	<10	53	10-20	<20		<2	<3	0.5-7	100
Stilbaai	<50	<12	<50	<10	<10	53		<20	35	<2	13	0.5-7	250
Vleesbaai	<50	<12	210	<10	<10	53		<20	150	<2	<3	0.5-7	3080
Glentana	<50	<12	<50	<10	<10	53	10-20	<20	90	<2	<3	0.5-7	200
Wilderness	<50	<12	<50	<10	<10	120-300	10-20	<20	80	<2	<3	0.5-7	400
Sedgefield	<50	<12	<50	<10	<10	53	30	<20	25	<2	<3	7	400
Buffalo Bay	<50	<12	<50	<10	<10	53		<20	70	<2	<3	0.5-7	700
Keurboom-strand	<50	<12	<50	<10	<10	53		<20	30	<2	<3	0.5-7	900
Oyster Bay	<50	<12	<50	<10	10-20	53	110	<20	60	<2	<3	0.5-7	
Van Stadens	<50	<12	<50	90	10-20	53	70	<20	50	<2	<3	0.5-7	250
Sundays	<50	<12	<50	<10	10-20	120-300		<20	170	<2	<3	0.5-7	650
Port Alfred	<50	<12	<50	<10	10-20	53	<10	<20	60	<2	<3	9	
East London	380	<12	<50	80	10-20	53	160	30	70	12	10	0.5-7	10
Bonza Bay	<50	<12	<50	<10	10-20	53	60	<20	35	<2	<3	0.5-7	250
Cintsa Bay	<50	<12	<50	<10	10-20	120-300	35	<20	170	<2	<3	0.5-7	300
Port St Johns		10-20	18		8	130		65	140		0.9	0.6	30
Ifafa		10-20	23		6	20		<20	20		2	0.5	20
Amanzimtoti		10-20	14		10	210		<20	45		0.4	1	250
Tongaat		<10	45		10	210		<20	80		0.8	0.5	40
Blythedale		<10	18		10	280		<20	160		0.6	0.7	50
Tugela	5	<10	2	35	12	70	180	<20	80	<0.3	<0.3	0.2	180
Mtunzini	5	<10	5	25	11	50	100	<20	50	<0.3	<0.3	0.2	60
Richard's Bay		<10	7		20	20		<20	65		<0.3	0.2	40
St Lucia	5	<10	15	16	31	60	25	<20	30	<0.3	<0.3	0.2	60
Cape Vidal		<10	20		<5	15		<20	30		<0.3	0.2	10
Sodwana	5	<10	6	25	<5	20	380	<20	18	<0.3	<0.3	0.2	60

The quality and quantity of ground water entering estuaries are great enough to enrich the benthos, thereby stimulating the productivity of the benthic algal and bacterial communities (Loeb and Goldman, 1979). Although ground water has been shown to be an important source of fresh water for the maintenance of the salinity status (Cooper *et al.*, 1964), until recently little attention has been placed on the role of ground water in terms of its nutrient load. This is possibly due to the perception that the extent and volume of discharge of ground water is generally smaller than other fresh water inputs (Capone and Bautista, 1985). However, especially where dams restrict water flow, ground water seepage will become a much more important source of water and nutrients.

Studies at Peel Inlet, Western Australia, identified urban ground water as a possible nutrient source for estuarine benthic algal blooms (Sewell, 1982). Although large quantities of nitrogen enter the inlet from rivers draining agricultural areas, the greatest input in terms of concentration was from urban ground water. The potential for transfer of nutrients from urban areas is very large and needs to be assessed.

4. DATA FOR SOUTH AFRICAN COASTAL AQUIFERS

This study is the first part (first year) of a four-year project currently undertaken by the Department of Water Affairs (Directorate of Geohydrology, Cape Town). It therefore serves to gather together all the existing data with respect to the physical characteristics of primary aquifers around the coastline of South Africa.

4.1 Methods

4.1.1 Literature Search

A variety of organizations and private persons were approached regarding work that had been done on coastal aquifers. They included the Department of Water Affairs; Universities; and private persons who have been involved with geohydrological work on coastal aquifers. A total of 259 reports was collected (Appendix 1). The data collected from the reports included the geology and geohydrology. In all cases the data were taken from the most recent report; with no check of accuracy done. The data was entered onto the database system *AskSam* (Seaside Software Inc., 1985-1988) (Appendix 2). *AskSam* is an information storage and retrieval system that can be used with both text and numerical values. Information is retrieved on the basis of any combination of words or symbols in a record or a document. *AskSam* can be used on all IBM-compatible Personal Computers.

Water quality information for each system was obtained from borehole data. These data were entered on the database system *dBase* (Ashton-Tate, 1984-1986) for a total of 570 boreholes. The *dBase* data were linked to the *MapInfo* geographical information system. *MapInfo* (version 4.5; MapInfo Corporation, Troy, N.Y.) is a desktop mapping system that enables one to display and visualize data geographically. It can also be used to create, manipulate and analyze any information displayed on maps. Maps can be created by *MapInfo* by layering independently controllable database files, namely boundary files (for example, a file containing the South African coastline), mapfiles, pointfiles (for example, a database of water quality) and image files (for example, place names). These databases can be used to create and display any information from an area relative to a point on the map. *MapInfo* allows one to magnify and zoom into areas on the map. *MapInfo* was linked with the *dBase* database management system so that information regarding a particular borehole, for example, could be linked to a given map by means of coordinates. Thematic mapping furthermore enables one to assign different symbols to different points into a specific map area, so that ranges in concentrations, for example, can be displayed. Data can be transferred from *MapInfo* to other systems via ASCII files.

Coastal ecosystems that overlie aquifers were identified by overlaying the Cenozoic deposit maps on vegetation maps supplied by EMATEK (CSIR, Stellenbosch). Vegetation maps were only available for the area between Waenhuiskrans near Cape Agulhas and the Transkei. A list of estuaries and rivers that traverse Cenozoic deposits was compiled from 1:50 000 topographic maps.

4.1.2 Databases

4.1.2.1 *AskSam*

One *AskSam* database contains all references used to compile this report. Another *AskSam* database contains a synthesis of information about each aquifer. The references from which the data were taken are also part of this database. The fields included in this database are:

- Aquifer
- Catchment
- Rainfall
- Geology
- Lithology
- Water Level
- Flow direction
- Saturated sand volume
- Volume stored
- Transmissivity
- Borehole yield
- Exploitation potential
- Recharge source
- Losses
- Salt water intrusion
- Vegetation
- Aquifer area
- Catchment area
- Aquifer type
- Gradient
- Thickness of Cenozoic deposits
- Water level fluctuations
- Total saturated volume
- Confined storage
- Storativity
- Permeability
- Short term exploitation potential
- Effective porosity
- Recharge volume
- Average total dissolved solids
- Estuaries
- References

4.1.2.2 *dBase*

All nutrient data, total dissolved solids (TDS) data and salinity data were entered into *dBase*. The fields of the *dBase* database are:

- Water depth
- Water elevation
- Thickness of deposits
- pH
- Total dissolved solids
- Conductivity
- Total alkalinity (CO_3)
- Total hardness (CO_3)
- Bicarbonate
- Sulphate
- Chloride
- Fluoride
- Silicon
- Silicate
- Sodium
- Potassium
- Calcium
- Magnesium
- Iron
- Nitrate
- Nitrite
- Ammonium
- Total nitrogen
- Total phosphorus
- Phosphate
- Soluble reactive phosphorus
- Suspended solids
- Dissolved organic carbon

4.1.2.3 *MapInfo*

The *MapInfo* database contains the outline of the coast of South Africa (traced from 1:50 000 topographic maps) as well as the outline of the Cenozoic deposits (traced from 1:1 000 000 geological map; Department of Mineral and Energy Affairs, 1984). The borehole water quality data from the *dBase* database is entered into *MapInfo* as a pointfile and located using borehole coordinates onto a boundary file containing the outline of the coast. Selected identification points on the outline as well as aquifer names are available as image files.

4.1.3 Questionnaires

Questionnaires were distributed to all municipalities and Regional Services Councils around the South African coastline, extending from Lake Sibaya to Port Nolloth. These questionnaires were used as an indication of areas where ground water is present as well as the extent to which ground water is used. A total of 137 questionnaires was sent out. Of these 107 replied, 42% indicating that ground water was used either exclusively or as a means of supplementing alternative water supplies. Appendix 3 is a copy of the questionnaire distributed.

4.2 Results

4.2.1 Literature Search

4.2.1.1 Nature and Magnitude of Coastal Aquifers

Since few of the reports examined identified the actual boundaries of the coastal aquifers, published boundaries of the Cenozoic deposits around the coastline were used as an indication of boundaries (Figure 1). Altogether the Cenozoic deposits cover approximately 29 600 km^2 in 24 main outcrop areas, each of which appears to be a hydraulically separate system. The map of the boreholes shows that several are outside these Cenozoic deposits (compare Figures 1 and 2). Most of these boreholes occurred in Table Mountain Sandstone, which may also contain unconfined aquifers or be hydraulically connected to the aquifer in the adjacent Cenozoic deposits. For ease of reference each aquifer system is given a name (Figure 3). There are two areas where no Cenozoic deposits, and presumably no primary aquifers, occur. These are the Tsitsikamma coast and the Transkei-Natal South coast region.

The west coast has two major aquifer systems, the Namaqualand and Saldanha aquifers (Figure 3), with two smaller systems between them. The west coast systems comprise 15 400 km^2, which is just over half of the total Cenozoic area. Cenozoic deposits are found along 86% of the west coast.

The east coast (east of the Kei River) contains only one major aquifer, the St. Lucia system. Two small systems occur near Durban. The east coast aquifers comprise 46% of the coastline north of the Kei Mouth, but the 6 530 km^2 of Cenozoic deposits is slightly less than 25% of the total aquifer area around the coast.

The south coast has the longest stretch of coastline. It comprises a series of log-spiral bays which breaks up the coastline into small sections. The Cenozoic deposits occur in a series of units (17 in all) along the coast. There are 5 major systems: Cape Flats; Agulhas; Struisbaai; Stilbaai and Algoa Bay. There are 12 minor systems which together only comprise just over 1 000 km^2. The total of the south coast Cenozoic deposits includes some 7 700 km^2 and occurs along 60% of the south coast.

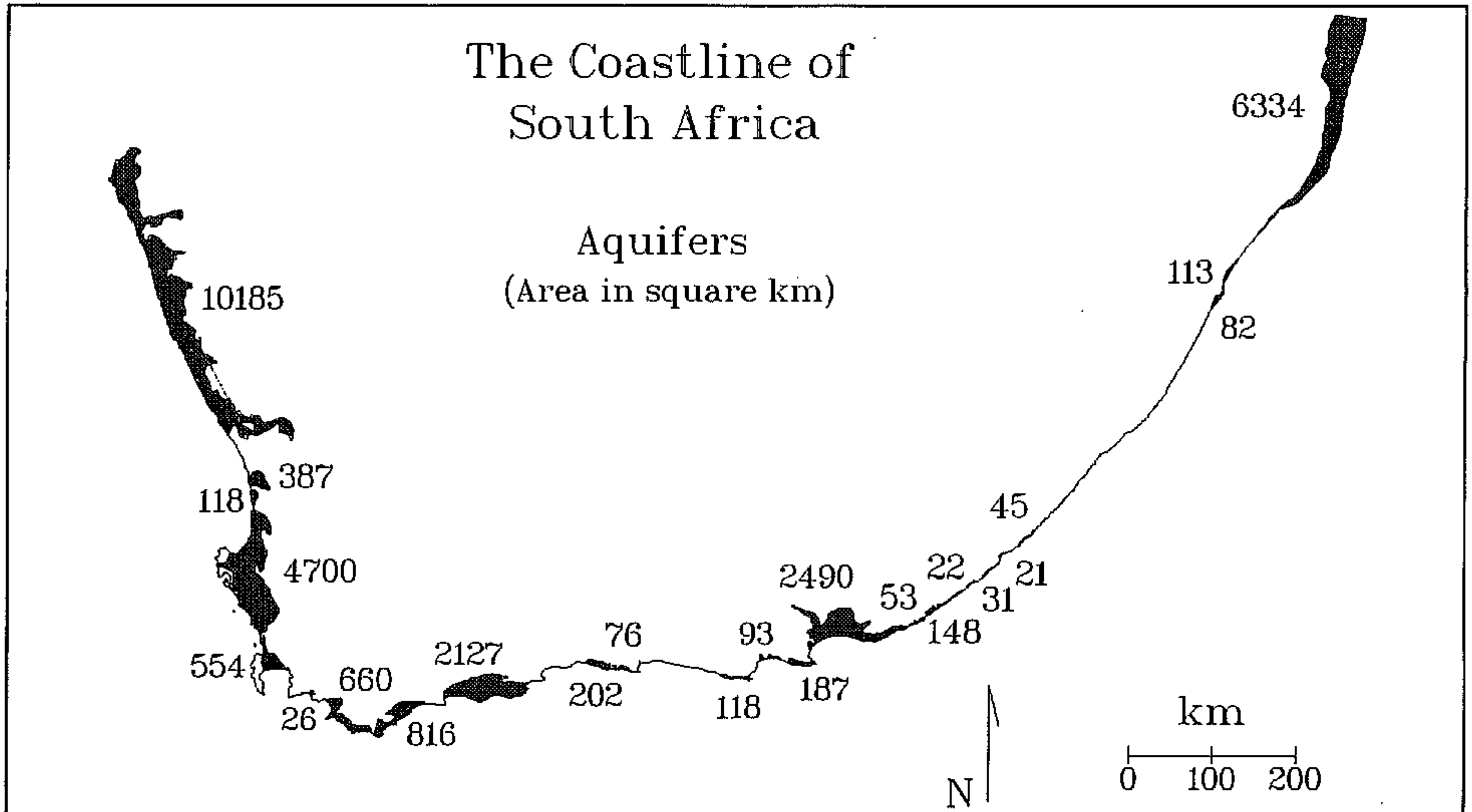


Figure 1. A map of the Cenozoic deposits of South Africa (after Dept. Mineral & Energy Affairs, 1984) used for the identification of the boundaries of coastal aquifers. Their surface area is given in square kilometres.

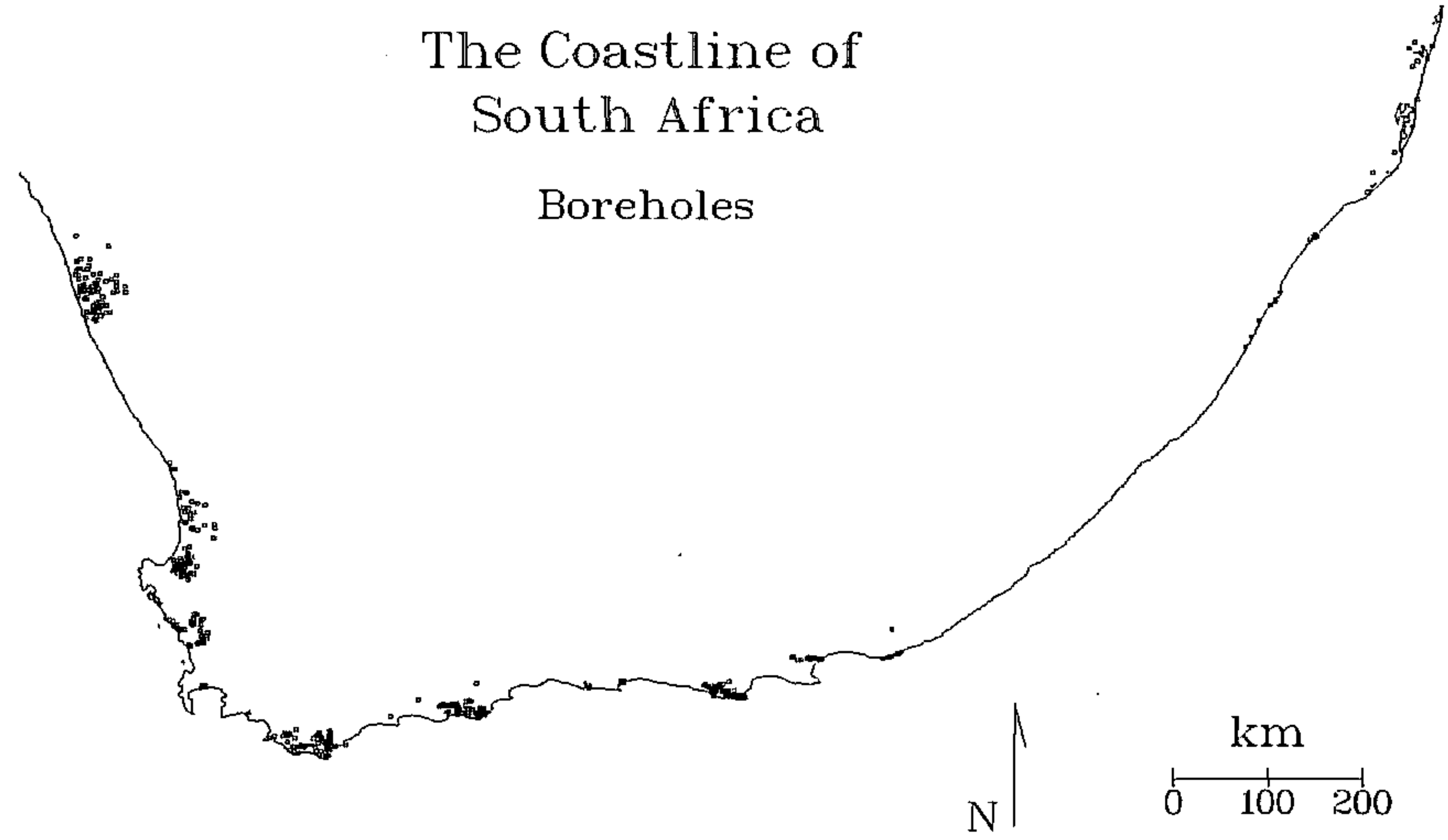


Figure 2. A map showing the location of the boreholes reported in this study.

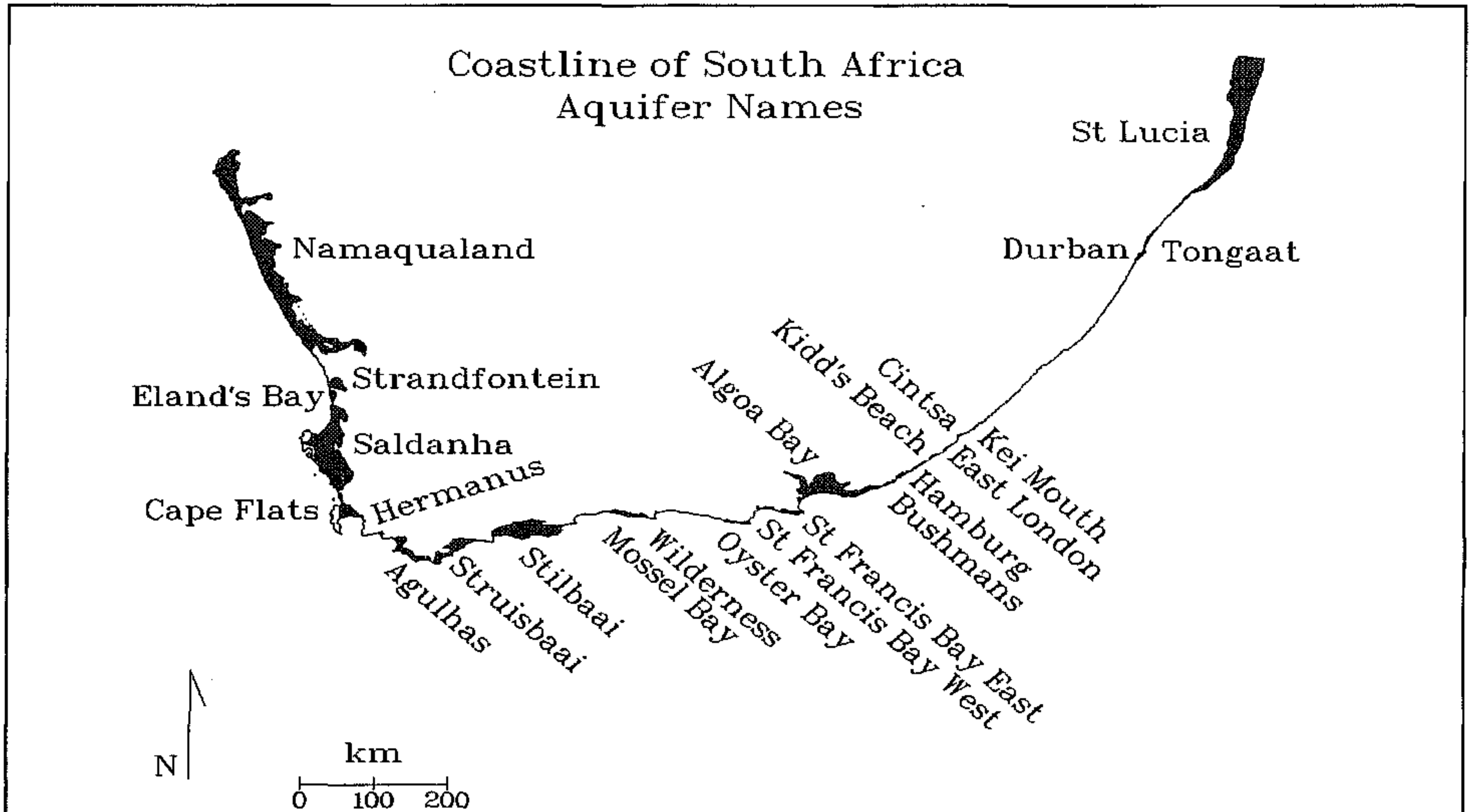


Figure 3. A map of the Cenozoic deposits of South Africa (after Dept. Mineral & Energy Affairs, 1984). Each aquifer system is given a name for ease of reference.

The physical characteristics of the aquifers, where available, are summarized in Table 2. The data is obtained from Appendix 2.

4.2.1.2 Aquifer Water Quality

A total of 259 reports were collected and the physical and chemical properties of each aquifer system, including water quality, were extracted. Water quality data were entered onto the *MapInfo* database from which maps can be generated depicting water quality for coastal aquifers in South Africa. Data presentation on a large scale is difficult. However, data can be viewed on *MapInfo* by scaling the map to suit the user's needs. The location of the boreholes is mapped on the west (Figure 4), south (Figures 5 and 6) and east (Figure 7) coasts separately.

Data were available for 13 of 24 aquifers. Only 5 of these had been representatively sampled while the others had been sampled only in limited areas.

Further manipulation of the database is demonstrated using the most important water quality variable from a consumption perspective: total dissolved solids (TDS) and the two most important water quality variables from an ecosystem perspective: silicon and nitrate.

The total dissolved solids (TDS) concentration is shown thematically for the west (Figure 8), south (Figure 9 and 10) and east (Figure 11) coast. TDS data are only available for two of the west coast systems (Figure 8). Sparse data are available for the south coast (Figures 9 and 10) with most of the data originating from a small area. The east coast (Figure 11) data, while sparse, are widely spread over most of the aquifer. When the lower TDS values are filtered out (Figure 12) it becomes apparent that high TDS concentrations occur in the Saldanha, Algoa Bay and St. Lucia aquifers.

The map of silicon concentrations only shows data for two west coast aquifers (Figure 13). Along the south coast (Figures 14 and 15) few data points are available on silicon concentrations. The east coast reports (Figure 16), however, contain several records of silicon concentrations for borehole water. When the lower silicon concentration values are filtered out (Figure 17), it is evident that the same boreholes which had the high TDS concentrations also had high silicon concentrations, i.e. Saldanha, Algoa Bay and St. Lucia aquifers (the silicon values did not account for a substantial amount of TDS, cf. Figures 12 and 17).

TABLE 2. A synthesis of the physical characteristics of the coastal aquifers in South Africa. The raw data is given in Appendix 2.

