Research into the Groundwater Abstraction in Residential Areas

G C Simpson

WRC Report No. 211/1/90

FINAL PROJECT REPORT

to the

WATER RESEARCH COMMISSION

RESEARCH INTO GROUNDWATER ABSTRACTION IN RESIDENTIAL AREAS

VOLUME I

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The following persons were, from time to time, associated with the steering committee responsible for the project:

Mr H C Chapman	Water Research Commission
Mr G C Simpson	Division of Building Technology
Mr P R Crabtree	Division of Building Technology
Mr P H S Cronje	Pretoria City Council
Mr Z A Coetzee	Pretoria City Council
Mr J A van Rooyen	Dept of Water Affairs
Mr W Schulz	Dept of Water Affairs
Mr A Reynders	Water Research Commission
Mr D Huyser	Water Research Commission

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Perhaps the most important contributors were all the borehole owners who made their properties and boreholes available to the researchers for the duration of the project.

Lastly, the authors would like to thank all the students and others who assisted with the data collection and processing.

AIMS OF THE PROJECT

The main aim of the project was to assess the annual quantity of water abstracted from private boreholes in Pretoria in relation to the quantity of water supplied by the Municipal water supply system.

The secondary aims that could conveniently be included in the project were as follows:

(i) To determine the variation in groundwater levels over the period of the project.

(ii) To determine the quality of the groundwater pumped from boreholes and its variation spatially and with time.

(iii) To assess the possibility that the quantity of groundwater obtained from private boreholes will increase significantly in the future.

EXECUTIVE SUMMARY

Up until about 1983, the quantity of water abstracted from private boreholes in urban areas was considered insignificant in comparison to the water abstracted from the municipal water supply.[1] Under the drought conditions, which prevailed until 1988, the shortage of surface water resources led to the imposition of rationing and punitive tariffs. The result was a proliferation of new boreholes in the suburban areas, as property owners, driven by the successes of their neighbours, kept the borehole industry busy.

The newspapers were equally busy reporting on and adding to the controversy that the drilling activity caused among the have-nots on the one hand, and the existing borehole owners on the other, who were concerned that the rapid growth in demand on the groundwater resource could seriously diminish their borehole yields, or at worst destroy the resource.

In November 1985, the Division of Building Technology, CSIR, (then called the National Building Research Institute) started a pilot study on seven boreholes in the Eastern suburbs of Pretoria. In April 1987, funds were made available by the Water Research Commission to extend the project over the whole of the Pretoria area. The main aim of the project was to quantify the amount of groundwater abstracted from private boreholes. Secondary aims included monitoring variations in the water tables, the quality of the groundwater and assessing the potential for a significant increase in the demand on the groundwater resources in the future.

Data collection stopped at the end of January 1990, when the water consumption records and water depth measurements covered a period of at least 24 months for the 106 monitored boreholes. Water quality analyses were undertaken twice a year over the last two years and surveys were undertaken to determine the number of boreholes in the residential areas.

In February 1989, the levels of O^{18} isotope in 20 groundwater samples were measured to see if this parameter could be used to trace the origin of the groundwater. The results, while interesting, were inconclusive possibly because the sample size was small and aerially too widely spaced[2:p106]. It is possible that a more selective and concentrated exercise would yield better results.

Aerial photography was used to provide groundcover data, so that the irrigation rates for gardens could be assessed. Rainfall and temperature data were obtained from the Weather Bureau for correlation with the changes in abstraction rates and water tables.

A reasonable estimate of the annual quantity of water abstracted from private boreholes in Pretoria was taken as the product of the mean borehole water consumption and the estimated number of properties with boreholes. A comparison was made with the quantity of water supplied by the Municipal water supply system. The report, "Estimating the annual quantity of groundwater abstracted in the Pretoria municipal area and its effect on municipal water consumption", by N J Van der Linde and C Elphinstone describes how this was done.

It was found that the proportion of residential properties with boreholes was 0.375 of the total number of 80536. A property with a borehole used an average quantity of water of 1.78 kl/day from the borehole and 0.82 kl/day from the municipal supply. From a sample of 439 properties without boreholes, the average municipal water consumption was 1.04 kl/day.

The average annual quantity of groundwater abstracted from private boreholes was estimated to be 20 063 Ml per year. This is roughly equal to the quantity of municipal water used per year at residential properties in Pretoria. Given that the average reduction in municipal water consumption is 0.21 kl/day for a property that acquires a borehole, the annual reduction in municipal water sales due to groundwater usage was 2 350 Ml per year.

It was noted that although the reduction in municipal water use was approximately 0.21 kl/day, this was replaced by a groundwater abstraction of 1.78 kl/day. This leads to two observations. Firstly, the supply of municipal water was severely constrained by availability and price during the period of the study. Secondly, although municipal water restrictions were lifted and the tariff structure reversed in September 1988, properties without boreholes have not increased their water consumption significantly, in fact the mean increased by only 50 litres/day.

Changes in the elevations of the groundwater tables were influenced by the aquifer characteristics, but in general were seasonal and no long term trends were observed, due the short duration of the data record. Longitudinal sections taken across the city illustrated that the water table tends to follow the ground contours, but is influenced by the local geology[3:p46].

The depth to the water table varied from less than a metre to about 100 metres, but the water surface was within 30 metres from the surface in most boreholes.

The chemical quality of the groundwater was found to compare favourably with the Municipal water quality and did not change significantly with time. In some areas, local minerals containing elements such as manganese and iron are dissolved in the groundwater in relatively high proportions. Two of the monitored sites were found to use only groundwater for all domestic purposes.

However it was found that the microbiological quality of the groundwater varied unpredictably. Variation in quality is attributed to stormwater run-off, either at or near the borehole site, and sewer ex-filtration at connections and broken pipes. It is advisable to sterilize all borehole water to be used for human consumption by boiling or by chlorination.

In an attempt to establish the potential for a significant increase in groundwater abstraction from private boreholes in the future, borehole contractors who operate in the Pretoria area were contacted for information on the number of boreholes drilled per year. This information could have formed the basis for developing a forecasting technique for the number of new boreholes likely to be drilled per year. Unfortunately, the contractors were very evasive and no historical data of value were obtained. It was also established that the Pretoria municipal records were not reliable enough to use for extrapolations, since many people had not registered their borehole.

A qualitative assesment, based on observation of the trends since 1985, suggests that the incentive for an individual to sink a borehole depends on the following factors, more or less in priority;

1) Restrictions on quantity of municipal water available
2) The price differential at the demanded quantity between the groundwater and the municipal water.
3) The probability of obtaining a good supply from a borehole on the individual's property.
4) The availability of capital to finance the borehole installation.

The incentive to sink a borehole is therefore primarily drought driven, since it is during a drought that the supply shrinks, leading to the imposition of restrictions on consumer demand and an increase in price.

It is thought that the limit to which private residential properties will utilise the groundwater in the Pretoria area can be based on the degree of utilisation observed in the older areas, where further development is unlikely. On this basis, the central area (Zone 4) has probably stabilized at a point where 60% of the residential properties have a borehole. It is assumed that in due course, the demand on the groundwater resource could be expected to increase by about 60% within the other defined areas, due to the increase in the proportion of properties with boreholes from 0.375 to 0.60.

However, the main limiting factor is the rate of recharge, which is not known. It would appear that a significant proportion of the recharge is occurring from areas which are outside the geographic boundaries monitored during the project. Should significant abstraction of groundwater occur from these areas, for whatever reasons, the effect on the Pretoria area could be a serious one for the residential borehole owners.

The failure of a large proportion of the private boreholes should not affect the burden on the municipal water supply, since the demand from this source would be controlled by restrictions and the tariffing structure. The environment would however suffer and this could have a demoralising effect on the inhabitants.

Pretoria July 1990

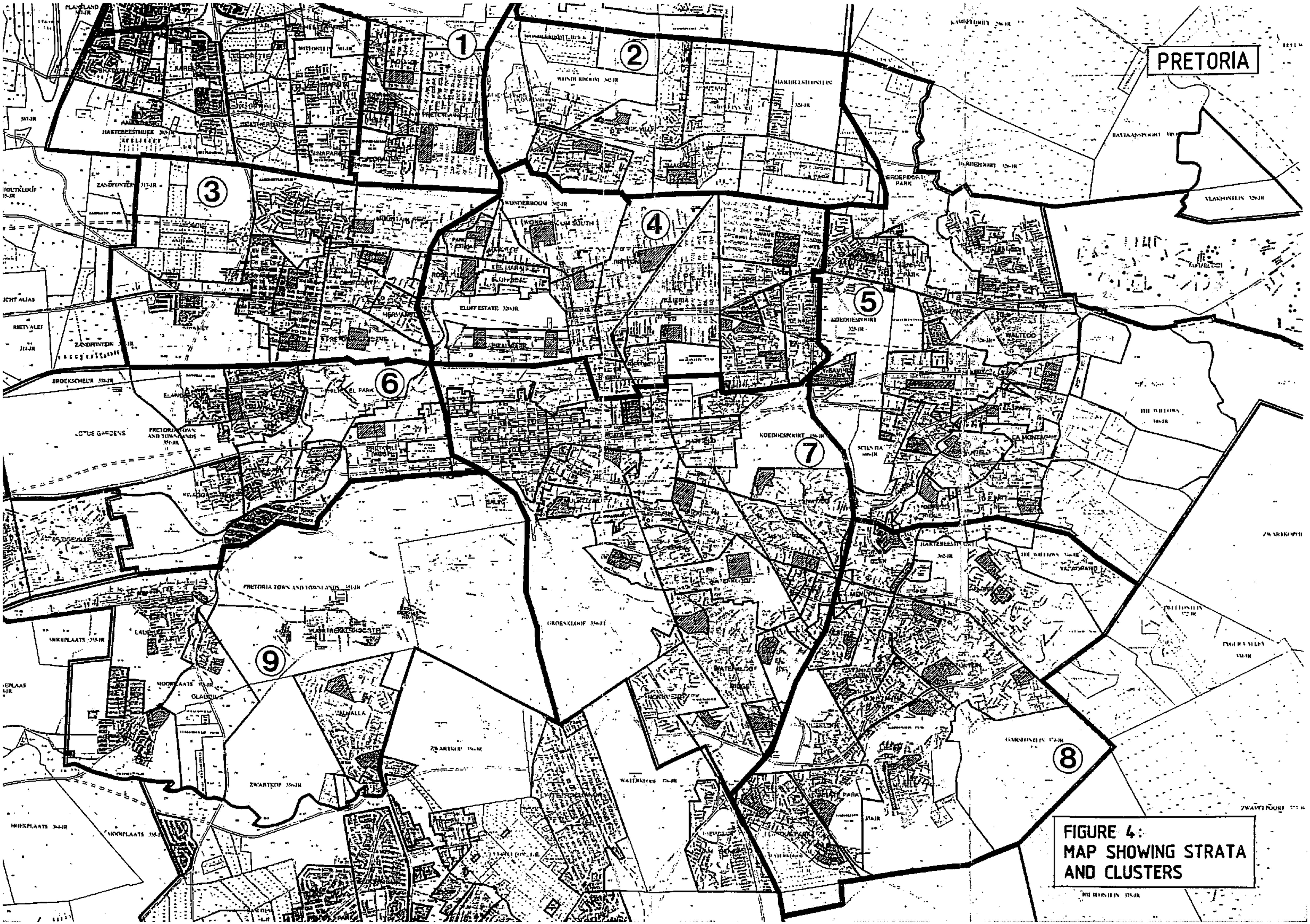


FIGURE 4: MAP SHOWING STRATA AND CLUSTERS

RESEARCH INTO GROUNDWATER ABSTRACTION IN RESIDENTIAL AREAS

INTRODUCTION

Up until about 1983, the quantity of water abstracted from private boreholes in urban areas was considered insignificant in comparison to the water abstracted from the municipal water supply.[1] Under the drought conditions, which prevailed between 1982 and 1988, the shortage of surface water resources led to the imposition of rationing and punitive tariffs. The result was a proliferation of new boreholes in the suburban areas, as property owners, driven by the successes of their neighbours in obtaining an underground water supply, kept the borehole industry busy.

The newspapers were equally busy reporting on and adding to the controversy that the drilling activity caused among the have-nots on the one hand, and the existing borehole owners on the other, who were concerned that the rapid growth in demand on the groundwater resource could seriously diminish their borehole yields, or at worst destroy the resource.

In November 1985, the Division of Building Technology, CSIR, started a pilot study on seven boreholes in the eastern suburbs of Pretoria. In April 1987, funds were made available by the Water Research Commission to extend the project over the whole of the Pretoria area. The main aim of the project was to quantify the amount of groundwater abstracted from private boreholes, but equally important was to determine the effect this was having on the groundwater resource. Other issues included in the project's aims were the quality of the groundwater and the potential for a significant increase in the demand on the groundwater resources in the future.

Building Technology stopped collecting data for the project at the end of January 1990. The water consumption records covered a period of between 24 months to 51 months for the 106 monitored boreholes. In addition, water quality analyses were undertaken twice a year over the last two years of the project and surveys were undertaken to determine the number of boreholes in the residential areas.

In February 1989, the levels of O^{18} isotope in 20 groundwater samples were measured to see if this parameter could be used to trace the origin of the groundwater. The results, while interesting, were inconclusive possibly because the sample size was small and was too widely spaced[2:p106]. It is possible that a more selective and concentrated exercise would yield better results.

Aerial photography was used to provide groundcover data, so that the irrigation rates for gardens could be assessed. Rainfall and temperature data were obtained from the Weather Bureau for correlation with the changes in water consumptions and water tables.

This report describes the methods used to achieve the aims of the project and the results obtained in the Pretoria area. The procedures developed could be applied in other urban areas to assess the degree to which groundwater is abstracted from private boreholes.

OVERVIEW OF THE PROJECT

The research was carried out in Pretoria, where the density and extent of boreholes in the urban area is probably the highest in the country, although a similar situation is thought to exist in the Johannesburg area. According to their local authorities, coastal cities do not have a significant number of private boreholes, although there was a marked increase in drilling activity in Port Elizabeth during the recent drought in 1989. In smaller centres, there can be a very high proportion of properties with a borehole, but because the size of the town is small the impact on the groundwater resource will be less when compared to a similar urban area in Pretoria.

The main task was to determine the volume of groundwater that was being abstracted from the private boreholes, while also monitoring changes in water tables and water quality. Figure 1 is a chart showing the elements of the project and their general relationship to each other. The chart can also be used as a planning guide for similar projects.

In task area 1 on the chart, the volume of groundwater abstracted can be estimated if the number of boreholes and the rate of abstraction per "average" borehole is known. This assumption led to the two main sub-task areas shown in the chart. Estimating the number of properties with boreholes was a relatively short duration task and could be completed in about two months. Determining average rates for groundwater and municipal water use was more complicated and required monitoring a number of boreholes across the city for at least 24 months.

The tasks of monitoring water table variations, shown as task area 2 on the chart, was carried out simultaneously with the monitoring of water consumptions. Similarly, monitoring water quality of the groundwater and municipal water at selected sites, shown as task area 3, was tacked on under the monitoring of water consumptions. The task of assessing the possibility that the quantity of groundwater obtained from private boreholes will increase significantly in the future was not fitted into the structure of the chart, since it is seen as an evaluation of the results of the other tasks, as well as numerous other factors.

Some of the items shown on the chart were tacked onto the project to obtain a better understanding of the behaviour of the groundwater aquifers, to investigate possible recharge relationships and to investigate the possibility of using remote sensing and aerial photography in identifying aspects of groundwater utilisation.

Not shown on the chart is the inevitable data checking and processing that was required to arrive at meaningful answers. Procedures had to be developed for each element in the project so that the data remained valid, even when the procedures were changed.

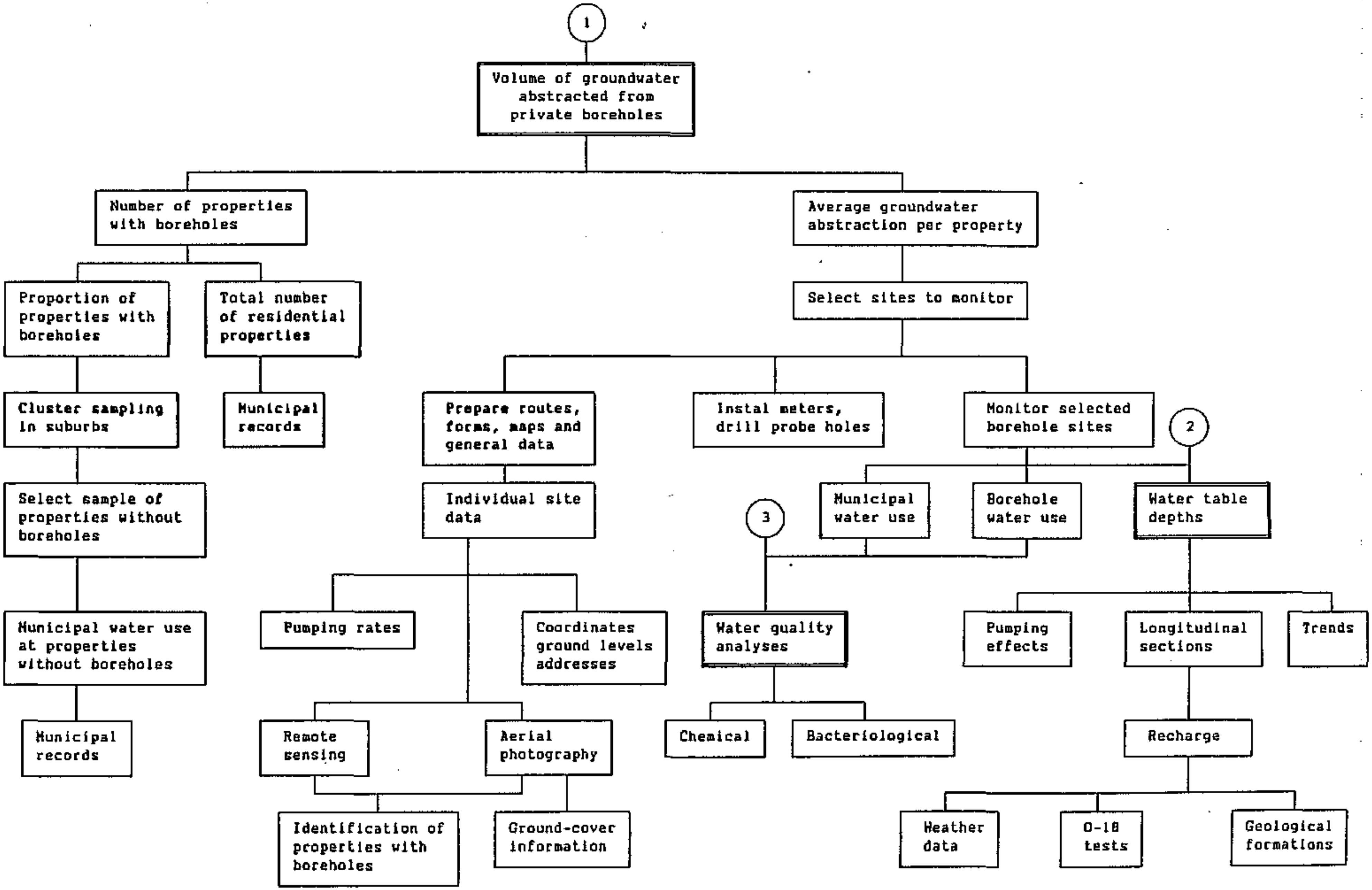


FIGURE 1 - CHART SHOWING ELEMENTS OF PROJECT

It was found that in the preliminary period, when borehole monitoring sites were being established, it was essential to obtain as much relevant information as possible, such as the erf numbers of the properties, number of occupants, borehole depths and pumping rates. Once monitoring started, it was much more difficult to go back and find the missing data. The lack of an erf number was a particular problem when trying to identify the erf on maps and aerial photographs.

ACHIEVEMENT OF THE MAIN TASK

The theory and calculations for the method used to determine the annual quantity of groundwater abstracted from private boreholes and its effect on the municipal water consumption are described in detail in the report by N J Van der Linde and C D Elphinstone. Their report is presented as an addendum to this report.

It can be observed in their report that the frequency distributions for groundwater and municipal water use have the same shape, suggesting that the source of water does not influence the demand patterns.

For the Pretoria area, it was found that the proportion of residential properties with boreholes was 0.375 of the total number of 80536 listed by the Municipality. A property with a borehole used an average quantity of water of 1.78 kl/day from the borehole and 0.82 kl/day from the municipal supply. From a sample of 439 properties without boreholes, the average municipal water consumption was 1.04 kl/day.

The average annual quantity of groundwater abstracted from private boreholes was estimated to be 20 063 Ml per year. This is roughly equal to the quantity of municipal water consumed per year. Given that the average reduction in municipal water consumption is 0.21 kl/day for a property that acquires a borehole, the annual reduction in municipal water sales due to groundwater usage was 2 350 Ml per year.

It was noted that although the average reduction in municipal water use was approximately 0.21 kl/day, this quantity was replaced by an average groundwater abstraction of 1.78 kl/day. Two observations can be made about this result. Firstly, the supply of municipal water was severely constrained by availability and price during the period of the study. Secondly, although municipal water restrictions were lifted and the tariff structure reversed in September 1988, properties without boreholes have not increased their water consumption significantly, in fact the mean increased by only 50 litres/day.

On the other hand, properties with boreholes appear to have increased their municipal water consumption, but not to the level of non-borehole properties. The abstraction of groundwater fluctuates widely, but does not appear to have any trend. This supports the view that the current distribution of groundwater abstraction represents the "norm" that applies in the Pretoria area for external garden watering requirements.

It is important to note that property owners have developed the groundwater water resource, which would otherwise not have been developed, to improve their environment at their cost and have indirectly provided additional sources of water for use in times of emergencies, disasters and droughts.

COLLECTION OF WATER CONSUMPTION AND WATER LEVEL DATA

Selection of monitoring areas

It was decided to cover as many suburbs in Pretoria as possible, rather than concentrate on a selected few. This was done initially by working outwards from those suburbs where monitoring was already taking place. Then a second appoach was tried where the city was segmented by a 2 x 2 kilometer grid. The objective was to obtain an even distribution of monitoring sites by selecting 2 or 3 sites in each square.

This was difficult to plan and the method of segmenting the city according to suburb boundaries was applied to obtain 17 segments bounded by major roads or geographic features. The establishment of 5 to 6 sites in each segment enabled the goal of monitoring at least 100 sites to be reached, while maintaining a reasonable dispersion of the sites across the residential areas of the city.

It was realised that if the monitored sites are close to each other, less time is required to take readings and measurements. However, this reduces the variety of the data and their usefulness as representative samples of the Pretoria areas as a whole. To obtain consistency in the selection of sites within areas the following guidelines were used when selecting new areas and monitoring sites:

(a) Access to the new area or suburb from the existing monitored sites should be relatively easy, to avoid excessive travel time during the monitoring journey.