	POROSITY %	TRANSMISSIVITY m^2/day	PERMEABILITY m/day	VOLUME STORED $m^3 \times 10^6$	RECHARGE $m^3 \times 10^6$/yr	HYDRAULIC GRADIENT	LOSSES kl/day
PORT NOLLOTH Gemsbokvlei	 20-30						
KLEINSEE	20			20.96			
STRANDFONTEIN	30	550		17	0.22464 over	0.005-0.01	
LAMBERTS BAY-GRAAFWATER	8-10	150-200	25	140	1.2	centre: 0.002	
WADRIF		200-2800	30				
ELANDS BAY		16-65					
LOWER BERG Bredasdorp Varswater Elandsfontyn Adamboerskraal Langebaan Road	 8 15	 0-451 2.6-1046 0-4664	 0-30.5 0-52.2 0-56.5	 3150 1200 1235	 27 25 36	0.001-0.012	
GROOTWATER Bredasdorp Varswater aquitard	 8 5	 400-900 10-400 20-100		300	7.1		
ATLANTIS artificial natural		50-1300	0-15	413.05	 1.9 11-16	0.01724	sea: 5.94246 at 32.25 m/day
CAPE FLATS	10-12	50-650	20	1500	S: 60	coast: 0.015 inland: 0.003	80% lost through evapotransp.
WAENHUISKRANS-GANSBAAI						0.0025-0.01	
KAFFERKUILS-GOURITZ RIVER						base = 25-60m	436
WITSAND		0.5-0.9					
KEURBOOMS-PLETTENBERG BAY	20-30		15	3840			
CAPE ST FRANCIS		264 kl day^{-1} m^{-1}			0.3 over 0.5 km^2	base = 40-55°	1.5 to sandstone aquifer
DIAS CROSS		157		1.117998	0.26-0.355	fixed dune: 0.007246	3.23287
BUSHMANS RIVER MOUTH back dune upper zone lower zone sandstones shales dune sands	 12 12 26	157 36 187 3.5 50		0.249336 0.384	0.1585	coast: 0.0004933 0.006211	0.347 to sea: 0.062 abstr: 0.285
BONZA BAY sandstone			102		 2200	0.004545	 657.534
RICHARD'S BAY-LAKE MZINGAZI Miocene recent estuarine and dune sands confined aquifer	 20	 15-20 140	 2.5 16	 5000	0.28047 80		260 subsurface: 1350 evap.: 15.91 (0.001-1.2 m^3/day/m) 3000 m^3/day/km
ST LUCIA			25			0.0033	8 cm/day

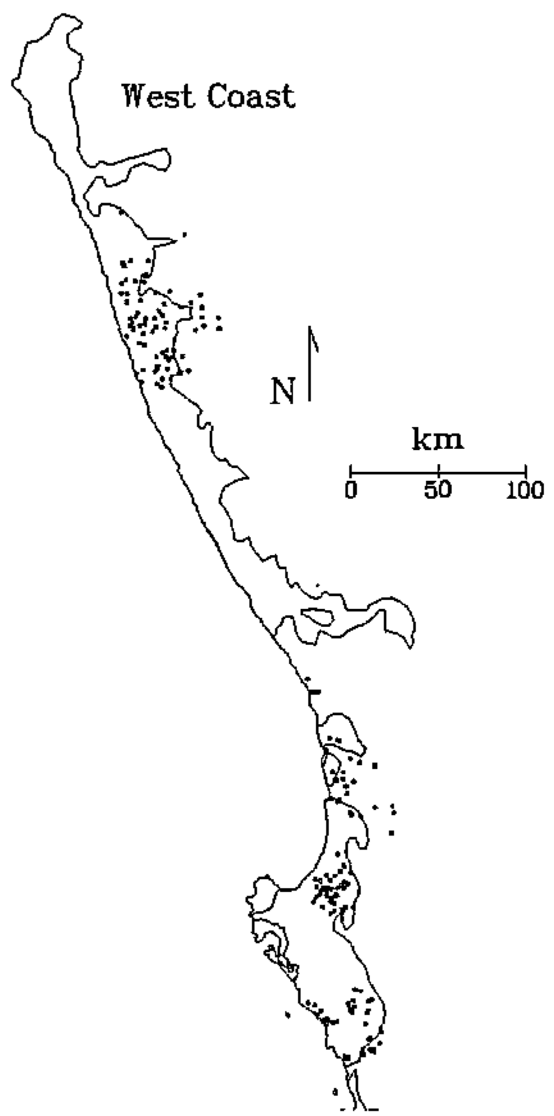


Figure 4. A map of the Cenozoic deposits of the west coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing the location of the boreholes used in this study.

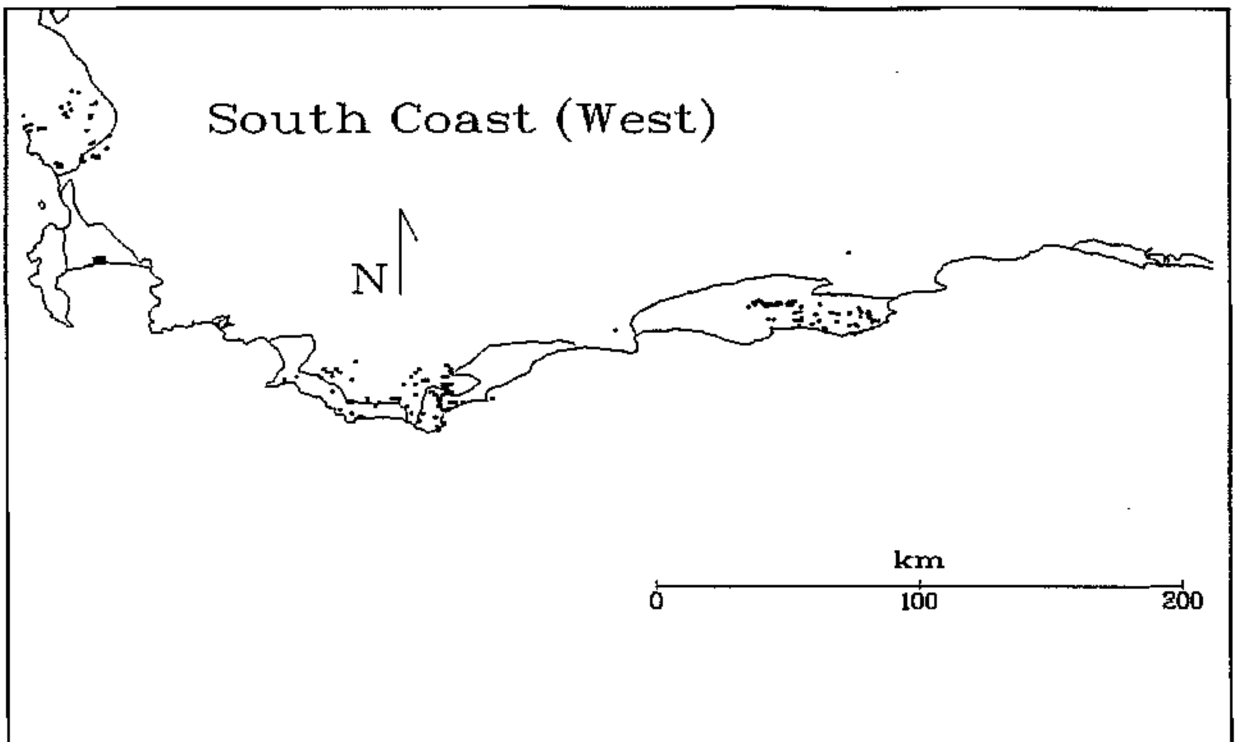


Figure 5. A map of the Cenozoic deposits of the western part of the south coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing the location of the boreholes used in this study.

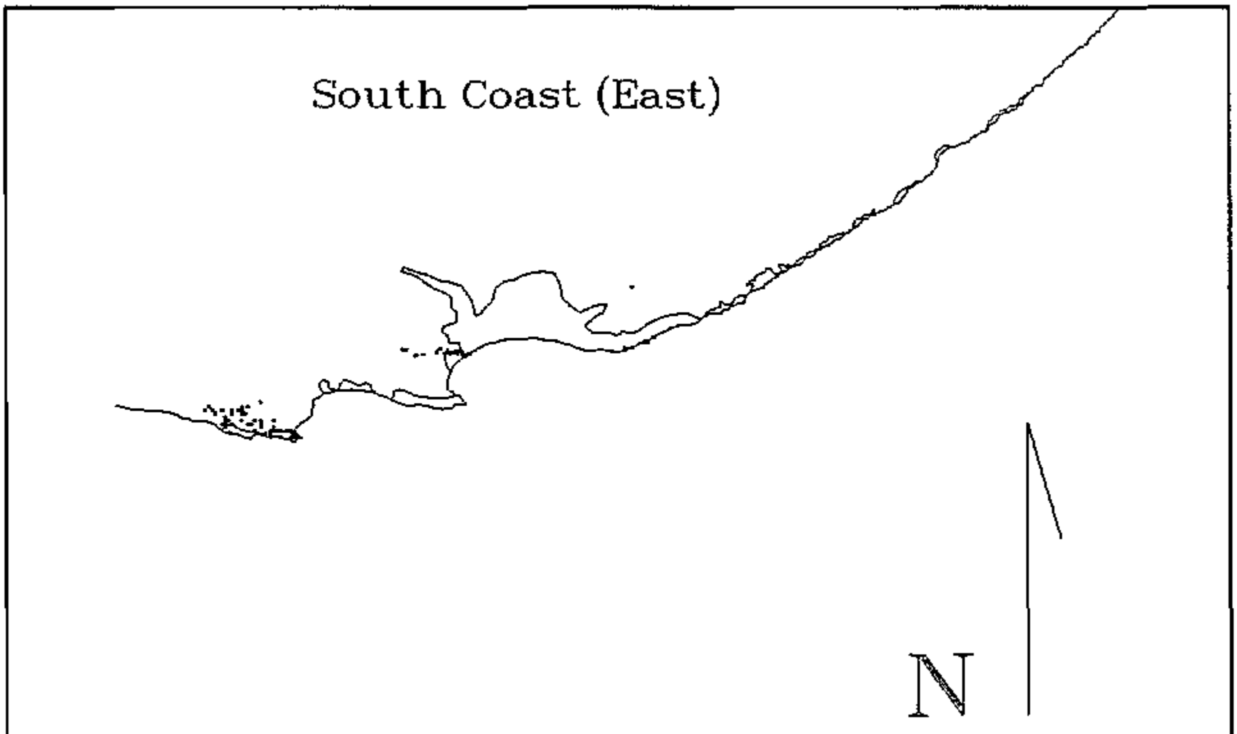


Figure 6. A map of the Cenozoic deposits of the eastern part of the south coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing the location of the boreholes used in this study.

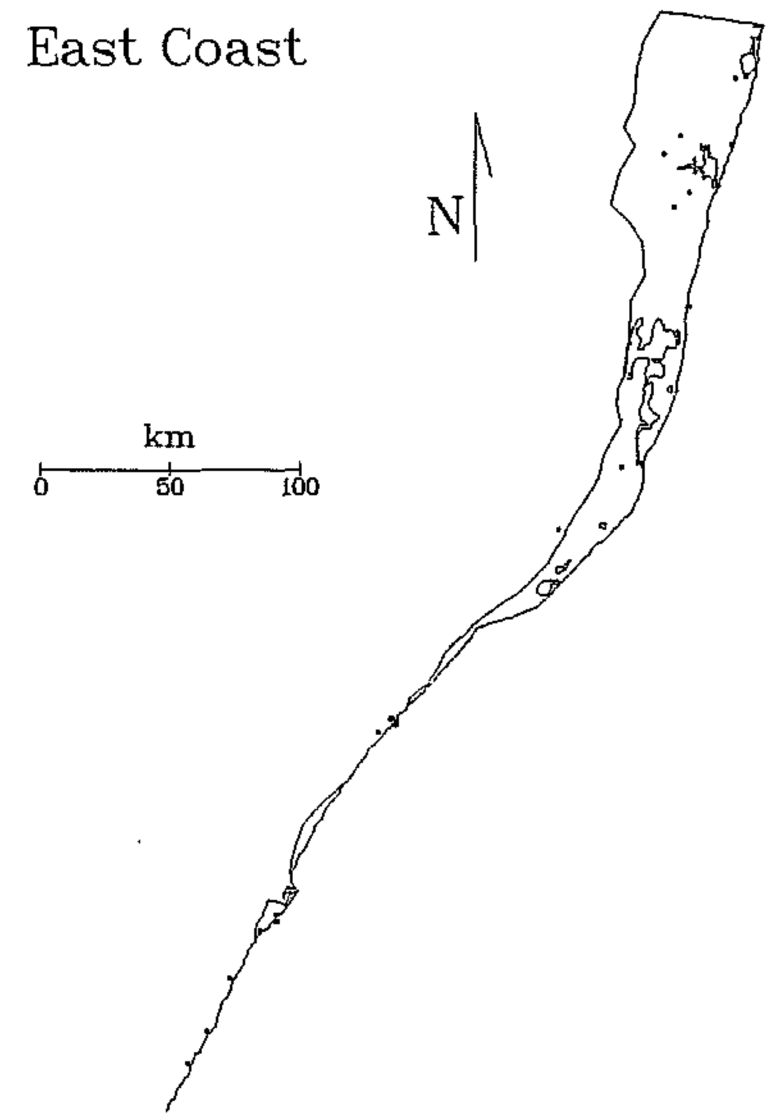


Figure 7. A map of the Cenozoic deposits of the east coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing the location of the boreholes used in this study.

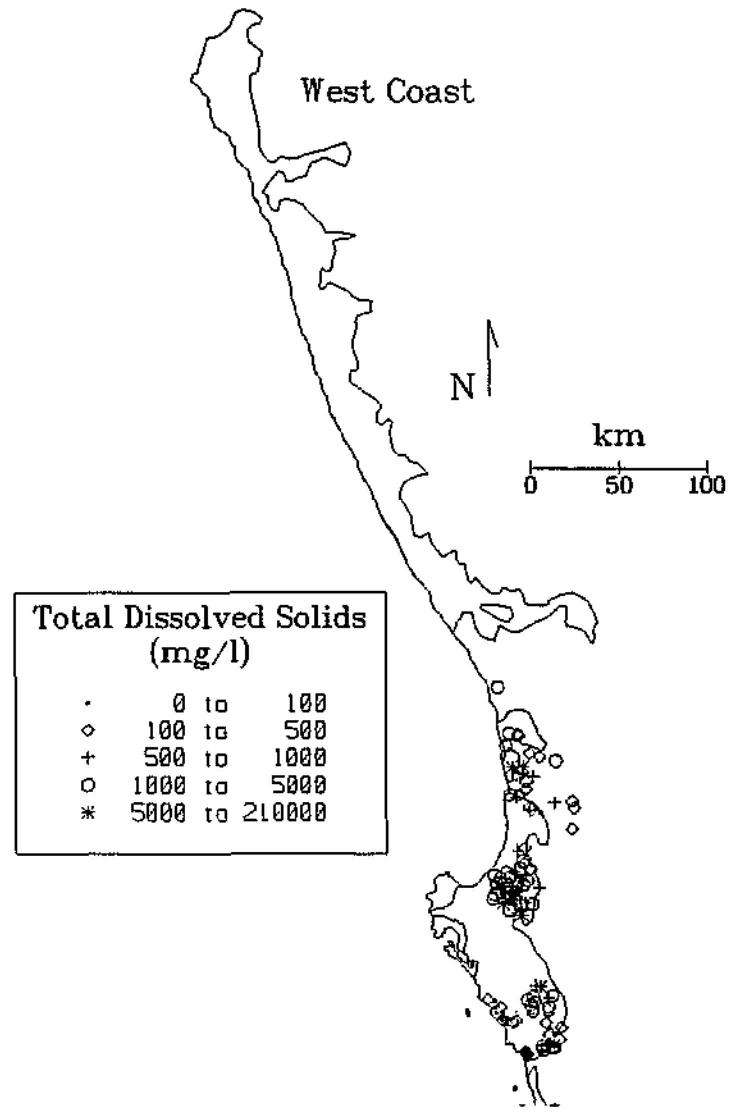


Figure 8. A map of the Cenozoic deposits of the west coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration values of total dissolved solids in borehole water.

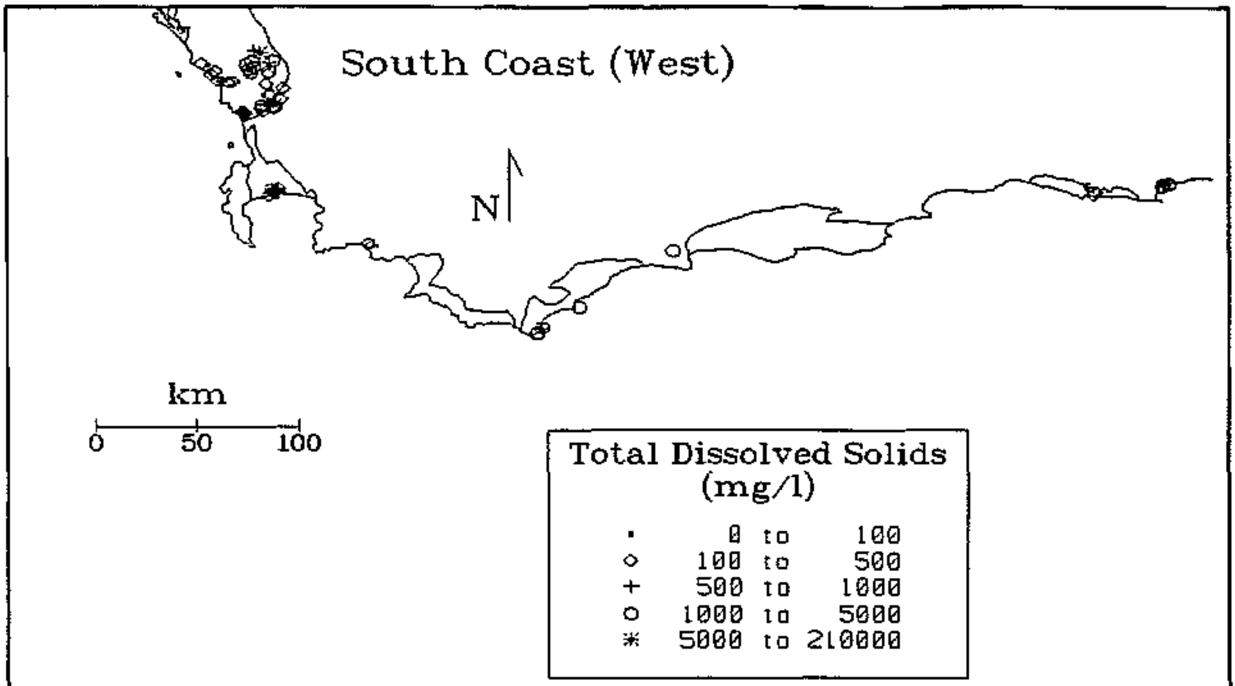


Figure 9. A map of the Cenozoic deposits of the western part of the south coast of South Africa (after *et al.*, 1984) showing thematically the concentration values of total dissolved solids in borehole water.

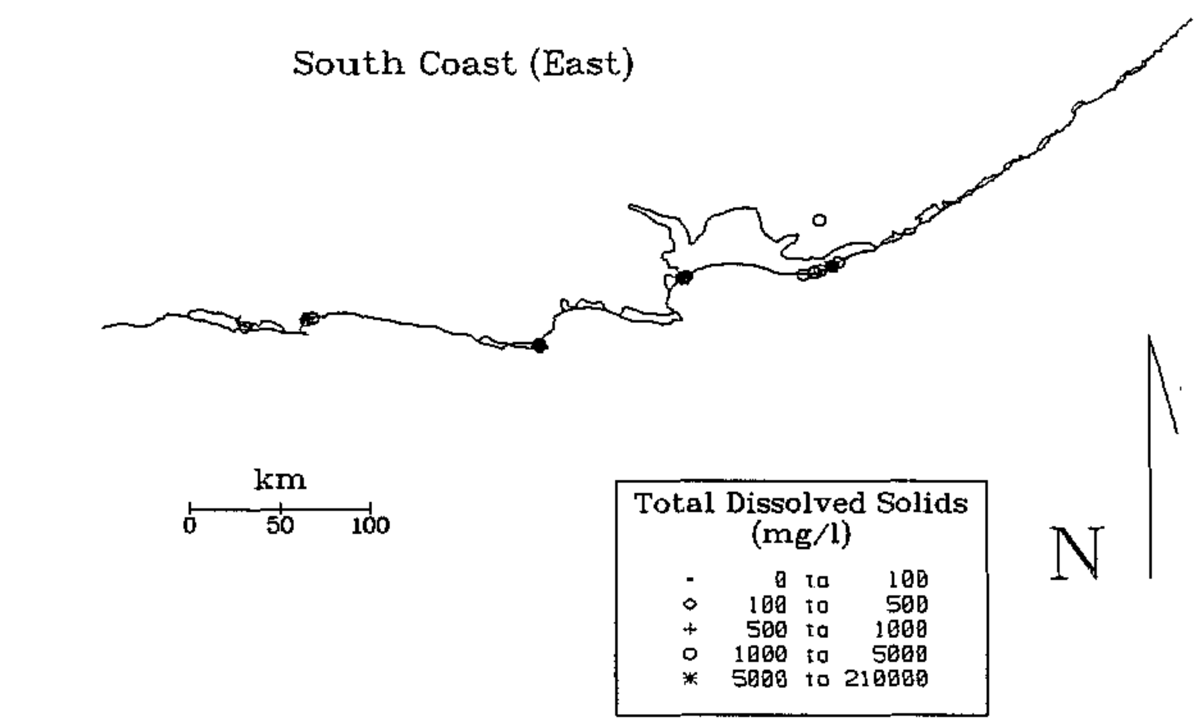


Figure 10. A map of the Cenozoic deposits of the eastern part of the south coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration of total dissolved solids in borehole water.

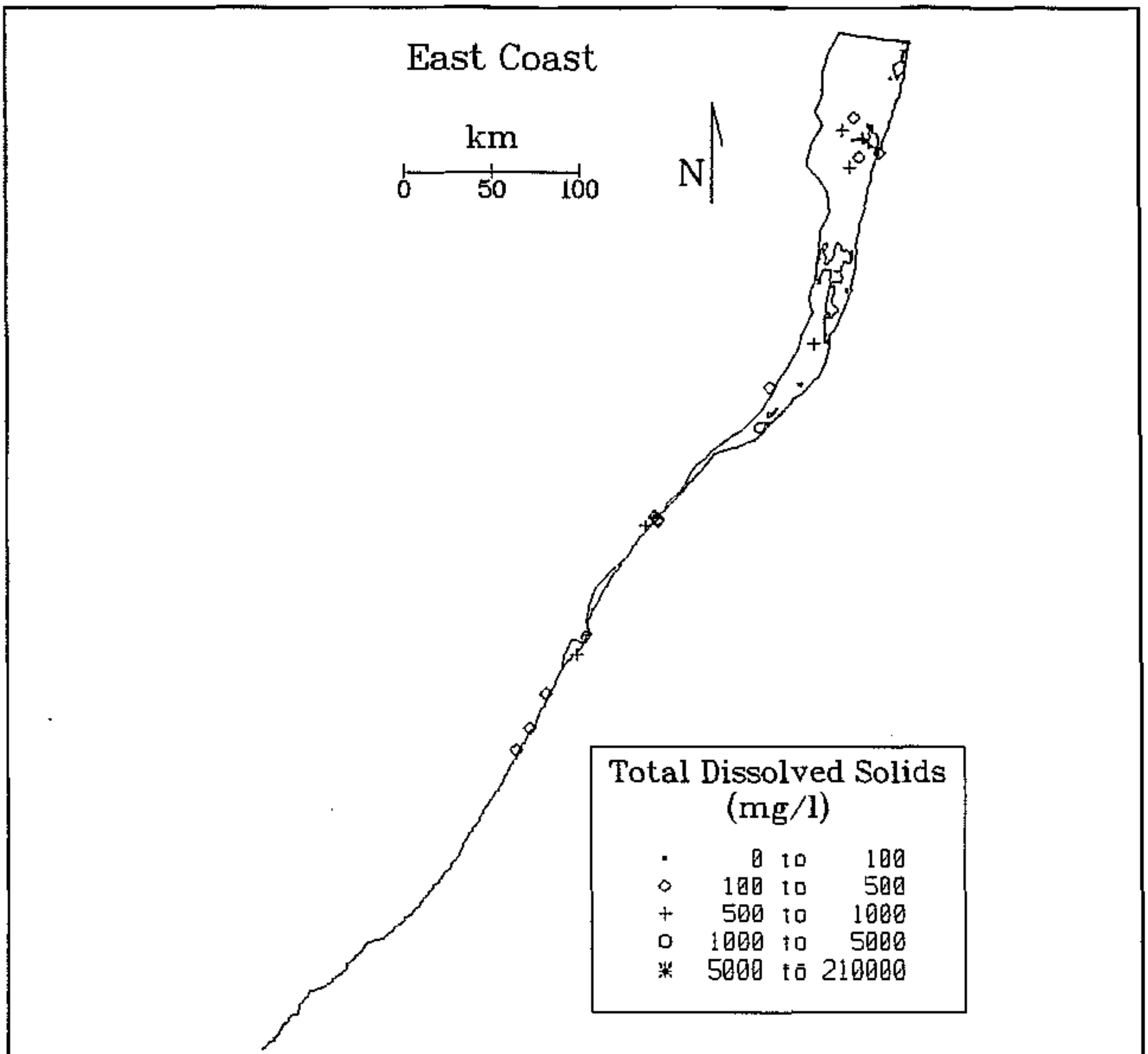


Figure 11. A map of the Cenozoic deposits of the east coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration values of total dissolved solids in borehole water.

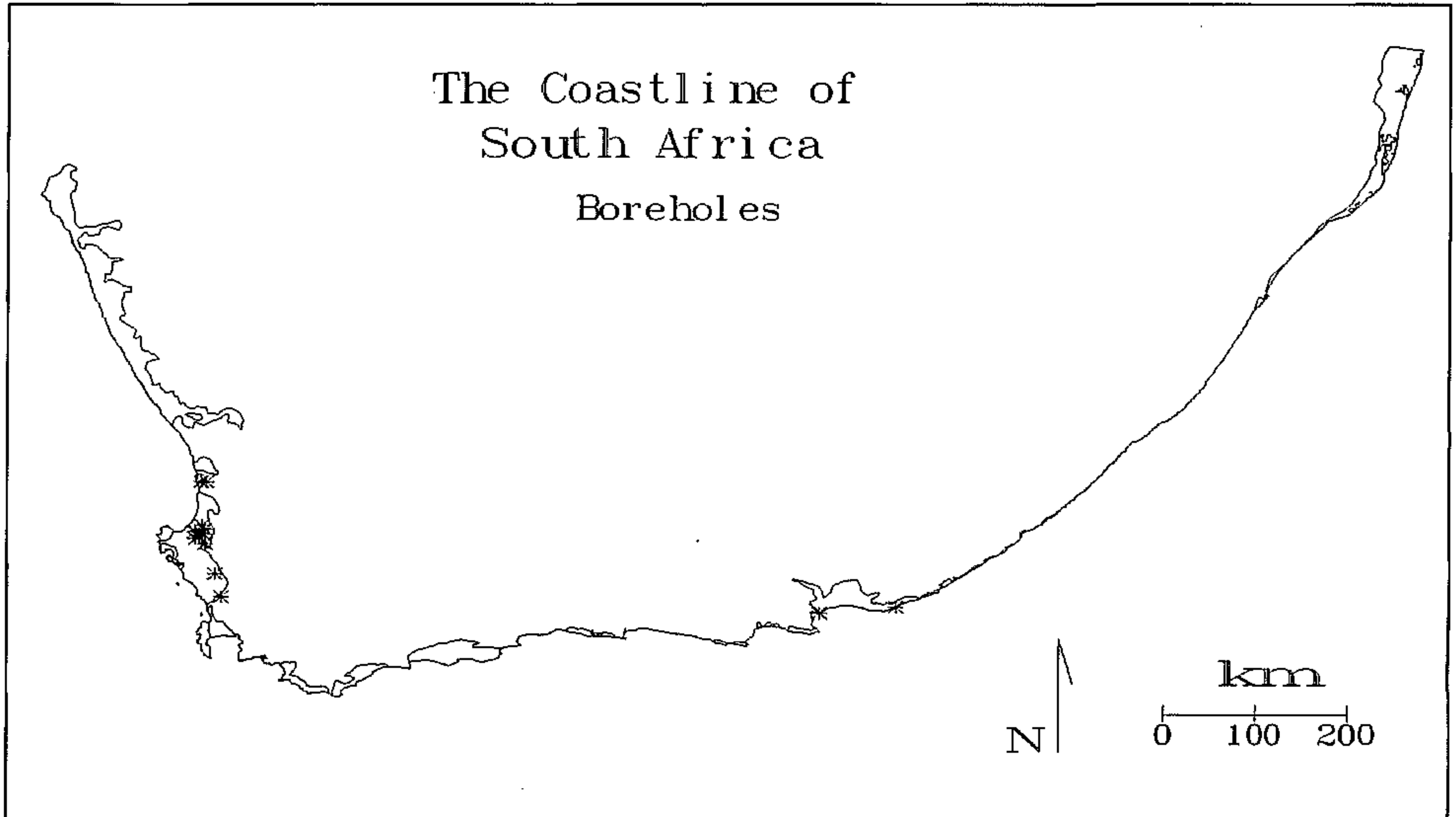


Figure 12. A map of the Cenozoic deposits of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing the boreholes where the water had a concentration values of total dissolved solids greater than 5 000 mg/l.

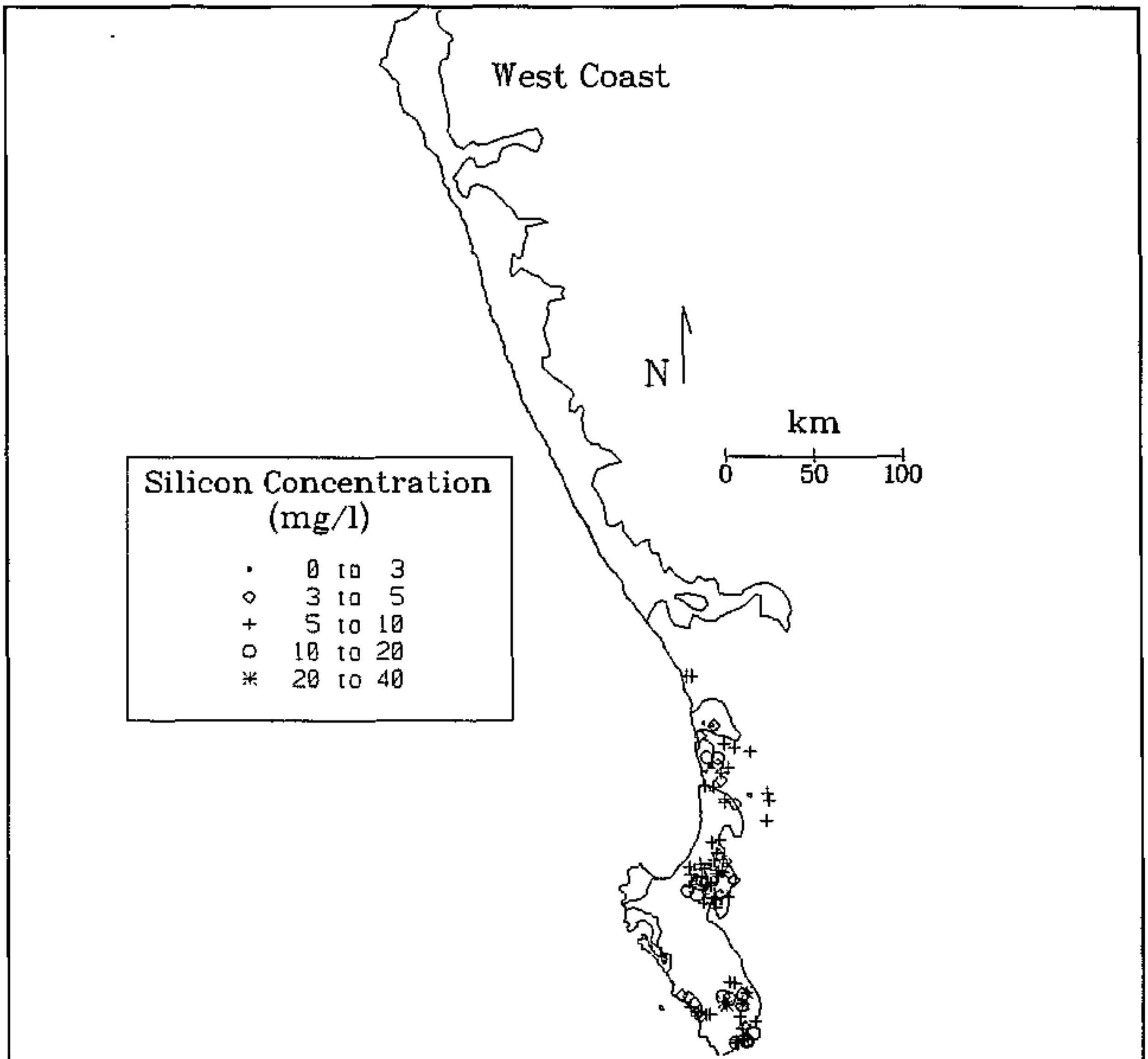


Figure 13. A map of the Cenozoic deposits of the east coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration values of silicon in borehole water.

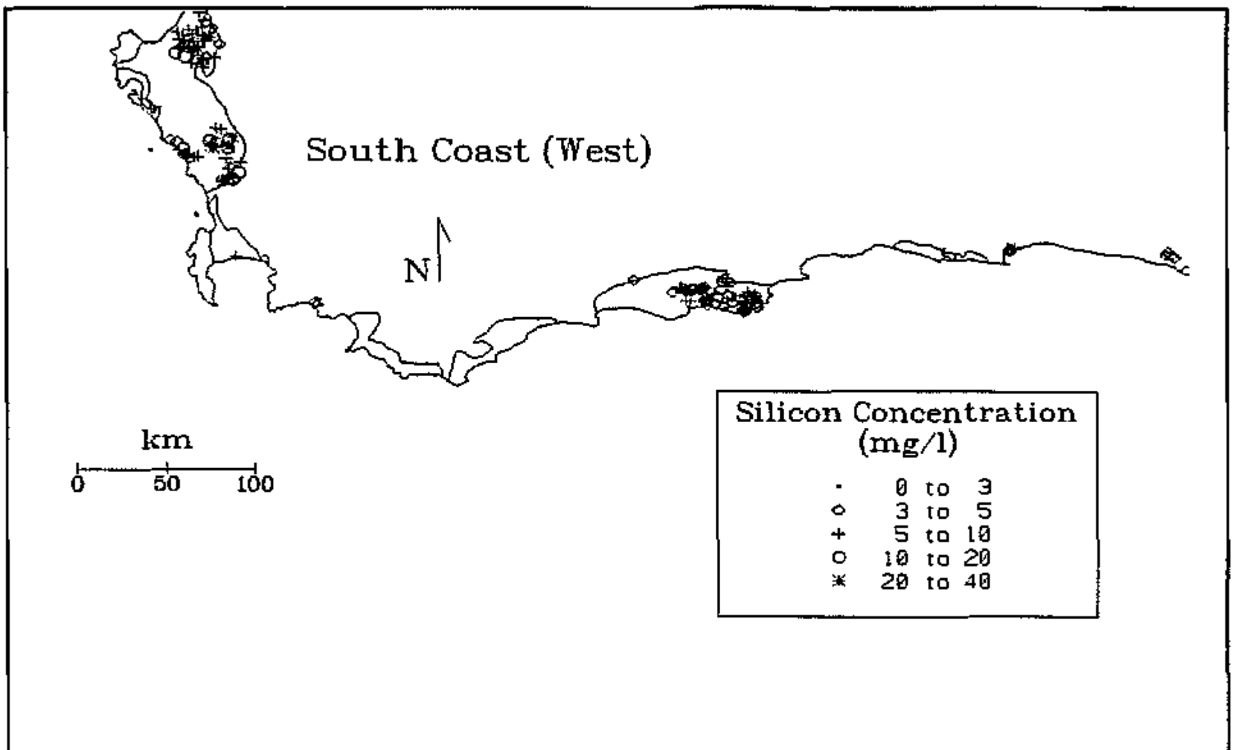


Figure 14. A map of the Cenozoic deposits of the western part of the south coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration values of silicon in borehole water.

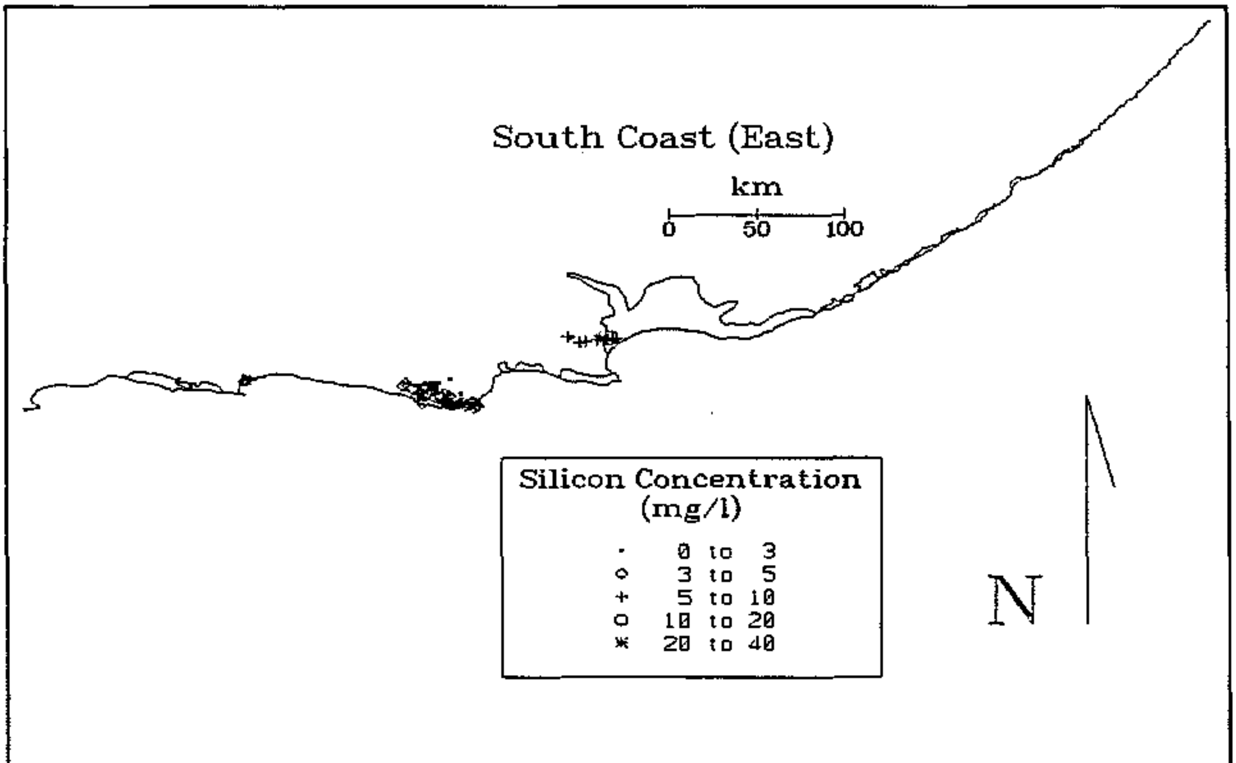


Figure 15. A map of the Cenozoic deposits of the eastern part of the south coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration values of silicon in borehole water.

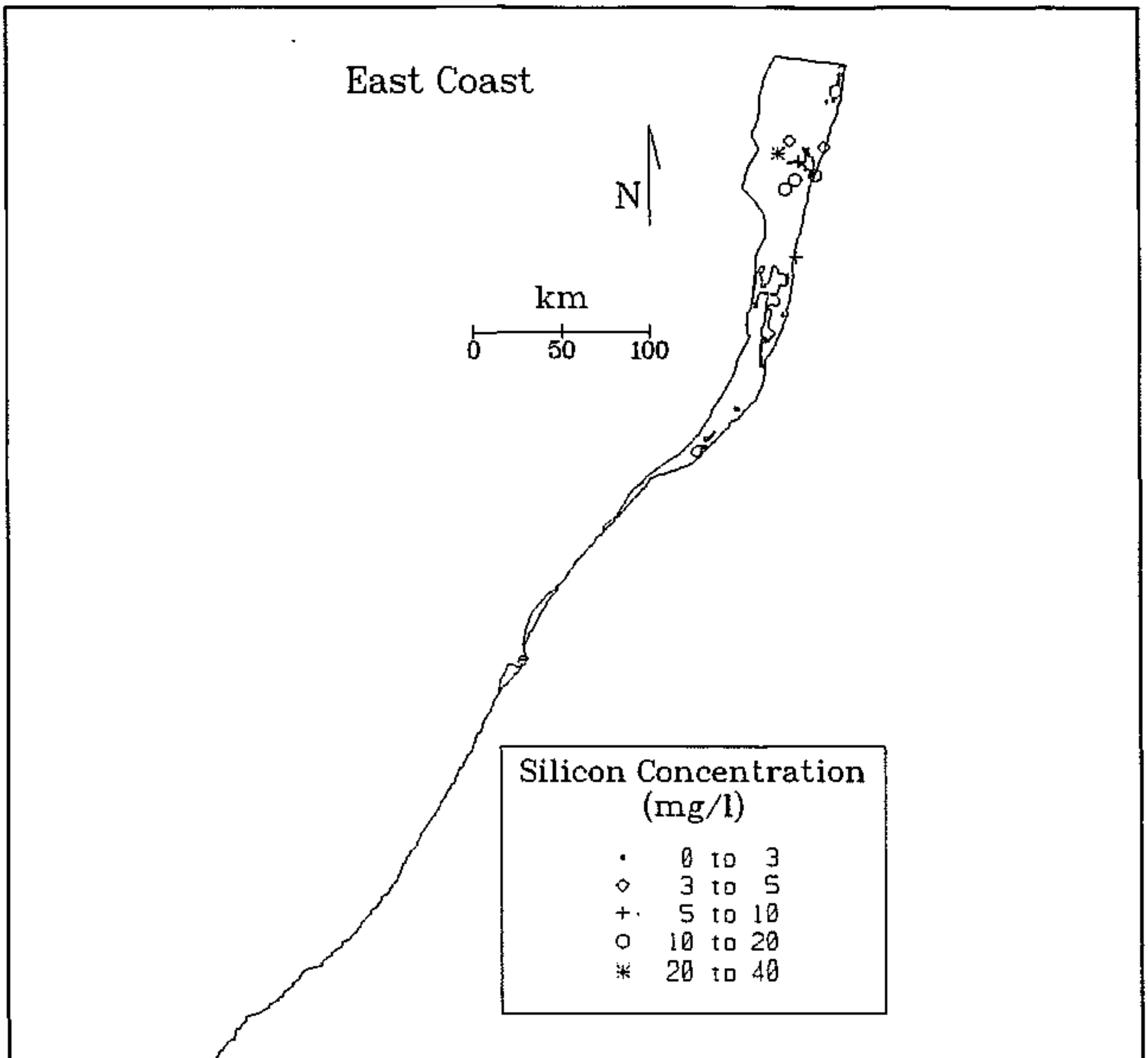


Figure 16. A map of the Cenozoic deposits of the east coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing the concentration values of silicon in borehole water.

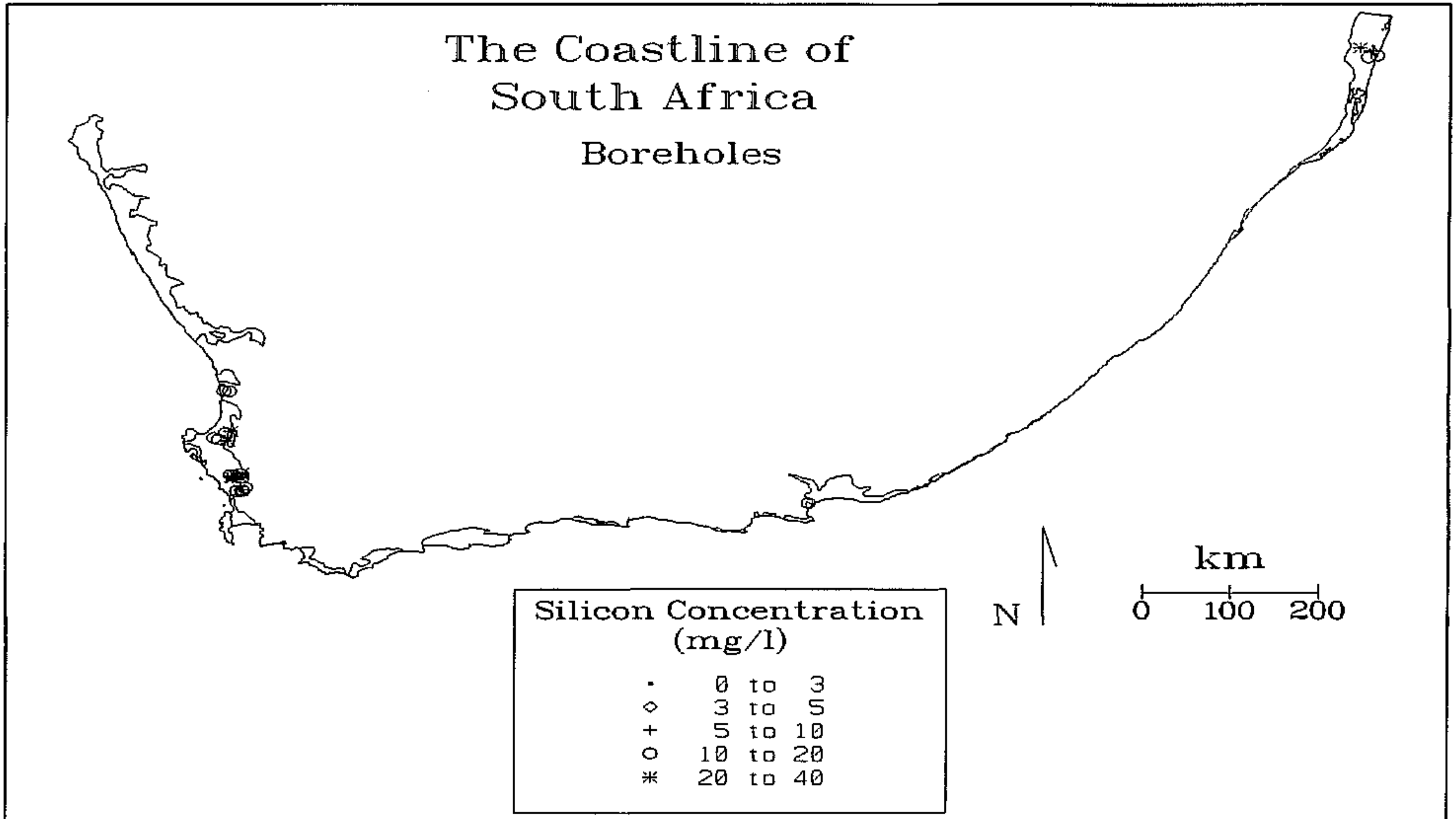


Figure 17. A map of the Cenozoic deposits of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing the silicon concentration values in borehole water greater than 10 mg/l.

The nitrate concentrations of the Saldanha and Eland's Bay aquifers are shown in Figure 18. There are also data available from the Namaqualand aquifer. The south coast aquifers, once again, have yielded little data (Figures 19 and 20). As before there is a reasonable spread of data for the east coast aquifers (Figure 21). With the low values excluded it is apparent that the Namaqualand, Saldanha, Struisbaai and St. Lucia aquifers are the ones with high nitrate concentrations (Figure 22).

The minimum and maximum values for each field in the *dBase* datafile (= *MapInfo* pointfile) as well as the mean and number of datapoints is presented in Table 3.

4.2.2 Questionnaires

Appendix 5 gives the results of the questionnaire along with the amount and quality of the water used. Salinity has been expressed qualitatively in terms of drinking standards.

Of the 136 questionnaires set out, 106 responded. Of these, 45 indicated the use of ground water. Only 27 of these were able to state how much ground water was being used. A total of 2 969 856 kl of water is reported to be abstracted for human use each year.

There is, however, some doubt about this number as, for example, the Gordon's Bay municipality reports the use of 2 kl of water per year, which is unlikely as the expense of the abstraction procedure far outweighs the saving by utilizing 2 kl of ground water. Clearly this type of data represents an error which still needs to be corrected. If we assume these figures to be reliable, and also that the remaining 18 users use an equivalent amount of water, total abstraction is approximately 5 million kl per year.

4.2.3 Ecosystems Associated with Coastal Aquifers

4.2.3.1 Estuaries

The rivers and estuaries associated with coastal aquifers are listed in Table 4. Sixty three rivers, estuaries and lakes appear to be linked to Cenozoic deposits, and therefore to coastal aquifers.

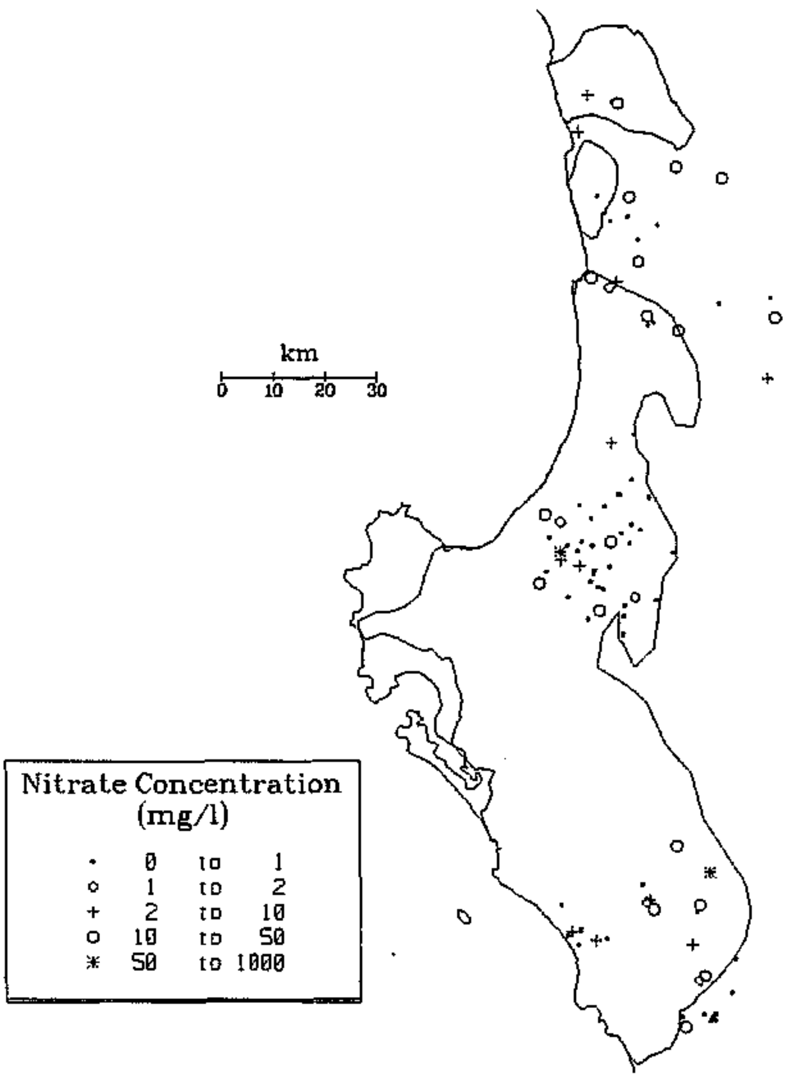


Figure 18. A map of the Cenozoic deposits of the west coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the nitrate concentration values of borehole water.