(b) Between three to five monitored sites should be selected in each area to represent the typical site in the area.

(c) Grouping of up to three sites relatively close to each other can be allowed, to reduce travelling time and enable a representative level of the water table to be measured, should one of the sites be pumping water at the time of measurement.

Selection of suitable sites

The pilot project was established by word-of-mouth. The researchers approached neighbours and colleagues and they in turn spread the word that we were looking for suitable sites to monitor. The number of boreholes offered for monitoring increased rapidly, particularly when the purpose of the research and the benefits to the borehole owner were explained. The size of the pilot project was limited by the number of available water meters.

When the project funds became available, the CSIR staff newspaper was used to advertise for new sites. The response was satisfactory, but the results were not ideal. It was found that many of the sites offered were not suitable because of their physical location, general access to the property, poor borehole yield, or impractical pipe layout. Another factor was the possible bias of the volunteer towards groundwater usage and the possibility that the consumption pattern may not be representative of the population.

The method for selecting a site, which was used successfully and is considered to be very efficient in terms of time and manpower resources, is described below:

(a) Identify the area where new sites are required,

(b) visit the area and look for properties where the borehole and municipal meter are conveniently accessible and the garden appears to benefit from the use of the groundwater, then

(c) approach the owner for permission to monitor the site, explaining the purpose of the research and what is involved.

(d) If this is given, check if a water meter can be installed on the pipe from the borehole before it branches.

(e) Install the meter and drill a 16 mm diameter probe hole in the borehole cover-plate, so that the water depth measuring tape can be lowered down the inside of the borehole casing.

A list of the monitored sites, which gives the address, coordinates and ground level of each site, is included in Appendix A. To facilitate negotiations with borehole owners, a fact sheet, explaining the purpose of the research and giving some of the results was prepared in English and in Afrikaans. A copy of the hand-out is given in Appendix B.

Preparation of borehole for monitoring

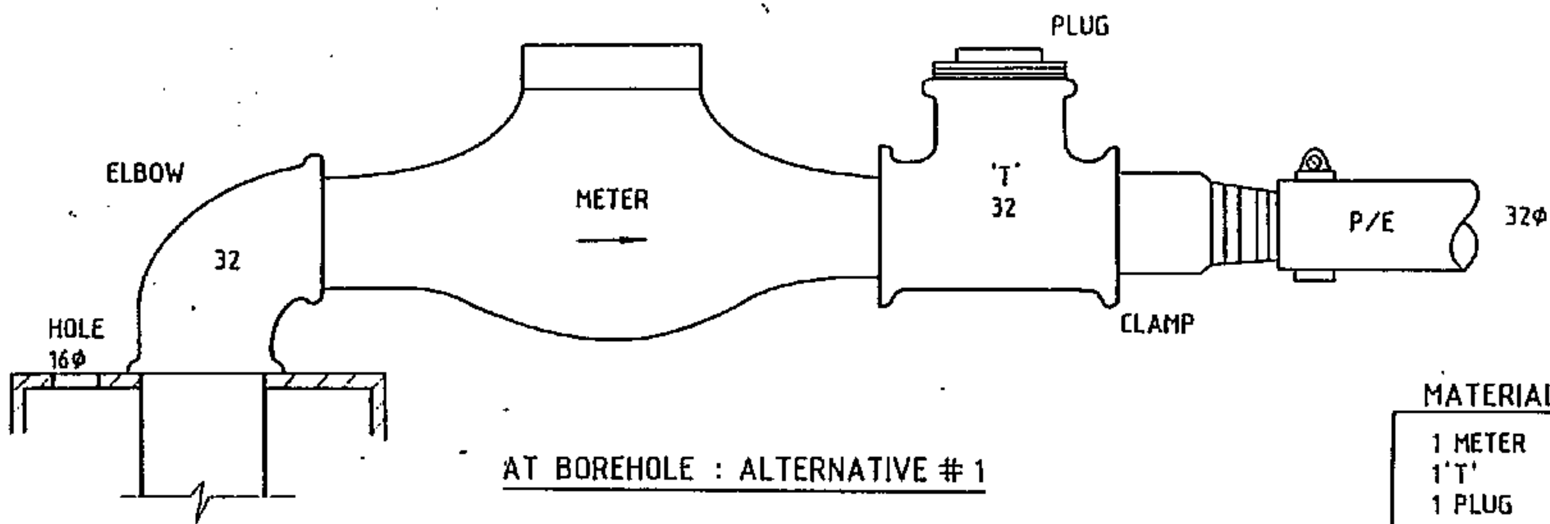
Most borehole installations use polyethylene pipe with a 32 mm outside diameter to reticulate the groundwater at the surface. A 25 mm water meter was installed in the main distribution pipe before any branches or off-takes. Where low density polyethylene (LDPE) pipe has been installed, the meter connections can be made using swage-nipples and clamps, otherwise the more expensive high density polyethylene (HDPE) Plasson fittings must be used.

Details for two types of meter installation are shown in Figure 2. Generally, the meter does not fit inside the box at the top of the borehole and a separate meter-box must be provided. Alternatively a short length of 150 mm diameter pipe, slotted to fit over the water pipe, may be used to protect and provide access to the meter dial. An end-cap or other suitable cover must be fitted to the top of the pipe, so that it is flush with the ground surface, to prevent accidents and ingress of soil, etc. Pitch fibre pipe and end-caps were found to be suitable for this purpose.

If no other access to the borehole was available for the insertion of the water level probe, a 16 mm diameter hole was drilled in the borehole cover-plate, mid-way between the edge of the plate and the riser pipe from the pump.

It is important to remember that in a project of this nature one is working on private property and care had to be taken to work neatly. Lawn and flower beds were restored after the meter installation was completed and in some cases the overall appearance of the borehole installation was improved.

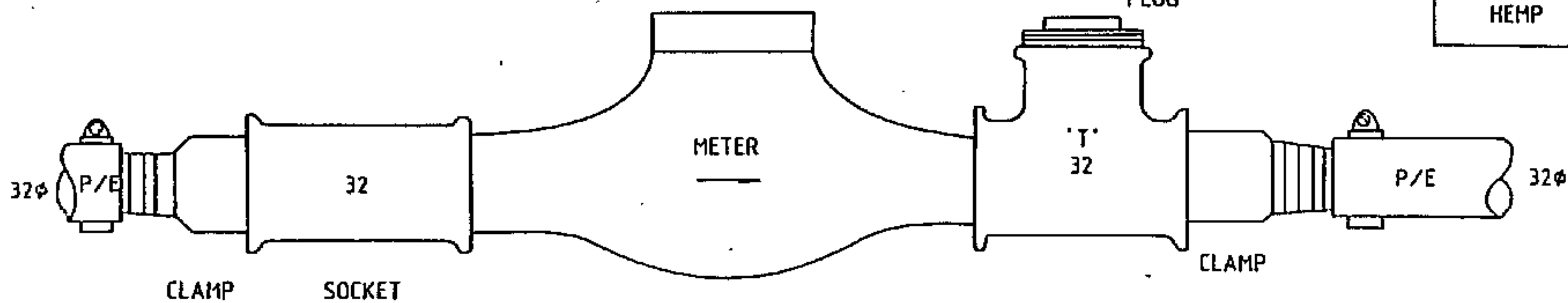
Sometimes it was necessary to convince the borehole owner that the water meter would not affect the performance of his supply system. A 32 mm water meter was found to visually satisfy most owners, even though a 15 mm water meter would have been adequate in many instances, as can be seen from the pressure drop curve for the Optima 2000 water meters given in Figure 3.



AT BOREHOLE : ALTERNATIVE # 1

MATERIALS # 1

1 METER
1 'T'
1 PLUG
1 SWAGE NIPPLE
1 CLAMP
HEMP



IN LINE : ALTERNATIVE # 2

MATERIALS # 2

1 METER
1 'T'
1 PLUG
2 SWAGE NIPPLES
2 CLAMPS
HEMP

NOTE: 1. MOST INSTALLATIONS USE 32 mm φ POLYETHYLENE PIPING AND ONE OF THE ABOVE METHODS CAN BE USED
2. THE 'T' IS REQUIRED FOR PRESSURE MEASUREMENT

FIGURE 2: BOREHOLE METER INSTALLATION ALTERNATIVES

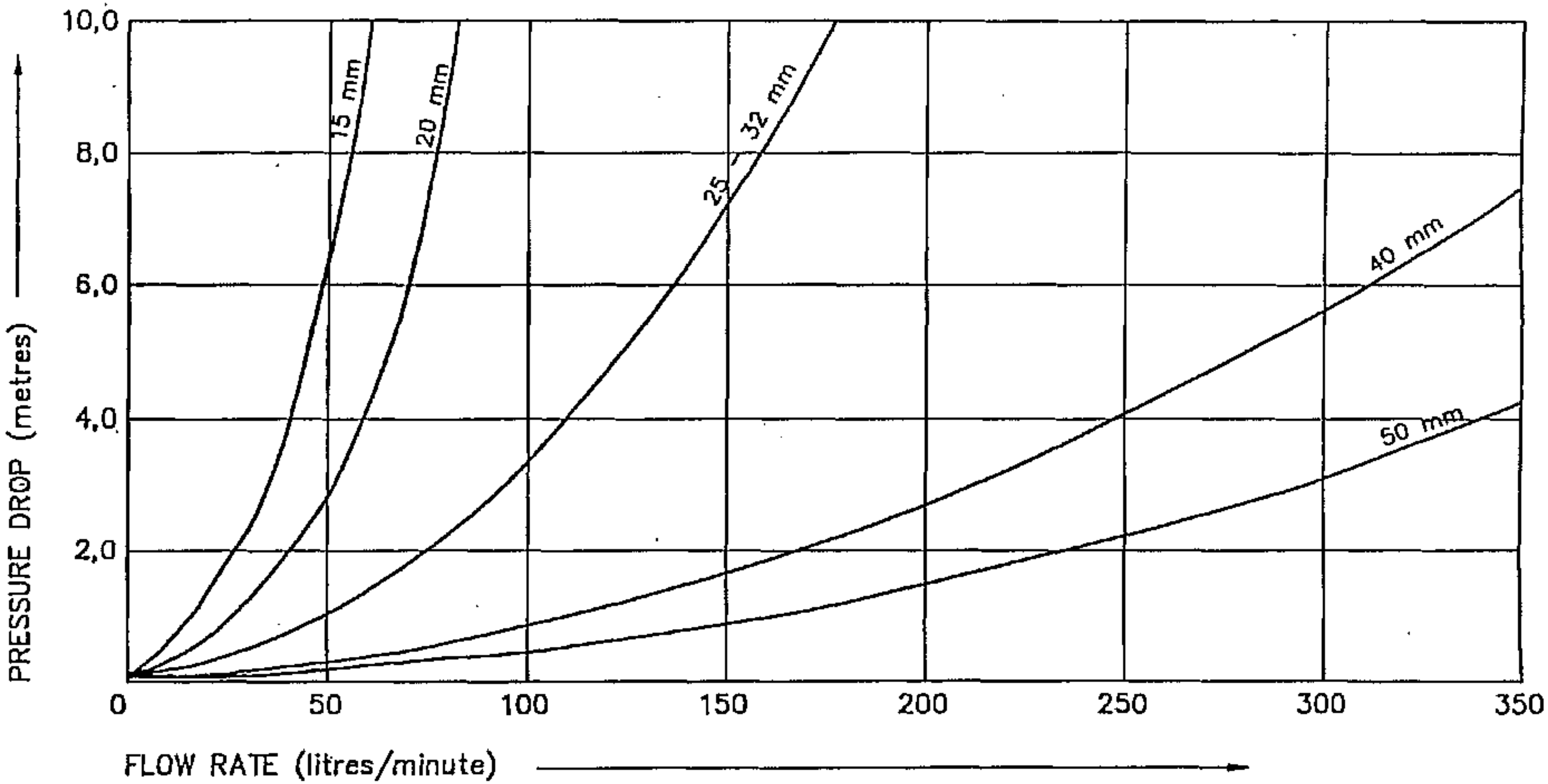


FIGURE 3: PRESSURE DROP ACROSS OPTIMA 2000 WATER METERS

In the initial stages of the project, one of the objectives was to collect data on pumping rates from boreholes and drawdown levels in the various areas. Since this was not strictly part of the aims of the project, the measurements were taken on an ad-hoc basis. If a borehole was being pumped when the monitoring team arrived at a site, the pumping rate would be measured by taking the time for a fixed volume of water to pass through the meter.

From the list of pumping rates, given in Volume 2, the average pumping rate was 40 litres/minute within a range from 92 litres/minute to 5 litres/minute. The highest rate of 92 litres/minute was measured at the Constantia Park primary school (BH15), but high rates were also measured at some of the residential properties.

Initially, it was thought that some of the data collection could be undertaken by the borehole owners themselves and a form was designed to enable them to record the water consumptions and related data. However the responses were erratic and it was accepted that the research team would be reponsible for the collection of all the data. The monitoring sites were split into two routes and a two-man team was assigned to each route.

<u>Monitoring of water consumptions and water table depths</u>

The maximum number of sites that could be monitored in one day was estimated from an analysis of the September 1987 monitoring run, which took two people 7 hours and 106 km of travel to complete the readings for 38 boreholes. About 3 minutes were required to take the readings at a site and the average travel speed over the route was estimated to have been 28 km/h, allowing for breaks and interruptions.

One hour was allowed for refreshment breaks. Interruption time depended on the number of occupants encountered during site readings, but could usually be restricted to under 30 minutes without being discourteous. A rough estimate of travel distance assumed 2,2 km per borehole, plus an overhead of 25 km.

From this information, the route for 50 boreholes was predicted to be 135 km long and would take 8,3 hours to complete, with breaks. The monthly monitoring runs were made as close to the beginning of a month as possible. The predictions regarding travel times and distances turned out to be reasonably accurate and it was possible to take a set of readings for each of the final set of 106 boreholes within one day, every month.

Minimum requirements for the monthly readings for each site were:

(a) Groundwater level to top of borehole coverplate, or other appropriate mark (to nearest centimeter)

(b) Borehole meter reading (to nearest litre)

(c) Municipal meter reading (to nearest litre)

(d) Time of readings (to nearest minute)

The monthly log-sheet was structured in the same sequence as the route order to facilitate the logging of the data. Back at the office, the data was transfered to a spreadsheet and then re-arranged in ascending order according to borehole number, before filing.

The data from the monthly log files were transferred to individual data files for each borehole site. From these, the final water consumption and water depth data files were prepared. Printouts of the files and corresponding graphs of the data are presented in Volume 2 : Data from the Research into Groundwater Abstraction in Pretoria. The data is also available on computer disks in ASCII, SUPERCALC and HARVARD GRAPHICS formats for the benefit of individuals or organisations who may want to process the data for their own purposes. To facilitate the further use of the data, an explanation of the ASCII file format is given in Volume 2.

The data files include the borehole site number identification followed by up to 51 records giving the date (day, month and year) at the end of the preceding period, the length of the period in days, the groundwater and municipal water consumptions in kilo-litres per day and the water table depth from ground level at the end of the period.

INDIVIDUAL SITE DATA

The coordinates and ground levels were determined for each borehole site from the 1:10 000 maps and orthophotos of Pretoria. This information was later used to evaluate the variations in water tables across Pretoria and develop longitudinal sections. In most cases the properties could easily be identified on the maps and photographs, however several sites were mis-placed on the map and consequently were initially given the wrong coordinates.

This problem could have been avoided if the erf numbers had been obtained when the monitoring site was established.

During the peak of the drought, properties with boreholes could be easily identified by their green lawns and Remote Sensing was considered for a time to be a possible means of identifying these properties. The best satellite image available was SPOT which in colour gave a resolution of 20 metres. Since most properties were in the order of 20 x 40 metres, it was realised that SPOT photographs would not be able to differentiate the "green-ness" of one property from another and the effects of the buildings and roads would influence the picture. Another problem with SPOT was the availability and cost of obtaining a current picture of the area since two adjacent photographs were needed to cover the project's area.

The use of a multi-spectral scanner was considered as a better alternative. The DADELIS system was mooted as well, but a project that could have provided scans of the target area never materialised.

In the end, aerial photography from a light aircraft was used, firstly to test the theory that properties with boreholes could be identified from the air, and secondly to obtain ground cover data for the monitored sites. It was found that good results could be obtained, provided the weather was clear with no wind or thermals.

To obtain the appropriate resolution, a 35 mm camera with an automatic winder and 200 shot reel was used at 1000 metres above the ground. The use of a low-wing aircraft, with no vertical vision, made photography of the correct sites difficult at this altitude.

Two methods of "hitting" the targets were tried. One involved the preparation of a detailed flight plan, with initial target points, bearings, speeds and the number of shots being identified for each run. The problem with this method was that any wind caused the aircraft to crab and drift off the flight path. Without vertical vision, it was not easy to establish that this was happening and the last targets in a run were often missed completely. The best results were obtained when the efforts of the navigator, pilot and cameraman were coordinated and the pilot was fully briefed beforehand.

The second method was a "hit and run" approach. Here the pilot banked around the target area until the target site was identified. The pilot then used his judgement, aided by the opinions of the navigator and cameraman to position the aircraft over the site in level flight. The cameraman would take three to four shots at the pre-determined rate as the aircraft passed the target. The results with this method were either very good or very bad.

The problem was that only the navigator knew exactly where the sites were located and what they looked like, in relation to the surrounding buildings and structures. Had the pilot and cameraman had the same knowledge, the efficiency of the operation would have been much better.

From the aerial photographs, the sites were plotted and the total area of the property was measured. The areas of each type of identifiable ground cover were measured according to the following classification;

1) Main house roofing

2) Out buildings

3) Driveways

4) Pool area and surrounding paving

The difference between the sum of these areas and the total area was assigned as potentially irrigable garden area. Details for 29 of the monitored sites are presented in the tables below. Garden areas ranged from 469 m^2 to 3054 m^2 for individual houses. The lowest ratio of garden area to total area was 0.23 for a townhouse complex while the largest ratio was 0.79 for a house in Narvors. For houses, the average ratio was 0.667 with a standard deviation of 0.095 .

TABLE 1 - GROUNDCOVER AREAS (SQUARE METRES)

BOREHOLE No.	19	2	3	4	31	7	32
ROOFED AREA	206	231	286	421	204	159	373
OUT-BUILDINGS	0	3	12			57	23
DRIVEWAYS	78	77	119	137	111	60	50
POOL & PAVING	64	62	103	103		46	132
TOTAL AREA	961	965	989	1155	1151	1185	1192
GARDEN AREA	613	592	469	494	842	864	615
GARDEN %	64	61	47	43	73	73	52

BOREHOLE No.	23	24	22	28	5	44	47
ROOFED AREA	181	218	244	332	382	288	254
OUT-BUILDINGS	51	53	65	0	23	55	93
DRIVEWAYS	195	25	0	150	191	149	110
POOL & PAVING	0	74	106	81		154	0
TOTAL AREA	1203	1203	1277	1315	1426	1489	1489
GARDEN AREA	776	833	862	751	830	842	1031
GARDEN %	65	69	68	57	58	57	69

TABLE 1 - (Continued)

BOREHOLE No.	6	40	38	37	29	41	42
ROOFED AREA	446	239	365	379	356	327	489
OUT-BUILDINGS	0	90	0	36	200	97	0
DRIVEWAYS	0	164	112	189	80	141	104
POOL & PAVING	59	0	135	241	0	218	0
TOTAL AREA	1754	1968	2006	2250	2254	2348	2401
GARDEN AREA	1249	1475	1395	1405	1618	1565	1808
GARDEN %	71	75	70	62	72	67	75

BOREHOLE No.	35	39	1	18	17	25
ROOFED AREA	319	466	332	566	488	525
OUT-BUILDINGS	188	0	97	59	107	21
DRIVEWAYS	99	120	255	156	194	136
POOL & PAVING	181	0	0	66	56	150
TOTAL AREA	2602	2817	3250	3250	3251	3887
GARDEN AREA	1815	2231	2566	2404	2406	3055
GARDEN %	70	79	79	74	74	79

TABLE 2 - Groundcover Summary for Residential Houses

	GRAND TOTAL SQ.METRES	PERCENT
ROOFED AREA	9075.2	17.7
OUT-BUILDINGS	1330.1	2.6
DRIVEWAYS	3200.4	6.3
POOL & PAVING	2030.0	4.0
GARDEN AREA	35404.5	69.4
TOTAL AREA	51040.2	100.0

TABLE 3 - Groundcover for Group Housing

	COVER AREA - SQ.METRES WOODGLEN	VILLA SAVANHA
ROOFED AREA	2302.8	11589.3
OUT-BUILDINGS	.0	.0
DRIVEWAYS	2156.1	6566.9
POOL & PAVING	.0	58.3
TOTAL AREA	5791.9	35001.9
GARDEN AREA	1333.0	16787.4
GARDEN %	23.0	48.0

DETERMINING THE NUMBER OF PROPERTIES WITH BOREHOLES

The Municipality's 1:10 000 map of Pretoria showed the positions of many of the registered boreholes in the city. Unfortunately, the map record was not kept up to date and could not be used to establish the number of properties with boreholes. A survey in any area showed that there were considerably more boreholes in existance than indicated by the map. It was also found that many borehole owners did not register their boreholes with the Municipality.

It was realised that a physical count of all the properties in Pretoria, by either ground or air based techniques, was not feasible. The number of properties with boreholes was therefore estimated by applying a stratified cluster sampling technique.

The Pretoria municipal area was divided into the 9 strata shown on the map in Figure 4. The strata differ mainly in a spatial sense, but this takes into account the geographic, geological and demographic differences to a large extent. Clusters of approximately 100 properties were selected within the strata. The clusters were selected so that their geographic distribution was as even as possible and approximately 10% of the total number of properties in the strata would be included in the clusters. The new 1:15 000 colour maps of Pretoria were very useful in preparing the location maps and property lists that were used in the field by the enumerators.

The enumerators visited each property in the clusters and determined if groundwater was used from a private borehole on the property. Usually there are sufficient signs to confirm the presence of an active borehole. These include the visibility of switch boxes, borehole covers, automatic sprinkler systems, a sign on the gate and a thriving garden. In a certain number of cases, the choice was not clear and where possible the owner was asked.

The techniques used by the enumerators were not fool-proof, and duplicate enumerations were done in small areas to check the effectiveness of the methods. It was found that the proportion of the determinations that could be wrong was about 2 per 100, or 2% error, which is considered to be relatively small.

The results of the exercise and comments on the theory are given in the report by Van der Linde and Elphinstone. The approach used could have been improved, but the added accuracy may not have justified the additional effort of clustering the entire city and then selecting sample clusters.

It should be noted that it would probably have been more useful to select the monitoring sites from within the sample clusters. Unfortunately, by the time the stratification and cluster sampling was done, the monitoring sites had already been established, according to a different stratification of the city, based on obtaining a certain number of monitoring sites within a 4x4 km grid system.