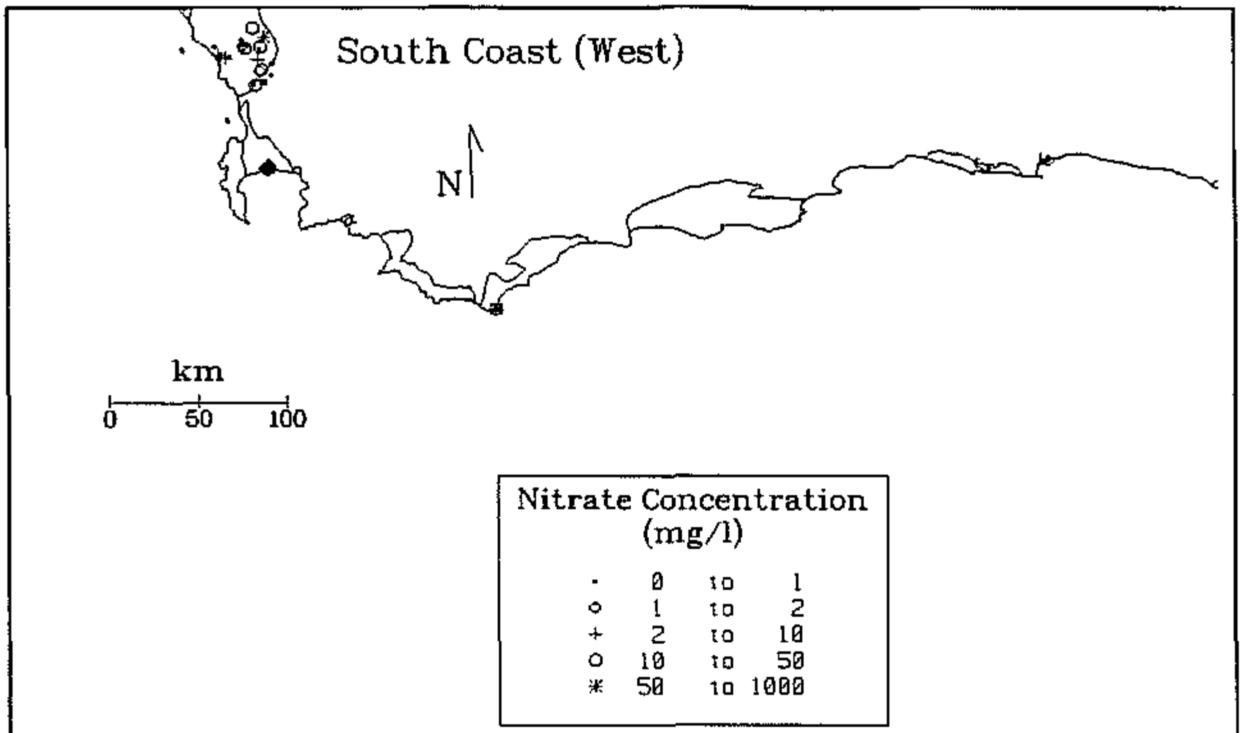


Figure 19. A map of the Cenozoic deposits of the western part of the south coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration values of nitrate in borehole water.

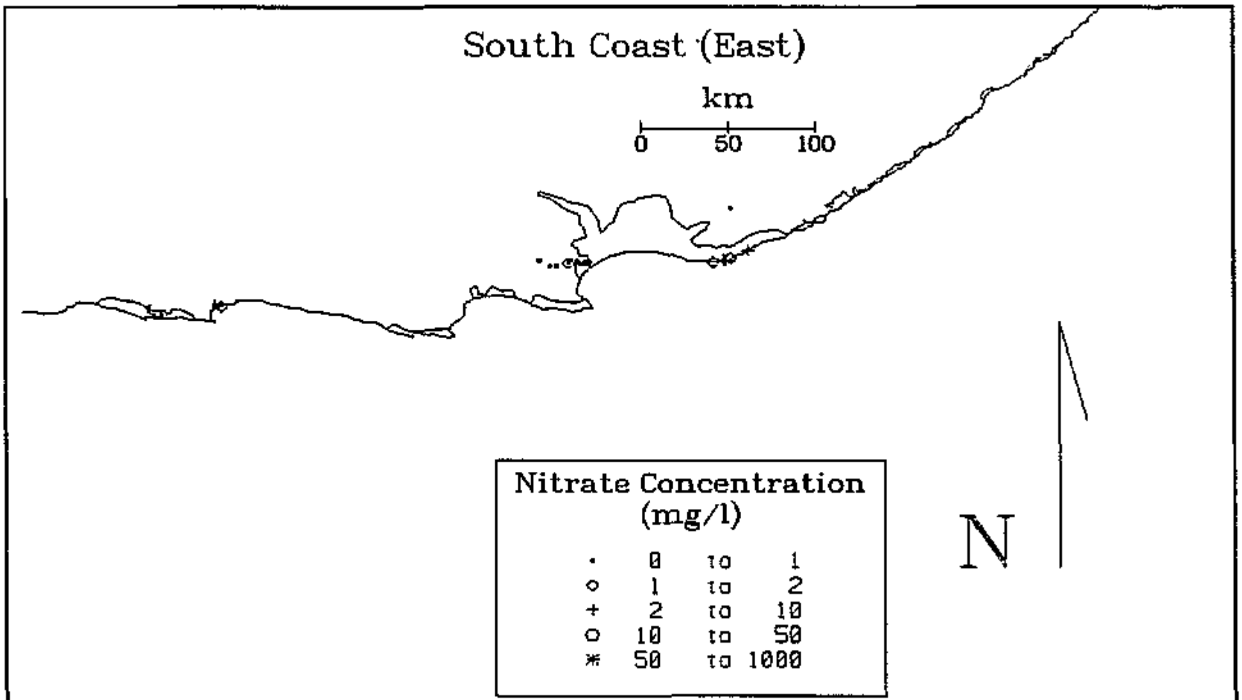


Figure 20. A map of the Cenozoic deposits of the eastern part of the south coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration values of nitrate in borehole water.

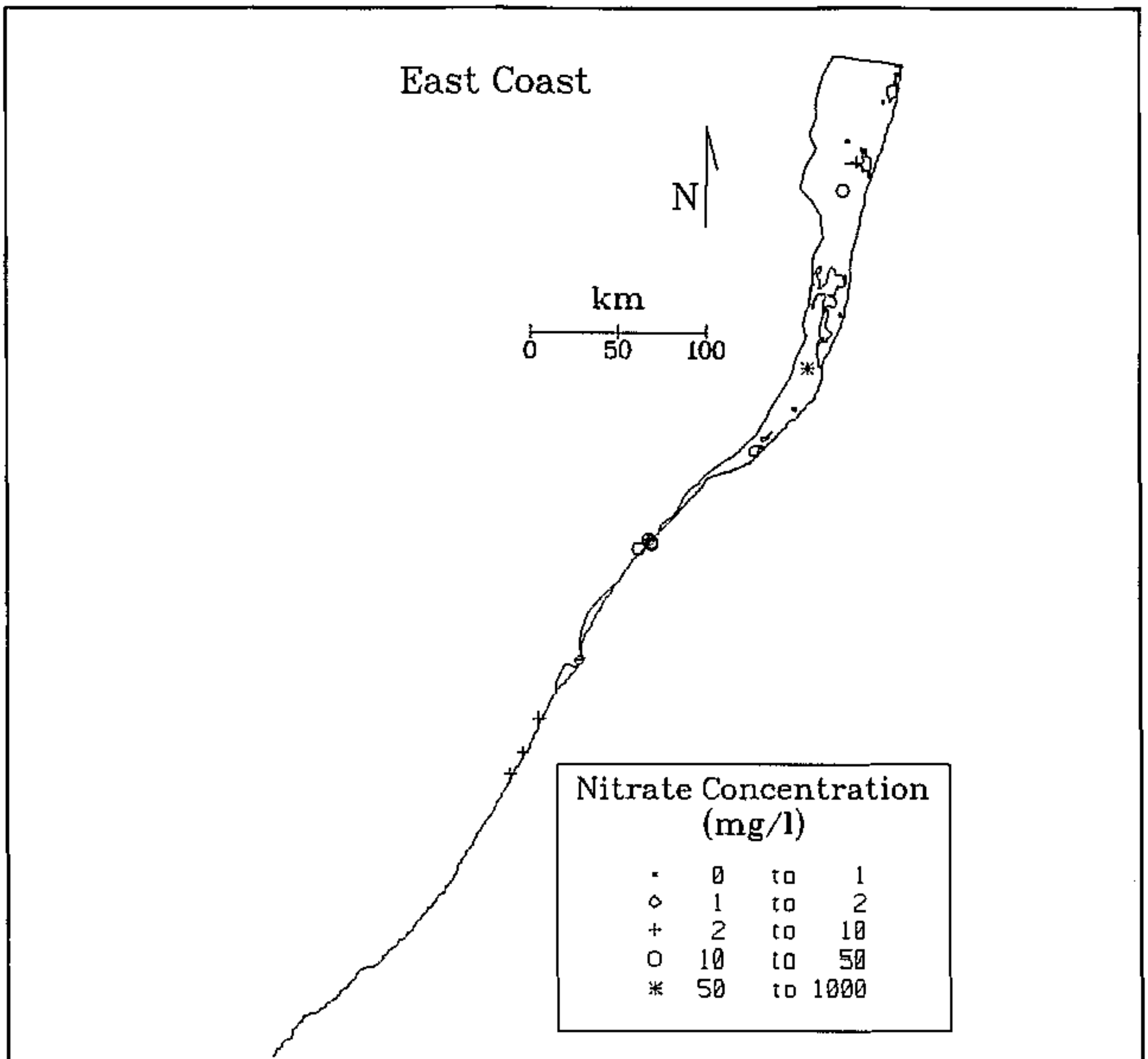


Figure 21. A map of the Cenozoic deposits of the east coast of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing the concentration values of nitrate in borehole water.

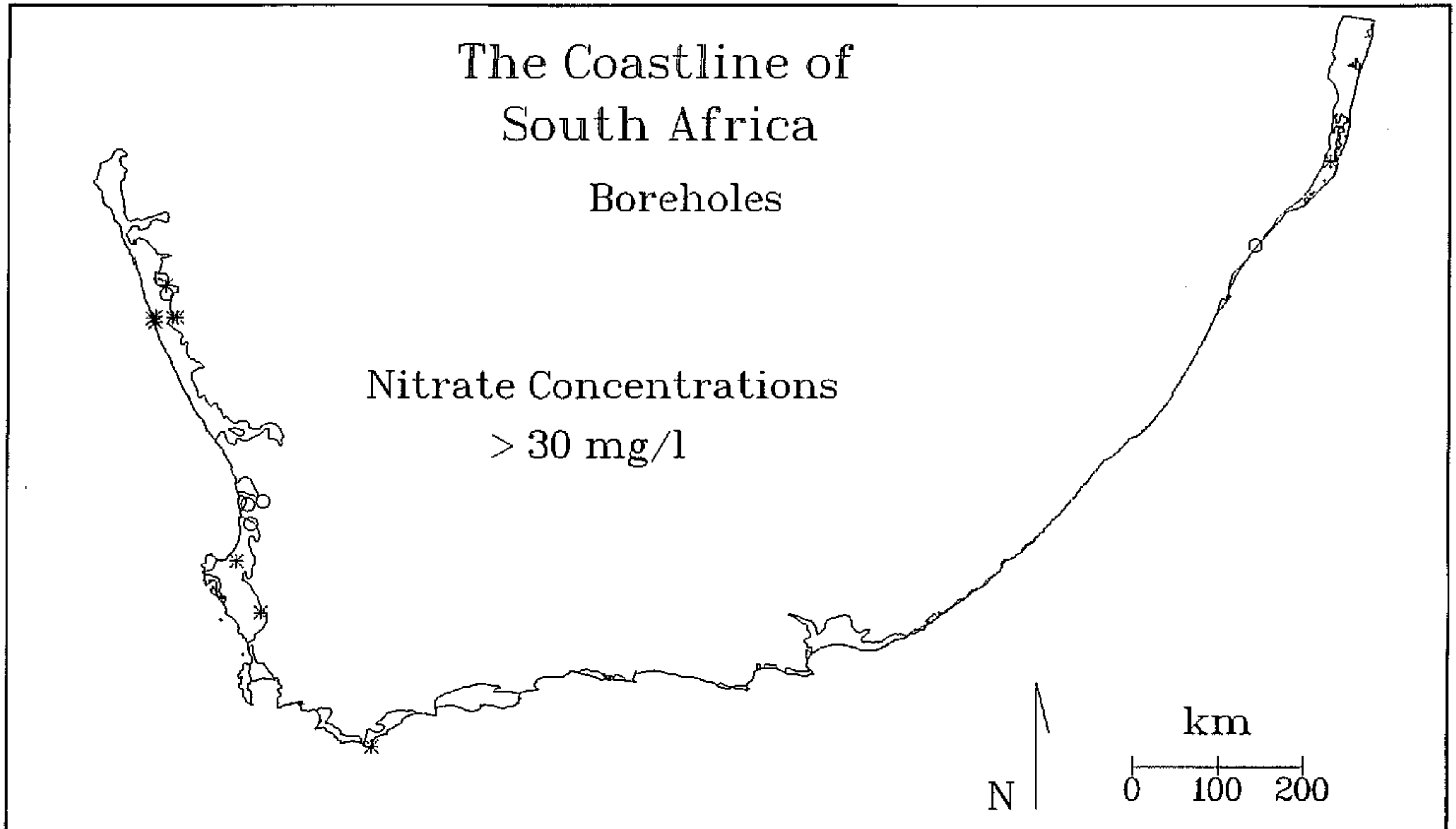


Figure 22. A map of the Cenozoic deposits of South Africa (after Dept. Mineral & Energy Affairs, 1984) showing thematically the concentration values of nitrate greater than 30 mg/l in borehole water.

Table 3. The variables of the *MapInfo* pointfile showing the units of the variable, the minimum and maximum values, the mean and number of datapoints.

Variable	Units	Maximum	Minimum	Mean	n
Water Depth	m	149.0	0.2	26.4	197
Water Elevation	m	230.0	0.3	71.4	168
Thickness	m	92	19	42.8	29
pH	pH	9.0	3.7	7.0	539
TDS	mg/l	209 653	6	2831	235
Conductivity	mS/m	14 994	28	1225	524
Total Alkalinity	mg/l	342	1.3	136	160
Total Hardness	mg/l	529	27.5	237	96
Bicarbonate	mg/l	874	0.3	167	365
Sulphate	mg/l	19 944	0.9	156	538
Chlorine	mg/l	116 707	24	1 053	547
Fluoride	mg/l	7.0	0.02	0.38	240
Silicon	mg/l	32.2	0.2	5.6	289
Silicate	mg/l	43.5	0.2	7.3	53
Sodium	mg/l	57 348	20	589	542
Potassium	mg/l	1 237	0.5	15.4	512
Calcium	µg/l	1 586	1	81.6	542
Magnesium	µg/l	14 087	1	86.4	540
Iron	µg/l	35 990	0.03	665	259
Nitrate	mg/l	1 000	0.01	14.2	239
Ammonium	mg/l	18.1	0.01	0.54	184
Total Nitrogen	mg/l	17.2	0.1	1.02	31
Total Phosphorus	mg/l	0.8	0.01	0.06	72
Phosphate	mg/l	0.9	0.01	0.07	103
Suspended Solids	mg/l	20	20	20	1
Dissolved Organic Carbon	mg/l	5.8	0.5	2.5	27

Table 4. The rivers and estuaries associated with coastal aquifers of South Africa.

Aquifer	River/Estuary
Namaqualand	River BOY 0002 Holgatrivier Buffelsrivier Swartlintjiesrivier Spoegrivier Bitterrivier Groenrivier Brakrivier
Eland's Bay	Jakkalsrivier Langvleirivier
Atlantis	Verlorevlei Papkuilsrivier Modderrivier Great Berg River Dwarsrivier
Cape Flats	Dieprivier Sandvlei Zeekoevlei Kuilsrivier Lourensrivier
Hermanus	Bot River
Struisbaai	Heuningnesrivier
Stilbaai	Duiwenhoksrivier Kafferkuilsrivier Gouritz River
Mossel Bay	Goukamma River
Wilderness	Noetzie River
St Francis Bay West	Slangrivier
St Francis Bay East	Gamtoos River Van Stadens River Maitland River
Algoa Bay	Coega River Sundays River Boknes River Bushmans River Kasouga River

Table 4 (cont.)

Aquifer	River/Estuary
Bushmans	Kleinemonde
Hamburg	Keiskamma River
East London	Buffalo River Nahoon River Gqunube River
Cintsa	Cintsa River
Kei Mouth	Great Kei River
Durban	Mlazi River
Tongaat	Umbeni River Umhlanga River Moloti River Tongaat River
St. Lucia	Tugela River Matigulu River Mlalazi River Mhlatuze River Msunduzi River Mfolozi River Hluhluwe River Myalazi River Mkuze River Lake Cubhu Lake Mzingazi Lake Bhangazi Lake Sibayi Lake Kosi

4.2.4.2 Terrestrial Vegetation

The vegetation communities that grow on coastal aquifers identified in the region Mossel Bay to the Kei River are listed in Table 5. Nineteen communities overlie Cenozoic deposits. The vegetation growing on the west coast and east coast deposits was not identified in the literature studied.

Acock's vegetation types (based on grazing potential), which overlie Cenozoic deposits, are listed in Table 6. Eleven of Acock's vegetation types appear to be linked to Cenozoic deposits, and therefore to coastal aquifers.

Table 5. The terrestrial vegetation communities associated with coastal aquifers of South Africa.

Aquifer : Orthophoto Map Number	Vegetation Community
Mossel Bay : 3420BD16 - 3422AA13,19,23	1. Renosterveld 2. Dune fynbos 3. Limestone fynbos 5. Dune slack and strand vegetation 6. Artificially established dune shrubland 7. Dense alien communities 8. Saltmarsh (undifferentiated) 9. Vlei 10. Secondary grassland 12. Xeric transitional thicket 14. Dune forest and thicket and stunted dune thicket 16. Halophytic rocky coast communities
Wilderness : 3422BA5 - 3423AB8,13,14	2. Dune fynbos 4. Mountain fynbos 5. Dune slack and strand vegetation 7. Dense alien communities 8. Saltmarsh 9. Vlei 10. Secondary grassland 13. Forest and thicket on ancient dunes 14. Dune forest and thicket and stunted dune thicket. 15. Afromontane forest
Oyster Bay and St Francis Bay West : 3424AB7,12 - 3424BB17,18	2. Dune fynbos 3. Limestone fynbos 5. Dune slack and strand vegetation 7. Dense alien communities 8. Saltmarsh 9. Vlei 10. Secondary grassland 11. Coastal grassland 12. Xeric transitional thicket 13. Dune thicket 14. Dune forest 15. Afromontane forest communities 16. Halophytic rocky coast communities
St. Francis Bay East : 3324DD20 - 3325CC21; 3324CC22 - 3324CC25	2. Dune fynbos 5. Dune slack and strand vegetation 7. Dense alien communities 10. Secondary grassland 12. Xeric transitional thicket 13. Dune thicket 16. Halophytic rocky coast communities.
Algoa Bay : 3325CC21 - 3326DC1	2. Dune fynbos 5. Dune slack and strand vegetation 6. Artificially established dune shrubland 7. Dense alien communities 8. Saltmarsh 9. Vlei 10. Secondary grassland 12. Xeric transitional thicket 13. Dune thicket 14. Dune forest 16. Halophytic rocky coast communities 17. Succulent transitional thicket 18. Stunted dune thicket 19. Acacia savanna
Bushmans : 3327CA1 - 3327CA3	2. Dune fynbos 5. Dune slack and strand vegetation. 6. Artificially established dune shrubland 7. Dense alien communities 8. Saltmarsh (undifferentiated) 12. Xeric transitional thicket 13. Dune thicket

Table 5 (cont.)

Aquifer : Orthophoto Map Number	Vegetation Community
Hamburg : 3327BA18 - 3327BA19	10. Secondary grassland 12. Xeric transitional thicket 13. Dune thicket 14. Dune forest 18. Stunted dune thicket 19. Acacia savanna
Kidd's Beach : 3327BA22 - 3327BA23; 3327BA14 - 3327BA17	5. Dune slack and strand vegetation 6. Artificially established dune shrubland 7. Dense alien communities 8. Saltmarsh 9. Vlei 10. Secondary grassland 12. Xeric transitional thicket 13. Dune thicket 14. Dune forest 18. Stunted dune thicket 19. Acacia savanna
East London : 3327BB3 - 3327BB8; 3227DD24 - 3227DD25; 3228CB16,21	2. Dune fynbos 5. Dune slack vegetation 7. Dense alien communities 8. Saltmarsh 9. Vlei 10. Secondary grassland 11. Coastal grassland 12. Xeric transitional thicket 13. Dune thicket 14. Dune forest 15. Afromontane forest communities 18. Stunted dune thicket 19. Acacia savanna
Cintsa : 3228CC8	5. Dune slack vegetation 8. Saltmarsh 10. Secondary grassland 12. Xeric transitional thicket 14. Dune forest 19. Acacia savanna
Kei Mouth : 3228CC5; 3228CB18 - 3228CB23	9. Vlei 10. Secondary grassland 12. Xeric transitional thicket 13. Dune thicket 14. Dune forest 15. Afromontane forest 16. Halophytic rocky coast communities 18. Stunted dune thicket 19. Acacia savanna

Table 6. Acock's Veldtypes that grow on coastal Cenozoic deposits of South Africa.

Aquifer	Acock's Veldtype (No. and Name)
Namaqualand	31. Succulent Karoo 34. Strandveld
Strandfontein	34. Strandveld
Eland's Bay	34. Strandveld 47. Coastal Fynbos
Saldanha	47. Coastal Fynbos
Cape Flats	69. Fynbos
Hermanus	47. Coastal Fynbos
Agulhas	46. Coastal Renosterveld 47. Coastal Fynbos
Struisbaai	46. Coastal Renosterveld 47. Coastal Fynbos
Stilbaai	46. Coastal Renosterveld 47. Coastal Fynbos
Mossel Bay	23. Valley Bushveld 46. Coastal Renosterveld
Wilderness	4. Knysna Forest
Oyster Bay	70. False Fynbos
St Francis Bay West	2. Alexandria Forest
St Francis Bay East	2. Alexandria Forest
Algoa Bay	2. Alexandria Forest 7. Eastern Province Thornveld 23. Valley Bushveld
Bushmans to Kei Mouth	1. Coastal Forest and Thornveld 2. Alexandria Forest 7. Eastern Province Thornveld 23. Valley Bushveld
Durban to St. Lucia	1. Coastal Forest and Thornveld

5. SUMMARY AND CONCLUSIONS

Coastal aquifers are defined as a water-bearing geological formation hydraulically connected to the sea (Johannes, 1980). This study was limited to unconfined aquifers, which comprises a permeable bed partly filled with water and overlying a relatively impervious layer. The upper boundary of the aquifer is formed by a free water table under atmospheric pressure (Kruseman and De Ridder, 1970).

From available information published by researchers, consultants and planners selected numerical data were extracted and entered into a database. This database is available from the authors upon request. No information was available with respect to the actual boundaries of coastal aquifers. For this reason, the magnitude of the aquifers could not be determined using this database and an accurate map of aquifers could not be compiled. However, the map showing Cenozoic deposits was used to estimate the position and extent of coastal aquifers. The quality of aquifer water was found to vary through several orders of magnitude, hence some of the data are suspect. A conclusion that can be drawn from an analysis of the reports collected is that, while data is available, it is confined to a few areas and some of the reports appear to be inaccurate. While there are some data available on the dependence of coastal ecosystems on aquifer water in the international literature, nothing has been published on this topic for South African systems. The international literature indicates that abstracting water from coastal aquifers influences different ecosystems in different ways. Lowering the water level in a dune system will most likely result in the decline of phreatic vegetation. Increased nutrient loading of the water will, however, not necessarily affect dune vegetation. Water level changes and increased nutrient loading in marshes are expected to have an effect on the vegetation. In the case of surf-zones, the amount of nutrient entering the sea from the aquifer is a significant factor and artificial influences such as nutrient loading or reduction of flow, will almost certainly upset the balance in this ecosystem. The importance of aquifer water to estuaries appears to be a complex relationship. The Water Research Commission is at present funding a study on the fresh water requirements of estuaries. This research is currently underway at the University of Port Elizabeth and the present report should not be seen as preempting ongoing research.

The last aim of this project was to present a list of research proposals based on available information, formulated at a workshop held specifically for this purpose. These proposals are listed in chapter 6.

From the many reports investigated during the course of this study, it was particularly obvious that ground water managers in general know little about the origin, nature and sensitivity of coastal aquifers. The present knowledge base covers only a small area of the potential total aquifer area of approximately 30 000 km^2. No estimates of the "safe yield" of these aquifers have been made, neither is the aquifer water requirement by associated ecosystems known. Whereas many reports exist on coastal aquifers, much of the data are not suitable for the development of management strategies. Applicable data must be collected before coastal authorities will be able to use ground water supplies with confidence.

6. RESEARCH PROPOSALS

The participants in this project are all botanists. To ensure that all relevant were involved in identifying subjects for future research a workshop was held on 8 and 9 October 1991. At this workshop, research proposals were ranked in terms of high, medium and low priority:

High Priority Projects

1. Geohydrological characterization of the coastal aquifers in South Africa:
   It was suggested that this project be undertaken by the Department of Water Affairs (Geohydrology). The project covers the entire coastline and includes all aquifer systems that are connected hydraulically to the sea.

2. Development of Water Balance Models:
   This includes inputs (recharge) and outputs (discharge, yields), both natural and artificial. The models will use geohydrological features determined in the DWA project (see point 1 above), such as transmissivity, flow rate and losses. A water balance model is required for selected regions, viz. the west coast north of Eland's Bay; the south-west coast; the south coast (up to the Kei River); the Natal coast and the Zululand coast.

Although these two projects were allocated the highest priority, the workshop participants felt that other, less urgent projects did not necessarily have to wait until the completion of top priority projects before research could be started on other projects.

Medium Priority (in no particular order)

1. The dependence of phreatic vegetation on ground water:
   This study would include the effect of water level fluctuations, water quality and the influence of rooting depth of different plants. For example, if aquifers are infiltrated with eutrophic water, will phreatic vegetation change in response to the altered water quality? This project is of a biological nature and suggested study areas are the Cape Flats and St. Lucia aquifers.

2. The dependence of estuaries on aquifer water:
   This project would cover both the biological and geohydrological aspects of estuaries and aquifers. Both small and large estuarine systems should be studied, as should closed and open systems. A suitable study area would be the south-east coast with its wide variety of riverine/estuarine systems. Some work could also be done in Natal.