Should the project be implemented elsewhere, it is recommended that the stratified cluster sampling technique be used to select the monitoring sites and the sample clusters for determine the number of properties with boreholes.

MUNICIPAL WATER CONSUMPTION FOR PROPERTIES WITHOUT BOREHOLES

The results from the cluster sampling exercise enabled a large number of properties without boreholes to be identified. A random sampling of these was used to prepare a list of 439 properties for which water consumption records were extracted by the Municipality.

For each property in the list, the Municipality supplied the monthly water consumption in kilolitres for the period February 1987 to January 1990. From the data, the average daily municipal water consumption for an individual property was 1.017 and 1.066 kilolitres per day in 1988 and 1989 respectively.

This information was compared to the results obtained for properties with boreholes to draw conclusions on the effect of groundwater abstraction on municipal use.

If only the total water consumption for all residential properties is available from the municipality, an alternative method of determining the difference in municipal water consumption between properties with boreholes and those without boreholes can be used. In 1988 it was estimated that there were 31 255 properties with a borehole and 43 341 properties without a borehole and the average municipal water consumption for all these properties was 875 litres per day. Based on these 1988 data, the proportion of properties with a borehole was 0.419 but this figure was later revised to 0.375 following further sampling.

The external water use for a house without a borehole was determined on the assumption that the average internal water-use is the same for all houses and is not influenced by the presence of a borehole. A value for the average internal water-use was obtained from the data on houses with boreholes.

Proportion of properties with a borehole	p	=	0.419
Proportion of properties without a borehole	q	=	0.581
Average municipal water consumption per house	x	=	875 litres
Internal water use for average house	y	=	763 litres

Let the external water-use for properties without boreholes = z

Then $$z = (x - y) / q \qquad (1)$$

where $$x = (p * y) + (q * y) + (q * z) \qquad (2)$$

Using the data given above, the value of z was found to be 193 litres per day, based on 1987/1988 data. From the sample of 439 houses without boreholes, the latest estimate based on 1988/1989 data is 210 litres per day. The difference is only 8%.

DETERMINING THE VARIATION IN GROUNDWATER LEVELS

The distance from the surface to the water level in the borehole was measured each month at all the monitored sites. The measurement was taken as a reasonable indication of the depth of the water table below the surface. Each monitoring team used a special tape with a water level probe attached to the end. A light on the tape drum indicated when the probe was in contact with the water in the borehole. The probe was 15 mm in diameter and was lowered down the borehole through a 16 mm hole drilled in the borehole cover plate. The water level was read to the nearest 0.01 metres.

On most occasions, a borehole would not be in use when the team arrived to take a reading. If the borehole was in use, the water depth would be logged and a note made on the log-sheet that the pump was on. Since it was uncommon for all the boreholes in a group to be pumping at the same time, the water level measurements at other boreholes in the group were used as an indication of the depth of the water table below the surface.

A full set of graphs, showing water levels fluctuations with time for each site, are contained in Volume 2 . However some features of these graphs require explaining and this is done by using selected examples from the set of graphs.

The data for site BH 67 in Pretoria North is shown in Figure 5. The graph shows the groundwater table to be very steady. The level has dropped from 17.65 m in January 1988 to 18.33 m in January 1990. This could be a cause for concern, but then the water table is relatively shallow.

The data for site BH 61 in Dorandia, 2.5 kilometres North-west of BH 67, is shown in Figure 6. The graph shows minor seasonal changes in the water table. A calculation reveals that the level of the water table at both sites is approximately 1222 metres above sea level. The "spike" in August of 1988 indicates the pump was on and the water table was drawn down by over 10 metres during pumping.

The data for site BH 25 on the Silverton ridge is shown in Figure 7. The graph indicates that when the recharge part of the cycle occurs, the water table does not rise above the level which is 50 metres below the surface. This level is interpreted as the overflow level of the aquifer. Note that in the seasonal cycle, **recharge** occurs between March and July and **mining** of the aquifer occurs from August to March of the following year.

The term **mining** is used here to indicate that the water table continues to drop below the overflow level as groundwater is extracted, similar to the operation of a surface impoundment during the dry season. If there is no replenishment of the resource, the term becomes equivalent in meaning to the mining of ore bodies, where the result is a void that may eventually be filled with something else.

An interesting feature of the groundwater tables is that there appears to be a base recharge rate, which manifests itself in autumn when the rates of garden watering and evapo-transpiration are at their minimums. The trend is reversed at the end of winter by the warm weather before the rains and sharp drops in the water table tend to occur at this time. The onset of the rains causes another reversal in the cycle and recharge occurs rapidly. Figure 7 show the response of the aquifer to recharge from good rains in September/October 1988 of 130 mm and heavy rains in February 1989 of 205 mm.

The data for site BH 8 in Queenswood is shown in Figure 8. The graph exhibits a seasonal trend in the water table, a maximum or over-flow level 11.9 m below surface and a draw-down to 20.6 m when pumping occurred in July 1988. Another dip in the water table in October was not attributed in the log-sheet to pumping at the site, but it is possible that other boreholes could have been in operation close-by and were reponsible for the lower water table.

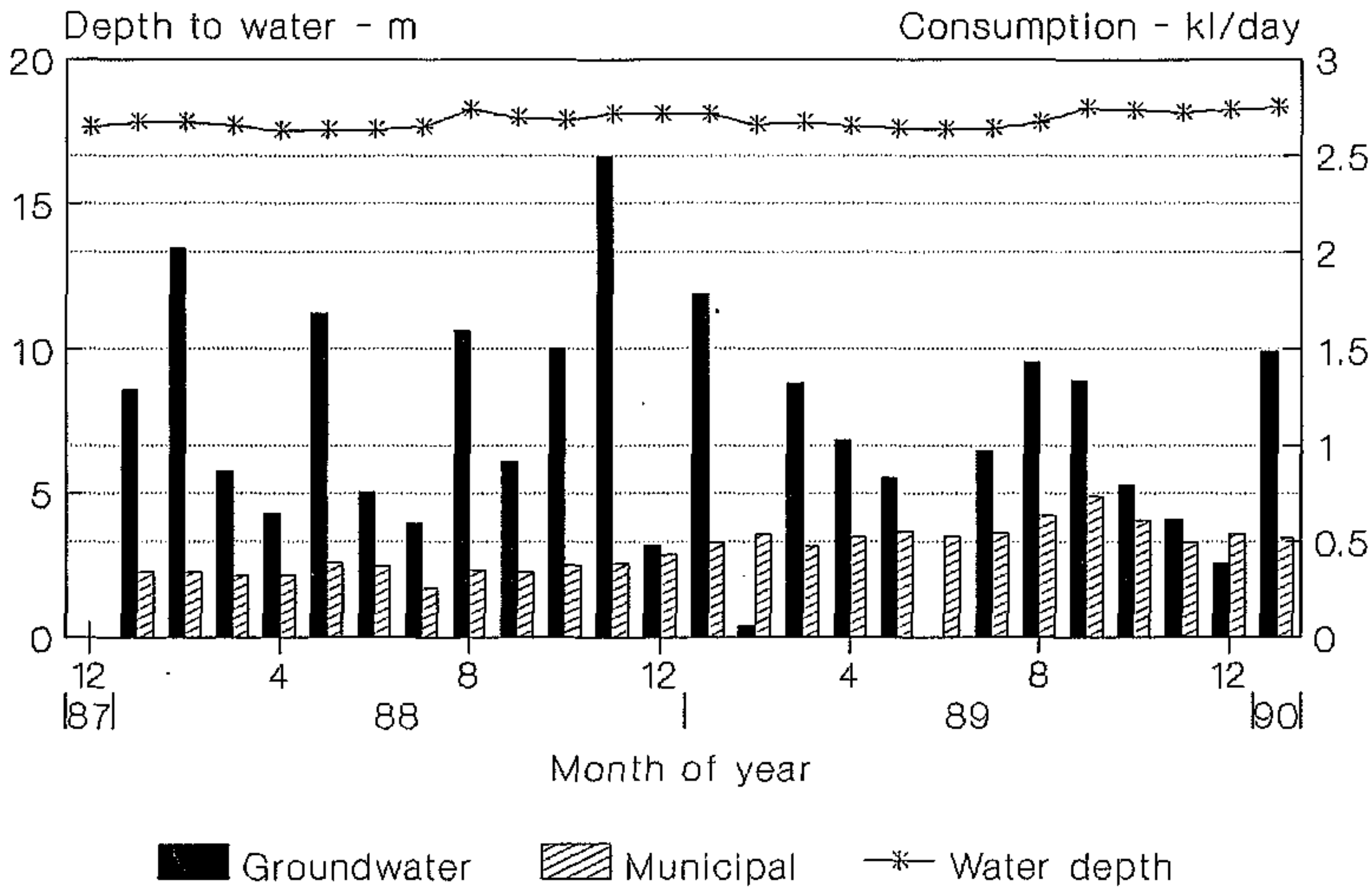


FIGURE 5, GROUNDWATER DATA FOR SITE BH67
WATER CONSUMPTION AND WATERTABLE DEPTH

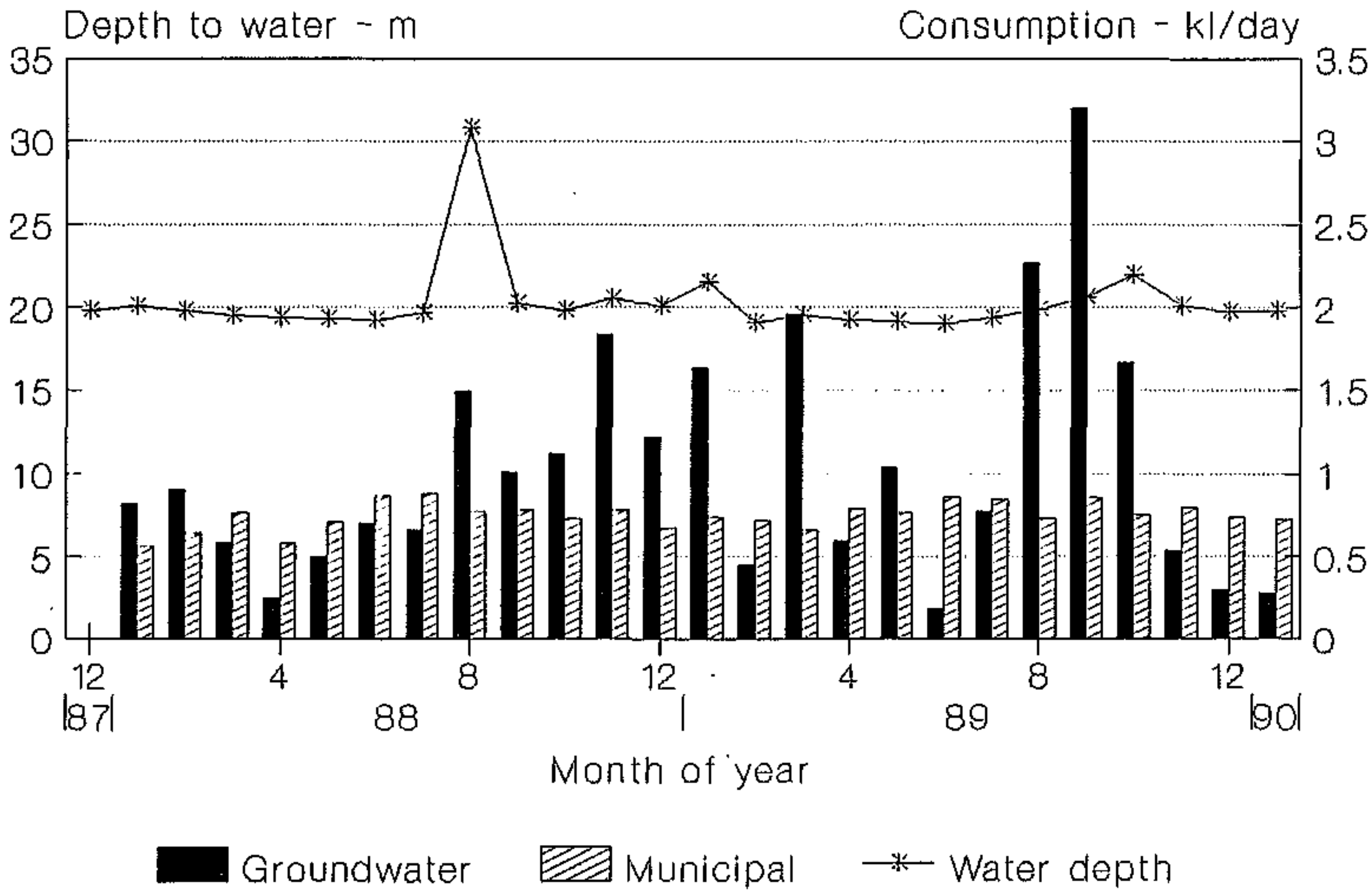


FIGURE 6, GROUNDWATER DATA FOR SITE BH61
WATER CONSUMPTION AND WATERTABLE DEPTH

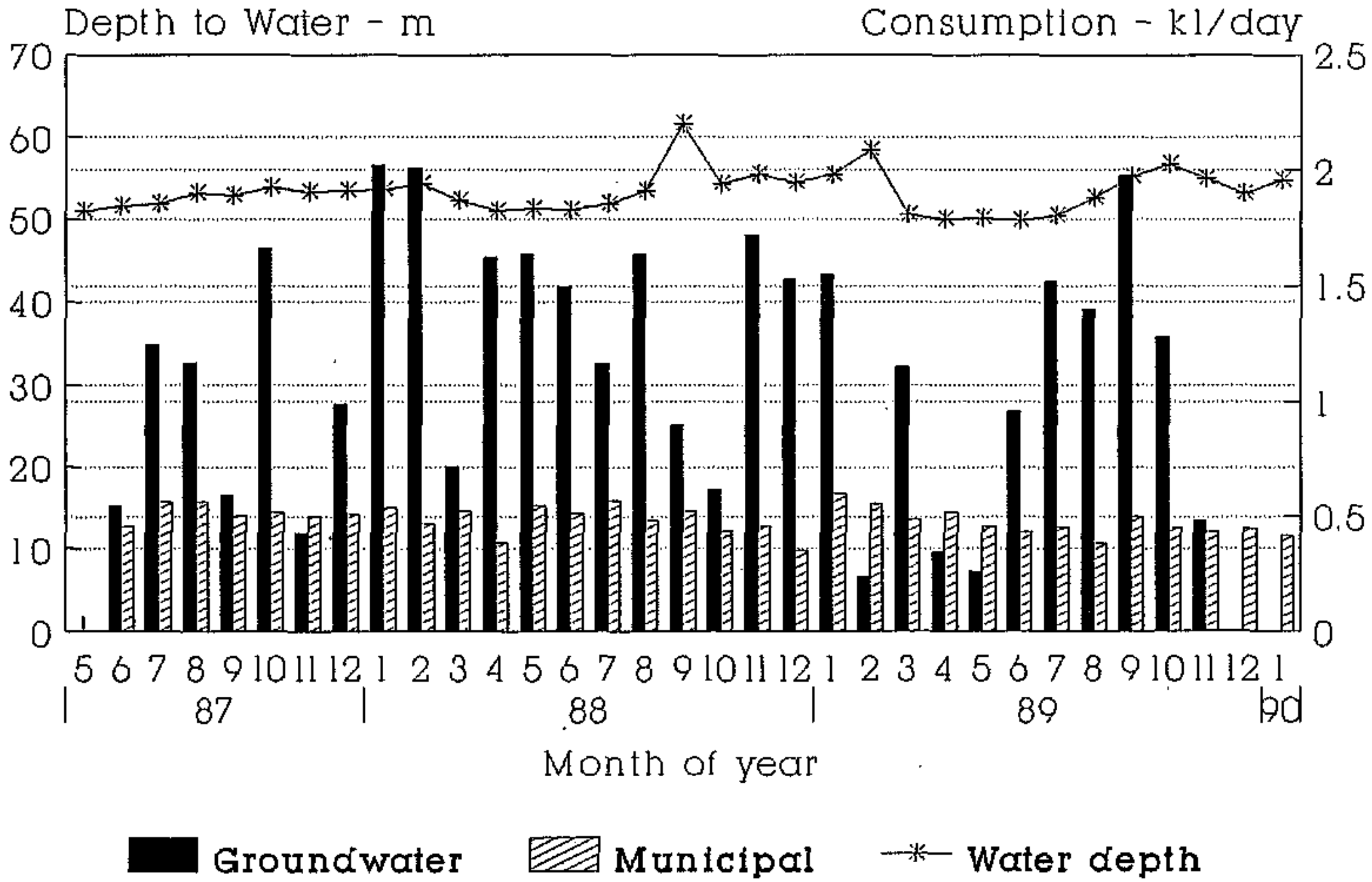


FIGURE 7, GROUNDWATER DATA FOR SITE BH25
WATER CONSUMPTION AND WATERTABLE DEPTH

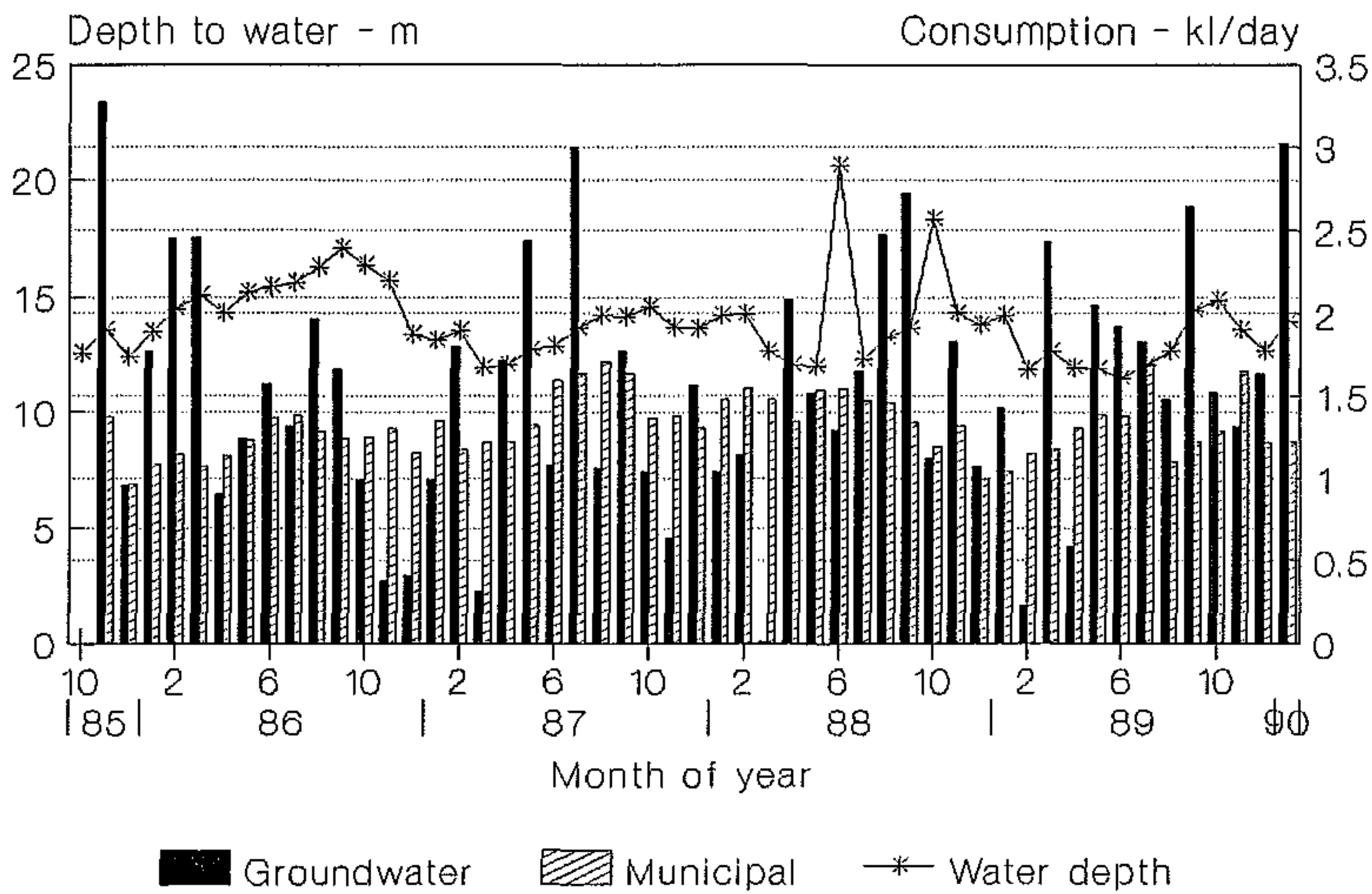


FIGURE 8, GROUNDWATER DATA FOR SITE BH 8
WATER CONSUMPTION AND WATERTABLE DEPTH

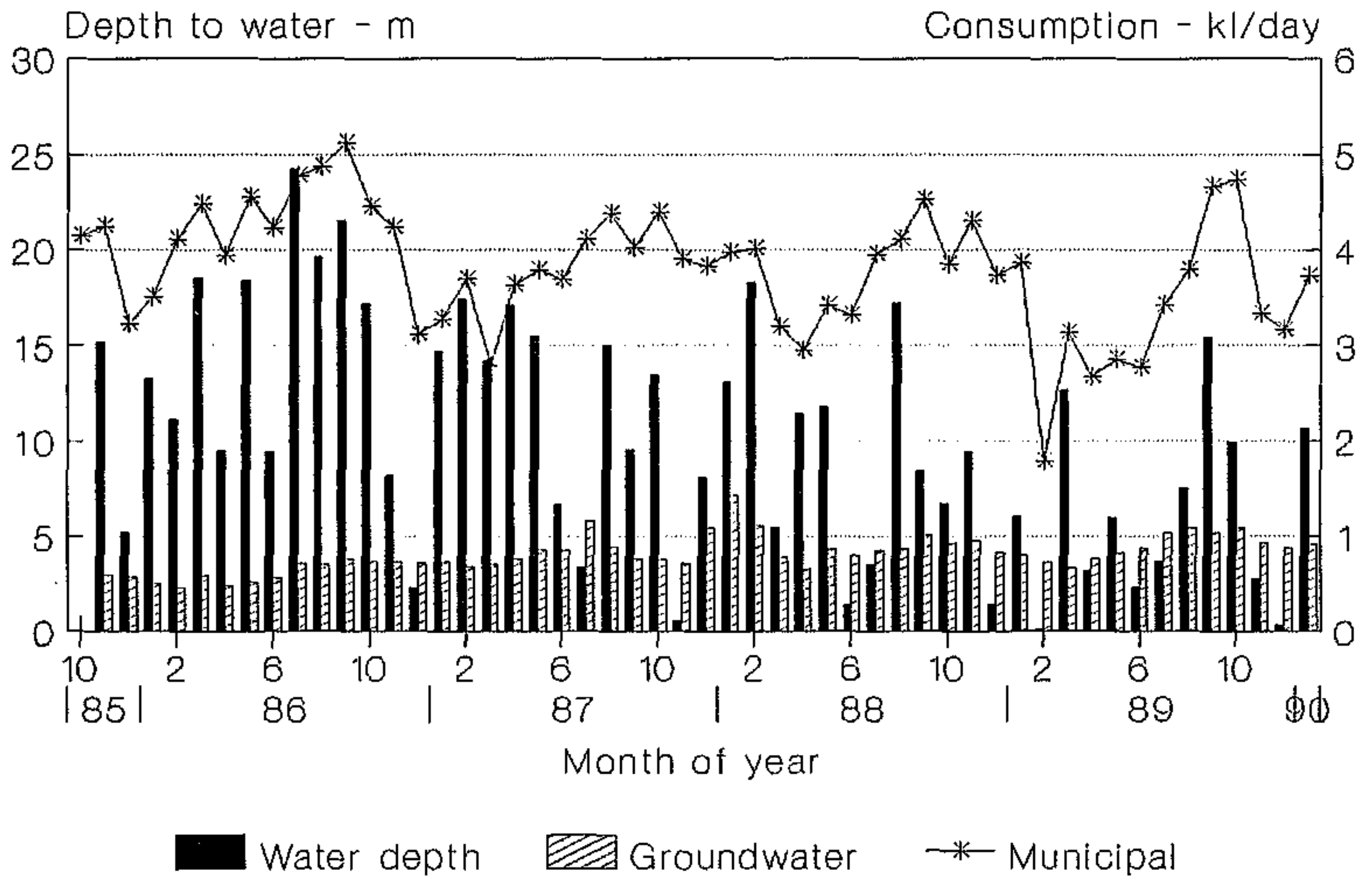


FIGURE 9, GROUNDWATER DATA FOR SITE BH 2

WATER CONSUMPTION AND WATERTABLE DEPTH

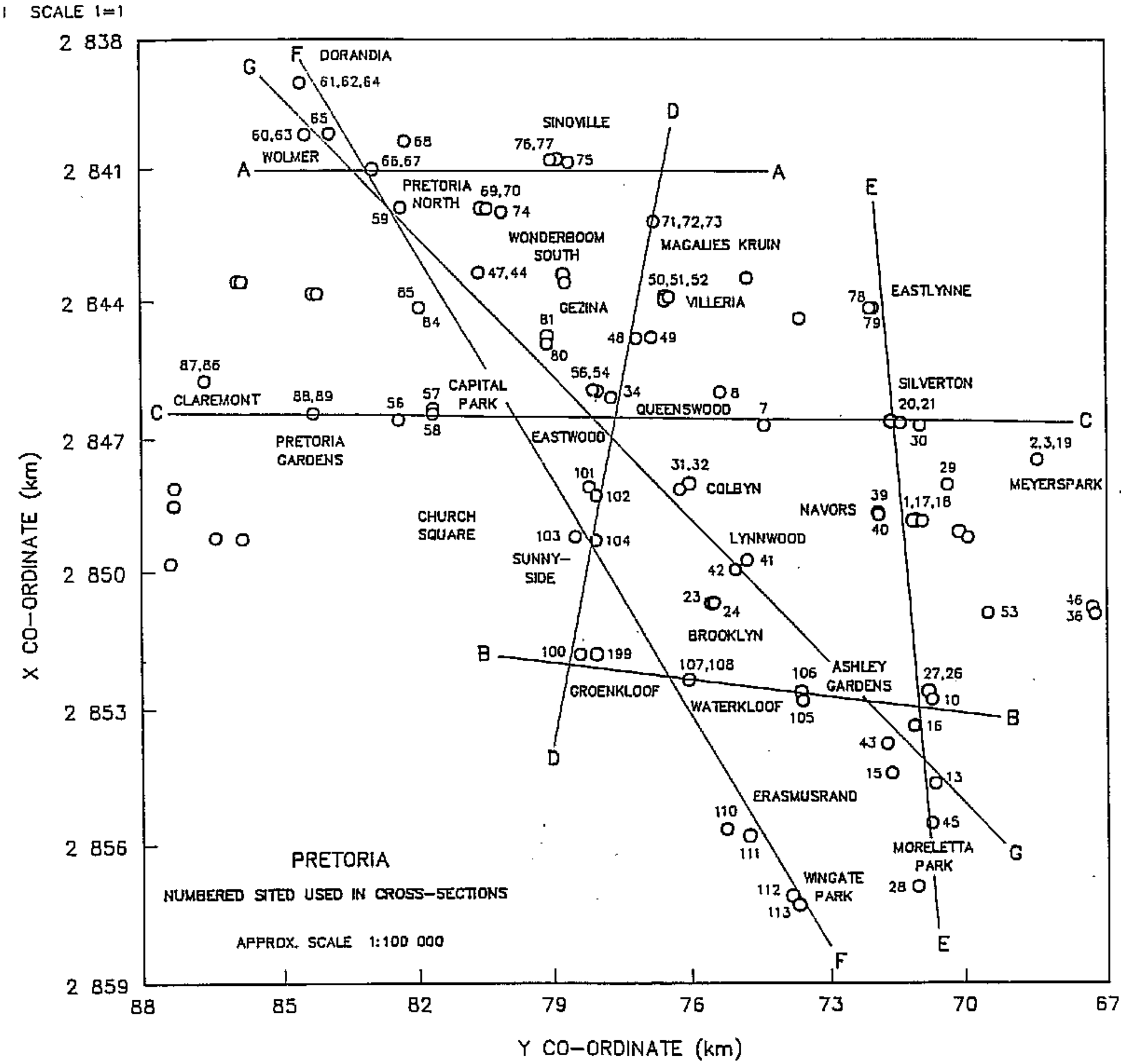


FIGURE 10: PLAN OF MONITORED BOREHOLE SITES WITH ALIGNMENTS FOR WATER-TABLE CROSS-SECTIONS

DBT87-8 50-C-4-2056/8 SCALE 1=1

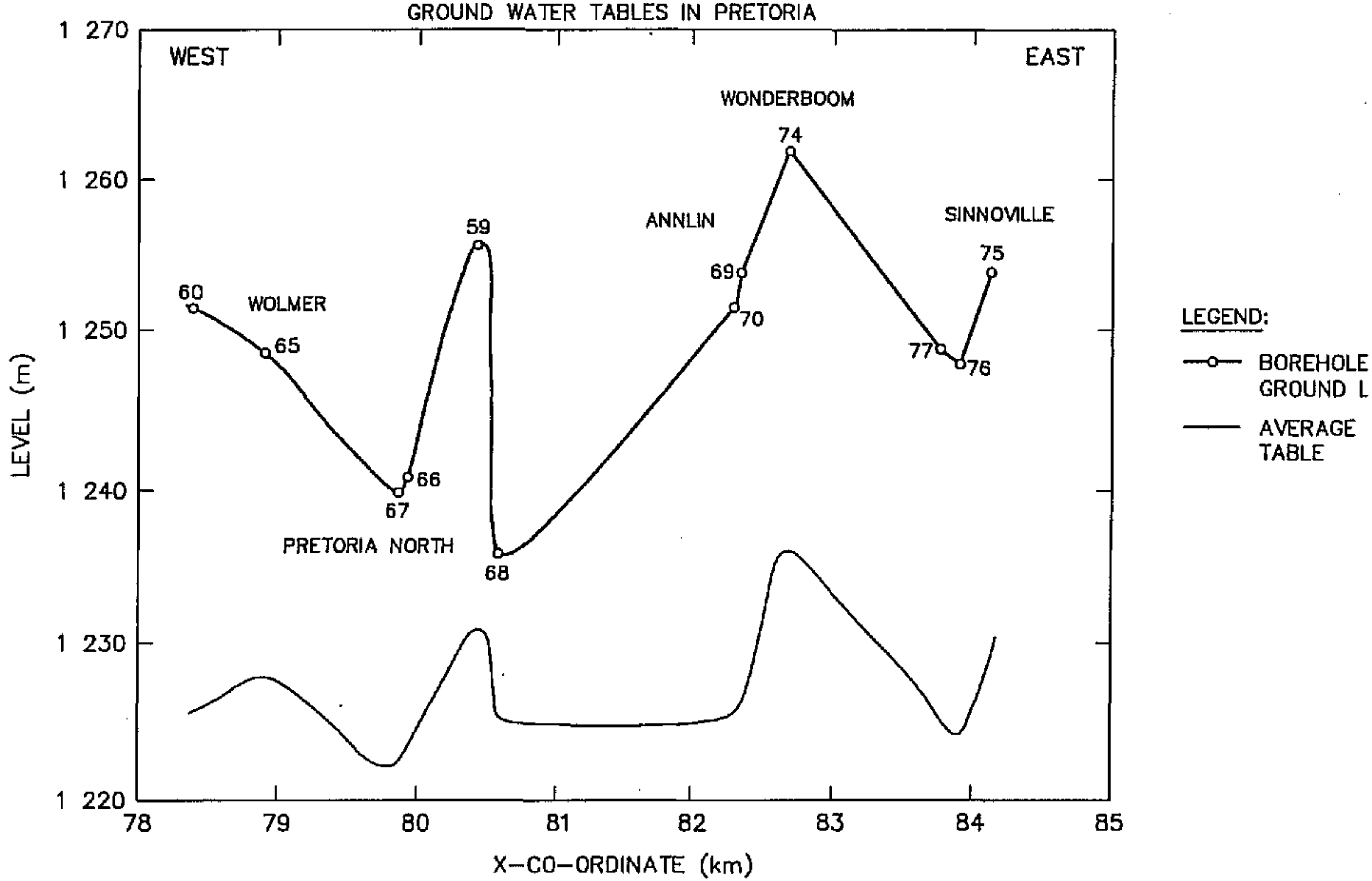


FIGURE 11: SECTION ON A-A FOR LINE x = 2 841 (km)

DBT87-2 50-C-4-2056/2 SCALE 1=1

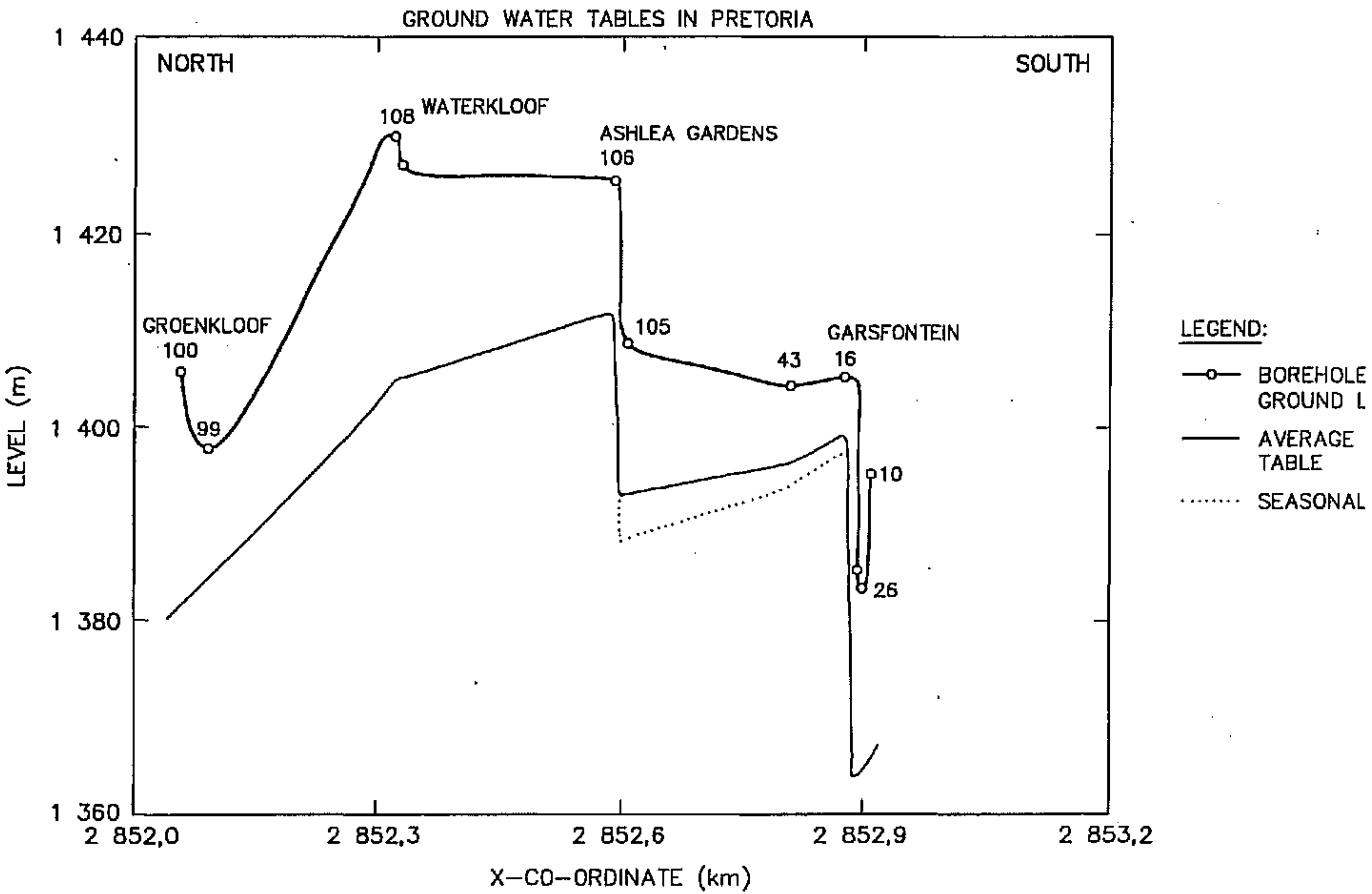


FIGURE 12: SECTION ON B-B FOR LINE y = 25 747 - 9,0x (km)

DBT87-5 50-C-4-2056/5 SCALE 1=1

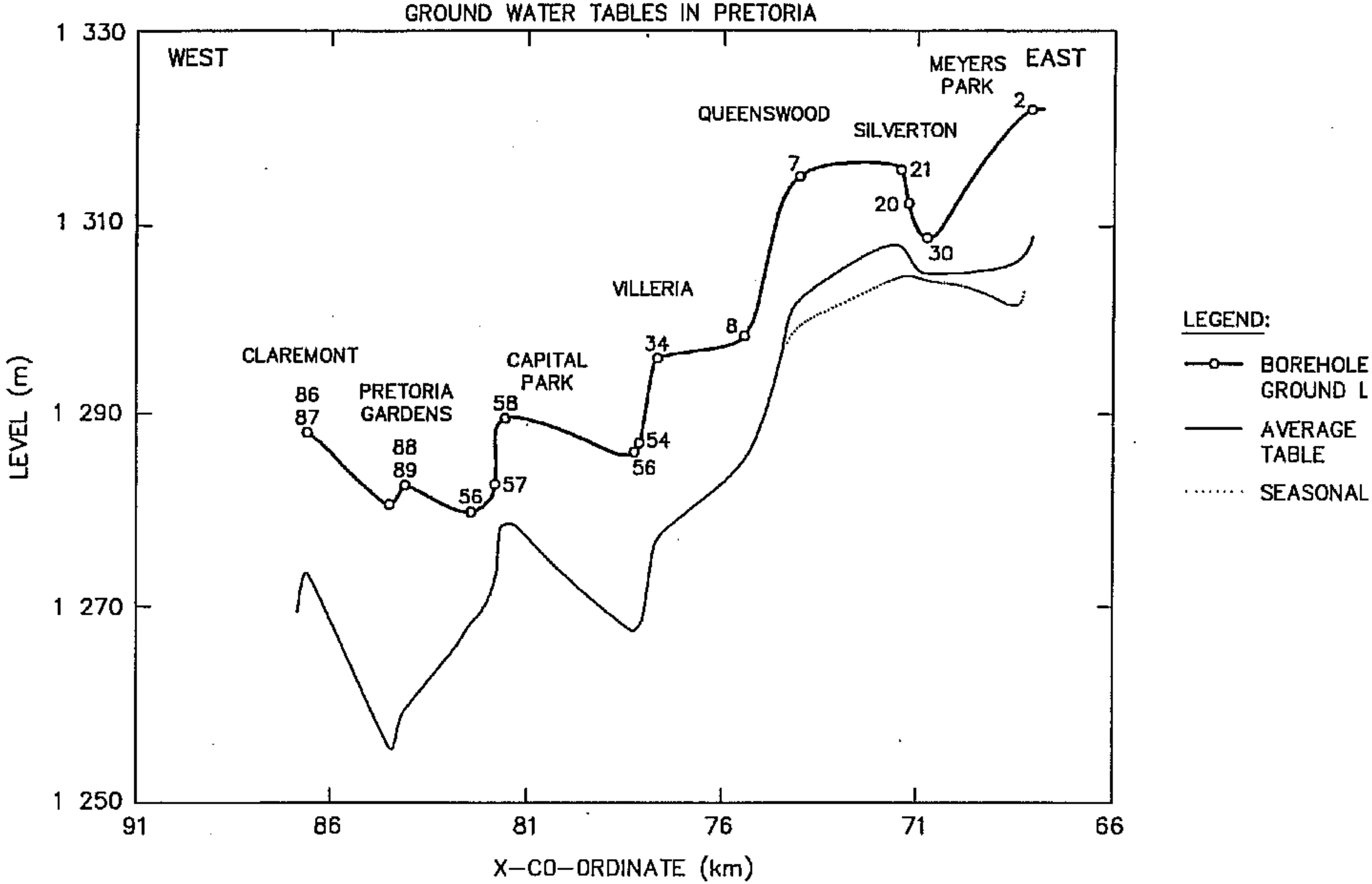


FIGURE 13: SECTION ON C-C FOR LINE x = 2 846,5 (km)

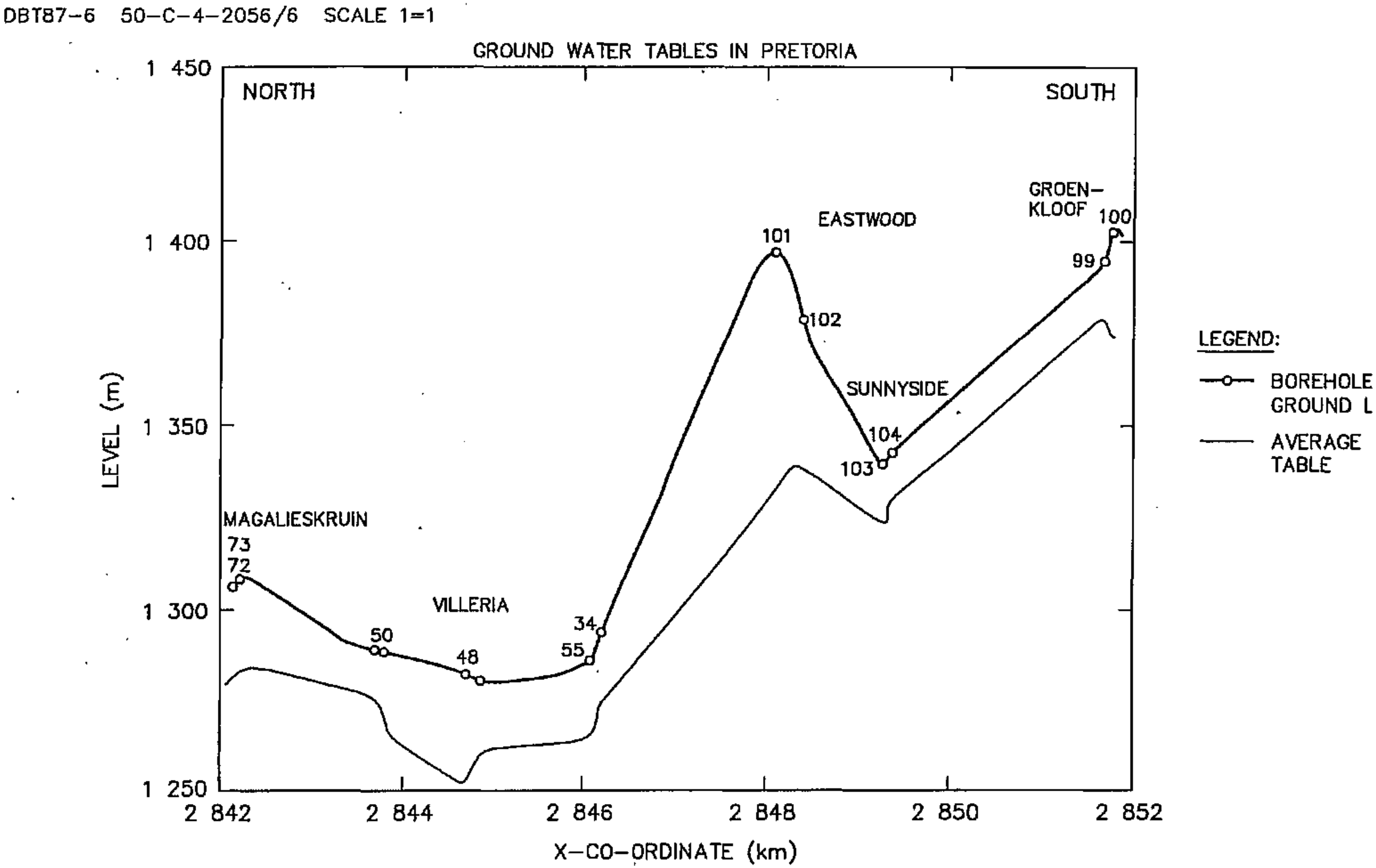


FIGURE 14: SECITON ON D-D FOR LINE $y = 491{,}6 - 0{,}2x$ (km)