3. The relationship between aquifers and surf-zone diatoms:
   Preliminary data suggest a possible dependence of surf ecosystems on aquifer-derived nutrients, e.g. in False Bay. These surf systems, which contain accumulations of diatoms, occur from False Bay to Cintsa, and this region of the coast would be suitable for such a study.

4. Land use and aquifer water quality:
   It is expected that housing development in recharge areas would have a deleterious effect on aquifer water quality. This project would be a hydrological study and the Cape Flats and Richard's Bay (St. Lucia aquifer) were recommended as study areas.

Low Priority (not in any particular order)

These projects were seen as low priority because they are site-specific or are peripheral to our understanding of aquifer importance. The projects should be designed to be predictive and with application to other systems.

1. Effects on coastal aquifers of practices such as coastal mining and artificial manipulation of ground water supplies:
   The study site should be Richard's Bay.

2. The role of ground water on the reduction of salt loads in marshlands:
   A study site could be anywhere along the south coast.

3. The use of aquifers for transporting water and as storage or disposal areas:
   The study site should be the Cape Flats.

4. Interstitial organisms as indicators of water quality in aquifers:

A study site could be the Cape Flats or anywhere along the south coast.

5. Possible association of red tides and aquifer eutrophication along the south coast: Study sites could be the Cape Flats and one other aquifer system along the south coast.

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APPENDIX 2. A SYNTHESIS OF INFORMATION ON THE MAGNITUDE AND NATURE OF COASTAL AQUIFERS IN SOUTH AFRICA. THE SOURCE OF THE MOST RECENT DATA IS REFERENCED IN BRACKETS.

Codes:

AQUIF = Aquifer
A body of rock that is sufficiently permeable to conduct ground water and to yield economically significant quantities of water to wells.

AAREA = Aquifer area
The area of the deposit which constitutes the aquifer.

CATCH = Catchment
A list of the rivers and run-off zones which supply the aquifer with surface water.

CATCA = Catchment area
The surface area of the catchment zone.

RAINF = Rainfall
The average rainfall in the area of the aquifer.

AQUIT = Aquifer type
The nature of the water-holding material.

GEOLO = Geology
The type of deposit forming the aquifer.

GRADI = Gradient
The slope of the base rock or impervious layer.

LITHO = Lithology
The physical character of the aquifer rock.

THICK= Thickness of Cenozoic deposits

WATLE= Water Level

The depth of the water table below the soil surface.

WATFL= Water level fluctuations

FLOWD= Flow direction

TSNDV= Total saturated volume

The maximum amount of water that can be held in the aquifer material.

SSNDV= Saturated sand volume

The volume of sand in the aquifer.

CONST= Confined storage

The amount of water held under pressure.

VOLST= Volume stored

The amount of water held in the aquifer.

STORA= Storativity

The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the head.

TRANS= Transmissivity

The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

PERME= Permeability

The property or capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure.

BOREY = Borehole yield

The volume of water discharged from a well in cubic meters per day.

S-TXP = Short term exploitation potential

The amount of water that can safely be delivered ("safe yield")

L-TXP = Long term exploitation potential

The amount of water that can safely be delivered taking long-term fluctuations in recharge into account.

EFPOR = Effective porosity

The percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

RESOU = Recharge source

The location of the recharge area.

REVOL = Recharge volume

The amount of water entering the aquifer per year.

LOSSE = Losses

The amount of water leaving the aquifer per year.

AVTDS = Average total dissolved solids

SWINT = Salt water intrusion

ESTRI = Estuaries

VEGET = Vegetation

REFER = References

AQUIF [**Port Nolloth**

AAREA [The Western Cape coastal plain is relatively flat, rising not more than 300 m amsl (1).

CATCH [

CATCA [

RAINF [< 100 mm yr^{-1} (1).

AQUIT [Julieshoogte,Gemsbokvlei-GrasvlakteCompartment,BuffelsRiver-Spektakelberg Compartment (2). Water occurs in depressions in the basement floor where it is held in voids between sand grains or weathered basement material (1). Water may also occur in dry river beds and paleo-lakes or lagoons (1). Unconfined aquifer=river beds and overburdens; confined aquifer=baserock.

GEOLO [Quaternary deposits overlying baserock of the Nossob System (Precambrian granite and granite-gneiss) (1).

GRADI [

LITHO [Littoral arenosols sands. Coarse to fine sands, Gemsbokvlei:- 69% coarse sands, 30% fine sand, 1% silt (2).

THICK [Mainly < 100 m (1), Julieshoogte=8-40 m, Gemsbokvlei=50-65 m (2).

WATLE [Depends on the thickness of the deposits, mainly shallow (5 m) (1). Gemsbokvlei=49 m (2).

WATFL [

FLOWD [Locally towards the rivers, regionally towards the coast (1).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [Gemsbokvlei=20-30% (2).

RESOU [There is no direct runoff and rainfall infiltrates directly into the sands, evaporating later (1).

REVOL [

LOSSE [

AVTDS [

SWINT [

ESTRI [Kamma River; Holgat River.

VEGET [Strandveld; Succulent Karroo.

REFER [1. LEVIN, M. 1990. Regional geohydrological investigation of the area between Hondeklip Bay in the South and Port Nolloth in the North on the Cape West Coast. ESKOM West Coast Project, Report No. PIN-1229/90 (B/R), GEA-943.

2. HAWKINS, HAWKINS and OSBORNE. 1983. Port Nolloth Watervoorsiening Skema.

AQUIF [**Kleinsee (Buffels River; Spektakelberg)**

AAREA [The Western Cape coastal plain is relatively flat, rising not more than 300 m amsl. The Sonnekwa depression or paleodrainage lies SW of Kleinsee, possibly representing an old river channel or lagoon (1).

CATCH [Catchment area lies within a winter rainfall region (210-250 mm), whereas the peneplain lies within a summer rainfall area (75-100 mm). The Buffels mouth is about 11 m bsl (1).

CATCA [

RAINF [< 100 mm yr^{-1} (1).

AQUIT [Water occurs in depressions in the basement floor where it is held in voids between sand grains or weathered basement material (1). Water may also occur in dry river beds, paleo-lakes or lagoons (1). Unconfined aquifer=river beds and overburdens; confined aquifer=base rock.

GEOLO [Quaternary deposits overlying Precambrian granite-gneiss.

GRADI [

LITHO [Littoral arenosols sands. Medium quartzitic sands at the mouth, coarse sands predominate typical Buffels river sands. At Spektakel, grain size increases as sand thickness increases (2).

THICK [Superficial deposits over 100 m in places, although mainly < 100 m (1).

WATLE [Depends on the thickness of the deposits. Shallow in the river beds (1).

WATFL [Lowering of water level due to transpiration, evaporation, pumping and subsurface flow (2).

FLOWD [Locally towards the rivers, regionally towards the coast (1).

TSNDV [

SSNDV [Effective saturated capacity=13.18 Ml (Spektakel Reservoir) (2).

CONST [

VOLST [Spektakel: 11.365 Ml (taking into account evaporation) (2). Total capacity=20.96 Ml (2).

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [Avg. total porosity of river sands=31%, avg. effective porosity=20% (2).

RESOU [There is no runoff and the rainfall percolates directly into the sand, evaporating later (1). Streamflow after heavy rainfalls and subterranean flow also serve as recharge sources (2).

REVOL [

LOSSE [Natural seepage of ground water in the Buffels River. Seepage is slow and therefore saline (1). Evaporation of river sands effective to about 3 feet (91 cm) (2).

AVTDS [

SWINT [

ESTRI [Buffels River.

VEGET [Strandveld, Succulent Karoo.

REFER [1. LEVIN, M. 1990. Regional geohydrological investigation of the area between Hondeklip Bay in the South and Port Nolloth in the North on the Cape West Coast. ESKOM West Coast Project, Report No. PIN-1229/90 (B/R), GEA-943.

2. CORNELISSEN, A.K. 1968. Water from the Buffels River. Department of Water Affairs, Technical Report, GH1447. 29 pp.

AQUIF [**Hondeklipbaai**

AAREA [Kanoep Dune area (SE of Hondeklipbaai), Noup Dune Formation (N of Swartlintjies River) (2).

CATCH [

CATCA [

RAINF [< 100 mm yr^{-1} (1).

AQUIT [Water occurs in depressions in the basement floor where it is held in voids between sand grains or weathered basement material (1). Water may also occur in dry river beds, paleo-lakes or lagoons (1). Unconfined aquifer=river beds and overburdens; confined aquifer=base rock.

GEOLO [Quaternary deposit overlying Precambrian granite-gneiss (1).

GRADI [

LITHO [Littoral arenosols sands.

THICK [Superficial deposit are over 100 m in places (1).

WATLE [Depends on the thickness of the deposits. Shallow in the river beds, but deeper in the higher lying areas (1).

WATFL [

FLOWD [Locally towards the rivers, regionally towards the coast (1).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [Low yields (1.5 l s^{-1}) and poor quality (2500 mg l^{-1} TDS) at Avontuur (2).

S-TXP [

L-TXP [

EFPOR [

RESOU [There is no direct runoff and rainfall infiltrates directly into the sands, evaporating later (1).

REVOL [

LOSSE [

AVTDS [Best water quality at Kanoep, Ghaams, Gemsbokvlakte (2). Alluvial deposits of the Spoeg River are only partially saturated with ground water in the quality range of 2500-3000 mg l^{-1} TDS (2).

SWINT [

ESTRI [Swartlintjies, Bitter, Spoeg River.

VEGET [Strandveld, Succulent Karoo.

REFER [1. LEVIN, M. 1990. Regional geohydrological investigation of the area between Hondeklip Bay in the South and Port Nolloth in the North on the Cape West Coast. ESKOM West Coast Project, Report No. PIN-1229/90 (B/R), GEA-943.

2. SMITH, C.P. and VANDOOLAEGHE, M.A.C. 1982. Hondeklip Bay water supply: A Ground Water survey on the Farms Avontuur, Ghaams and Vorentoe. Department of Water Affairs, Technical Report, GH3165. 5 pp.

AQUIF	[	**Strandfontein (Sandlaagte)**
AAREA	[	2.85 km^2 (1).
CATCH	[	
CATCA	[	
RAINF	[	197.2 mm yr^{-1}.
AQUIT	[	
GEOLO	[	
GRADI	[	More extreme gradients at the coastline (0.005 inland and 0.01 at coastline) (1).
LITHO	[	Estuarine sand and gravel (2).
THICK	[	< 50 m (2).
WATLE	[	22-40 m (1).
WATFL	[	Water level fluctuations in response to pumping/abstraction (1).
FLOWD	[	
TSNDV	[	
SSNDV	[	
CONST	[	
VOLST	[	Aquifer volume=59.2 M m^3; ground water storage=1.7 M m^3 of which 7 M m^3 is located below sea level (2).
STORA	[	
TRANS	[	550 m^2 day^{-1} (1).
PERME	[	
BOREY	[	1375 m^3 day^{-1} (501 875 m^3 yr^{-1}) from inland areas to production boreholes (1).
S-TXP	[	
L-TXP	[	
EFPOR	[	30% (1).
RESOU	[	Infiltration of ephemeral runoff is the most important recharge since direct percolation of runoff is rare because of the infrequency and low intensity of rainfall events (2).
REVOL	[	Recharge by rainfall is taken as 7% (1). This is 224 640 m^3 yr^{-1} (for recharge area of 15.36 km^2) (1).
LOSSE	[	Abstraction (1989/90=401 220 m^3), seepage to coast=1100 m^3 day^{-1} (401 000 m^3 yr^{-1}). Volume lost to sea decreases as pumping inland lowers water table and thus the gradient. Evapotranspiration unimportant because of depth of water table (1).

AVTDS [

SWINT [Likely to occur if over pumped.

ESTRI [Olifants River.

VEGET [Strandveld, Succulent karoo.

REFER [1. JOLLY, J.L. 1991. A Re-evaluation of the Sandlaagte aquifer, Strandfontein (West Coast). Department of Water Affairs, Technical Report, GH3712. 18 pp.

2. VANDOOLAEGHE, M.A.C. and JOLLY, J.L. 1989. A Re-assessment of the Sandlaagte Primary Aquifer near Strandfontein (West Coast). Department of Water Affairs, Technical Report, GH3668. 8 pp.

AQUIF [**Lamberts Bay and Graafwater**

AAREA [Primary aquifer to the N of Lamberts Bay and in a paleochannel around Graafwater.

CATCH [

CATCA [

RAINF [250 mm yr^{-1} (1).

AQUIT [Secondary aquifer formed by the fractures in the TMS (2).

GEOLO [Cenozoic sediments (Bredasdorp, Varswater, Elandsfontyn Formation) overlie rocks of the Table Mountain Group. Isolated outcrops of this rock occurs in places.

GRADI [Around Graafwater basement slopes towards the Jakkals River. Between Lambert's Bay and Wadrif the basement slopes towards the coast (3).

LITHO [Fluviatile clean very fine sands alternative with more silty layers (1). Towards the bottom coarse sands alternates with clay, which indicate an unstable sedimentation environment (1).

THICK [2 areas: thickest succession of alluvium and water-saturated succession is to the N of Eland's Bay, the second area is to the N of Graafwater. South of Lambert's Bay no appreciable succession occurs. These areas are > 40 m (3).

WATLE [

WATFL [

FLOWD [

TSNDV [

SSNDV [2.9x109 m^3 for investigated area (1).

CONST [

VOLST [Approx. 1.4x108 m^3 (using effective porosity of 5%) (1).

STORA [

TRANS [Saturated thickness of up to 70 m gives a transmissivity of 150 to 200 m^2 day^{-1} (1).

PERME [Hydraulic conductivity=0.4-9.6 m day^{-1}. The lower values are for muddy to very fine sands. Avg. horizontal conductivity=2.5 m day^{-1} (1). A low hydraulic gradient ($2x10^{-3}$) is found at the sediment of the local watershed in the central part where the greatest thickness occurs. This gradient increases to $1x10^{-2}$ towards the north (1).

BOREY [5 l s^{-1} (1).

S-TXP [

L-TXP [Ground water exploitation potential of the area = 1x106 m^3 yr (1).

EFPOR [8-10% (because very fine sands) (1).

RESOU [Mainly by infiltration of precipitation in the central and western part of the study area (1).

REVOL [Favourable recharge rates occurs in the central and western part because of the low piezometric gradient and the good water quality (1). Recharge rate = 8% of the rainfall (= approx. $1.2x10^6$ m^3 yr^{-1} reaches the water table) (1).

LOSSE [Underground outflow and evapotranspiration. Evapotranspiration rates are higher in the vicinity of Graafwater (1).

AVTDS [Water of the Jakkals River is often brackish due to evaporation (3). Water is brackish in areas underlain by Graafwater formation (3). Good quality water occurs in the thin alluvium cover S of Lambert's Bay around the farm Steenboksfontein.

SWINT [

ESTRI [Jakkals River.

VEGET [Succulent karoo.

REFER [1. TIMMERMAN, L.R.A. 1985/6. Sandveld region: Possibilities for the development of a ground water supply from a Primary aquifer North West of Graaf Water. Department of Water Affairs, Technical Report, GH3471. 13 pp.

2. TIMMERMAN, L.R.A. 1985. Water Supply of the Sandveld area between Strandfontein and Elands Bay: Evaluation of existing data and proposed additional field investigations. Department of Water Affairs, Technical Report, GH3429. 9 pp.

3. MEYER, R., DUVENHAGE, A.W.A., BLUME, J., VALLENDUUK, J.W. and HUYSSEN, R.M.J. 1983. Report on the geophysical and geohydrological investigation of the ground water potential between Lambert's Bay and Graafwater and the coastal region between Lambert's Bay and Eland's Bay. Department of Water Affairs, Technical Report, GH3251. 54 pp.

4. SCHREUDER, D.N. 1978. Weskus projek Berg tot Olifantsrivier. 'n Oorsig van die Grondwaterpotensiaal van die area tussen die Berg-tot die Olifantsrivier. Department of Water Affairs, Technical Report, GH3094. 14pp.

AQUIF	[	**Wadrif**
AAREA	[	20 m thick by 1000 m wide (2).
CATCH	[	
CATCA	[	
RAINF	[	200-300 mm yr^{-1} (2).
AQUIT	[	Secondary aquifer formed by fractures in the TMS (1).
GEOLO	[	Cenozoic sediments=Bredasdorp, Varswater, Elandsfontyn Formation (1). Alluvial sediments of Neogene to Quaternary age with scattered outcrops of Graafwater and Peninsula Formation of the TMG to the south of the Langvlei River (2). North dipping dyke (2).
GRADI	[	1:200 (2).
LITHO	[	
THICK	[	> 20 m (2).
WATLE	[	
WATFL	[	
FLOWD	[	
TSNDV	[	
SSNDV	[	
CONST	[	
VOLST	[	
STORA	[	Specific yield=1.5-9.03x10^{-3} (3,4); Q/s (specific capacity)=53-413 m/m^3 day^{-1} (3).
TRANS	[	200-2800 m^2 day^{-1} (3,4).
PERME	[	30 m day^{-1} (3,4).
BOREY	[	5.6-35 l s^{-1} (2,3,4).
S-TXP	[	
L-TXP	[	
EFPOR	[	
RESOU	[	Upper portion of the Langvlei River, mainly from subsurface flow but also during the rainy season (2).
REVOL	[	c=9-51 days (4).
LOSSE[		
AVTDS	[	Quality increases from N to S region (2), 370 mg l^{-1} (4).
SWINT	[	
ESTRI	[	Wadrif Salt Pan, Langvlei River.

VEGET [Strandveld, Succulent Karoo.

REFER [1. TIMMERMAN, L.R.A. 1985. Water Supply of the Strandveld area between Strandfontein and Elands Bay: Evaluation of existing data and proposed additional field investigations. Department of Water Affairs, Technical Report, GH3429. 9 pp.

2. MEYER, R., DUVENHAGE, A.W.A., BLUME, J., VALLENDUUK, J.W. and HUYSSEN, R.M.J. 1983. Report on the geophysical and geohydrological investigation of the ground water potential between Lambert's Bay and Graafwater and the coastal region between Lambert's Bay and Eland's Bay. Department of Water Affairs, Technical Report, GH3251. 55 pp.

3. MEYER, R. 1981. 'n Geofisiese en geohidrologiese ondersoek van die Lambertsbaai-Elandsbaai gebied. Tussentydse verslag oor die reultate verkry tydens pomptoetse te Wadrif, ten suide van Lambertsbaai. Department of Water Affairs, Technical Report, GH3170. 11 pp.

4. VANDOOLAEGHE, M.A.C. 1981. Pumping tests on Production Well G31350 Wagendrift-Lambert's Bay. Department of Water Affairs, Technical Report, GH3178. 6 pp.

5. SCHREUDER, D.N. 1978. Weskus projek Berg tot Olifantsrivier. 'n Oorsig van die Grondwaterpotensiaal van die area tussen die Berg- tot die Olifantsrivier. Department of Water Affairs, Technical Report, GH3094. 14 pp.

AQUIF [**Eland's Bay**

AAREA [Two distinct areas: coastal plain NE of Elands Bay and a low-lying area N of the shoreline of the Velorevlei (2).

CATCH [Swartberg and Olifantsrivierberge (E), Piketberge (S). The Verlorevlei river drains the entire catchment area, other rivers include Jakkals River and Langvlei (1).

CATCA [

RAINF [Catchment lies within a winter rainfall, with 80% of the rain occurring between April and September, <300 mm (1).

AQUIT [Secondary type aquifers associated with TMG (1).

GEOLO [Cenozoic deposits (Bredasdorp Formation, Varswater Formation, Elandsfontyn Formation) overlying TMG (Piekenierskloof, Graafwater and Peninsula Formation) (1). Alluvium of Neogene to Quaternary age (2).

GRADI [

LITHO [NE of EB: Gravelly, muddy succession of fluviatile sediments associated with the former course of the Verlorevlei estuary (4).

THICK [NE Eland's Bay saturated thickness of alluvial deposits > 40 m in places (2).

WATLE [N of Eland's Bay there is an area of about 7 km^2 where the water table is about 3 m below the surface. NE of Eland's Bay water table very shallow in places.

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [NE of EB: storage coefficient=$4x10^{-4}$ (4).

TRANS [NE of EB (BH3): 65 m^2 day^{-1}, N of EB (G31294): 16 m^2 day^{-1} (low due to technical errors (4).

PERME [

BOREY [100 m^3 day^{-1} (BH3) (4).

S-TXP [Max permissable pumping rate without saline intrusion (BH3)=147 m^3 day^{-1} (4).

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [< 1000 mg l^{-1} (3), Verlorevlei itself is relatively brackish. Water from the dunes N of Elands Bay is too poor. Water level in the Verlorevlei is about 2 m below sea level and has a conductivity of 430 mS m^{-1} (2). NE of EB: 380 mg l^{-1} (4).

SWINT [Salt water intrusion possible if over pumped (2).

ESTRI [Verlorevlei, Langvlei River.

VEGET [Strandveld.

REFER [1. TIMMERMAN, L.R.A. 1985. Water supply of the Sandveld area between Strandfontein and Elands Bay: Evaluation of existing data and proposed additional field investigations. Department of Water Affairs, Technical Report, GH3429. 9 pp.

2. MEYER, R., DUVENHAGE, A.W.A., BLUME, J., VALLENDUUK, J.W. and HUYSSEN, R.M.J.. 1983. Report on the geophysical and geohydrological investigation of the ground water potential between Lambert's Bay and Graafwater and the coastal region between Lambert's Bay and Eland's Bay. Department of Water Affairs, Technical Report, GH3251.

3. SCHREUDER, D.N. 1978. 'n Oorsig van die grondwaterpotensiaal van die area tussen die Berg- tot Olifantsrivier. Department of Water Affairs, Technical Report, GH3094.

4. STEFFEN, ROBERTSON & KIRSTEN. 1985. Proposal to develop the Ground Water resources of Eland's Bay. Report KP4934/3.

AQUIF [**Lower Berg River Unit** (includes Langebaan Road, Elandsfontyn, Adamsboerkraal Primary aquifer unit).

AAREA [Berg, Sout, Brak, Groen Rivers, Vredenburg headland, Darling batholith, zero-flow boundary from Langebaan to Hopefield (2).

CATCH [Langebaan Road, Sout River, Elandsfontyn, & Groen River catchment area.

CATCA [

RAINF [200-300 mm (May-August) (1).

AQUIT [Confined=Elandsfontyn, semi-confined to unconfined=Varswater, Bredasdorp (1,2). Depending of which formations forms the aquifers, 2 units recognized, namely Langebaan Road Primary aquifer unit & Elandsfontyn Primary aquifer unit.

GEOLO [Post-Miocene=Bredasdorp & Varswater Formation; Elandsfontyn Formation. Elandsfontyn aquifer is located in 4 major channels (Adamboerskraal, Woesteheuwel, Wegloperheuwel, Papkuils channel). Base rock= Malmesbury Group (Tygerberg and Moorreesburg Formation), intruded by TMG (Cape Granite Suite) (1,2).

GRADI [Base rock elevation=-31 m-32 m amsl; gradient=0.001-0.012 (1).

LITHO [Bredasdorp=mainly aeolian sands; Varswater=marine sands; Elandsfontyn=fluviatile sandy deposits (1,2).

THICK [Cenozoic deposits=0-120 m (3); Bredasdorp=0-54 m; Varswater=0-53 m; Elandsfontyn=0-54 m (2).

WATLE [

WATFL [

FLOWD [Towards the sea in the northernmost part, towards the Berg River in the southern most part, towards both directions in the central part (1).

TSNDV [Langebaan aquifer=13.1×10^9 m^3 (2); Elandsfontyn aquifer=27.6×10^9 m^3 (2).

SSNDV [Unconfined=2600×10^6 m^3; semi-confined=14.6×10^9 m^3 (1); confined: Langebaan=6.9×10^9 m^3 (2), Elandsfontyn=5×10^9 m^3 (2). Total: Langebaan=10×10^9 m^3 (2), Elandsfontyn=24×10^9 m^3 (2).

VOLST [Adamboerskraal=1200×10^6 m^3; Langebaan Road=1235×10^6 m^3; Elandsfontyn=3150×10^6 m^3; Grootwater=218×10^6 m^3; Total volume=5800×10^6 m^3 (3).

CONST [109×10^6 m^3 (3).

STORA [Varswater semi-confined aquifer=3.6×10^{-4} (2); semi-confined=3×10^{-4} - 8×10^{-3};

confined (Elandsfontyn) = $3.1x10^{-3}$ (1,2).

TRANS [Bredasdorp = 0-451 m^2 day^{-1}, Varswater = 2.6-1046 m^2 day^{-1}; Elandsfontyn = 0-4664 m^2 day^{-1} (2).

PERME [Hydraulic conductivity: Bredasdorp = 0-30.5 m day^{-1}, Varswater = 0-52.2 m day^{-1}, Elandsfontyn = 0-56.5 m day^{-1} (2), 1-120 m day^{-1} (1); vertical permeability: Bredasdorp = 0-29.1 m day^{-1}, Varswater = 0-22 m day^{-1}, Elandsfontyn = 0-75 m day^{-1} (2).

BOREY[

S-TXP [$51.7x10^6$ m^3 $year^{-1}$ (3).

L-TXP [78x106 m^3 $year^{-1}$ (3).

EFPOR [Unconfined = 8%; semi-confined = 15% (1).

RESOU [Direct infiltration of precipitation (15%), as well as runoff from high lying areas (1).

REVOL [Adamboerskraal = $25x10^6$ m^3; Langebaan Road = $36x10^6$ m^3; Elandsfontyn = 27x106 m^3; Grootwater = 7.1x106 m^3; Total recharge volume = $94.9x10^6$ m^3 yr^{-1} (2). c: Bredasdorp = 0.2-5350 days, Varswater = 0.42-1820 days, Elandsfontyn = 0.05-2025 days (2).