DBT87-3 50-C-4-2056/3 SCALE 1=1

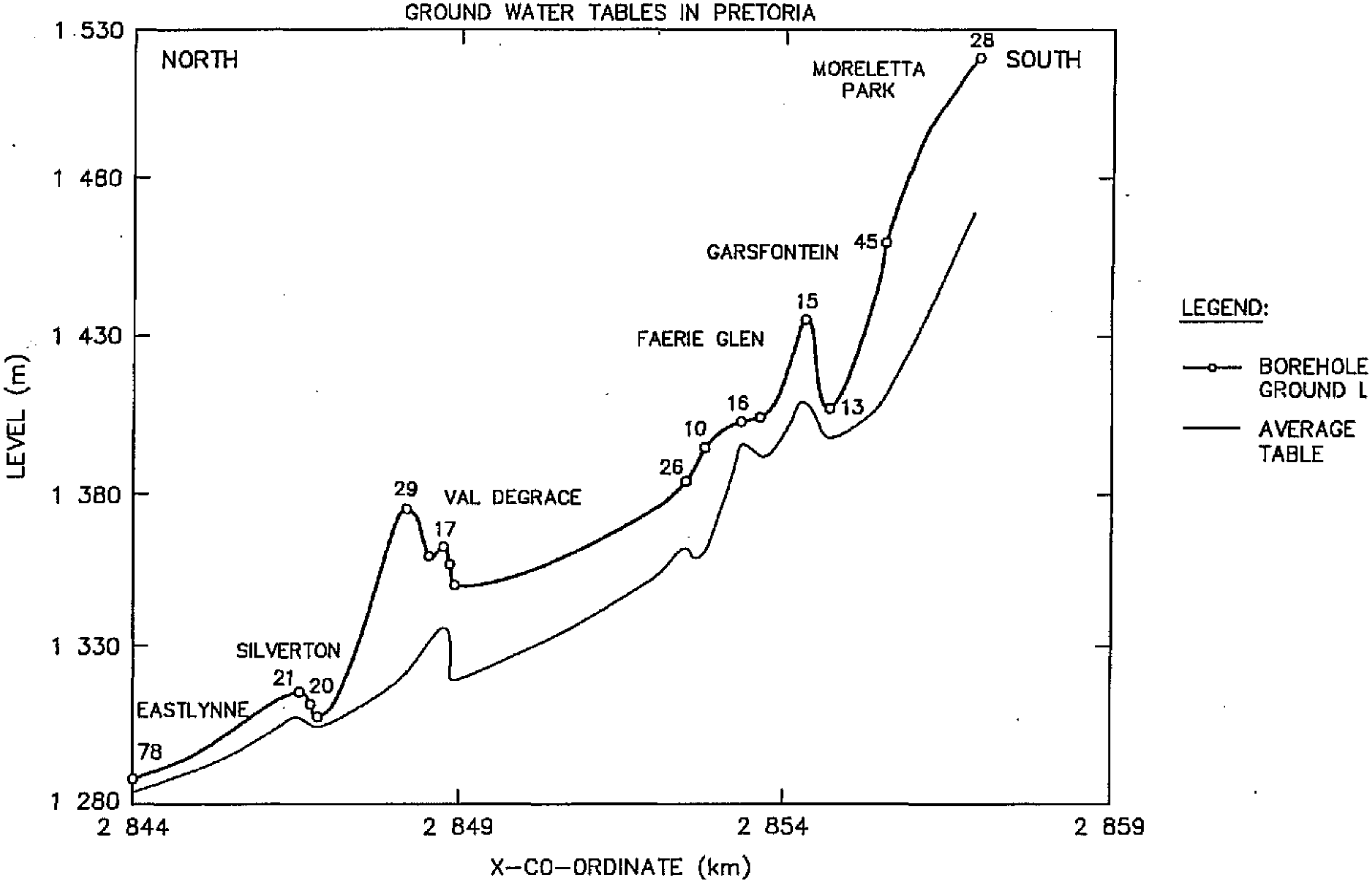


FIGURE 15: SECTION ON E-E FOR LINE y = −330,937 − 0,09x (km)

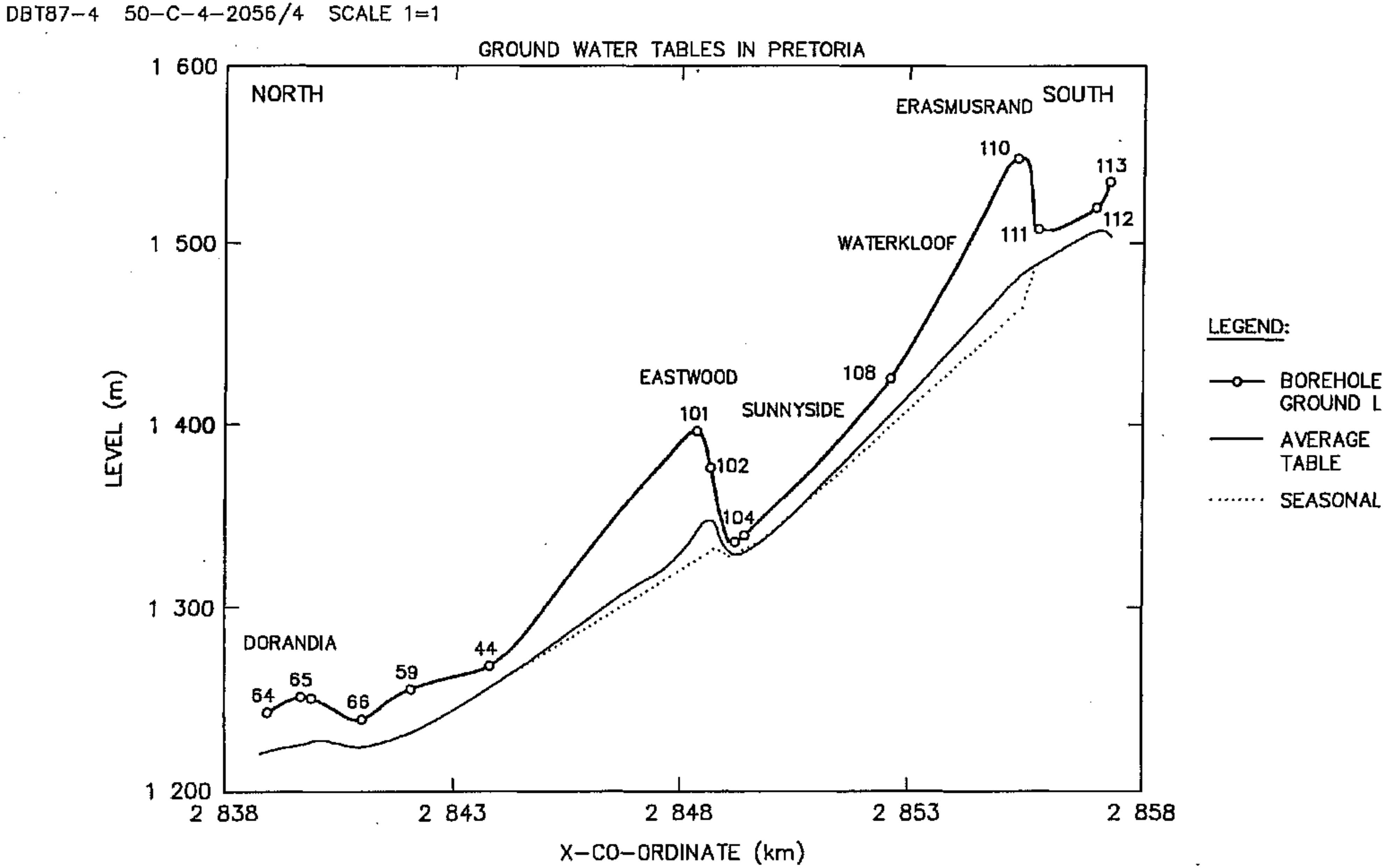


FIGURE 16: SECTION OF F-F FOR LINE y = 1 787,8 − 0,6x (km)

DBT87-7 50-C-4-2056/7 SCALE 1=1

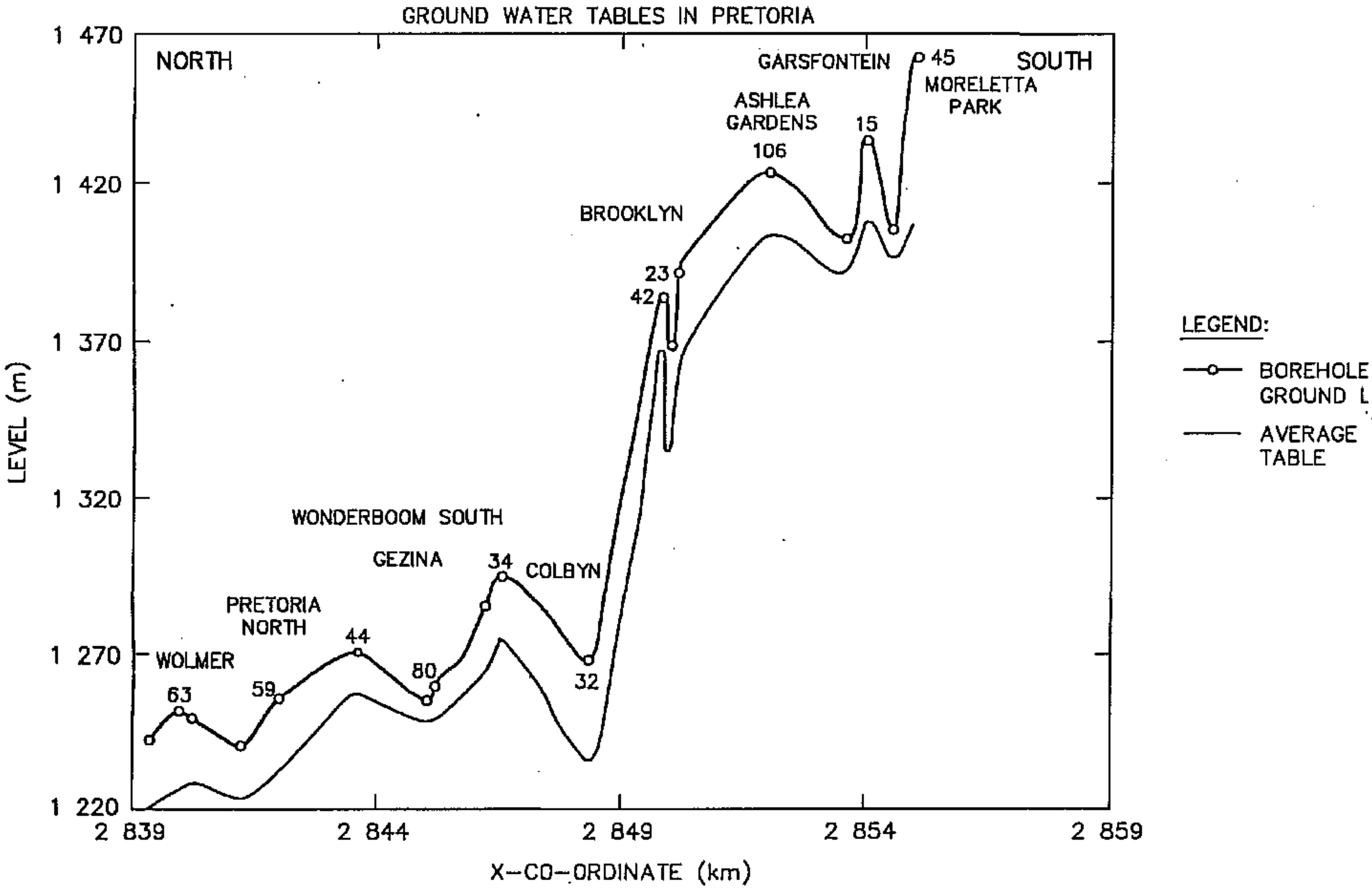


FIGURE 17: SECTION ON G-G LINE y = 2 809,458 - 0,96x (km)

Finally, the data for site BH 2 in Meyerspark is shown in Figure 9. The graph illustrates a seasonal trend, but with a large variation of up to 10 metres in the depth to the water table. Another feature is an apparent overcharging of the aquifer in February 1989, following the heavy rain noted above. The effect, also observed in BH 3, did not last long and suggests that the aquifer is relatively small.

WATER TABLE VARIATION ACROSS THE CITY

Figure 10 is a plan showing the monitored sites and the alignments of seven cross sections. The cross sections, given in Figures 11 to 17, show the approximate ground level along the section and the average water table.

The borehole sites used to develop the water tables for the cross sections do not all lie on the line and the average water table was interpolated from the data for the boreholes depending on the normal distance from the borehole to the line. A plot was made for the water table at intervals of three months. These were overlaid and the average taken as representing the water table.

In most cases it was difficult to identify the seasonal variation due to the scale of the cross sections, except for sections B, C and F, where it is shown as a dotted line. The east-west sections, A-A and B-B are not true reflections of the ground and water level profile, because of the use of boreholes that lie lower to the north and higher to the south of the line, but whose levels have been applied to the sections.

Section C-C indicates a drop in the water table of 50 metres over a distance of 19 kms from East to West (0.00263 slope). By contrast from South to North along section E-E the water table drops 150 metres in 12 kilometres (0.0125 slope).

A feature of the North-South sections is that recharge appears to occur at the ridges. This could be due to storage of rainfall which infiltrates relatively easily into the rocky areas, or a feature of the geology which allows groundwater to percolate along strata from higher zones until they outcrop at the surface. The springs at the tops of the sandstone outcrops in the Uitenhage artesian system would be an example of this phenomenon.[3:p46]

Unfortunately, figures 11 to 17 are of limited accuracy and are useful only for obtaining a general idea of the variations in the water table across Pretoria. A more useful approach may be to generate a three dimensional plot from the data for each month of the record. This could reveal a better dynamic picture of how the water table behaves in response to the seasonal influences.

RECHARGE OF GROUNDWATER

Rainfall and temperature data were collected for 8 stations across Pretoria. The data are tabulated in Appendix C. Figure 18 shows the average monthly rainfall with the maximum and minimum temperatures.

It was found that the monthly rainfall figures for the eight stations did not differ significantly and the average monthly rainfall could be used to represent the rainfall in any area of Pretoria.

A statistical analysis undertaken on the data collected up to May 1988 indicated that rainfall accounted for approximately 30% of the variation in groundwater abstraction. A model to predict groundwater use was formulated as;

$$WATER = 2015 + 105.7*(TEMP - 25.11) - 8.95*(RAIN - 63) \qquad (3)$$

Where WATER = average groundwater use in litres/month/property
TEMP = maximum average temperature for month in degrees C
RAIN = monthly rainfall in mm

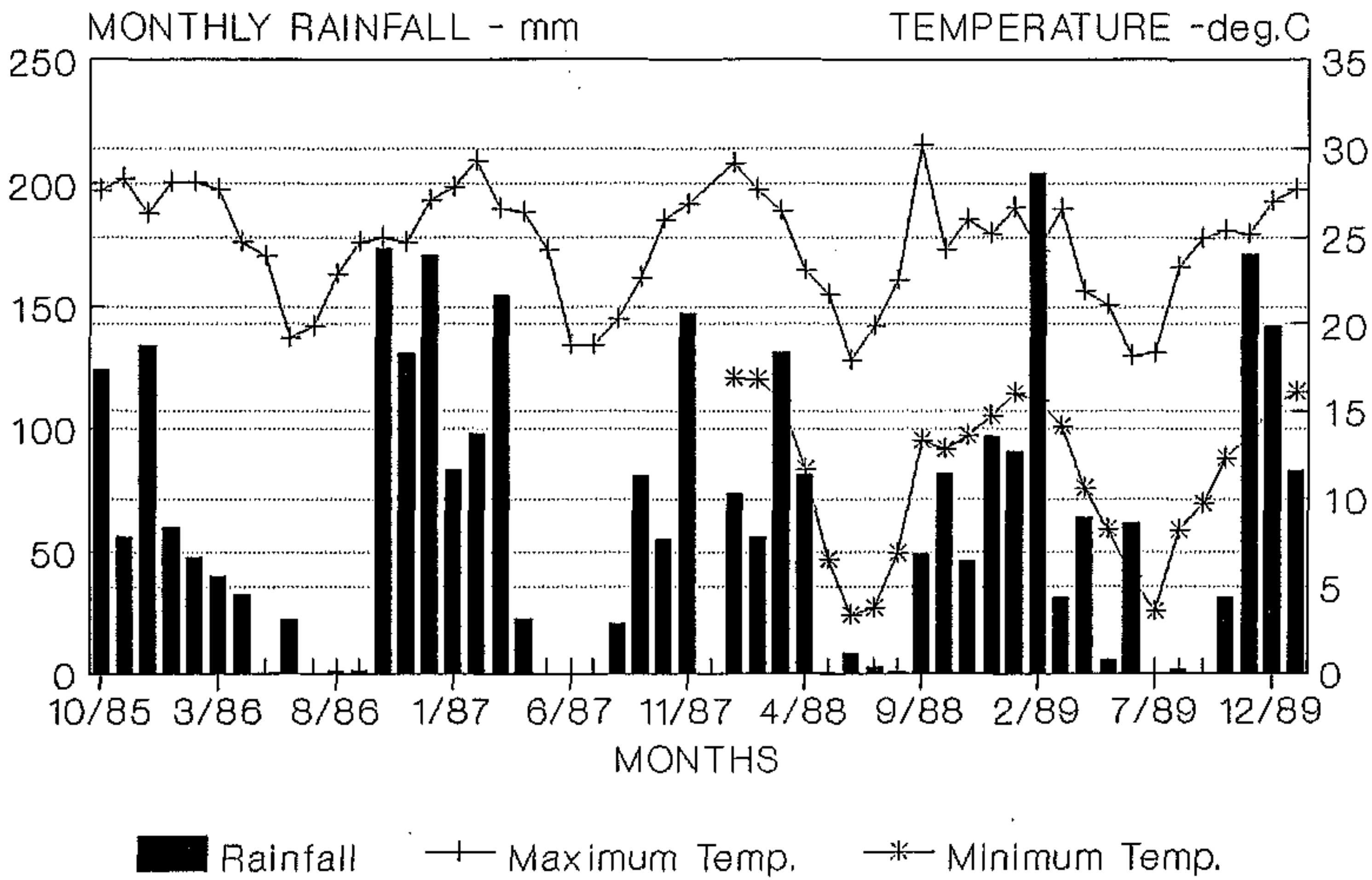


FIGURE 18, PRETORIA WEATHER DATA
AVERAGE RAINFALL AND TEMPERATURES

The full set of data has not been analysed statistically, but a visual comparison of water table graphs and the rainfall graph shows that water table levels rise in accordance with the amount of monthly rainfall in the area. Rainfall has a significant effect in reducing groundwater abstraction, so that recharge occurs faster than the draw-down caused by the mining of the water.

It was observed that water tables recovered during the winter months in most areas. This is probably due to the reduced rate of groundwater abstraction and evapo-transpiration. Temperature therefore indirectly affects the recharge of the aquifers. A point to note is that if water tables rise in winter when there is no direct rainfall, then the recharge must be infiltrating from the surrounding strata, or aquifers.

The obvious major source of recharge, besides direct rainfall and local aquifer balancing, is the dolomites to the south of Pretoria. As the cross-sections indicate, the hydraulic gradient is substantial and the geological maps show numerous faults across the area. Following reports in the literature, O^{18} tests were included in the water quality analyses in February 1989 to see if this parameter could be used to trace the origin of the groundwater.

Variations in the ratios of the stable isotopes of water, $O^{18}:O^{16}$, occur in each step of the hydrological cycle and can provide supplementary information for the tracing of water[2:p102]. The isotope ratio is measured and reported in ‰ (parts per thousand) as a relative deviation from the ratio found in sea water.

Samples of groundwater from the 20 sites, selected for water quality analyses, were sent to the Division of Earth, Marine & Atmospheric Science and Technology for analysis of O^{18} content. The results are given below and values greater than -2‰ would represent water that was subjected to considerable evaporation prior to recharge into the aquifer. The mean oxygen-18 content of Pretoria rainfall is -4.0 ‰.

TABLE 4 - O^{18} TEST RESULT FEBRUARY 1989

BH	SUBURB	d18o	BH	SUBURB	d18o
73	MAGALIESKRUIN	-5.090	15	CONSTANTIA PARK	-3.650
111	ELARDUS PARK	-4.920	78	EASTLYN	-3.600
88	PRETORIA GARDENS	-4.830	107	WATERKLOOF	-3.380
98	WESPARK	-4.810	2	MEYERSPARK	-3.200
112	WINGATE PARK	-4.700	87	CLAREMONT	-3.060
69	ANNLIN	-4.690	67	PRETORIA NORTH	-2.980
36	WILLOW GLEN	-4.620	102	EASTWOOD	-2.950
92	MOUNTAIN VIEW	-4.415	100	GROENKLOOF	-2.630
56	CAPITAL PARK	-4.050	62	DORANDIA	-2.460
8	QUEENSWOOD	-3.875	84	MOUNTAIN VIEW	-.525

TABLE 5 - PAST O^{18} TEST RESULTS

CSIR CAMPUS	-3.7 TO -4.8	3 SAMPLES
MUCKLENEUK RIDGE	-4.7	1 SAMPLE
MEYERSPARK	-3.6 TO -3.9	4 SAMPLES
WIERDA PARK	-4.1	1 SAMPLE
RIETVLEI DOLOMITES	-4.0 TO -4.9	10 SAMPLES
FOUNTAINS	-3.9	1 SAMPLE

There may be a measure of regional grouping, but the samples are spread too thin to confirm this. So although no conclusive results were obtained, high density sampling in areas where some contrast is evident could be worthwhile. If groundwater was being recharged along fault lines, then it would make sense to concentrate on these lines by sampling water characteristics and water levels at points along and adjacent to the fault lines. However the geological formations dip at about 15 degrees to the north and weathered and fractured zones containing groundwater could be confined in the vertical plane by the overlying, impervious strata.

A study of the recovery rates of the water table at a number of boreholes in an area could give an indication of the location of the main source of recharge to an area. Although the scope of the project did not allow this aspect to be investigated in depth and the construction of the borehole and other factors would complicate the analysis, it may be useful to employ the method in a future study on recharge aspects of the Pretoria groundwater aquifers.

WATER QUALITY

The third aim of the project was to determine the quality of the groundwater pumped from boreholes and its variation spatially and with time. To achieve this aim, water samples were taken from 20 selected sites at half-yearly intervals and analysed according to requirements of SABS 241-1984 [4].

Inorganic chemical analyses were carried out on both the borehole water and the municipal water samples from each site. The borehole waters were also tested for microbiological quality, by carrying out a total coliform count, a standard plate count and faecal coliform count.

The first and second samplings were for boreholes concentrated in the eastern half of Pretoria. Since there was no significant change between the samplings, except in the case of the microbiological quality, it was decided to select new sites for the third sampling to obtain a more comprehensive coverage of the Pretoria area. A new set of twenty sites was selected, which included four from the original set, for comparative purposes.

The water quality results for all four samplings are given in Appendix D. The recommended and maximum allowed limits for the determinants[4,5] are given in Table 6 below.

Inorganic Chemistry

The four sets of results from the analyses were compared with the limits given in Table 6 and the samples for which one or more of the inorganic chemical limits were exceeded are given in Table 7. No particular significance is placed on the comparison, since the actual values are of more importance, but it does indicate that the groundwater is of similar quality to the municipal water.

High levels of zinc are attributed to erosion of the galvanising from galvanised pipes and suggests that the sampling technique did not allow enough time to purge the pipework before the water sample was taken.

TABLE 6 - LIMITS FOR WATER QUALITY DETERMINANTS

DETERMINANT		RECOMMENDED LIMIT	MAXIMUM ALLOWABLE
TURBIDITY (NTU)		1	5
pH		6 - 9	5.5-9.5
ELEC.CONDUCTIVITY (mS/m)		70	300
COLOUR (mg/l Pt)		20	
SODIUM (Na)	mg/l	100	400
POTASSIUM (K)	mg/l	200	400
CALCIUM (Ca)	mg/l	150	200
MAGNESIUM (Mg)	mg/l	70	100
NITRATES+NITRITES (N)	mg/l	6	10
NITRITES-NITROGEN (N)	mg/l	6	10
SULPHATES (SO-4)	mg/l	200	600
ORTHO-PHOSPHATES (P)	mg/l		
CHLORIDES (Cl)	mg/l	250	600
ALKALINITY (CaCO-3)	mg/l	20-300	650
CHEM.OXYGEN DEMAND	mg/l		
BORON (B)	ug/l	500	2000
CHROMIUM (Cr)	ug/l	100	200
CADMIUM (Cd)	ug/l	10	20
COPPER (Cu)	ug/l	500	1000
LEAD (Pb)	ug/l	50	100
MANGANESE (Mn)	ug/l	50	1000
NICKEL (Ni)	ug/l	250	500
ZINC (Zn)	ug/l	1000	5000
IRON (Fe)	ug/l	100	1000
FLOURIDE (F)	ug/l	1000	1500
TOTAL COLIFORMS (per 100 ml)		0	5
FAECAL COLIFORMS (per 100 ml)		0	0
STANDARD PLATE COUNT (per ml)		100	

TABLE 7 - SAMPLES EXCEEDING RECOMENDED LIMITS

SAMPLING	SITE	WATER	LIMITS EXCEEDED
1	BH 2	BOREHOLE	FLOURIDE
3	BH 102	BOREHOLE	NITRATES+NITRITES
3	BH 102	MUNICIPAL	ZINC, IRON, NITRATES+NITRITES
3	BH 36	BOREHOLE	IRON, TURBIDITY
3	BH 84	BOREHOLE	TURBIDITY
3	BH 98	BOREHOLE	TURBIDITY
3	BH 112	BOREHOLE	TURBIDITY
4	BH 102	MUNICIPAL	ZINC, NITRATES+NITRITES
4	BH 102	BOREHOLE	NITRATES+NITRITES
4	BH 84	MUNICIPAL	IRON
4	BH 36	BOREHOLE	TURBIDITY
4	BH 112	BOREHOLE	MANGANESE
4	BH 15	BOREHOLE	FLOURIDE

TABLE 8 - AVERAGE WATER QUALITY COMPARISONS

DETERMINANTS		WATER	NOV 87	JUN 88	FEB 89	OCT 89
TURBIDITY (NTU)		MUN	.9	.8	2.5	
		BH	1.7	.6	4.6	5.0
pH		MUN	7.6	7.6	7.7	7.7
		BH	7.1	6.9	7.1	6.8
CONDUCTIVITY (mS/m)		MUN	45.3	32.1	28.0	30.4
		BH	40.4	39.1	47.0	42.2
COLOUR (mg/l Pt)		MUN	11.9	<5	<5	<5
		BH	12.1	<5	<5	<5
SODIUM (Na)	mg/l	MUN	24.2	15.9	13.6	16.4
	mg/l	BH	12.6	11.8	13.0	11.6
POTASSIUM (K)	mg/l	MUN	5.4	3.9	3.3	2.7
	mg/l	BH	2.1	2.1	2.1	1.8
CALCIUM (Ca)	mg/l	MUN	45.9	36.4	26.6	30.2
	mg/l	BH	34.7	32.2	37.2	34.2
MAGNESIUM (Mg)	mg/l	MUN	6.9	5.5	6.3	7.0
	mg/l	BH	22.3	21.1	23.5	18.9
NITRATES+TRITES (N)	mg/l	MUN	1.5	.6	1.2	1.1
	mg/l	BH	2.8	2.8	4.5	3.8
NITRITES-NITROGEN	mg/l	MUN	.1	<.1	<.1	<.1
	mg/l	BH	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	MUN	69.0	20.5	22.6	20.1
	mg/l	BH	31.4	18.7	35.9	25.2
CHLORIDES (Cl)	mg/l	MUN	33.8	.4	.3	.4
	mg/l	BH	19.1	16.8	25.9	20.8
ORTHO-PHOSPHATE (P)	mg/l	MUN	-	16.9	15.4	17.2
	mg/l	BH	-	.3	.2	.3
CHEM.OXYGEN DEMAND	mg/l	MUN	10.9	12.6	7.2	8.5
	mg/l	BH	6.1	12.9	9.0	5.3
ALKALINITY (CaCO-3)	mg/l	MUN	77.6	106.0	75.8	98.4
	mg/l	BH	139.4	140.2	123.9	128.8
BORON (B)	ug/l	MUN	100.2	119.8	85.2	143.3
	ug/l	BH	78.3	108.0	84.0	109.4

TABLE 8 - AVERAGE WATER QUALITY COMPARISONS (Continued)

DETERMINANTS		WATER	NOV 87	JUN 88	FEB 89	OCT 89
CHROMIUM (Cr)	ug/l	MUN	<25	<25	<25	<25
	ug/l	BH	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	MUN	5.5	<5	<5	<5
	ug/l	BH	<5	<5	<5	<5
COPPER (Cu)	ug/l	MUN	<25	<25	<25	<25
	ug/l	BH	53.0	<25	94.5	40.0
LEAD (Pb)	ug/l	MUN	90.0	<50	<50	<50
	ug/l	BH	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	MUN	95.0	<25	<25	<25
	ug/l	BH	155.3	111.0	128.8	314.6
NICKEL (Ni)	ug/l	MUN	<25	<25	<25	<25
	ug/l	BH	<25	<25	<25	<25
ZINC (Zn)	ug/l	MUN	550.6	103.8	836.8	569.8
	ug/l	BH	402.6	84.0	352.6	313.7
IRON (Fe)	ug/l	MUN	78.4	57.1	353.6	1044.5
	ug/l	BH	151.3	181.8	240.4	588.7
FLOURIDE	ug/l	MUN	154.3	353.8	181.9	421.3
	ug/l	BH	295.9	264.7	198.4	447.8

The conclusion drawn from the comparisons in Table 8 is that the chemical quality of the groundwater compares favourably with the Municipal water quality and does not change significantly with time.

In some areas, local minerals such as manganese and iron have been dissolved in the groundwater in relatively high proportions, although the materials used in the pipework and fittings probably contribute to high readings in many cases.

Note that electrical conductivity is another measure of total dissolved solids. For most queries relating to drinking water, adequate discussion on the properties and limits assigned to the determinands is provided in the report by Kempster and Smith [5].

Microbiological Water Quality

The tests were performed only on the groundwater samples. The average values for all 20 samples and the number that exceeded the recommended and maximum allowed limits given in SABS 241-1984 are shown in Table 9.

TABLE 9 - AVERAGE BOREHOLE MICROBIOLOGICAL WATER QUALITY

DETERMINANTS	NOV 87	JUN 88	FEB 89	OCT 89
TOTAL COLIFORMS (/100 ml)	52.3	221.9	1164.0	421.2
NUMBER IN 20 EXCEEDING LIMIT	9	7	20	16
FAECAL COLIFORMS (/100 ml)	1.7	3.0	35.7	1136.9
NUMBER IN 20 EXCEEDING LIMIT	4	4	13	20
STANDARD PLATE COUNT (/ml)	879.6	412.3	1563.9	95.1
NUMBER IN 20 EXCEEDING LIMIT	14	17	19	13

It can be seen that the microbiological quality of the groundwater varies unpredictably. Variation in quality is attributed to stormwater run-off, either at or near the borehole site, and sewer ex-filtration at connections and broken pipes.

No borehole water within the city environment can be considered safe to drink, that is; there is always a risk that the groundwater contains pathogenic bacteria or parasites. If borehole water is to be used for human consumption, it is advisable to sterilize the water by boiling or by chlorination.

Two of the monitored sites in the city area and one of the plots in the East used the groundwater for all purposes, as can be seen from the water consumption records. The city sites are apparently two of fourteen known sites that have received permission from the Municipality to use groundwater for domestic purposes. It was not established if the supplies were cross-connected, but the absence of flow through the municipal meter suggests that there was no cross connection.

A number of queries relating to the quality of the groundwater for potable and other domestic purposes were received from Pretorians during the course of the project. While most of these did not appear to relate to cross connection between the borehole and municipal supplies, with the large number of boreholes in the city, it is likely that some of these will have been cross connected to the municipal system via the domestic water supply. The number of existing cross connections could be very difficult to estimate, without detailed inspections of suspicious sites.

On the whole, the public was aware of regulations prohibiting a cross connection between the borehole and municipal water systems.

POTENTIAL FOR SIGNIFICANT INCREASES IN GROUNDWATER ABSTRACTION

In an attempt to establish the potential for a significant increase in groundwater abstraction from private boreholes in the future, borehole contractors who operate in the Pretoria area were contacted for information on the number of boreholes drilled per year. Thirty three firms connected with the borehole industry were identified with the help of the Borehole Water Association of Southern Africa and the Yellow Pages. About twenty of these advertised as being able to provide a drilling service.

The information could have formed the basis for developing a forecasting technique for the number of new boreholes likely to be drilled per year. Unfortunately, the contractors in Pretoria were very evasive and no historical data of value was obtained. A similar attitude was found in Port Elizabeth, when an attempt was made to establish the number of new boreholes commissioned as a result of the drought, which ended in 1989.

A qualitative assesment, based on observation of the trends since 1985, suggests that the incentive for an individual to sink a borehole depends on the following factors, more or less in priority:

1) Restrictions on quantity of municipal water available

2) The price differential at the demanded quantity between the groundwater and the municipal water.

3) The probability of obtaining a good supply from a borehole on the individual's property.

4) The availability of capital to finance the borehole installation.

The incentive to sink a borehole is therefore primarily drought driven, since it is during a drought that the supply shrinks, leading to the imposition of restrictions on consumer demand and an increase in price.

It is thought that the limit to which private residential properties will utilise the groundwater in the Pretoria area can be based on the degree of utilisation observed in the older areas, where further development is unlikely. On this basis, the central area (Zone 4) has probably stabilized at a point where 60% of the residential properties have a borehole. It is assumed that in due course, the demand on the groundwater resource could be expected to increase by about 60% within the other defined areas, due to the increase in the proportion of properties with boreholes from 0.375 to 0.60.

It is assumed that the average groundwater abstraction rate and the frequency distribution for groundwater abstraction rates will not change significantly in the future. This is not strictly true, since climatic factors can affect the degree to which groundwater is mined from existing areas.

For example, September 1989 was a month when the proportion of boreholes in use at the time of monitoring was higher than usual and it was observed that several water tables had dropped to unusually low levels for that time of year. This can be explained by the fact that no rainfall fell in the 3 month period to the end of September and the maximum average temperature rose to from 18.3 to 23.3 to 25 deg.C.

However, the main factor limiting groundwater utilisation is the rate of recharge, which is not known with any certainty. It would appear that, in addition to rainfall on the surface, recharge is also occuring from areas which are outside the geographic boundaries monitored during the project. Should significant abstraction of groundwater occur from these outside areas, for whatever reasons, the effect on the groundwater table in the Pretoria area could be a serious one for the residential borehole owners.

The failure of a large proportion of the private boreholes should not affect the burden on the municipal water supply, since the demand from this source would be controled by restrictions and the tarrifing structure. The environment would however suffer and this could have a demoralising effect on the inhabitants.

Although the project has not been able to quantify the future trend in groundwater abstraction from private boreholes, the parameters thought to influence the trend have been identified. From these it can be predicted that the borehole population should remain stable until the next drought begins. Economics and the seriousness of rationing and restrictions to the property owner will then determine if there is sufficient incentive to sink a borehole.

CONCLUSIONS

1. The main objectives of the project were achieved with the estimation of the quantity of groundwater extracted from private boreholes in Pretoria and the determination of groundwater levels across the city between November 1985 to January 1990.

2. The proportion of residential properties with boreholes was estimated to be 37.5% of the total number of 80536.

3. A property with a borehole used an average quantity of water of 1.78 kl/day from the borehole and 0.82 kl/day from the municipal supply. From a sample of 439 properties without boreholes, the average municipal water consumption was 1.04 kl/day.

4. The average annual quantity of groundwater abstracted from private boreholes was estimated to be 20 063 Ml per year. This is roughly equal to the quantity of municipal water used per year on residential properties in Pretoria.

5. Given that the average reduction in municipal water consumption is 0.21 kl/day for a property that acquires a borehole, the annual reduction in municipal water sales due to groundwater usage was equivalent to 2 350 Ml per year.

6. The results indicate that a reduction in municipal water use of approximately 0.21 kl/day, was replaced by a groundwater abstraction of 1.78 kl/day for external purposes, leading to two observations:

   a) The supply of municipal water was severely constrained by availability and price during most of the period of the study.

   b) Although municipal water restrictions were lifted and the tariff structure reversed in September 1988, properties without boreholes have not increased their water consumption significantly, in fact the mean increased by only 50 litres/day.

7. Changes in the groundwater tables were influenced by the aquifer characteristics and followed a seasonal trend. No long term trends were observed, due the short duration of the data record.

8. The chemical quality of the groundwater was found to compare favourably with the Municipal water quality and did not change significantly with time.

9. The microbiological quality of the groundwater varied unpredictably, probably as a result of stormwater run-off and sewer ex-filtration at connections and broken pipes. It is therefore advisable to sterilize all borehole water to be used for human consumption by boiling or by chlorination.

10. The incentive for an individual to sink a borehole depends on the following factors:

    a) Restrictions on quantity of municipal water available
    b) The price differential at the demanded quantity between the groundwater and the municipal water.
    c) The probability of obtaining a good supply from a borehole on the individual's property.
    d) The availability of capital to finance the borehole installation.

11. In due course, the demand on the groundwater resource could be expected to increase by about 60% due to an increase in the proportion of properties with boreholes from 37.5% to 60%.

12. The main factor limiting groundwater utilisation is the rate of recharge. Significant abstraction of groundwater from areas outside Pretoria could affect the groundwater tables in the Pretoria area.

13. The failure of a large proportion of the private boreholes should not affect the burden on the municipal water supply, since the demand from this source would be controled by restrictions and the tarrifing structure. The environment would however suffer and this could have a demoralising effect on the inhabitants.

14. The borehole population should remain stable until the next drought begins. Economics and the seriousness of rationing and restrictions to the property owner without a borehole will then determine if there is sufficient incentive to sink a borehole.

15. The data that has been collected has potential for further analysis and is available to anyone who has an interest in the subject.

16. The methods used to obtain and analyse the data were developed so that they could be implemented elsewhere and are not specific to Pretoria.

17. The co-operation of borehole owners is required if a study of this nature is to succeed, but it was found that there were few owners who were not willing to participate in the project. However it is important to keep them informed as much as possible about the state of the groundwater resource in their area.

18. Recalling the public debates between 1982 and 1987 concerning the private use of groundwater in urban areas, it is hoped that in the future, the data from this project can be used in the rational planning processes for water resources and their control.

RECOMMENDATIONS

This project has concentrated on the abstraction of groundwater and only touched on the recharge aspects. The long term reliability of the groundwater aquifers, which are linked together by the geological formations, is not known, but it has been found that individual property owners and rates payers have an interest in the groundwater resource through their considerable investment in the development of the resource. Future research in this area should bear this in mind.

General recommendations

Proposals which emanate out of the work done on the project include;

1. The maintenance of the database on groundwater levels to determine long term variations. This can best be done by installing recorders on observation boreholes. The results should be published in the local paper along with rainfall data.

2. The establishment of an effective reporting procedure for drilling contractors to notify the municipality of the location of new boreholes together with the drilling details.

3. Since the effective monitoring of a groundwater resource requires quantity of water abstracted to be measured, the incentives

required by borehole owners to install water meters should be investigated, as well as the establishment of a system for collecting borehole meter readings and analysing the data.

4. All borehole cover-plates sold commercially should be pre-drilled with 16mm hole to accommodate a depth probe. The pump contractors should be advised in no uncertain terms not to use the hole to tie off support cables.

5. Sewer inspections should be undertaken in areas where high faecal contaminations of the groundwater are detected, to establish if the condition of the sewer could be responsible for the pollution. This implies the establishment of an information channel from testing laboratories to the responsible authority.

6. Should the project be implemented elsewhere, it is recommended that the stratified cluster sampling technique proposed in this report should be used to select the monitoring sites and the sample of clusters to determine the number of properties with boreholes.

<u>Research recommendations</u>

1. Further research work that was beyond the scope of this project, but could be undertaken in this field include the following nine suggestions made by the Department of Water Affairs. These do not appear to involve field work of a test and measurement nature and could be accomplished through literature searches and the analysis of economic, social and political alternatives. The approach may be based on the probabilities of the various events or scenarios occuring, using the results from this project to quantify the evaluations.

    a) Consideration of the geology of successful borehole sites.

    b) The cost of borehole water to the owner-user and its comparison with the cost of communal municipal supplies.

c) The desirability of developing groundwater resources and its justification towards:

- the community and its needs
- the individual and his rights
- the implicit discrimination of the present legal framework in the access to water and its use
  (individuals owning property in areas having the resource and individuals having the financial muscle to avail themselves of the resource, against those who do not)
- the environment.

d) Possible environmental effects (of urban groundwater abstraction)

e) Consequences to the community and the environment of different pumping options of unrestricted pumping, selective pumping and no pumping.

f) Analysis of municipal water tariff policy to encourage or discourage groundwater pumping.

g) Analysis of the groundwater use in the context of alleviating supply pressures on the existing system during peak demand periods and to postpone new large scale investment to supplement existing supplies.

h) The desirability of the development of groundwater by the community as opposed to private development.

i) Analysis of groundwater development and consumption in the context of larger established or potential communal supplies, from the point of view of economic viability, reliability, tariff policy and the phasing in and out of such a scheme.

2. An investigation of the inter-relationship between underground and surface catchments in the Pretoria area is required to address the question of groundwater recharge. The study would need to monitor stream flow in the main surface catchments, rainfall and groundwater levels, as well as flows in the engineering services including water supply, sewer and stormwater systems. The groundwater aspect would be a part of the holistic approach to modelling hydrogical aspects of catchment behaviour and determining the catchement water balance.

3. Research into the water quality of groundwater in the Pretoria area should consider the effects of industrial pollution on the groundwater. Potential sources of pollution should be identified and the direction of the resulting pollution plume or fracture flow determined. Test sampling for identified polluting determinants could be carried out at selected sites.

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APPENDICES

APPENDIX A - COORDINATES AND LEVELS FOR MONITORING SITES

BH No.	COORDINATES - METRES Y+	X+	GROUND LEVEL	ERF No.	ADDRESS
1	71,082.8	848,796.6	1,355	38	51 Maroela St, Val de Grace
2	68,461.8	847,457.2	1,321	788	176 Anna Marie, Meyerspark
3	68,462.6	847,475.6	1,322	1045	175 Anna Marie, Meyerspark
7	74,438.7	846,656.8	1,315	800	7 Corry St, Queenswood
8	75,468.2	846,052.4	1,298	197	1193 Meara Rd, Queenswood
10	70,809.2	852,710.4	1,395	12	Villa Savannah, Faerie Glen
13	70,722.9	854,621.3	1,407	1088	477 Falda Rd, Garsfontein
15	71,643.8	854,398.4	1,436	880	Glenstantia Primary School
16	71,120.2	853,348.1	1,405	1672	Sun Garden NS, Garsfontein
17	71,185.2	848,789.8	1,358	35	45 Maroela St, Val de Grace
18	70,976.1	848,807.2	1,350	41	57 Maroela St, Val de Grace
19	68,434.3	847,447.2	1,322	789	180 Anna Marie, Meyerspark
20	71,458.1	846,652.2	1,312	469	357 Moreletta St, Silverton
21	71,621.1	846,618.5	1,316	464	317 Moreletta St, Silverton
22	75,671.1	850,717.0	1,395	302	325 Murray St, Brooklyn
23	75,602.1	850,622.7	1,393	269	344 Murray St, Brooklyn
24	75,582.7	850,672.9	1,393	269	348 Murray St, Brooklyn
25	70,415.0	848,012.4	1,376	1221	100 vd Merwe, Silverton Ridge
26	70,911.5	852,497.8	1,383	7	La Paloma(1), Faerie Glen
27	70,965.8	852,461.7	1,385	7	La Paloma(2), Faerie Glen
28	71,096.5	856,885.2	1,520	938	710 Tetra Ave, Moreletta Park
29	70,429.0	848,057.9	1,375	1206	99 v d Merwe, Silverton Ridge
30	71,046.1	846,710.8	1,308	66	437 Alpha St, Silverton
31	76,132.7	848,000.1	1,268	66	46 Allcock St, Colbyn
32	76,325.3	848,122.6	1,268	46	94 Allcock St, Colbyn
33	74,859.0	843,475.3	1,318	434	1291 Walter Ave, Waverley
34	77,871.4	846,112.9	1,296	2120	331 22nd Ave, Villieria
35	73,681.6	844,367.2	1,290	1038	1438 Dunwoodie, Waverley
36	67,192.9	850,865.7	1,369	11	11 Libertas Way, Willow Glen
37	70,164.3	849,055.6	1,328	47	32 Erica St, Murrayfield
38	70,011.7	849,172.7	1,334	75	38 Willie Bam, Murrayfield
39	71,950.5	848,617.1	1,361	2	4 Snyman Rd, Navorsing
40	71,816.2	848,700.8	1,363	19	11 Snyman Rd, Navorsing
41	74,770.0	849,635.3	1,370	41	49 Farmers Folly, Lynnwood
42	75,072.2	849,897.0	1,386	61	23 Farmers Folly, Lynnwood
43	71,771.6	853,717.6	1,404	746	Woodglen Flats Waterkloof Glen
44	80,766.9	843,327.8	1,270	150	987 6th St, Wonderboom South
45	70,803.6	855,491.8	1,462	174	510 Pyp St, Moreletta Park
46	67,165.4	850,756.0	1,367	10	10 Libertas Way, Willow Glen
47	80,847.2	843,323.8	1,271	99	984 6th St, Wonderboom South
48	76,954.4	844,768.9	1,283	2014	1000 Ben Swart St, Villiera
49	77,287.3	844,809.5	1,280	2020	948 Ben Swart St, Villieria
50	76,673.3	843,914.6	1,288	1978	759 30th Ave, Villiera
51	76,631.9	843,848.1	1,288	1971	772 30th Ave, Villiera
52	76,674.8	843,794.9	1,288	1978	777 30th Ave, Villieria
53	69,554.4	850,886.3	1,392	15	Pro-Plant, Lynnwood Ridge
54	78,165.4	845,973.0	1,288	1842	780 Pierneef St, Villieria
55	78,252.1	845,941.0	1,286	1868	360 19th Ave, Villieria
56	82,519.8	846,559.2	1,280	879	42 Flower St, Capital Park
57	81,862.7	846,287.1	1,283	327	93 Trouw St, Capital Park
58	81,769.6	846,459.8	1,290	1552	Church 4th Ave, Capital Park
59	82,487.2	841,871.7	1,256	1354	176 Jan v Riebeek, Pta North

APPENDIX A (CONT)