LOSSE [Seepage to Langebaan Lagoon, Saldanha Bay and Berg River; directly into the sea; evapotranspiration; artificial abstraction (1). Springs occur along the westernmost extent of the Elandsfontyn-Hopefield dune ridge (2). Upward ground water flow takes place in the Saldanha Bay area, area bordering the Berg River, in the vicinity of the Langebaan Lagoon, Geelbek area (2).

AVTDS [< 2000 mg l^{-1} (<100 mS m^{-1}), generally deteriorating towards the sea. About 10% of total ground water volume is brackish to saline (1,2).

SWINT [

ESTRI [Berg River, Langebaan Lagoon.

VEGET [Strandveld; Coastal Macchia; intensive farming.

REFER [1. TIMMERMAN, K.M.G. 1985. Preliminary report on the geohydrology of the Cenozoic sediments of part of the coastal plain between the Berg River and Eland's Bay (Southern Section). Department of Water Affairs, Technical Report, GH3370. 22 pp.

2. TIMMERMAN, L.R.A. 1985. Preliminary report on the geohydrology of the Langebaan Road and Elandsfontyn aquifer units in the lower Berg River region. Part I: Text and Illustrations. Department of Water Affairs, Technical Report,

GH3373. 51 pp.
3. TIMMERMAN, L.R.A. 1985. Possibilities for the development of ground water from the Cenozoic sediments in the lower Berg River region. Department of Water Affairs, Technical Report, GH3374. 24 pp.

AQUIF	[	**Langebaan Road Primary Aquifer Unit**
AAREA	[	Bounded by the channels of the Berg and Sout Rivers (E & NE); Vredenburg headland (NW); Saldanha Bay (W); internal zero-flow boundary from Langebaan to Hopefield (S) (1).
CATCH	[	
CATCA	[	
RAINF	[	280 mm (2).
AQUIT	[	Bredasdorp unconfined aquifer, Elandsfontyn clay aquitard, Elandsfontyn sand and gravel confined aquifer (1,2).
GEOLO	[	Cenozoic deposits=Bredasdorp, Varswater, Elandsfontyn; base rock=Malmesbury Formation and TMG (Cape Granite Suite) (1).
GRADI	[	
LITHO	[	Unconfined=Langebaan Limestone; aquitard=clay; confined=coarse sand and gravel (1).
THICK	[	Bredasdorp unconfined=10-20 m; aquitard=10-20 m; Elandsfontyn confined=40-60 m (2).
WATLE	[	
WATFL	[	
FLOWD	[	Saldanha Bay; Berg River.
TSNDV	[	
SSNDV	[	
CONST	[	Elandsfontyn aquifer=$21.9x10^6$ m^3 (1).
VOLST	[	Elandsfontyn aquifer=$1035x10^6$ m^3; post-Miocene aquifer=$200x10^6$ m^3; total volume=$1235x10^6$ m^3 (1).
STORA	[	Elandsfontyn confined=$3.1x10^{-3}$ (2).
TRANS	[	Unconfined= <100 m^2 day^{-1} confined aquifer=10-4000 m^2 day^{-1} (1,2).
PERME	[	
BOREY	[	
S-TXP	[	$19.5X10^6$ m^3 yr^{-1} (1,2).
L-TXP	[	$30x10^6$ m^3 yr^{-1} (1,2).
EFPOR	[	
RESOU	[	Direct infiltration of precipitation only (15%) (1).
REVOL	[	$36x10^6$ m^3 yr^{-1} (1,2).
LOSSE	[	

AVTDS [

SWINT [Possible from confined aquifer.

ESTRI [Berg, Sout River, Langebaan Lagoon.

VEGET [Strandveld, Coastal Fynbos, Coastal Renosterveld.

REFER [1. TIMMERMAN, L.R.A. 1985. Preliminary report on the geohydrology of the Langebaan Road and Elandsfontyn aquifer units in the Lower Berg River region. Department of Water Affairs, Technical Report, GH3373. 51 pp.

2. TIMMERMAN, L.R.A. 1985. Possibilities for the development of ground water from the Cenozoic deposits of the Lower Berg River Region. Department of Water Affairs, Technical Report, GH3374. 23 pp.

3. TIMMERMAN, L.R.A., TIMERMAN, K.M.G. and VANDOOLAEGHE, M.A.C. 1985. Proposal for the development of a Departmental Production Wellfield in the Langebaan Road Primary Aquifer Unit. Deaprtment of Water Affairs, Technical Report, GH3375. 22 pp.

AQUIF [**Elandsfontyn Primary Aquifer Unit**

AAREA [Langebaan Lagoon (W); Darling batholith (S); Brak River (SE); Groen River (E); zero-flow boundary (N) (1).

CATCH [

CATCA [

RAINF [320 mm (2).

AQUIT [Bredasdorp (Springfontyn) unconfined aquifer; Bredasdorp (Noordhoek) aquitard; Varswater (PPM) aquitard; Varswater (QSM) semi-confined; Elandsfontyn clay aquitard; Elandsfontyn sand and gravel confined aquifer (1,2).

GEOLO [Cenozoic deposits=Bredasdorp, Varswater, Elandsfontyn; base rock=Malmesbury Formation and TMG (Cape Granite Suite) (1).

GRADI [

LITHO [Elandsfontyn sand and gravel sequence (1).

THICK [Bredasdorp unconfined=5-20 m; Bredasdorp aquitard=5-60 m; Varswater aquitard=0-20 m; Varswater semi-confined=0-30 m; Elandsfontyn aquitard=10-30 m; Elandsfontyn confined=10-30 m (2).

WATLE [

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [Elandsfontyn aquifer=$15.5x10^6$ m^3 (1).

VOLST [Elandsfontyn aquifer=$750x10^6$ m^3; post-Miocene aquifer=$2400x10^6$ m^3; total volume=$3150x10^6$ m^3 (1).

STORA [S: Varswater semi-confined=$3.6x10^{-4}$; Elandsfontyn confined=10^{-3} (2).

TRANS [Elandsfontyn confined aquifer=5-600 m^2 day^{-1}; Varswater semi-confined=100-1000 m^2 day^{-1}; Bredasdorp unconfined=50-500 m^2 day^{-1} (1,2).

PERME [

BOREY [

S-TXP [$15.5x10^6$ m^3 yr^{-1} (2).

L-TXP [$25x10^6$ m^3 yr^{-1} (2).

EFPOR [

RESOU [Direct infiltration of precipitation only (15%) (1).

REVOL [$27x10^6$ m^3 yr^{-1} (1,2).

LOSSE [

AVTDS [About 500 mg l^{-1} (1); brackish to saline in the discharge zones (Langebaan Lagoon, Saldanha Bay, Berg River) (1).

SWINT [

ESTRI [Brak, Groen River.

VEGET [Strandveld, Coastal Fynbos, Costal Renosterveld.

REFER [1. TIMMERMAN, L.R.A. 1985. Preliminary report on the geohydrology of the Langebaan Road and Elandsfontyn aquifer units in the Lower Berg River region. Department of Water Affairs, Technical Report, GH3373. 51 pp.

2. TIMMERMAN, L.R.A. 1985. Possibilities for the development of ground water from the Cenozoic sediments of the Lower Berg River Region. Department of Water Affairs, Technical Report, GH3374. 23 pp.

AQUIF [**Adamboerskraal Primary Aquifer Unit**

AAREA [Zero-flow boundary between Dwakersbos and Aurora (N), Berg River (S), Atlantic Ocean (W), escarpment (E).

CATCH [

CATCA [

RAINF [320 mm (1).

AQUIT [Bredasdorp unconfined aquifer, Elandsfontyn clay aquitard, Elandsfontyn sand and gravel confined aquifer (1).

GEOLO [Cenozoic sediments=Bredasdorp, Varswater, Elandsfontyn. Base rock=Malmesbury Group and Cape Granite Suite (TMG).

GRADI [

LITHO [Elandsfontyn clay, sand and gravel (1).

THICK [Unconfined=10-20 m; aquitard=20-30 m; confined aquifer=20-40 m (1).

WATLE [

WATFL [

FLOWD [S to SW direction towards the Berg River (3).

TSNDV [

SSNDV [

CONST [Elandsfontyn aquifer=70.3x10^6 m^3 (1).

VOLST [Elandsfontyn aquifer=1100x10^6 m^3; post-Miocene aquifer=100x10^6 m^3; total volume=1200x10^6 m^3 (1).

STORA [S: confined=10-3 (1).

TRANS [Unconfined=100 m^2 day^{-1}; confined=500 m^2 day^{-1} (1).

PERME [

BOREY [

S-TXP [9.6x10^6 m^3 yr^{-1} (1).

L-TXP [13x10^6 m^3 yr^{-1} (1).

EFPOR [

RESOU [Mainly direct infiltration of ppt. (15%), as well as runoff from the high lying areas (1).

REVOL [25x10^6 m^3 yr^{-1} (1).

LOSSE [

AVTDS [

SWINT [

ESTRI [Berg River.

VEGET [Strandveld, Coastal Fynbos, Coastal Renosterveld.

REFER [1. TIMMERMAN, L.R.A. 1985. Possibilities for the development of ground water from the Cenozoic sediments in the Lower Berg River Region. Department of Water Affairs, Technical Report, GH3374. 23 pp.

AQUIF	[	**Grootwater Primary Aquifer Unit**
AAREA	[	Modder River & Darling Granite hills (E), zero-flow boundary from Yzerfontein due E and the Atlantic Ocean.
CATCH	[	4 subcatchments: Modder River, southern Dwars River, northern Dwars River, a small catchment to the north of the Yzerfontein saltpan (2).
CATCA	[	
RAINF	[	350 mm (1), 220 mm - 700 mm, max. during May to August (2).
AQUIT	[	Bredasdorp (Springfontyn) unconfined aquifer; Bredasdorp (Noordhoek) aquitard; Varswater (PPM) aquitard; Varswater (QSM) semi-confined aquifer (1).
GEOLO	[	Cenozoic sediments=Bredasdorp, Varswater, Elandsfontyn. Base rock=Malmesbury Group and Cape Granite Suite (TMG) (2).
GRADI	[	
LITHO	[	Sandy sediments of marine and aeolian origin (2).
THICK	[	Bredasdorp unconfined=10-20 m; Bredasdorp aquitard=10-30 m; Varswater aquitard=10-20 m; Varswater semi-confined=10-20 m (2).
WATLE	[	Significant portion of the Grootwater primary aquifer unit lies below sea level (2). Water table is very shallow (especially in the N part), with levels between surface level and 2-4 m below the surface (2).
WATFL	[	
FLOWD	[	Towards the Atlantic Ocean against a steep gradient (1,2).
TSNDV	[	
SSNDV	[	Bredasdorp=1.64×10^9 m^3; Varswater (including aquitard)=1.74×10^9 m^3 (2).
CONST	[	Varswater=1.8×10^6 m^3 (1).
VOLST	[	Varswater semi-confined=87×10^6 m^3 (2); post-Miocene=218×10^6 m^3 (1).
STORA	[	Bredasdorp=6.7×10^{-4} - 1.5×10^{-2} (2); Varswater semi-confined=2.2×10^{-3} - 1.4×10^{-3} (1,2).
TRANS	[	Bredasdorp unconfined=400-900 m^2 day^{-1}; Bredasdorp aquitard=20-100 m^2 day^{-1}; Varswater semi-confined=10-400 m^2 day^{-1} (1,2).
PERME	[	Hydraulic conductivity: Varswater semi-confined=1-2 m day^{-1} or 29.6 m day^{-1} (2); Bredasdorp (Springfontyn) unconfined=20-50 m day^{-1} (2); Bredasdorp (Noordhoek) aquitard=factor 10 less than Springfontyn (2).
BOREY	[	30-40 l s^{-1} (1,2).
S-TXP	[	7.1×10^6 m^3 yr^{-1} (1).

L-TXP [10x20^6 m^3 yr^{-1} (1).

EFPOR [Bredasdorp=8%, Varswater=5% (2).

RESOU [Mainly direct infiltration of ppt. (15%), as well as runoff from the high lying areas (1,2).

REVOL [7.1x10^6 m^3 yr^{-1} (1).

LOSSE [Riverbank seepage and spring flow to the Modder River and possibly Kransduinen River. Movement between unconfined and confined. Losses due to evapotranspiration (2).

AVTDS [80% has TDS < 1000 mg l^{-1}, 30% of which falls below 500 mg l^{-1} (2).

SWINT [Since a large portion of the deep aquifer is situated below sea level, salt water intrusion is likely to occur (2).

ESTRI [Modder River, Kransduinen River, Yzerfontein saltpan.

VEGET [Strandveld, Coastal Fynbos, Coastal Renosterveld.

REFER [1. TIMMERMAN, L.R.A. 1985. Possibilities for the development of ground water from the Cenozoic sediments in the Lower Berg River Region. Department of Water Affairs, Technical Report, GH3374. 23 pp.

2. TIMMERMAN, L.R.A. 1985. Preliminary report on the Geohydrology of the Grootwater Primary Aquifer unit between Yzerfontein and the Modder River. Department of Water Affairs, Technical Report, GH3372. 31 pp.

AQUIF	[	**Atlantis**
AAREA	[	Coastal flat about 5km wide, parallel to the coast. Land rises at Atlantis-Wesfleur (4).
CATCH	[	Surface drainage = Buffels River (NW), Groen & Diep River (E), Sout River (S).
CATCA	[	
RAINF	[	369-465 mm (April to September) (1,4), avg. annual potential evaporation = 1,613m (1).
AQUIT	[	Semi-confined with delayed yield (1), unconfined (4).
GEOLO	[	Cenozoic sediments = Bredasdorp (Springfontein, Witzand & Mamre member) (aeolian), Varswater (Duynefontein & Silwerstroom) (marine) Formation; Base rock = Malmesbury Formation or clay shales (1).
GRADI	[	1:58 in a SW direction towards the coast (6).
LITHO	[	Quartz sands with various grain sizes from very fine to coarse (1).
THICK	[	Max. thickness = 70 m (1).
WATLE	[	Steep ground water-gradient running parallel to the coast. About 9 km inland water table rises from about 50m to about 150 m amsl. This gradient is positive towards the coast and separates the Silwerstroom and Witzand production fields from the Atlantis-Wesfleur production fields. General range is 0-180 m (4).
WATFL	[	In response to artificial recharge, as well as pumping (1).
FLOWD	[	Positive gradient towards the coast, general flow is towards the sea.
TSNDV	[	
SSNDV	[	4136.05x10^{6} m^{3} (4).
CONST	[	
VOLST	[	413.05x10^{6} m^{3} (10% effective porosity-1979) (4).
STORA	[	0.05-0.27, avg = 0.175 (17.5%) (4).
TRANS	[	50-1300 m^{2} day^{-1} (1).
PERME	[	Steep conductivity gradient between Silwerstroom-Witzand and Atlantis-Wesfleur (4). Hydraulic conductivity: 0-15 m day^{-1}, avg. = 10.06 m day^{-1} (100.08 at G29749) (4). Permeability at Pan7 = 5.8-24.3 m day^{-1} (1).
BOREY	[	2 pumping schemes: Witzand = 4.57x10^{6} m^{3} yr^{-1}, Silwerstroom = 1.32x10^{6} m^{3} yr^{-1} (1).
S-TXP	[	safe yield = 18x10^{6} m^{3} yr^{-1} (5), 11x10^{6} m^{3} yr^{-1} (6).
L-TXP	[	
EFPOR	[	

RESOU [Drift sands at the farms Buffels River, Dynefontein, Kleine Springfontyn serve as recharge areas (4). Natural recharge in the Witzand field by infiltration, augmented by artificial recharge by means of a surface impoundment, pan 7 (1). Natural recharge in the Silwerstroom area has been calculated to be 25% of rainfall (2).

REVOL [Artificial (Witzand) = 1.9×10^6 m^3 yr^{-1} (1); natural (Witzand) = 4.603×10^6 m^3 yr^{-1}(4); total natural = 11-16×10^6 m^3 yr^{-1} (1,3,5); recharge by rainfall = 8-25% (2,4).

LOSSE [N near Mamre; SE part; extreme S near Melkbosstrand (4); springs, eg. Silwerstroom spring (1); seepage to sea = 2.169×10^6 m^3 yr^{-1} (using rate = 32.25 m day^{-1}, over 9212.5 m^2 area) (=3% of rainfall) (4); evapotranspiration by *Acacia* sp.; abstraction.

AVTDS [40-4000 mg l^{-1} Cl (1).

SWINT [Silwerstroom bedrock lies below sea level, facilitating salt water intrusion (4). Low quality water intrusion from Malmesbury Formation.

ESTRI [Silwerstroom Beach, Buffels River (NW), Diep River (E), Sout River (S).

VEGET [Coastal Fynbos, Coastal Macchia, Coastal Renosterveld, Strandveld.

REFER [
1. FLEISCHER, J.N.E. 1990. The geochemistry of natural ground water in the West Coast Sand Aquifer. Part I: Atlantis. CSIR-Division of Water Technology. Project No.: 670/2605/4. 16 pp.

2. BREDENKAMP & VANDOOLAEGHE, 1982 see (3).

3. TREDOUX, G. 1987. The role of artificial recharge in ground water management at Atlantis. CSIR-Division of Water Technology. 11 pp.

4. MULLER, J.L. and BOTHA, J.F. 1986. A preliminary investigation of modelling the Atlantis aquifer. Institute of Ground Water Studies, University of Orange Free State. 174 pp.

5. TREDOUX, G. 1987. The application of hydrogeochemical techniques in ground water investigations. In: Proceedings of the 1987 Hydrological Sciences Symposium. Vol I. (Hughes, D.A. & Stone, A.W.). Hydrological Institute, Rhodes University. pp 207-222.

6. MURRAY, A.S., BISHOP, A.T.P. and TREDOUX, G. 1988. The efficient utilization of a sand aquifer: The Atlantis water resource management scheme. CSIR-Division of Water Technology. 13 pp.

AQUIF [**Cape Flats Aquifer.**

AAREA [Extends over 630 km^2 (5).

CATCH [

CATCA [

RAINF [MAR=509 mm (344-751 mm), rainfall occurs between May to September.

AQUIT [Semi-confined to semi-unconfined; generally unconfined; aquifer=Bredasdorp/Varswater depending on which is present; Elandsfontyn=aquitard with Varswater.

GEOLO [Cenozoic deposits=Bredasdorp (Witzand, Langebaan Limestone, Springfontyn); Varswater (CSM, SGM/Strandfontein); Elandsfontyn. Base rock=Malmesbury metasediments.

GRADI [1 km coastal strip has a relatively steep gradient (0.015), flattens inland (0.003) (2).

LITHO [

THICK [Deposits: Max=45-50 m which occurs near the False Bay coastline (5); aquifer thickness=10-30 m (2).

WATLV [0-45 m (3), in many areas water level is close to the surface.

WTLFL [Abstraction generates a rather limited regional water decline (2).

FLOWD [Towards the sea, 1 km coastal strip has a relatively steep gradient (0.015) (2).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [T=50-650 m^2 day^{-1} (>200 in S-Central part and between Eerste and Macasssar) (Low transmissive Varswater in the coastal zone, with more transmissive Bredasdorp further back) (1), highest transmissivities occur in a SE-NW trending zone which represents a paleo-river channel (4).

PERME [Hydraulic conductivity=20 m day^{-1} (4) Bredasdorp=30-40 m day^{-1} (2), Varswater=1-10 m day^{-1} (2), the vertical permeability is 1-10% of the horizontal permeability (5).

BOREY [

S-TXP [

L-TXP [Sustainable yield=15-20 M m^3 yr^{-1} (1), long-term yield=18x10^6 m^3 yr^{-1} (5), long-term yield = 17 l s^{-1} (5).

EFPOR [0.10-0.12, with max = 0.25 (5).

RESOU [Natural recharge during the rainy season. Recharge practically takes place over the whole area (5).

REVOL [S part = $60x10^6$ m^3 yr^{-1}, of which more than 80% is lost by evapotranspiration (1), net recharge in the urban areas is greater than in the natural areas. Recharge represents between 15-37% of the rainfall (1).

LOSSE [80% of recharge lost through evapotranspiration (1).

AVTDS [400-875 mg l^{-1} (2), most < 700 mg l^{-1}, 218-1161 (630 mg l^{-1}) (3).

SWINT [The presence of a low transmissive zone in the vicinity of the coastline may act as a barrier against SWINT (2,3). The steep water level gradient in the coastal strip also serves as a barrier.

ESTRI [Zeekoevlei, Kuils River marshes, Eerste River, Elsieskraal River.

VEGET [Coastal Fynbos, Coastal Renosterveld.

REFER [
1. VANDOOLAEGHE, M.A.C. 1990. The Cape Flats Aquifer. Department of Water Affairs, Technical Report GH 3687.

2. VANDOOLAEGHE, M.A.C. 1989. The Cape Flats Ground Water development-Pilot Abstraction scheme. Department of Water Affairs, Technical Report, GH3655. 98 pp.

3. EDWARDS, G.W. 1989. Ground Water quality Cape Flats Ground Water Development Scheme Pilot Abstraction scheme. Department of Water Affairs, Hydrological Research Institute. 101 pp.

4. DU TOIT, A.J. 1987. The Granulometric and hydraulic properties of the unconsolidated sand deposits in the Cape Flats. In: Proceedings of the 1987 Hydrological Sciences Symposium, Vol. I. (Hughes, D.A. and Stone, A.W., eds.). Hydrological Research Institute, Rhodes University. pp 349-363.

5. TREDOUX, G. 1983. The Ground water Pollution Hazard in the Cape Flats. Unpubl. Report.

6. GERBER, A. 1981. A digital model of ground water flow in the Cape Flats aquifer. CSIR Report C Wat 46, pp.1-139.

7. WESSELS, W.P.J. and GREEFF, G.J. 1980. 'n Ondersoek na doe optimale benutting van Eersterivierwater deur opberging in sandafsettings of ander metodes. Dept. Civil Engineering, University of Stellenbosch, Report for WRC.

AQUIF [**Agulhas**

AAREA [

CATCH [

CATCA [

RAINF [400-500 mm (May to September) (1).

AQUIT [Primary aquifer=Bredasdorp; secondary aquifer=base rocks (1).

GEOLO [Bredasdorp; Base rock=Naradouw Sandstone (TMS); Naradouw sandstone, Cedarberg Formation & Peninsula Formation are exposed at high water mark along the coastline around Agulhas (1).

GRADI [1:100 to 1:400 (3).

LITHO [Bredasdorp=half consolidated, sandy limestone (1).

THICK [Bredasdorp=2-21 m (1).

WATLE [

WATFL [

FLOWD [Seawards (1).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [Infiltration of rainwater (1).

REVOL [

LOSSE [

AVTDS [795-1860 mg l^{-1} (1).

SWINT [Likely if over pumped (1).

ESTRI [

VEGET [Coastal Fynbos.

REFER [1. MEYER, P.S. 1986. 'n Waardering van Agulhas se grondwaterbronne.

Department of Water Affairs, Technical Report, GH3486. 8 pp.
2. SPIES, J. and VEGTER, J.R. 1959. Pumping tests and water supply of Agulhas, C.P. Department of Water Affairs, Technical Report, GH1075. 5 pp.
3. LEVIN, M. 1988. Regional geohydrological investigations of the area between the Uilkraals and Heuningnes Rivers, Bredasdorp and Caledon districts. ESKOM Southern Cape Project, PIN-1087(B/R), GEA-812. 32 pp.

AQUIF [**De Hoop**

AAREA [Cape Agulhas to Bree River Mouth.

CATCH [

CATCA [

RAINF [

AQUIT [Unconfined aquifer = Bredasdorp.

GEOLO [Bredasdorp; base rock = Bokkeveld Shale (1).

GRADI [

LITHO [

THICK [Up to 55 m thick (1).

WATLE [< 16 m (1).

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [0.45-9 m^3 hr^{-1} (1).

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [660-1540 mg l^{-1} (1).

SWINT [Water quality alternates with water in De Hoop Vlei, in summer, when levels drop, water quality is likely to deteriorate (1).

ESTRI [Bree River; De Hoop Vlei.

VEGET [Coastal Fynbos.

REFER [1. VAN DER MERWE, A.J. 1977. de Hoop natuurreservaat: Watervoorsiening, distrik Bredasdorp. Department of Water Affairs, Technical

Report, GH2962. 5 pp.

AQUIF	[	**Gansbaai to Waenhuiskrans (Uilkraals to Heuningnes Rivers)**
AAREA	[	
CATCH	[	
CATCA	[	
RAINF	[	400-500 mm yr^{-1}, but less over the coastal plain, winter rainfall (May to September) (1).
AQUIT	[	Bredasdorp=unconfined aquifer; Secondary aquifers=quartzitic rocks, shale rocks (1).
GEOLO	[	Cenozoic deposits=Bredasdorp; Base rock=Bokkeveld Shale and Table Mountain Quartzite of the Cape Super Group; Malmesbury Group (1).
GRADI	[	1:100 to 1:400; along the eastern part around Heuningnes River and Struisbaai, the gradient is relatively flat and ground water movement is slow (1).
LITHO	[	Bredasdorp=sandy limestone.
THICK	[	
WATLE	[	
WATFL	[	
FLOWD	[	Seawards and towards river valleys (1).
TSNDV	[	
SSNDV	[	
CONST	[	
VOLST	[	
STORA	[	
TRANS	[	
PERME	[	
BOREY	[	Low yields (1).
S-TXP	[	
L-TXP	[	
EFPOR	[	
RESOU	[	Rainfall.
REVOL	[	
LOSSE	[	Numerous springs and seepage ending in vleis and marshes occur inland (1).
AVTDS	[	6461 mg l^{-1} (1).
SWINT	[	Salt water intrusion occurs along pre-historic drainage lines (1).
ESTRI	[	Uilkraals, Haelkraal, Ratel, Heuningnes Rivers; large pans and vleis.