BH No.	COORDINATES - METRES Y+	X+	GROUND LEVEL	ERF No.	ADDRESS
60	84,604.7	840,109.1	1,252	379	343 Deetlefs St, Wolmer
61	84,682.1	838,953.0	1,242	608	480 Justin St, Dorandia
62	84,631.3	838,956.9	1,242	647	487 Justin St, Dorandia
63	84,602.3	840,072.2	1,252	378	345 Deetlefs St, Wolmer
64	84,713.8	838,988.7	1,242	618	480 Earl St, Dorandia
65	84,090.3	840,154.0	1,249	409	340 Japie Fourie, Wolmer
66	83,083.3	841,001.8	1,241	925	299 Emily Hobhouse, Pta North
67	83,086.5	840,978.0	1,240	925	301 Emily Hobhouse, Pta North
68	82,405.9	840,323.9	1,236	569	335 Jan v Riebeek, Pta North
69	80,629.4	841,867.4	1,254	190	18 Anna Ave, Annlin
70	80,677.8	841,844.3	1,252	234	13 Anna Ave, Annlin
71	76,865.0	842,133.0	1,308	450	437 Braam Pret, Magalies Kruin
72	77,019.5	842,138.9	1,306	532	413 Braam Pretorius, Magal/Kr
73	76,893.6	842,197.2	1,310	463	433 Petrea Ave, Magalies Kruin
74	80,289.6	841,945.1	1,262	73	47 Dikbas Ave, Wonderboom
75	78,818.0	840,818.9	1,254	108	232 Marija St, Sinoville
76	79,070.5	840,745.8	1,248	86	263 Miriana St, Sinoville
77	79,164.0	840,759.0	1,249	58	256 Miriana St, Sinoville
78	72,210.6	844,085.0	1,287	62	103 Stegmann Rd, East Lynne
79	72,142.4	844,098.6	1,287	63	109 Stegmann Rd, East Lynne
80	79,325.8	844,930.6	1,260	149	622 13th Ave, Gezina
81	79,297.9	844,771.4	1,255	79	638 Haarhoff St, Gezina
82	78,909.4	843,543.7	1,276	978	886 17th Ave, Wonderboom
83	78,961.2	843,402.9	1,284	912	911 17th Ave, Wonderboom
84	82,095.5	844,119.0	1,250	238	776 Morgan Ave, Parktown
85	82,125.8	844,126.3	1,250	198	779 Morgan Ave, Parktown
86	86,687.7	845,759.9	1,288	241	424 Bremer St, Claremont
87	86,693.2	845,790.8	1,288	241	946 Hanny St, Claremont
88	84,402.9	846,459.3	1,283	402	410 Weir St, Pretoria Gardens
89	84,410.6	846,491.2	1,281	522	421 Weir St, Pretoria Gardens
90	86,005.1	843,547.8	1,274	394	756 Witby St, Suiderberg
91	85,933.5	843,574.6	1,272	394	720 Dunedin St, Suiderberg
92	84,355.0	843,813.4	1,260	554	485 Ivor Ave, Mountain View
93	84,302.2	843,820.0	1,260	554	471 Ivor Ave, Mountain View
94	87,376.9	848,500.1	1,331	2362	80 Delaney St, Danville
95	87,325.5	848,091.7	1,322	2169	180 Ledger St, Danville
96	86,499.4	849,218.9	1,324	112	130 Mimosa Ave, Proc. Hill
97	85,895.3	849,251.3	1,330	174	711 Acacia Ave, Proc. Hill
98	87,459.1	849,794.8	1,370	372	30 Iscor Road, Wast Park
99	78,209.6	851,777.6	1,397	439	81 Bronkhorst St, Groenkloof
100	78,522.3	851,765.8	1,406	453	52 Frans Oerder
101	78,390.6	847,962.1	1,400	904	790 Government Ave, Eastwood
102	78,218.4	848,255.0	1,380	970	843 Merton Ave, Eastwood
103	78,635.7	849,175.3	1,340	1326	9 Maple Ave, Sunnyside
104	78,178.8	849,295.3	1,344	820	426 Farenden Ave, Sunnyside
105	73,621.0	852,793.5	1,408	39	51 Lebombo St, Ashlea Gardens
106	73,684.9	852,535.9	1,425	20	24 Selati St, Ashlea Gardens
107	76,085.8	852,320.3	1,426	457	318 Albert St, Waterkloof
108	76,116.6	852,359.9	1,430	582	313 Albert St, Waterkloof
109	76,085.8	852,320.3	1,550	3	350 Rigel Ave, Waterkloof
110	75,274.9	855,640.0	1,552	96	218 Oom Jockem, Erasmusrand
111	74,781.7	855,798.2	1,510	287	274 Albertus Ave, Erasmusrand
112	73,842.9	857,132.9	1,523	38	774 Barnard St, Wingate Park
113	73,707.1	857,313.4	1,537	25	802 Morag St, Wingate Park

APPENDIX B - INFORMATION SHEETS IN ENGLISH AND AFRIKAANS

NATIONAL BUILDING RESEARCH INSTITUTE - BUILDING SERVICES DIVISION

RESEARCH ON GROUNDWATER ABSTRACTION IN URBAN AREAS

PROJECT BACKGROUND, AIMS AND RESULTS

During 1985 and 1986, local newspapers were full of stories concerning groundwater exploitation in the Pretoria area. It was decided that some factual data should be obtained and the project began with the installation of surplus water meters on boreholes in the Eastern suburbs of Meyerspark, Val de Grace, Queenswood, Faerie Glen and Garsfontein.

Fourteen properties were selected for monitoring, even though only seven meters were available. The borehole meter (where installed), Council meter and depth of water table have been monitored at these properties since November 1985. However, funds provided by the Water Research Commission now enables us to monitor more properties with boreholes. We are hoping to have meters installed on at least 100 boreholes before the rains start and are currently looking for suitable boreholes on which to install water meters. If you can help please let us know.
The Pretoria City Engineer's Department has kindly offered to supply water meters and assist with the installation of these meters, as their contribution to this research project.

The main aim of the project is to assess the annual quantity of water abstracted from private boreholes in relation to the quantity of water supplied by the municipal water supply system.

Secondary aims are :
a) To determine the variation in groundwater levels.
b) To determine the quality of groundwater from boreholes.
c) To assess the possibility that the demand on the groundwater resource will increase significantly in the future.

Some of the data collected so far is illustrated in the attached graphs. A preliminary analysis of the data indicates that:

* Average daily in-house water consumptions are between 400 and 1200 litres per house with an overall average of 737 litres.
* Average daily groundwater consumptions are between 1230 and 3300 litres per house with an overall average of 2067 litres.
* Average total daily water consumption for a property with a borehole is 2800 litres, of which 74 per cent is abstracted from the ground.

However these figures are based on a very small sample of the total number of properties with boreholes and it is essential that this number be increased if the figures are to be meaningful.

Your co-operation in helping us to achieve this would be greatly appreciated.

G C Simpson, Project Co-ordinator.

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APPENDIX B (CONT)

NASIONALE BOUNAVORSINGSINSTITUUT - AFDELING GEBOUDIENSTE

NAVORSING INSAKE GRONDWATERONTTREKKINGS IN STEDELIKE GEBIEDE

AGTERGROND, DOELWITTE EN RESULTATE VAN PROJEK

Gedurende 1985 en 1986 het die koerante wye publisiteit gegee aan die eksploitering van grondwater in die Pretoria-gebied. In 'n poging om geloof te heg aan die stories is besluit om feite in te samel en die projek is afgeskop met die installering van surplus watermeters op boorgate in die Oostelike voorstede, nl. Meyerspark, Val de Grace, Queenswood, Faerie Glen en Garsfontein.

Alhoewel slegs sewe meters beskikbaar was, is veertien eiendomme uitgekies omdat die boorgatmeter (waar geinstalleer), die Stadsraad se meter en die watertafel reeds sedert November 1985 op hierdie eiendomme gemonitor word. Die fondse wat die Waternavorsingskommissie vir hierdie projek bewillig het, stel ons egter in staat om meer eiendomme met boorgate te monitor. Ons hoop om meters op ten minste 100 boorgate geinstalleer te hê voor die volgende reenseisoen en is dus op die uitkyk vir geskikte boorgate daarvoor. Laat ons asseblief weet as u kan help. Die Stadsingenieursdepartement van Pretoria het goedgunstiglik aangebied om tot hierdie projek by te dra deur die watermeters te voorsien en te help met die installering daarvan.

Die hoofdoel van hierdie projek is om die hoeveelheid water wat jaarliks uit boorgate op privaateiendomme onttrek word in verhouding tot die hoeveelheid water wat d.m.v. die munisipale watertoevoerstelsel voorsien word, te evalueer.

Bykomstige doelwitte is om:
a) die variasie in grondwatervlakke te bepaal
b) die gehalte van boorgatgrondwater te bepaal
c) die moontlikheid dat die aanvraag na die grondwaterbron in die toekoms aansienlik kan toeneem, vas te stel.

Sommige van die gegewens wat tot dusver versamel is, word in die aangehegte grafieke uiteengesit. 'n Voorlopige ontleding van hierdie gegewens wys daarop dat:

* die gemiddelde daaglikse verbruik in die huis tussen 400 en 1200 liters per huis wissel, met 'n algehele gemiddelde van 737 liters

* die gemiddelde daaglikse grondwaterverbruik tussen 1230 en 3300 liters per huis wissel, met 'n algehele gemiddelde van 2067 liters

* die gemiddelde totale daaglikse waterverbruik op 'n eiendom met 'n boorgat 2800 liters beloop, waarvan 74 persent uit die grond onttrek is.

Hierdie syfers is egter gegrond op 'n baie klein monster van die totale getal eiendomme met boorgate; om betekenisvolle syfers te bekom is dit dus noodsaaklik dat meer eiendomme gemonitor moet word.

U samewerking in hierdie onderneming sal hoog op prys gestel word.

G C Simpson, Projekkoordineerder

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APPENDIX C - RAINFALL AND TEMPERATURE DATA FOR PRETORIA

TABLE C1 : MONTHLY TOTAL RAINFALL FOR PRETORIA (mm)

STATION: YEAR	MONTH	513/255 PRETORIA KRAGSTASIE	513/374 PWD NURSERY	513/380 WATERKLOOF AIR BASE	513/404 RIETONDALE	513/528 CONSTANTIA PARK	513/556 WILGERS	513/558 GARSFONTEIN	513/465 PRETORIA UNIVERSITY	AVERAGE MONTHLY RAINFALL
1985	OCT	117	122	105	102	148	128	134	137	124.1
1985	NOV	77	21	57	112	55	59	56	14	56.4
1985	DEC	144	133	134	144	120	138	120	140	134.1
1986	JAN	95	58	60	40	40	64	69	56	60.3
1986	FEB	24	41	64	25	59	57	60	55	48.1
1986	MAR	44	48	42	27	50	46	44	22	40.4
1986	APR	28	39	31	38	30	39	27	32	33.0
1986	MAY	0	0	0	0	0	0	0	0	.0
1986	JUN	22	26	27	20	23	19	22	19	22.3
1986	JUL	0	0	0	0	0	0	0	0	.0
1986	AUG	2	2	1	1	1	1	1	1	1.3
1986	SEP	0	0	5	0	1	2	2	0	1.3
1986	OCT	154	177	151	176	186	196	188	164	174.0
1986	NOV	105	102	100	136	144	137	170	153	130.9
1986	DEC	165	159	160	176	157	198	171	182	171.0
1987	JAN	91	84	79	81	76	87	93	78	83.6
1987	FEB	51	121	94	112	68	90	103	143	97.8
1987	MAR	109	188	91	163	169	162	196	160	154.8
1987	APR	20	42	8	35	21	19	24	13	22.8
1987	MAY	0	0	0	0	0	0	0	0	.0
1987	JUN	0	0	0	0	0	0	0	0	.0
1987	JUL	0	0	0	0	0	0	0	0	.0
1987	AUG	6	11	34	18	26	28	26	17	20.8
1987	SEP	77	82	93	72	80	83	91	70	81.0
1987	OCT	33	57	43	62	65	62	69	50	55.1
1987	NOV	154	144	142	153	160	131	163	132	147.4
1987	DEC	— no data obtained —								

TABLE C1 (CONT) : MONTHLY TOTAL RAINFALL FOR PRETORIA (mm)

STATION: YEAR	MONTH	513/255 PRETORIA KRAGSTASIE	513/374 PWD NURSERY	513/380 WATERKLOOF AIR BASE	513/404 RIETONDALE	513/528 CONSTANTIA PARK	513/556 WILGERS	513/558 GARSFONTEIN	513/465 PRETORIA UNIVERSITY	AVERAGE MONTHLY RAINFALL
1988	JAN	68	82	71	52	93	91	80	54	73.9
1988	FEB	31	53	39	43	79	69	90	46	56.3
1988	MAR	108	160	118	159	129	120	139	120	131.6
1988	APR	55	83	75	84	90	98	85	83	81.6
1988	MAY	0	0	1	0	0	1	1	0	.4
1988	JUN	6	13	9	11	8	9	8	8	9.0
1988	JUL	5	3	0	4	3	2	2	3	2.8
1988	AUG	0	0	0	2	0	1	1	2	.8
1988	SEP	44	54	49	56	47	45	50	50	49.4
1988	OCT	63	72	93	93	101	71	95	69	82.1
1988	NOV	40	39	46	48	43	56	49	50	46.4
1988	DEC	44	96	94	56	115	109	139	121	96.8
1989	JAN	135	72	71	134	62	95	65	93	90.9
1989	FEB	208	236	175	243	186	213	178	199	204.8
1989	MAR	8	20	66	26	37	32	39	23	31.4
1989	APR	51	55	103	60	74	46	67	56	64.0
1989	MAY	28	12	1	2	0	2	1	1	5.9
1989	JUN	64	15	33	81	62	85	70	84	61.8
1989	JUL	0	0	0	0	0	0	0	0	.0
1989	AUG	1	7	1	0	1	2	2	2	2.0
1989	SEP	0	0	0	0	0	0	0	0	.0
1989	OCT	17	0	42	43	35	37	36	42	31.5
1989	NOV	168	262	179	167	150	149	141	158	171.8
1989	DEC	66	103	137	188	119	158	173	191	141.9
1990	JAN	109		270	18	39	30	30		82.7
AVERAGE/MONTH		56	62	63	64	62	64	66	62	

TABLE C2 : MAXIMUM AND MINIMUM AVERAGE TEMPERATURES FOR PRETORIA (Deg.C)

STATION:		513/465 PRETORIA UNIVERSITY		513/380 WATERKLOOF AIR BASE		513/314 FORUM BUILDING		513/385 IRENE		AVERAGE MAXIMUM	AVERAGE MINIMUM
YEAR	MONTH	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	DEG.C	DEG.C
1985	OCT	27.6								27.6	
1985	NOV	28.3								28.3	
1985	DEC	26.3								26.3	
1986	JAN	28.1								28.1	
1986	FEB	28.1								28.1	
1986	MAR	27.7								27.7	
1986	APR	24.7								24.7	
1986	MAY	23.9								23.9	
1986	JUN	19.2								19.2	
1986	JUL	19.9								19.9	
1986	AUG	22.9								22.9	
1986	SEP	24.7								24.7	
1986	OCT	25.0								25.0	
1986	NOV	24.7								24.7	
1986	DEC	27.1								27.1	
1987	JAN	27.8								27.8	
1987	FEB	29.3								29.3	
1987	MAR	26.6								26.6	
1987	APR	26.4								26.4	
1987	MAY	24.2								24.2	
1987	JUN	18.8								18.8	
1987	JUL	18.8								18.8	
1987	AUG	20.3								20.3	
1987	SEP	22.7								22.7	
1987	OCT	26.0								26.0	
1987	NOV	26.9								26.9	
1987	DEC	-								-	

TABLE C2 (CONT) : MAXIMUM AND MINIMUM AVERAGE TEMPERATURES FOR PRETORIA (Deg.C)

STATION:	513/465 PRETORIA UNIVERSITY		513/380 WATERKLOOF AIR BASE		513/314 FORUM BUILDING		513/385 IRENE		AVERAGE MAXIMUM	AVERAGE MINIMUM
YEAR MONTH	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	DEG.C	DEG.C
1988 JAN	29.2	16.4	28.6	16.8	30.2	18.7	28.6	15.5	29.2	16.9
1988 FEB	27.9	16.5	27.1	16.6	28.8	18.8	27.1	15.3	27.7	16.8
1988 MAR	26.6	15.0	25.6	15.7	27.6	17.5	26.2	14.3	26.5	15.6
1988 APR	23.3	11.6	22.1	11.7	24.0	13.2	23.0	10.1	23.1	11.7
1988 MAY	21.8	6.4	20.6	6.6	22.6	8.0	21.6	5.4	21.7	6.6
1988 JUN	18.2	3.4	17.0	3.5	18.7	4.5	17.6	2.2	17.9	3.4
1988 JUL	20.2	3.9	19.1	3.6	20.8	5.1	19.6	2.7	19.9	3.8
1988 AUG	22.7	6.8	21.6	6.4	23.4	8.5	22.1	6.0	22.5	6.9
1988 SEP	24.1	10.4	23.2	9.9	24.9	11.9	23.6	9.2	30.2	13.3
1988 OCT	24.6	12.9	23.7	12.1	25.3	14.4	23.7	11.6	24.3	12.8
1988 NOV	26.4	13.1	25.4	13.1	26.9	15.6	25.2	12.5	26.0	13.6
1988 DEC	25.6	14.7	24.4	14.2	26.4	16.1	24.2	13.8	25.2	14.7
1989 JAN	26.7	15.9	26.1	15.4	27.9	18.0	25.9	14.7	26.7	16.0
1989 FEB	24.3	15.6	23.5	15.0	25.6	17.0	23.4	14.6	24.2	15.6
1989 MAR	26.6	13.8	25.6	13.7	28.1	16.0	25.9	12.7	26.6	14.1
1989 APR	22.4	10.4	20.8	10.2	22.8	12.3	21.4	9.6	21.9	10.6
1989 MAY	21.5	7.6	20.0	8.3	22.0	9.4	20.7	7.7	21.1	8.3
1989 JUN	18.5	5.3	17.2	5.3	19.2	7.0	17.9	4.6	18.2	5.6
1989 JUL	18.6	3.4	17.4	3.8	19.3	4.9	17.9	2.4	18.3	3.6
1989 AUG	23.5	8.4	22.5	7.7	24.1	9.8	23.1	6.8	23.3	8.2
1989 SEP	25.0	9.5	24.0	9.6	25.9	11.3	24.5	8.2	24.9	9.7
1989 OCT	25.5	11.9	24.8	12.3	26.1	13.7	25.0	11.1	25.4	12.3
1989 NOV	25.7	13.4	24.5	13.5	26.1	15.2	24.6	12.3	25.2	13.6
1989 DEC	27.0	15.1	26.1	15.2	28.2	16.7	26.5	14.0	27.0	15.3
1990 JAN	-	-	27.1	15.8	28.7	17.9	27.2	14.5	27.7	16.1
AVERAGES	24.4	10.9	23.1	11.0	25.9	13.3	23.5	10.1	23.5	10.1

APPENDIX D - RESULTS OF WATER QUALITY ANALYSES

This appendix consists of sixteen tables.

There are four tables for each of the four bi-annual sets of analyses.

The twenty sites included in each sampling were divided into two groups of ten.

For each group, there are two tables - one reporting on the municipal water quality and the other reporting on the borehole water quality.

TABLE M1 : NOVEMBER 1987 TEST RESULTS (NATIONAL INSTITUTE FOR WATER RESEARCH)

BOREHOLE NUMBER		1	2	8	13	15	23	27	30	32	33
SUBURB CODE		VALDEG	MEYER	QUEENS	GARSFNT	CONSTANT	BROOKL	FAERIE	SILVTN	COLBYN	WAVERLY
MUNICIPAL WATER QUALITY											
LAB.No.		14817	14804	14800	14802	15290	15276	15292	14825	15278	14824
TURBIDITY (NTU)		1	.5	.6	.7	1.5	1.5	.8	.6	1.6	.6
pH		7.8	7.8	7.9	7.8	6.5	7.4	7.5	8	7.5	7.7
ELEC.CONDUCTIVITY (mS/m)		52.53	53.87	50.66	47.47	40.75	40.17	41.49	53.23	41.06	52.65
COLOUR (mg/l Pt)		13	12	10	13	12	17	10	15	12	12
SODIUM (Na)	mg/l	22	23	9	17	27	30	28	32	31	28
POTASSIUM (K)	mg/l	6	6	6	6	7	8	5	6	6	6
CALCIUM (Ca)	mg/l	49	57	56	53	40	35	43	57	36	49
MAGNESIUM (Mg)	mg/l	8	8	8	7	4	8	5	8	8	13
NITRATES+NITRITES (N)	mg/l	2	1.3	1.4	1.4	1.3	.8	1.5	1.6	.8	2.1
NITRITES-NITROGEN (N)	mg/l	<0.1	.1	<.1	.1	<.1	<.1	<.1	<.1	<.1	.1
SULPHATES (SO-4)	mg/l	36	109	89	92	69	46	79	104	49	51
CHLORIDES (Cl)	mg/l	41	39	37	36	31	30	32	42	30	37
ORTHO-PHOSPHATES (P)	mg/l										
ALKALINITY (CaCO-3)	mg/l	101	60	59	56	63	97	61	94	95	127
CHEM.OXYGEN DEMAND	mg/l	12	13	13	14	9	12	8	12	11	14
BORON (B)	ug/l	100	113	116	110	55	120	87	107	125	104
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	5	<5	6	<5	6	<5	<5	5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	90	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	1526	428	164	414	2217	203	1353	721	187	133
IRON (Fe)	ug/l	27	46	<25	40	52	96	44	42	87	<25
FLOURIDE	ug/l	160	160	150	160	165	160	154	160	146	160

TABLE M1 (CONT) : NOVEMBER 1987 TEST RESULTS (NATIONAL INSTITUTE FOR WATER RESEARCH)

BOREHOLE NUMBER		35	36	38	40	41	44	45	48	50	55
SUBURB CODE		WAVERLY	WILGLEN	MURRAYF	NAVOURS	LYNNWD	WBSOUTH	MORLETP	VILLRIA	VILLRIA	VILLRIA
MUNICIPAL WATER QUALITY											
LAB.No.		14806	14798	15280	15294	15282	15296	15298	14819	14823	15284
TURBIDITY (NTU)		.6	.5	.8	1.2	1.3	1.1	1	.8	.8	1.3
pH		7.8	7.5	7.8	7.9	7.5	7.4	7.4	7.8	7.8	7.6
ELEC.CONDUCTIVITY (mS/m)		53.46	51.19	42.48	41.17	42.59	35.65	39.91	45.32	45.8	35.23
COLOUR (mg/l Pt)		13	12	11	9	11	9	15	11	12	9
SODIUM (Na)	mg/l	32	13	25	26	29	20	24	26	26	15
POTASSIUM (K)	mg/l	6	1	6	5	5	4	5	5	5	4
CALCIUM (Ca)	mg/l	53	54	39	41	42	37	41	48	49	38
MAGNESIUM (Mg)	mg/l	8	7	6	5	6	4	5	6	7	6
NITRATES+NITRITES (N)	mg/l	1.3	1.3	1	1.2	1.4	1.3	1.3	2.9	2.5	1.1
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	.2	<.1	<.1	<.1	<.1	.2	<.1
SULPHATES (SO-4)	mg/l	107	76	78	72	83	48	67	32	54	39
CHLORIDES (Cl)	mg/l	41	40	34	32	34	25	33	29	31	21
ORTHO-PHOSPHATES (P)	mg/l										
ALKALINITY (CaCO-3)	mg/l	61	56	62	61	63	68	72	112	113	70
CHEM.OXYGEN DEMAND	mg/l	13	14	9	9	7	6	9	16	10	7
BORON (B)	ug/l	130	124	88	77	102	81	88	89	82	106
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	342	56	183	59	87	102	580	144	1152	960
IRON (Fe)	ug/l	40	437	<25	35	<25	62	33	69	73	71
FLOURIDE	ug/l	160	140	154	146	146	146	165	160	<100	140