VEGET [Thick scrub and bush (indigenous forest) occur along the coast and in river valleys. Grassland dominates the plains and is interspersed with fynbos on hill slope and dune areas (1).

REFER [1. LEVIN, M. 1988. Regional geohydrological investigations of the area between the Uilkraals and Heuningnes Rivers, Bredasdorp and Caledon districts. ESKOM Southern Cape Project, PIN-1087(B/R), GEA-812. 32 pp.

AQUIF	[	**Pearly Beach (see Gansbaai to Waenhuiskrans)**
AAREA	[	
CATCH	[	
CATCA	[	
RAINF	[	400-500 mm yr^{-1} (2), (May to September) evaporation?=1100 mm yr^{-1} (2).
AQUIT	[	Primary unconfined aquifer=Bredasdorp; secondary aquifer=faults in the Peninsula Formation; independent of each other (1).
GEOLO	[	Bredasdorp Formation (1). Base rock=Bokkeveld Shale and Table Mountain Quartzite of the Cape Super Group; Malmesbury Formation (3).
GRADI	[	Between 1:100 and 1:400 (3).
LITHO	[	Bredasdorp=sandy limestone.
THICK	[	
WATLV	[	
WTLFL	[	
FLOWD	[	Seawards and towards river valleys (3).
TSNDV	[	
SSNDV	[	
CONST	[	
VOLST	[	
STORA	[	
TRANS	[	
PERME	[	
BOREY	[	Low yields (3); 1000 m^3 day^{-1}, not enough to meet the demands of the people (1).
S-TXP	[	
L-TXP	[	
EFPOR	[	
RESOU	[	
REVOL	[	
LOSSE	[	Various natural springs.
AVTDS	[	
SWINT	[	Abstraction from the secondary aquifer (fault zones) is likely to result in SWINT (1). SWINT also likely to occur in primary aquifer if water is abstracted (1).
ESTRI	[	
VEGET	[	Coastal Fynbos; Thick scrub and bush (indigenous forest) occur along the coast

and river valleys (3). Grassland dominates the plains and is interspersed with fynbos on hill slopes and dune areas (3).

REFER [1. MEYER, P.S. 1990. Die moontlikheid van aanvullende grondwatervoorsiening by Pearly Beach. Department of Water Affairs, Technical Report, GH 3707.

2. NINHAM SHAND. 1985. Tegniese verslag oor Waenhuiskrans drinkwatervoorsiening en verkennende verslag oor drinkwatervoorsiening aan kusdorpe. Report No. HN 958/3959, Report to Bredasdorp-Swellendam Council.

3. LEVIN, M. 1988. Regional geohydrological investigations of the area between the Uilkraals and Heuningnes Rivers, Bredasdorp and Caledon districts. ESKOM Southern Cape Project, AEC Progress Report No. 8.

AQUIF [**Waenhuiskrans (see Gansbaai to Waenhuiskrans)**

AAREA [

CATCH [

CATCA [

RAINF [400-500 mm yr^{-1}, May to September (2).

AQUIT [Bredasdorp=unconfined aquifer, secondary aquifers in base rocks (2).

GEOLO [Cenozoic sediments=Bredasdorp; Base rock=Bokkelveld Shale and Table Mountain Quartzite of the Cape Super Group and Malmesbury Formation (2).

GRADI [1:100 to 1:400 (2).

LITHO [Bredasdorp=sandy limestone.

THICK [

WATLE [

WATFL [

FLOWD [Seawards and towards river valleys (2).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [Low yields (2).

S-TXP [

L-TXP [

EFPOR [

RESOU [Mainly rainfall infiltration.

REVOL [

LOSSE [

AVTDS [2420 mg l^{-1} (1,2).

SWINT [

ESTRI [

VEGET [Coastal Fynbos.

REFER [1. NINHAM SHAND. 1985. Tegniese verslag oor Waenhuiskrans drinkwatervoorsiening en verkennende verslag oor drinkwatervoorsieing aan

kusdorpe. Report No. NS 958/3959, Report to Bredasdorp-Swellendam Council.
2. LEVIN, M. 1988. Regional geohydrological investigations of the area between the Uilkraals and Heuningnes Rivers, Bredasdorp and Caledon districts. ESKOM Southern Cape Project, AEC Progress Report No. 8.

AQUIF [**Struisbaai (see Gansbaai to Waenhuiskrans)**

AAREA [Cenozoic aquifers restricted to flat plain between Struisbaai and Bredasdorp (2).

CATCH [

CATCA [

RAINF [400-500 mm yr^{-1} (May to September) (1).

AQUIT [Primary aquifer=Bredasdorp; secondary aquifer=base rock.

GEOLO [Cenozoic deposits=Bredasdorp (half- to unconsolidated sandy limestone). Base rock=Bokkeveld and Table Mountain Quartzite of Cape Super Group l; Malmesbury Formation (1).

GRADI [1:100 to 1:400, extremely flat, so that ground water movement is very slow (3).

LITHO [

THICK [Bredasdorp (5-12 m) (1).

WATLV [8-12.19 m (1).

WTLFL [

FLOWD [Seawards and towards river valleys.

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [6.3-13.9 l s^{-1} (1); Base rock=6-14 l s^{-1} (1).

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [870-1002 mg l^{-1} (1).

SWINT [

ESTRI [

VEGET [Thick scrub and bush (indigenous forest) occurs along the coast and in the river valleys (2). Grassland dominates the plains and is interspersed with fynbos on the hill slopes and in the dune areas (2).

REFER [1. MEYER, P.S. 1986. 'n Waardering van Struisbaai se grondwatervoorsiening in die lig van verwagte groei na inskakeling by die nasionale kragnetwerk. Department of Water Affairs, Technical Report GH 3485.

2. LEVIN, M. 1988. Regional geohydrological investigations of the area between the Uilkraals and Heuningnes Rivers, Bredasdorp and Caledon districts. ESKOM Southern Cape Project, AEC Progress Report No. 8.

AQUIF [**Witsand**

AAREA [

CATCH [

CATCA [

RAINF [

AQUIT [

GEOLO [Cenozoic=Bredasdorp; base rock=TMG sandstone and BG shale (1).

GRADI [

LITHO [

THICK [

WATLV [26.6 m (1).

WTLFL [Water level dropped from 27.7 m to 74.88 m after 40 minutes and thereafter to 83.43 m after 3000 minutes (1).

FLOWD [Generally towards the sea, but towards river valleys where they occur (2).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [0.5 and 0.9 m^2 day^{-1} (1).

PERME [

BOREY [3.3-1.8 l s^{-1} (1).

S-TXP [

L-TXP [Yields up to 40000 m^3 yr^{-1} are not likely to result in sea water intrusion (1).

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [At beginning of pump test tds=695 mg l^{-1} and deteriorated to 871 mg l^{-1} (1); Dec. 1983 Doep se Boorgat=2350 mg l^{-1} (4).

SWINT [Salt water found to occur at about 27 m deep (1) pumping resulted in salt water intrusion (1).

ESTRI [Bree River Lagoon.

VEGET [Coastal Fynbos, Coastal Rhenosterveld.

REFER [

1. MEYER, P.S. 1987. Rehabilitasie en toets van produksieboorgat WD1 by Witsand, distrik Swellendam. Department of Water Affairs, Technical Report, GH 3512.

2. LEVIN, M. 1988. Regional geohydrological investigations of the area between the Uilkraals and Heuningnes Rivers, Bredasdorp and Caledon districts. ESKOM Unpublished Progress Report No. 8. 17pp.

3. CARTER, R.A. 1983. Estuaries of the Cape Part II: Synopses of available information on individual systems. Report No. 21, Bree (CSW 22), Heydorn, A.E.F. and Grindley, J.R., eds).

4. DZIEMBOWSKI, Z.M. and VENTER, B.L. 1985. Verbraking van Doep se Boorgat te Witzand, Distrik Swellendam. Department of Water Affairs, Technical Report, GH3428. 8 pp.

AQUIF [**Duine** (Duiwehoks to Kafferkuils River, South Riversdale district)

AAREA [East=Kafferkuils River, West=Duiwehoks River, South=sea, Vlakte=North of the Duine.

CATCH [Duine hills=180 m above sea level (1).

CATCA [

RAINF [380-500 mm (1).

AQUIT [Sub-Neogene aquifer (1).

GEOLO [Alexandria Formation, Bredasdorp Formation (1); base rocks of the Cape System (Bokkeveld Shale and Table Mountain Sandstone) most of the water is obtained from the base rocks (1).

GRADI [

LITHO [

THICK [Neogene up to 225 m (1).

WATLE [

WATFL [

GRADI [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [Stilbaai (Olienhoutfontein, Palinggat, Torelle spring): 1328-1942 mg l^{-1} (2). Other springs=620-4200 mg l^{-1} (1).

SWINT [

ESTRI [

VEGET [Coastal fynbos, occasional thorn and melkbos trees.

REFER [1. WHITTINGHAM, J.K. 1971. Geohydrological investigations of underground water in the Duine between Duiwehoks and Kafferkuils Rivers, Riversdale District. Department of Water Affairs, Technical Report GH 1566.
2. SCOTT & DE WAAL. 1984. Report on Stilbaai Water Supply Scheme. Report to Still Bay Municipality. Unpublished Report Reg. No: 73/16932/21.

AQUIF [**Kafferkuils River to Gouritz River**

AAREA [West=Stilbaai, Kafferkuils River, East=Gouritz River, South=sea, North=Aasvoelberge; Smit (1983) recognized 5 areas: Aasvoelberge, duineveld, hardeveld, Gouritz Basin, Coastal zone. Two depressions=Canca se Laagte and Grootkloof (1).

CATCH [Gouritz and Kafferkuils=perennial rivers.

CATCA [

RAINF [410 mm yr^{-1} (April to November). Evaporation exceeds ppt in Summer months (1).

AQUIT [Bredasdorp=unconfined; CSG=confined (1).

GEOLO [Cenozoic=Bredasdorp Formation; Alexandria Formation; Base rock=Cape Super Group (TMG, BG) (1).

GRADI [TMG-dips 25-60 degrees south (3); relatively flat with slow ground water movement (1).

LITHO [Aeolian dune sands; alluvial valley deposits; Reworked aeolian and alluvial cover (3).

THICK [Bredasdorp up to 164 m east of Stilbaai (3).

WATLV [3 deep areas >100m, otherwise ground water fairly shallow, <100 m (3).

WATFL [

FLOWD [Towards the sea or drainage areas, namely Gouritz, Canca and Kaffirkuils basins (3).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [Springs along rivers and coast=up to 40 000 l h^{-1} (1); Springs along Aasvoelberge=5400 l day^{-1}. Avg. yield=5 000 l h^{-1} (1).

S-TXP [

L-TXP [

EFPOR [

RESOU [Rainfall infiltrates the dune sands and drains out through springs along the

Gouritz River, Kafferkuils River and the coast (1); Ystervarkpunt=recharge area (3).

REVOL [Isotopic dating suggests that ground water movement and recharge is slow (3).

LOSSE [Springs where contact between Bredasdorp Formation and Cape Group (1,2). Found around vlei areas or along the coast where they can be seen at low tide. Flow rate along the coast is about 4000 gph, with a TDS of about 1010 ppm (1).

AVTDS [534 mg l^{-1} (3).

SWINT [Avg salinity=500 mg l^{-1}, but may reach 2000 mg l^{-1} (3).

ESTRI [Kafferkuils, Gouritz River.

VEGET [Coastal Fynbos, Coastal Rhenosterveld.

REFER [
1. LEVIN, M. 1987. The geohydrology of the coastal area between the Gouritz and Kafferkuils Rivers, Riversdale District. In: Proceedings of the 1987 Hydrological Sciences Symposium. Vol. I. (Hughes, D.A. & Stone, A.W., eds.). HRI, Rhodes University. pp312-323.

2. SPIES, T.J. 19??. Ondersoek in watervoorsiening te Stilbaai Distrik Riversdale. Department of Mines, DWA Technical Report GH1078.

3. LEVIN, M. and JOUBERT, W.R. 1985. Gouriqua project site selection Regional geohydrological investigation of the area between the Gouritz- and the Kafferkuils Rivers, Riversdale District. NUCOR Progress Report No. 18. 72 pp.

4. SMIT 1983.

5. SCOTT AND DE WAAL 1984. Report on Stilbaai Water Supply Scheme. Report to Still Bay Municipality. Unpublished Report Reg. No: 73/16932/21.

AQUIF	[	**Hermanus**
AAREA	[	
CATCH	[	
CATCA	[	
RAINF	[	508 mm yr^{-1} (May to September) (1).
AQUIT	[	Neogene calcareous sandstones and limestones aquifer (1); secondary with aquifer associated brecciated/strongly fractured zones in quartzite of the TMS (1).
GEOLO	[	Cenozoic deposits=calcareous sandstone and limestone of Neogene age; Base rock=Cape System (TMS and BS) (1).
GRADI	[	
LITHO	[	
THICK	[	
WATLV	[	Water levels at the coast are not more than 50 feet amsl, but further inland near Stanford, 100 feet amsl (1).
WTLFL	[	No fluctuations of water levels with tides have been reported in these wells (1).
FLOWD	[	
TSNDV	[	
SSNDV	[	
CONST	[	
VOLST	[	
STORA	[	
TRANS	[	
PERME	[	
BOREY	[	Stanford=60000 gph, Springfontein=30000-40000 gph, Die Kelders=12000 gph, Gansbaai=4500 gph, Groot Hagel Kraal=30000-40000 gph (1).
S-TXP	[	
L-TXP	[	
EFPOR	[	
RESOU	[	
REVOL	[	
LOSSE	[	(springs at Stanford, Springfontein, Die Kelders, Gansbaai, Groot Hagel Kraal) (1).
AVTDS	[	

SWINT [

ESTRI [Klein River Estuary.

VEGET [Coastal fynbos.

REFER [1. WHITTINGHAM, J.K. 1970. Water supplies a Hermanus municipality, Caledon district C.P. Department of Water Affairs, Technical Report, GH1497. 10 pp.

2. WHITTINGHAM, J.K. 1970. Hermanus area, District Caledon - Geological and geohydrological investigations for ground-water supplies. Department of Mines, DWA Technical Report GH 1574.

AQUIF [**Mossel Bay**

AAREA [

CATCH [

CATCA [

RAINF [

AQUIT [TMS quartzite aquifer, unconfined aquifer in Cenozoic sediments.

GEOLO [Cape Super Group (TMQ, Bokkeveld Shale) (1).

GRADI [

LITHO [

THICK [

WATLV [67 m and 120 m (in rock) (1).

WTLFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [1400 l h^{-1}, up to 4000 l h^{-1} (1).

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [

SWINT [

ESTRI [

VEGET [

REFER [1. WHITTINGHAM, J.K. 1972. Mossel Bay Commonage, District Mossel Bay. Department of Water Affairs, Technical Report, GH1744.

AQUIF [**Sedgefield Unconfined aquifer**

AAREA [

CATCH [Touw River, Diep River, Hoekkraal River, Karatara River, Homtini River, Knysna River.

CATCA [

RAINF [About 800 mm yr^{-1}.

AQUIT [

GEOLO [Bokkeveld Shales (1); Quaternary/recent sands underlain by Tertiary sandstones (Bredasdorp Formation) (1).

GRADI [

LITHO [

THICK [

WATLV [Up to 30 m (1), At Groenvlei fresh water seepage through recent sands at 5.5 m amsl (1).

WTLFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [7-10 m^3 hr^{-1} (1).

S-TXP [

L-TXP [

EFPOR [

RESOU [Superficial-infiltration of meteoric water into the sands (1), upward losses from fissures in base rocks (1).

REVOL [

LOSSE [Fresh water seepage from recent sands at low tide into Groenvlei (1).

AVTDS [

SWINT [Possible risk if over pumped (2).

ESTRI [

VEGET [

REFER [
1. WHITTINGHAM, J.K. 1973. Sedgefield Watervoorsiening. Department of Water Affairs, Technical Report, GH1824.

2. NINHAM SHAND. 1981. Preliminary Report on Augmentation of Water Supply, Report to Sedgefield Municipality, Report No. 666/3555.

AQUIF [**Brenton-on-Sea (Knysna)**

AAREA [

CATCH [

CATCA [

RAINF [50-800 mm yr^{-1}.

AQUIT [

GEOLO [

GRADI [

LITHO [

THICK [

WATLE [

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [408 mg l^{-1} (1).

SWINT [

ESTRI [Knysna lagoon & river, Goukamma River.

VEGET [Coastal Fynbos.

REFER [1. NINHAM SHAND. 1980. Brenton-on-Sea Township: Proposed permanent water supply. Unpublished report to Brenton Development Company, 8 pp.

AQUIF	[	**Keurbooms-Plettenberg Bay**
AAREA	[	Keurbooms River flood-plain is about 3-6 m amsl (2). Lateral boundaries=sea, Keurbooms River, shale of Enon Formation in the N (2).
CATCH	[	
CATCA	[	
RAINF	[	649 mm (August-October); in Tsokwane area=850 mm (2); 800-1200 mm.
AQUIT	[	
GEOLO	[	Bokkeveld slate and shale, Enon Conglomerate, shale of the Kirkwood Formation (3).
GRADI	[	
LITHO	[	Keurbooms sand aquifer=reasonably well sorted, well rounded, very fine to medium coarse sand, with shell fragments (2).
THICK	[	Saturated thickness=5,3-16,3 m (3), actual thickness unknown because uncertain of vertical boundaries (2).
WATLV	[	1-1.5 m (3), < 2m (2).
WTLFL	[	
FLOWD	[	Seawards and towards the river (2).
TSNDV	[	
SSNDV	[	19.2 M Kl (2).
CONST	[	
VOLST	[	3.84 M Kl (2).
STORA	[	
TRANS	[	
PERME	[	Minimum trasmissivity coefficient=15% (2), hydraulic conductivity=15 m day^{-1} (2).
BOREY	[	
S-TXP	[	50000-300000 Kl (3).
L-TXP	[	50000-300000 Kl (3), =0.05-0.3x10^6 m^3 (2).
EFPOR	[	Sands=20-30% (2).
RESOU	[	Direct infiltration and surface run-off from mountains in the North, as well as from the Tsokwane River (drains the mountains in the N). Tsokwane supplies most of its flow to the underground water flow. Represented as a marshy area (2,4).
REVOL	[	

LOSSE [To sea, Keurbooms River, abstraction (about 40000 Kl yr^{-1}), direct evaporation from shallow water table, evapotranspiration (2).

AVTDS [Keurbooms sand aquifer = 100-380 mS m^{-1} (2), 511-1902 mg l^{-1} (2).

SWINT [Lateral sea water intrusion is not the primary cause of decrease in water quality, but rather through upconing of poor quality water from the base rock, the Enon Formation (2). Salt water wedge occurs in the paleo-channel of the Keurbooms River (4).

ESTRI [Keurbooms River and dune slack wetland area, Tsokwane marsh area.

VEGET [Dune pioneer species, south coast dune fynbos, south coast evergreen thicket, dune slack, wetland, grassland/bushclump mosaic (5).

REFER [1. MEYER, P.S. 1986. Grondwatervoorsiening vir die Outeniqua afdelingsraad by Keurboomsrivier. Department of Water Affairs, Technical Report, GH3401.

2. MEYER, P.S. and VANDOOLAEGHE, M.A.C. 1987. Die moontlikheid van grondwaterontginning vir stedelike gebruik in die Keurboomsriviervlakte. Department of Water Affairs, Technical Report, GH3484. 14 pp.

3. RUST, I. 1982.

4. RUST, I. 1987. Coastal aquifer charcteristics-St Francis Bay and Plettenberg Bay. In: Proceedings of the 1987 Hydrological Sciences Symposium, Vol. I. (Hughes, D.A. and Stone, A.W., eds.). Hydrologcial Research Institute, Rhodes University.

5. COASTAL AND ENVIRONMENTAL SERVICES. 1991. Report on the proposed Sanbonani Hotel and housing development - Keurbooms River.

AQUIF	[	**Cape St Francis**
AAREA	[	
CATCH	[	
CATCA	[	638-689 mm (5).
RAINF	[	
AQUIT	[	Upper primary sand (and calcrete) aquifer (low yields); secondary sandstone aquifer (=main aquifer); primary aquifer associated with the Sand river (=extention of the primary aquifer) (1).
GEOLO	[	Recent sands (Tertiary to Quaternary) with calcrete lenses; base rock=TMG (Peninsula & Nardouw Sandstone Formation) and Bokkeveld Group (shale) (1).
GRADI	[	TMG dips between 40-55 degrees to the NE (2).
LITHO	[	Sands are fine grained, sometimes clayey and interbedded with calcrete and silcretes (2,3).
THICK	[	Avg=14 m; up to 40 m at airfield 4 (1,2); Sea Vista=2.1-6 m; avg. saturated sand thickness=3 m (4).
WATLE	[	Headland bypass dune about 30 m amsl (3); static water level is about 1.5 m below ground level at Sea Vista (4).
WATFL	[	Abstraction, recharge.
FLOWD	[	South-east towards the sea and into the Kromme River (1,3).
TSNDV	[	
SSNDV	[	
CONST	[	
VOLST	[	
STORA	[	Storage coefficient (primary)=$5.4x10^{-3}$ (2).
TRANS	[	Primary=264 Kl day^{-1} m^{-1} (2).
PERME	[	
BOREY	[	Very low yields from the primary aquifer, continuous yields of 10 l s^{-1} (1).
S-TXP	[	
L-TXP	[	
EFPOR	[	
RESOU	[	Recent sands are an important source of recharge to the underlying sandstone. Recharge is by direct rainfall infiltration (1). Main area of recharge is the shifting f=dune sands known as the Sand River. This covers an area of about 12 km^2 (7).

REVOL [Area of 1/2 km^2 receives 300000 m^3 yr^{-1} (Sea Vista) (4).

LOSSE [To sea, Kromme River and canal, secondary aquifer. Throughflow in the sandstone aquifer = 1500 m^3 day^{-1} (550000 m^3 yr^{-1}) (3).

AVTDS [

SWINT [Likely in the secondary aquifer (1).

ESTRI [Kromme River estuary, Sand River.

VEGET [Headland bypass dune both vegetated and mobile (Sand River bypass dune).

REFER [1. STEFFEN, ROBERTSON & KIRSTEN. 1990. Wellfield development at St Francis-on-Sea. Summary Report. Report 171719/6 for Santareme Bay Ltd. 15 pp.

2. STEFFEN, ROBERTSON & KIRSTEN. 1990. Ground water resource evaluation at St Francis Bay: Project Review. Report 171719/5 for Santareme Bay Ltd.

3. STEFFEN, ROBERTSON & KIRSTEN. 1989. Ground water resource evaluation at St Francis Bay. Technical Report. Report 171719/2. 36 pp.

4. RUST, I.C. 1975. Report on Potential Underground Water Supplies at Sea Vista.

5. STEFFEN, ROBERTSON & KIRSTEN. 1989. Ground water resource evaluation at St Francis Bay. Appendix Report. Report 171719/3.

6. MEYER, P.S. and VANDOOLAEGHE, M.A.C. 1989. Die ontwikkeling en bestuur van 'n gehalte grondwaterbron by St Francisbaai. Department of Water Affairs, Technical Report. GH3420. 26 pp.

7. RUST, I.C. 1986. Coastal aquifer characteristics-St Francis Bay and Plettenberg Bay. In: Proceedings of the 1987 Hydrological Sciences Symposium. Vol I. (Hughes, D.A. & Stone, A.W.). Hydrological Institute, Rhodes University.

8. LEVIN, M. 1986. Regional geohydrological investigations of the area between the Kromme and Tstitsikamma Rivers, Humansdorp Districts. AEC Progress Report No. 8, 55 pp.

AQUIF [**Coega River Mouth and Hougham Park**

AAREA [

CATCH [

CATCA [

RAINF [380-640 (2).

AQUIT [Alexandria Formation=main aquifer; deeper TM Sandstone aquifer (1).

GEOLO [Recent sands, Tertiary limestone (=Alexandria Formation) (semi-consolidated sand, calcrete, shell and basal conglomerate) (shelly limestone), Lower Cretaceous Uitenhage Series, Cape System (1,2).

GRADI [

LITHO [

THICK [Alexandria Formation=9-15 m (1,2).

WATLE [0.6 m (2).

WATFL [

FLOWD [Seawards.

TSNDV [

SSNDV [

CONST [

VOLST [Total depth of fresh water=23 m (2).

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [Direct infiltration (1).

REVOL [

LOSSE [Losses to sea through springs at high water mark (1).

AVTDS [860-6600 ppm (1).

SWINT [

ESTRI [

VEGET [

REFER [1. MEYER, P.S. 1967. Grondwaterondersoek: Coegariviermond en Hougham

Park. Department of Water Affairs, Technical Report, GH1364.
2. MORRIS, T.O. 1948. Notes on the underground water supply prospects in the Algoa Bay area, with particular reference to Hougham Park. Department of Water Affairs, Technical Report, GH777.

AQUIF [**Cape Padrone**

AAREA [

CATCH [

CATCA [

RAINF [

AQUIT [

GEOLO [Recent alluvium, shelly gravel and dune sand, semi-consolidated alluvium of Tertiary age, semi-consolidated aeolian sand, Alexandria Formation sandstone, Bokkeveld shale and sandstone (1).

GRADI [

LITHO [Tertiary sands = uniformly coarsely-grained, conglomerate = fine silt and chalk (1).

THICK [Calcrete layer = 2-3 m, Tertiary sands avg = 14 m, conglomerate layer = 0.5 m (1).

WATLE [

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [400-600 mg l^{-1} (1).

SWINT [

ESTRI [

VEGET [

REFER [1. MARAIS, J.A.H 1962. Geologiese verslag oor die fonteine aan die kus by

Kaap Padrone distrik Alexandria KP. Department of Water Affairs, Technical Report, GH1166.

AQUIF [**Cannon Rocks**

AAREA [

CATCH [

CATCA [

RAINF [686 mm (2).

AQUIT [Sandstone aquifer=main aquifer (1).

GEOLO [Tertiary sands, calcified sandstone of the Alexandria Formation, Bokkeveld Series (shale) (2).

GRADI [

LITHO [

THICK [

WATLE [

WATFL [

FLOWD [Seawards, discharging below sea level (1).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [1690 mg l^{-1} (1).

SWINT [

ESTRI [

VEGET [

REFER [1. BOWLER, VAN HEERDEN & PARTNERS. 1969. Report on pumping tests on two boreholes to be used as source of supply of domestic water for the

Cannon Rocks Pleasure Resort in the district Alexandria CP. Department of Water Affairs, Technical Report GH1424.

2. DIPPENAAR, S.Z.E. 1965. Verslag oor pomptoets van boorgat vir watervoorsiening aan die beplande plesieoord te Cannon Rocks, 'n gedeelte van Middelplaas, Distrik Alexandria. Department of Water Affairs, Technical Report, GH1303.

AQUIF [**Bakanas (Boknes)**

AAREA [

CATCH [

CATCA [

RAINF [

AQUIT [

GEOLO [Sand, pebble and gravel, Bokkeveld Shale (1).

GRADI [

LITHO [

THICK [Borehole just above high water mark: sand, pebble and gravel=0-12 m; BS=12-32.6 m (1).

WATLE [

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [1775 mg l^{-1} (1).

SWINT [

ESTRI [

VEGET [

REFER [1. MEYER, P.S. 1967. Pomptoets op boorgate te Bakanas (Boknes). Department of Water Affairs, Technical Report, GH1823.

AQUIF [**Dias Cross**

AAREA [Avg width=800 m (2); avg length=1250 m (2); Bounded at the top by fine dune sands and below by Bokkeveld Group (1).

CATCH [

CATCA [

RAINF [600-900 mm (3).

AQUIT [Semi-unconfined sand aquifer (1); upper storage zone and a lower conduit zone (2); unconfined sand aquifer; unconfined sandstone aquifer (main aquifer); semi-confined shale aquifer (3).

GEOLO [Unconsolidated to consolidated sands of recent to Mio-Pliocene age (recent to Alexandria Formation), underlain by the Bokkeveld Group (shale and sandstone) (2,3).

GRADI [Vicinity of fixed dune=1:138, vicinity of sea=1:492 (2).

LITHO [Coarse grained, semi-consolidated shelly sand horizon (1); upper storage zone=beach sand, shell fragments and pebbles; lower conduit zone=coarse semi-consolidated beach sand and/or basal conglomerate (2).

THICK [Avg thickness=8.3 m; upper storage zone=4.2 m, lower conduit zone=2.6 m; avg saturated thickness=6.8 m (2).

WATLE [< 4m (1).

WATFL [Fluctuates with natural drainage, evaporation and abstraction (1); up to 0.2m as a result of abstraction, up to 0.3m as a result of tides (100 m from high tide mark) (2).

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [Conduit=675999 m^3 (2); storage zone=503999 m^3 (2); total stored=1179998 m^3 (2).

STORA [

TRANS [

PERME [

BOREY [Highest yield from sandstone aquifer, followed by sands and then shales (3).

S-TXP [

L-TXP [300000 m^3 yr^{-1} (2).

EFPOR [Lower zone=0.02 (20%) (2).

RESOU [Direct recharge from Richmond Vlei (ephemeral pan) (2).

REVOL [Rainfall=260000-355000 $m^3 yr^{-1}$ (2).

LOSSE [To sea=1179998 $m^3 yr^{-1}$ (2).

AVTDS [Large variations=512-1536 mg l^{-1}, due to seepage from back dunes (Richmond Vlei) (8000 mg l^{-1}), clay layers in dunes, recent recharge from Richmond Vlei (2).

SWINT [

ESTRI [

VEGET [

REFER [
1. STEFFEN, ROBERTSON & KIRSTEN. 1990. Wellfield development at Dias Cross. Report 176819 for Albany Coastal Water Board. 19 pp.

2. REYNDERS, A.G. 1984. Hydrogeological investigation of the coastal sand aquifers between Boesmanriviermond and Boknes, Eastern Cape Province. Department of Water Affairs, Technical Report, GH3441. 36 pp.

3. JOLLY, J.L. 1983. A geohydrological investigation of the coastal area between Bushmans River Mouth and Cape Padrone, Eastern Cape, South Africa. M.Sc Thesis, Rhodes University. 80 pp.

AQUIF [**Bushmans River Mouth**

AAREA [Avg aquifer width=300 m, avg aquifer length=800 m (1).

CATCH [

CATCA [

RAINF [600-900 mm (3).

AQUIT [Unconfined aquifer; upper storage zone and a lower conduit zone (1); unconfined sand aquifer; unconfined sandstone aquifer (main aquifer); semi-confined shale aquifer (3).

GEOLO [Unconsolidated to consolidated sands of recent to Mio-Pliocene age (recent to Alexandria Formation), underlain by the Bokkeveld Group (shale and sandstone) (1,3).

GRADI [Vicinity of fixed dune=1:161, vicinity of sea=1:2027 (1).

LITHO [Upper storage zone=beach sand, shell fragments and pebbles; lower conduit zone=coarse semi-consolidated beach sand and/or basal conglomerate (1).

THICK [Avg sand thickness=7.7 m; upper storage zone=3.6 m, lower conduit zone=2.19 m. Avg saturated thickness=5.79 m (1).

WATLE [

WATFL [Up to 0.2m as a result of abstraction, up to 0.3m as a result of tides (100 m from high tide mark) (1).

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [Back dune sand aquifer=384000 m^3; Bushmans: conduit zone=136656 m^3; storage zone=103680 m^3; total=249336 m^3 (total input=158500 m^3 yr^{-1}, total output=126000 m^3 yr^{-1}) (1).

STORA [Storage coefficient=2,9-1,3x10^{-1} (1).

TRANS [157 m^2 day^{-1} (158-423 m^2 day^{-1}) (sandstone); back dune sand aquifer=36 m^2 day^{-1} (1); sandstones=187 m^2 day^{-1}, shales=3.5 m^2 day^{-1}; dune and blind valley sands=6.2 m^2 day^{-1}, although probably 50 m^2 day^{-1} underestimates) (3).

PERME [

BOREY [Highest yield from sandstone aquifer, followed by sands and then shales (3).

S-TXP [

L-TXP [158500 m^3 yr^{-1} (1).

EFPOR	[	back dune aquifer=12%; upper zone=12%; lower zone=26% (1).
RESOU	[	Direct recharge from aquifer below Klipfontein Vlei (1).
REVOL	[	Recharge by rainfall=85248 m^3 yr^{-1}; from back dune aquifer=96000 m^3 yr^{-1} (1).
LOSSE	[	Total output=126000 m^3 yr^{-1} (22630 m^3 lost to sea, 104067 m^3 abstracted) (1); drainage factor=8.3 m (1).
AVTDS	[	Fairly constant 1450 mg l^{-1}; Klipfontein Vlei=2000-2500 mg l^{-1} (1).
SWINT	[	
ESTRI	[	Bushmans River.
VEGET	[	
REFER	[	1. REYNDERS, A.G. 1984. Hydrogeological investigation of the coastal sand aquifers between Boesmanriviermond and Boknes, Eastern Cape Province. Department of Water Affairs, Technical Report, GH3441. 36 pp. 2. HAWKINS, HAWKINS & OSBORNE. 1991. Chemical results from borehole water at Bushmans River Mouth. 3. JOLLY, J.L. 1983. A geohydrological investigation of the coastal area between Bushmans River Mouth and Cape Padrone, Eastern Cape, South Africa. M.Sc Thesis, Rhodes University. 80 pp.

AQUIF [**Ciskei Coastal Belt**

AAREA [

CATCH [

CATCA [

RAINF [

AQUIT [

GEOLO [Dune sands overlying sedimentary rocks which provide local fractured aquifers (1).

GRADI [

LITHO [

THICK [

WATLE [

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [< 10 m^3 hr^{-1}, with isolated yields up to 30 m^3 hr^{-1}, for example at Hamburg (1).

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [300->2000 mg l^{-1} ((1).

SWINT [

ESTRI [

VEGET [

REFER [1. ROSEWARNE et al. 1987.

AQUIF [**Kidd's Beach**

AAREA [

CATCH [

CATCA [

RAINF [

AQUIT [Main aquifer=Katberg Sandstone Formation, overlying sands are not a source of water (1).

GEOLO [Semi-consolidated and vegetated recent sands overlying Katberg Sandstone Formation (Beaufort Group of the Karoo Sequence (1).

GRADI [Katberg Sandstone dips southwards between 10-15 degrees (1).

LITHO [

THICK [

WATLE [

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [

REVOL [

LOSSE [

AVTDS [Katberg sandstone=600-900 mg l^{-1} (1).

SWINT [

ESTRI [Mcantsi River.

VEGET [

REFER [1. STEFFEN, ROBERTSON & KIRSTEN. 1989. Well-field development at

Kidd's Beach. Phase I Feasibility Study. Report CE7113. 6 pp.

AQUIF [**Bonza Bay, East London**

AAREA [Study area=3.5 km^2 (1).

CATCH [

CATCA [

RAINF [593 mm (1967-1968) (1).

AQUIT [Sandstone aquifer (1).

GEOLO [Dune sand over Beaufort shale and sandstone (1).

GRADI [Natural water-level gradient=1:220 (1).

LITHO [

THICK [

WATLE [20-44 m in sandstone (1).

WATFL [

FLOWD [Towards sea (1).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [102 m day^{-1} (1).

PERME [

BOREY [

S-TXP [

L-TXP [

EFPOR [

RESOU [Rainfall (1).

REVOL [Rainfall: 1967-1968=$2.2x10^9$ l; =10.8% infiltration (1).

LOSSE [To sea: 1967-1968=$2.4x10^8$ l (1).

AVTDS [866 ppm (1).

SWINT [Not problem because of water-level gradient (1).

ESTRI [

VEGET [

REFER [1. BOEHMER, W.K. 1969. Report on the results of a pumping test on bore-hole A on the P.S.A. Holiday Resort at Bonza Bay, District East London. Department of Water Affairs, Technical Report, GH1414. 9 pp.

AQUIF [**Richards Bay-Lake Mzingazi**

AAREA [Lake Mzingazi = 162 km^2 (1); two hydrological regimes = Mhlatuze flood-plain and Mzingazi-Nhlabane coastal catchment areas (1).

CATCH [

CATCA [

RAINF [900-1300 mm yr^{-1} (1).

AQUIT [Pleistocene aquitard, main Miocene aquifer (1).

GEOLO [Holocene (alluvial and estuarine deposits), Upper Pleistocene-Holocene (dune and beach sand, sand and aeolianite-Kwa-Mbonambi Formation), Late Middle Pleistocene (Port Durnford Formation), Miocene (Uloa Formation), Palaeocene (Richards Bay Formation), Cretaceous (St Lucia Formation-siltstone), Jurassic (Letaba Formation-basalt), Triassic (Nyoka Formation-mudstone, sandstone, shale and grit), Precambrian (Tugela Complex-granite-gneiss) (1).

GRADI [

LITHO [

THICK [Cretaceous/Palaeocene siltstones = 50- > 700 m; Miocene = < 10 m, but up to 15 m in places; Port Durnford = 25-30 m at coast; coastal dune belt > 100 m in places, recent estuarine and alluvial sands = 7-10 m (1).

WATLE [Flood plain = sea level to over 12 m amsl further inland (1); perched water tables in places occurring above shallow discontinuous clays (1). Miocene siltstones = -10 m amsl at the coast to 5 m amsl inland (1).

WATFL [Change in 0.7 m has been shown to have no effect on the marginal vegetation (1).

FLOWD [Majority towards Lake Mzingazi (1).

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [245x10^6 m, Miocene: mean storage coefficient = 5.7x10^{-4}, recent estuarine and alluvial sands = 3.3x10^{-3} (1).

TRANS [Miocene: 15-20 m day^{-1}; recent estuarine and alluvial sands = 140 m^2 day^{-1} (1)

PERME [Miocene: mean horizontal hydraulic conductivity = 2.5 m day^{-1} (1); recent estuarine and alluvial sands = 16 m day^{-1} (1).

BOREY [

S-TXP [

L-TXP [Estimated exploitable yield= 500 m^3 day^{-1} $km^{2\ -1}$.

EFPOR [Avg. porosity=20%.

RESOU [Mainly rainfall and possible seepage from rivers and streams (1). Area of recharge=Mzingazi catchment and aquiferous sands of the Mhlatuze floodplain.

REVOL [Input (Mzingazi): ppt over Lake Mzingazi system=43110 m^3 day^{-1}, surface inflow=159190 m^3 day^{-1}, subsurface inflow=78170 m^3 day^{-1}, total inflow=280470 m^3 day^{-1} (1). 24% of rainfall.

LOSSE [Seepage=0.001-1.2 m^3 day^{-1} m^{-1} per aquifer width (Miocene); outflow (Mzingazi): abstraction+surface outflow=260000 m^3 day^{-1}, subsurface outflow=1350 m^3 day^{-1}, evaporation=15910 m^3 day^{-1}, change in storage=3210 m^3 day^{-1} (1).

AVTDS [Cretaceous/Palaeocene siltstones=3500 mg l^{-1}, Tertiary-Quaternary sands=450 mg l^{-1} (1). Recharge areas=low TDS (1); 120-600 ppm with avg=350 ppm (1).

SWINT [Likely around the margins of the Mhlatuze floodplain where shallow water table (1).

ESTRI [Lake Mzingazi, Mhlatuze River, Nseleni River, Nsezi Lake, Cubhu Lake.

VEGET [Forestry in plateaux areas to the N and S (1)

REFER [1. WORTHINGTON, P.F. 1978. Ground water conditions in the Zululand Coastal Plain around Richards Bay. Geophysics Division-CSIR. Report RFIS 182. 209 pp.

AQUIF	[	**Lake Sibayi and Lake Kosi**
AAREA	[	
CATCH	[	
CATCA	[	
RAINF	[	
AQUIT	[	Confined aquifer of Uloa Formation with shallow aquifer of Port Durnford Formation in some places (supports marsh and open water bodies) (1).
GEOLO	[	
GRADI	[	
LITHO	[	
THICK	[	Uloa Formation=25 m (1).
WATLE	[	
WATFL	[	
FLOWD	[	
TSNDV	[	
SSNDV	[	
CONST	[	
VOLST	[	$5x10^9$ m^3 (Uloa Formation) (1).
STORA	[	Mean storage coefficient= $1x10^{-3}$ (1).
TRANS	[	avg=40 m^2 day^{-1} (1).
PERME	[	
BOREY	[	12.8 l s^{-1} (1).
S-TXP	[	
L-TXP	[	
EFPOR	[	10% (1).
RESOU	[	Mainly from rainfall (1).
REVOL	[	21% of annual rainfall (approx. $8x10^8$ m^3 yr^{-1}) (1).
LOSSE	[	Seepage ($30x10^3$ m^3 day^{-1} km^{-1} coast).
AVTDS	[	
SWINT	[	Regional geohydrology prevents salt water intrusion (1).
ESTRI	[	
VEGET	[	
REFER	[	1. MEYER and KRUGER. 1987.

AQUIF [**Lake St Lucia**

AAREA [

CATCH [

CATCA [Lake eastern catchment = 170 km^2; Estuary eastern catchment = 55 km^2 (1).

RAINF [700-1300 mm (1).

AQUIT [Sandy Miocene limestone or alluvial channel deposits (1).

GEOLO [Holocene sands, Unconsolidated Pleistocene sand of alluvial, estuarine and aeolian origin, Cretaceous siltstones (1).

GRADI [Base rock dips slightly eastward, at eastern shores are below sea level (1).

LITHO [

THICK [

WATLE [Eastern shore = 0-3 m (1).

WATFL [

FLOWD [

TSNDV [

SSNDV [

CONST [

VOLST [

STORA [

TRANS [

PERME [Horizontal heterogeneity so that horizontal hydraulic conductivity is greater than the vertical conductivity. Hydraulic conductivity also decreases with depth due to finer sands of the Pleistocene (1). Pleistocene = 1.2×10^{-6} m sec^{-1} (2).

BOREY [

S-TXP [

L-TXP [

EFPOR [30-50% (1).

RESOU [Lake eastern area, Estuary eastern catchment (mainly through rainfall) (1).

REVOL [Lake eastern area: 37×10^6 m^3 yr^{-1}: estuary eastern catchment = 9×10^6 m^3 yr^{-1} (1).

LOSSE [Gross evaporation = 62.7% of water budget (1).

AVTDS [100-300 mg l^{-1} (1).

SWINT [Not likely because of the high fresh water ridge beneath the coastal dune and ground water from the dunes are discharging into the sea (1).

ESTRI [Mkuze, Mzinene, Hluluwe, Nyalazi, Mpate Rivers.

VEGET [

REFER [1. LINDLEY and SCOTT. 1987.

2. WORTHINGTON. 1978.

APPENDIX 3. THE QUESTIONNAIRE DISTRIBUTED TO VARIOUS ORGANIZATIONS AND MUNICIPALITIES AROUND THE SOUTH AFRICAN COAST.

QUESTIONNAIRE

Should you have any enquiries with regard to the questionnaire, please contact Jeff Jolly (DWA - 021 457025) or Taryn Parker-Nance (UPE - 041 5311304).

1. Name of your organization (municipality, water board, RSC etc):

   ____

2. Address of your organization:

   ____

   ____

3. Telephone number of your organization: (______)____________________

4. The Town or City this form represents: ____________________________

5. Do you use groundwater (from springs, boreholes or wells) totally, or as a supplement to your water supply?YES ____ NO ____

6. What volume of groundwater do you abstract annually? ______ kl.

7. What is the average quality (salinity) of this groundwater? ______________

8. Have you employed any consultants in the exploration or design of your groundwater abstraction schemes? Please name all of them, including the contact person and his/her address and telephone number.

9. Does your organization have any groundwater data (i.e. reports, water levels, chemical analyses, abstraction rates, etc.) from your groundwater scheme? What data exists? (Tick the appropriate ones).

   Consultant's Reports______

   Water Level Data______

   Chemical Analyses______

   Abstraction rates______

   Borehole Details (depths, logs, etc.)______

   Other ____________________________

   Other ________________________

Name	Company and Address	Telephone

10. Who is the contact person in charge of your abstraction scheme, who would answer any queries we might have?________________________________

Thank you for your time.

APPENDIX 4. SOURCES OF BOREHOLE DATA USED FOR WATER QUALITY ANALYSIS. THE FULL REFERENCES CAN BE OBTAINED IN APPENDIX 1.

SITE	NO. OF BOREHOLES	REFERENCE	DATE
Agulhas	3 2	Spies & Vegter Meyer	1959 1986
Atlantis	17 26	Bertram et al. Timmerman	1984 1985
Berg to Olifants River	54	Schreuder	1979
Brenton-on-Sea	1	Ninham Shand	1972
Bushmans River Mouth	12	Jolly	1984
Cape Flats	28	Edwards	1990
Cape St Francis	14 5	SRK Meyer & Vandoolaeghe	1990 1989
Coega	20	Venables	1985
Dias Cross	16	Reynders	1984
Durban North	2	Van Wijk	
Gouriqua	88	Levin	1988
Grootwater	10	Jolly	
Hougham Park	12	Meyer	1967
Humansdorp	63	Levin	1986
Keurbooms	6		
Lower Berg	16	Timmerman	1985
Natal	6	Sapref	
Port Nolloth	71	Levin	1990
Strandfontein	5	Vandoolaeghe & Timmerman; Jolly & Seward	1988; 1991
Struisbaai	3	Meyer	1986
Uitkraals to Heuningnes	76	Levin	1988
Waenhuiskrans	1	Ninham Shand	1985
Witsand	1	Dziembowski	1983
Zinkwasi	6	Gustein, Forsythe & Joubert	1990
Zululand	7	Meyer	198*

APPENDIX 5. RESULTS OF QUESTIONNAIRES DISTRIBUTED TO VARIOUS MUNICIPALITIES AND OTHER ORGANIZATIONS REGARDING GROUND WATER USE. GROUND WATER USE IS INDICATED BY EITHER "YES" OR "NO", OR A BLANK FOR NO REPLY. THE VOLUME OF GROUND WATER USED IS EXPRESSED IN KILOLITRES PER ANNUM AND THE QUALITY OF THE WATER IS EXPRESSED AS EITHER QUANTITATIVE OR QUALITATIVE SALINITY.

GROUND WATER USERS	Y/N	VOL. kl	SALINITY
Agulhas	Y	60 985	17 ppt?
Albany Coastal Water Board	Y	200 000	
Alexander Bay	N		
Alexandria	Y		Unknown
Alexandria Municipality	Y		
Amanzimtoti Municipality			
Amanzimtoti Regional Services Corporation			
Amatola Regional Services Council	Y	5 000	Good
Bazley	N		
Beacon Bay Municipality	N		
Betty's Bay Municipality	N		
Bloubergstrand	N		
Boggoms Bay	Y	2 282	900 ppm
Boknes & Cannon Rocks	Y	45 000	Poor
Borough of Verulem			
Bot River	Y	103 147	112 ppm
Buffels Bay			
Cape Vidal	N		
Cape Town			
Cape St Francis	Y	40 000	Good
Darnall Municipality	N		
De Kelders	Y	51 334	Unknown
Department of Agric. and Forestry - KwaZulu	Y		
Divisional Council of St Francis Bay	Y		
Divisional Council of Diaz			
Doornbaai/Strandfontein	Y	232 500	Very Poor
Durban Municipality	N		
DWAFE-Alexandria	Y		
East London Municipality	N		

Elands Bay	Y	73 200	Reasonable
Elysium	N		
Empangeni Municipality	N		
Fish Hock	N		
Gansbaai Municipality	N		
Glentana			
Gonubie Municipality	N		
Gordon's Bay Municipality	Y	2	Fresh
Gouritsmond	Y		
Groenriviermond	N		
Groot Brakrivier Municipality	N		
Hartenbos Municipality	N		
Hermanus			
Herolds Bay			
Hibberdene Municipality			
Hondeklip Bay	Y		
Hout Bay	N		
Ifafa	N		
Illovo Beach Municipality			
Isipingo Municipality			
Jeffreys Bay Municipality	Y	820 000	300 ppm
Jongensfontein	Y		
Kei Mouth Municipality	N		
Kelso Beach	N		
Kenton-on-Sea	Y	80 000	
Kenton-on-Sea Municipality	Y		
Kingsborough Municipality	N		
Klein Brakrivier	N		
Kleinbaai	Y	9 039	Unknown
Kleinmond Municipality	Y	5 000	Good
Knysna Municipality	Y	85 000	Unknown
Kooingnaas	Y	216 000	
KwaZulu: Bureau of Natural Resources	N		
Laaiplek-Veldrift	N		
Lamberts Bay	Y	332 343	Very good
Langebaan	N		

Margate Municipality	N		
Melkbosstrand	N		
Milnerton	N		
Mtunzini Town Board	N		
Mooi River Municipality			
Mossel Bay Municipality	N		
Mtwalume	N		
Natal Town and Regional Planning Commission	N		
Noetzie			
Noordhoek	N		
Ocean View	N		
Onrus Municipality	N		
Oyster Bay	Y	10 000	Good
Papendorp			
Park Rynie	N		
Paternoster	N		
Pennington	N		
Pinetown Municipality	N		
Plettenberg Bay Municipality			
Port St Johns Municipality	Y	Most	Good
Port Shepstone Water Works			
Port Nolloth	N		
Port Edward Town Board	N		
Port Alfred Municipality			
Port Shepstone Municipality	N		
Ramsgate Municipality	N		
Richards Bay Minerals	Y		
Richards Bay Municipality	N		
Saldanha/Vredenburg	N		
Sandbaai			
Scottburg	N		
Scottburg South	N		
Seafield Local Area	Y	30 000	Good
Seapark Municipality			
Sedgefield Municipality	N		
Sezela	N		

Shakaskraal			
Shelley Beach Municipality	N		
Simons Town Municipality	Y	50	Unknown
Southern Cape RSC	Y	Unknown	Poor
Southgate Municipality			
Southport Municipality			
St Helena's Bay	N		
St Francis Bay	Y	150 000	Good
Stanger Municipality			
Still Bay Municipality	Y	Unknown	Good
Stompneusbaai	N		
Strand	N		
Strandfontein	Y		
Struisbaai	Y	334 223	1179ppm
Suiderstrand	Y	Unknown	Unknown
Tongaat Municipality	N		
Umdoni Park	N		
Umgeni Water Board - Pinetown			
Umgeni Water Board	Y	2 000	Variable
Umhlali Town Board	Y		Acceptable
Umhlanga Rocks Municipality	Y		
Umkomaas Municipality	N		
Umkomaas Town Board			
Umzinto	N		
Umzinto North	N		
Umzinto Regional Water Services			
Vanwyksdorp	Y	79 469	3328 ppm
Velddrif Municipality	N		
Victoria Bay	Y		
Vleesbaai	Y	2 282	900 ppm
Waenhuiskrans	Y		
Water Supply Officer-Alexcor	N		
West Coast National Park	Y	1 000	3 ppt
Wilderness			
Witsand			
Yzerfontein			