TABLE B1 : NOVEMBER 1987 TEST RESULTS (NATIONAL INSTITUTE FOR WATER RESEARCH)

BOREHOLE NUMBER		1	2	8	13	15	23	27	30	32	33
SUBURB CODE		VALDEG	MEYER	QUEENS	GARSFNT	CONSTANT	BROOKL	FAERIE	SILVTN	COLBYN	WAVERLY
BOREHOLE WATER QUALITY											
LAB.No.		14816	14803	14799	14801	15289	15275	15291	14824	15277	14820
TURBIDITY (NTU)		.3	.8	.3	1.6	1.9	.6	.5	.6	.9	.2
pH		5.9	7.1	7.2	7.5	6.7	7	7.1	7	6.6	7.6
ELEC.CONDUCTIVITY (mS/m)		11.07	37.89	63.22	38.48	17.77	80.49	52.97	47.06	23.14	39.22
COLOUR (mg/l Pt)		5	6	5	9	6	<5	<5	8	<5	<5
SODIUM (Na)	mg/l	7	10	17	17	4	13	12	18	6	18
POTASSIUM (K)	mg/l	1	2	1	1	2	2	2	1	2	2
CALCIUM (Ca)	mg/l	7	31	58	44	18	66	46	50	13	25
MAGNESIUM (Mg)	mg/l	5	22	32	14	8	52	23	21	12	31
NITRATES+NITRITES (N)	mg/l	4.8	.5	2.7	.4	.2	6.4	5	.3	3.3	6.1
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	3	24	31	11	8	60	25	42	7	87
ORTHO-PHOSPHATES (P)	mg/l										
CHLORIDES (Cl)	mg/l	7	5	32	6	6	68	27	19	14	12
ALKALINITY (CaCO-3)	mg/l	19	165	227	175	72	212	154	176	75	102
CHEM.OXYGEN DEMAND	mg/l	<5	5	7	6	<5	5	<5	<5	<5	7
BORON (B)	ug/l	63	79	92	81	<50	87	72	72	69	55
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	5
COPPER (Cu)	ug/l	<25	<25	29	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	155	<25	<25	110	<25	<25	166	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	<25	93	316	115	340	30	162	80	58	728
IRON (Fe)	ug/l	<25	46	37	148	234	<25	50	110	<25	<25
FLOURIDE	ug/l	<100	410	200	270	320	<100	<100	290	105	<100
TOTAL COLIFORMS (per 100 ml)		3	2	3	30	0	0	5	0	50	13
FAECAL COLIFORMS (per 100 ml)		0	0	1	20	0	0	0	0	9	0
STANDARD PLATE COUNT (per ml)		2103	132	2430	1170	178	670	520	446	2830	85

TABLE B1 (CONT) : NOVEMBER 1987 TEST RESULTS (NATIONAL INSTITUTE FOR WATER RESEARCH)

BOREHOLE NUMBER		35	36	38	40	41	44	45	48	50	55
SUBURB CODE		WAVERLY	WILGLEN	MURRAYF	NAVOURS	LYNNWD	WBSOUTH	MORLETP	VILLRIA	VILLRIA	VILLRIA
BOREHOLE WATER QUALITY											
LAB.No.		14805	14797	15279	15293	15281	15295	15297	14818	14822	15283
TURBIDITY (NTU)		.2	3.1	.4	1.1	.7	1.6	16	.3	<.2	.8
pH		7.4	6.6	7.5	7.2	7	6.8	6.6	7.4	7.3	7.5
ELEC.CONDUCTIVITY (mS/m)		75.12	15.6	30.12	18.67	42.59	33.86	21.33	54.44	68.23	35.91
COLOUR (mg/l Pt)		7	9	<5	<5	5	<5	66	<5	7	<5
SODIUM (Na)	mg/l	17	15	9	5	12	10	4	28	25	5
POTASSIUM (K)	mg/l	4	6	2	2	2	2	2	2	2	2
CALCIUM (Ca)	mg/l	61	33	29	14	37	15	20	40	46	40
MAGNESIUM (Mg)	mg/l	42	9	17	10	23	21	10	29	47	17
NITRATES+NITRITES (N)	mg/l	2.5	.4	1.4	.3	3.6	1.7	<.2	5.5	6.4	2.4
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	51	33	5	7	12	28	10	86	87	11
ORTHO-PHOSPHATES (P)	mg/l										
CHLORIDES (Cl)	mg/l	52	29	9	4	20	19	6	18	14	15
ALKALINITY (CaCO-3)	mg/l	229	66	147	82	175	101	82	155	225	148
CHEM.OXYGEN DEMAND	mg/l	7	<5	<5	<5	<5	<5	<5	6	<5	<5
BORON (B)	ug/l	100	83	82	<50	89	61	100	66	82	76
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	5	<5	5	<5	<5	<5	<5	<5	5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	77	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	95	<25	<25	<25	<25	190	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	696	205	1695	778	318	180	135	581	737	<25
IRON (Fe)	ug/l	<25	<25	<25	25	27	157	931	25	26	<25
FLOURIDE	ug/l	200	<100	<100	<100	<100	<100	770	310	180	200
TOTAL COLIFORMS (per 100 ml)		240	2	150	40	1	63	23	29	1	390
FAECAL COLIFORMS (per 100 ml)		0	0	1	0	0	0	0	2	0	0
STANDARD PLATE COUNT (per ml)		700	206	1560	940	320	680	>1000	143	40	1560

TABLE M2 : JULY 1988 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		1	2	8	13	15	23	27	30	32	33
SUBURB CODE		VALDEG	MEYER	QUEENS	GARSFNT	CONSTANT	BROOKL	FAERIE	SILVTN	COLBYN	WAVERLY
MUNICIPAL WATER QUALITY											
LAB.No.		7179	7001	7003	7005	7187	7171	7173	7175	7007	7009
TURBIDITY (NTU)		.9	.6	.5	.7	1.2	.6	.8	.9	.4	.7
pH		7.6	7.6	7.9	7.5	7.8	7.5	7.6	7.6	7.7	7.7
ELEC.CONDUCTIVITY (mS/m)		35.6	32.43	27.9	26.53	36.13	40.02	28.1	34.74	28.1	32.98
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	20	17	10	10	20	31	12	21	12	17
POTASSIUM (K)	mg/l	5	4	3	4	4	5	3	4	4	5
CALCIUM (Ca)	mg/l	36	39	39	36	39	33	36	35	35	38
MAGNESIUM (Mg)	mg/l	6	5	4	4	5	9	4	5	4	6
NITRATES+NITRITES (N)	mg/l	.4	.7	.7	.7	.5	.5	.8	.5	.6	.6
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	23	22	15	14	23	36	17	25	15	22
ORTHO-PHOSPHATES (P)	mg/l	.4	.2	<.2	<.2	.5	.6	<.2	.3	.3	<.2
CHLORIDES (Cl)	mg/l	18	17	31	11	19	28	11	18	12	19
ALKALINITY (CaCO-3)	mg/l	104	109	187	88	112	107	94	102	94	104
CHEM.OXYGEN DEMAND	mg/l	15	6	9	8	17	12	12	12	7	6
BORON (B)	ug/l	113	101	105	115	97	149	116	129	117	239
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	49	61	<25	<25	387	76	354	37	<25	<25
IRON (Fe)	ug/l	32	<25	<25	<25	260	27	<25	57	30	37
FLOURIDE	ug/l	127	2250	720	310	750	127	110	150	265	245

TABLE M2 (CONT) : JULY 1988 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		35	36	38	40	41	44	45	48	50	55
SUBURB CODE		WAVERLY	WILGLEN	MURRAYF	NAVOURS	LYNNWD	WBSOUTH	MORLETP	VILLRIA	VILLRIA	VILLRIA
MUNICIPAL WATER QUALITY											
LAB.No.		7011	7189	7191	7181	7193	7183	7185	7013	7177	7015
TURBIDITY (NTU)		.7	1	.9	.9	1.5	.7	1	.6	.7	.5
pH		7.6	7.6	7.7	7.6	7.7	7.5	7.5	7.5	7.7	7.5
ELEC.CONDUCTIVITY (mS/m)		33.38	35.2	35.97	34.53	28.42	26.09	35.36	27.28	26.65	36.4
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	16	20	21	20	11	10	19	9	11	10
POTASSIUM (K)	mg/l	4	4	4	4	4	3	4	3	4	3
CALCIUM (Ca)	mg/l	37	36	40	35	37	32	38	35	33	38
MAGNESIUM (Mg)	mg/l	5	5	5	6	4	4	6	4	4	14
NITRATES+NITRITES (N)	mg/l	.6	.5	.5	.5	.8	.7	.5	.5	.6	1.2
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	25	22	22	25	17	16	25	15	15	15
ORTHO-PHOSPHATES (P)	mg/l	<.2	.3	.5	.3	<.2	<.2	.5	<.2	<.2	<.2
CHLORIDES (Cl)	mg/l	18	19	19	19	12	12	17	11	11	15
ALKALINITY (CaCO-3)	mg/l	107	103	107	103	91	88	108	92	94	125
CHEM.OXYGEN DEMAND	mg/l	8	27	22	15	22	12	13	9	15	5
BORON (B)	ug/l	121	107	113	111	92	87	113	115	121	135
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	46	43	30	28	60	84	210	59	70	67
IRON (Fe)	ug/l	43	53	40	35	67	29	45	44	<25	<25
FLOURIDE	ug/l	166	450	127	110	110	<100	177	245	140	143
CHEMICAL BALANCE		BAL	BAL	BAL	BAL	BAL	BAL	BAL	BAL	BAL	BAL

TABLE B2 : JULY 1988 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		1	2	8	13	15	23	27	30	32	33
SUBURB CODE		VALDEG	MEYER	QUEENS	GARSFNT	CONSTANT	BROOKL	FAERIE	SILVTN	COLBYN	WAVERLY
BOREHOLE WATER QUALITY											
LAB.No.		7178	7000	7002	7004	7186	7170	7172	7174	7006	7008
TURBIDITY (NTU)		.3	.4	<.2	.4	1	.7	.7	.9	<.2	.2
pH		5.8	7	7.2	7.3	6.5	7.2	6.7	6.6	6.6	7.7
ELEC.CONDUCTIVITY (mS/m)		10.02	37.46	53.93	36.4	17.1	82.39	48.27	44.95	22.11	38.31
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	8	11	19	18	4	14	14	19	4	6
POTASSIUM (K)	mg/l	2	3	2	2	2	2	2	2	2	3
CALCIUM (Ca)	mg/l	4	32	50	42	17	54	48	46	15	15
MAGNESIUM (Mg)	mg/l	3	21	26	12	7	52	24	20	14	28
NITRATES+NITRITES (N)	mg/l	4.2	.4	2.8	.2	<.2	6.9	2.7	.2	3.6	5.4
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	8	19	21	8	13	60	24	40	7	9
ORTHO-PHOSPHATES (P)	mg/l	<.2	.3	<.2	<.2	.3	<.2	<.2	<.2	<.2	<.2
CHLORIDES (Cl)	mg/l	9	7	31	7	6	66	18	10	10	16
ALKALINITY (CaCO-3)	mg/l	11	155	187	170	52	221	181	167	73	127
CHEM.OXYGEN DEMAND	mg/l	20	11	9	9	11	19	16	15	9	10
BORON (B)	ug/l	103	94	105	115	66	145	128	127	99	121
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	169	<25	28	74	<25	<25	159	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	<25	<25	<25	<25	227	<25	91	55	27	<25
IRON (Fe)	ug/l	<25	<25	<25	<25	112	<25	<25	41	<25	<25
FLOURIDE	ug/l	<100	460	590	380	280	110	114	140	235	210
TOTAL COLIFORMS (per 100 ml)		3	107	6	5	0	0	1	3	2	137
FAECAL COLIFORMS (per 100 ml)		0	0	0	0	0	0	0	0	0	35
STANDARD PLATE COUNT (per ml)		773	220	115	78	283	38	273	149	79	690

TABLE B2 (CONT) : JULY 1988 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		35	36	38	40	41	44	45	48	50	55
SUBURB CODE		WAVERLY	WILGLEN	MURRAYF	NAVOURS	LYNNWD	WBSOUTH	MORLETP	VILLRIA	VILLRIA	VILLRIA
BOREHOLE WATER QUALITY											
LAB.No.		7010	7188	7190	7180	7192	7182	7184	7012	7176	7014
TURBIDITY (NTU)		.7	.9	.5	.2	.5	.3	2	.4	.4	.3
pH		7.5	6.5	6.8	7.1	6.9	6.7	6.5	7.2	7.6	7.2
ELEC.CONDUCTIVITY (mS/m)		70.77	13.62	35.05	18.4	46.72	35.2	20.29	49.68	66.37	35.24
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	17	6	10	4	12	10	4	24	28	3
POTASSIUM (K)	mg/l	2	1	2	2	2	3	2	2	2	2
CALCIUM (Ca)	mg/l	63	11	33	16	42	16	21	36	44	39
MAGNESIUM (Mg)	mg/l	40	5	16	9	26	23	10	27	42	17
NITRATES+NITRITES (N)	mg/l	2.9	<.2	1.9	.3	4.6	1.8	<.2	3	5	1.9
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	45	8	8	11	9	28	12	18	18	8
ORTHO-PHOSPHATES (P)	mg/l	<.2	<.2	<.2	<.2	<.2	<.2	.4	<.2	<.2	<.2
CHLORIDES (Cl)	mg/l	45	7	11	5	17	18	5	18	18	11
ALKALINITY (CaCO-3)	mg/l	223	53	135	65	184	103	85	190	283	139
CHEM.OXYGEN DEMAND	mg/l	5	15	15	21	14	19	18	7	10	5
BORON (B)	ug/l	133	73	85	108	91	97	95	129	129	117
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	92	<25	<25	<25	<25	144	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	58	<25	<25	<25	107	<25	60	104	27	<25
IRON (Fe)	ug/l	<25	470	<25	<25	<25	<25	104	<25	<25	<25
FLOURIDE	ug/l	220	105	<100	<100	<100	127	750	195	164	155
TOTAL COLIFORMS (per 100 ml)		940	1	3	1	370	127	4	2680	17	31
FAECAL COLIFORMS (per 100 ml)		19	0	0	0	0	3	0	2	0	0
STANDARD PLATE COUNT (per ml)		287	9	1093	21	547	1720	873	687	283	28

TABLE M3 : FEBRARY 1989 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		2	15	36	100	102	107	111	112	8	56
SUBURB CODE		MEYERS	CONSTANT	WILLOWGL	GROENKLF	EASTWOOD	WATERKLF	ELARDUS	WINGATE	QUEENS	CAPITAL
MINICIPAL WATER QUALITY											
LAB.No.		1372	1374	1376	1378	1380	1382	1384	1386	1388	1390
TURBIDITY (NTU)		<0.2	<0.2	4	2	3	2	3	3	3	2
pH		7.7	7.6	7.6	7.5	7.55	7.8	7.6	7.8	7.8	7.8
ELEC.CONDUCTIVITY (mS/m)		34.55	25.22	33.14	23.03	79.64	25.11	23.59	23.31	22.97	26.91
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	24	9	23	10	14	11	10	14	11	21
POTASSIUM (K)	mg/l	3	2	3	4	2	3	4	3	3	4
CALCIUM (Ca)	mg/l	28	30	30	23	79	26	24	25	24	23
MAGNESIUM (Mg)	mg/l	7	4	7	5	39	5	5	4	4	6
NITRATES+NITRITES (N)	mg/l	.8	.7	.9	.2	11.3	.6	.7	.6	.6	.5
NITRITES-NITROGEN (N)	mg/l	<0.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	27	11	25	34	66	17	20	20	22	22
ORTHO-PHOSPHATES (P)	mg/l	.3	<.2	.3	<.2	<.2	<.2	.2	<.2	<.2	.2
CHLORIDES (Cl)	mg/l	20	10	20	12	52	12	11	12	12	16
ALKALINITY (CaCO-3)	mg/l	109	76	103	53	188	78	62	66	57	86
CHEM.OXYGEN DEMAND	mg/l	10	7	7	6	<5	6	<5	7	8	7
BORON (B)	ug/l	111	98	119	86	125	93	89	53	93	100
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	44	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	11	<5	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	64	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	47	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	31	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	1478	339	61	<25	1956	322	444	50	<25	<25
IRON (Fe)	ug/l	36	<25	127	36	2778	<25	<25	<25	44	44
FLOURIDE	ug/l	220	196	155	280	113	<100	114	135	130	<100

TABLE M3 (CONT) : FEBRARY 1989 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		62	67	69	73	78	84	87	88	92	98
SUBURB CODE		DORANDIA	PTANORTH	ANNLIN	MAGALIES	EASTLYN	MOUNTVW	CLAREMNT	PTAGRDNS	MOUNTVW	WESTPARK
MUNICIPAL WATER QUALITY											
LAB.No.		1392	1394	1396	1398	1400	1402	1404	1406	1408	1410
TURBIDITY (NTU)		2	3	3	2	3	2	3	1	2	2
pH		7.9	7.7	7.7	7.8	8	7.6	7.8	7.7	7.7	7.65
ELEC.CONDUCTIVITY (mS/m)		23.08	22.66	22.77	25.15	33.81	25.15	22.94	22.83	23.05	21.24
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	12	9	10	10	23	10	9	10	10	21
POTASSIUM (K)	mg/l	3	3	4	4	5	4	3	3	3	3
CALCIUM (Ca)	mg/l	23	22	23	20	26	21	22	21	22	20
MAGNESIUM (Mg)	mg/l	6	3	3	4	6	4	4	3	4	3
NITRATES+NITRITES (N)	mg/l	.6	.7	.7	.7	.3	.3	.7	.6	.8	.7
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	23	14	14	20	30	5	23	18	20	20
ORTHO-PHOSPHATES (P)	mg/l	<.2	<.2	<.2	<.2	.4	<.2	<.2	<.2	<.2	.2
CHLORIDES (Cl)	mg/l	13	12	12	10	23	13	12	11	13	11
ALKALINITY (CaCO-3)	mg/l	64	61	57	58	78	60	56	61	62	81
CHEM.OXYGEN DEMAND	mg/l	9	8	7	7	8	8	6	6	6	7
BORON (B)	ug/l	65	65	89	68	105	<50	50	93	60	57
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	<25	<25	<25	<25	<25	<25	<25	2044	<25	<25
IRON (Fe)	ug/l	<25	44	<25	<25	<25	<25	<25	29	44	<25
FLOURIDE	ug/l	<100	<100	<100	<100	117	<100	235	235	290	145

TABLE B3 : FEBRARY 1989 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		2	15	36	100	102	107	111	112	8	56
SUBURB CODE		MEYERS	CONSTANT	WILLOWGL	GROENKLF	EASTWOOD	WATERKLF	ELARDUS	WINGATE	QUEENS	CAPITAL
BOREHOLE WATER QUALITY											
LAB.No		1371	1373	1375	1377	1379	1381	1383	1385	1387	1389
TURBIDITY (NTU)		3	3	6	2	<.2	1	3	7	4	2
pH		6.7	6.9	6.9	6.7	7.2	6.7	4.7	7.6	7.4	7.6
ELEC.CONDUCTIVITY (mS/m)		15.39	24.6	22.3	39.59	80.83	26.29	8.27	23.2	50.31	41.2
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	4	5	6	8	17	5	3	3	17	8
POTASSIUM (K)	mg/l	2	1	2	2	2	2	2	2	2	2
CALCIUM (Ca)	mg/l	8	23	24	27	75	16	4	21	49	39
MAGNESIUM (Mg)	mg/l	6	10	6	24	37	15	3	11	26	22
NITRATES+NITRITES (N)	mg/l	3.3	.3	.3	8	11.7	2.9	.5	.3	2.4	7.7
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	6	9	8	29	73	5	7	9	41	35
ORTHO-PHOSPHATES (P)	mg/l	<.2	<.2	<.2	<.2	.2	<.2	<.2	<.2	<.2	.2
CHLORIDES (Cl)	mg/l	11	11	6	23	53	11	5	4	21	19
ALKALINITY (CaCO-3)	mg/l	20	76	77	89	176	76	17	99	181	109
CHEM.OXYGEN DEMAND	mg/l	<5	<5	<5	<5	<5	<5	<5	10	8	<5
BORON (B)	ug/l	54	81	132	70	109	58	54	60	123	70
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	149	40	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	38	87	381	<25	<25	<25	<25	72	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	<25	417	<25	61	294	178	61	<25	<25	1048
IRON (Fe)	ug/l	<25	287	1789	69	60	<25	104	489	44	44
FLOURIDE	ug/l	200	350	<100	<100	118	<100	114	114	178	<100
TOTAL COLIFORMS (per 100 ml)		81	340	7	30	23	383	2000	2153	2640	173
FAECAL COLIFORMS (per 100 ml)		0	1	0	0	0	0	135	166	78	0
STANDARD PLATE COUNT (per ml)		490	833	903	593	240	797	1650	1693	653	507
LAB No.		2735	2740	2741	2745	2746	2744	2743	2742	2739	2737
O-18 ISOTOPE TESTS		-3.2	-3.67	-4.62	-2.59	-2.95	-3.38	-4.92	-4.7	-3.87	-4.05
			-3.63		-2.67					-3.88	

TABLE B3 (CONT) : FEBRARY 1989 TEST RESULTS . (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		62	67	69	73	78	84	87	88	92	98
SUBURB CODE		DORANDIA	PTANORTH	ANNLIN	MAGALIES	EASTLYN	MOUNTVW	CLAREMNT	PTAGRDNS	MOUNTVW	WESTPARK
BOREHOLE WATER QUALITY											
LAB.No.		1392	1394	1396	1398	1400	1402	1404	1406	1408	1410
TURBIDITY (NTU)		2	2	1	4	1	12	<.2	2	<.2	24
pH		7.8	7.5	7.2	7.4	7.5	6.75	7.7	7.5	7.1	7.65
ELEC.CONDUCTIVITY (mS/m)		62.97	53.05	42.58	18.92	81.29	153.19	76.56	33.3	48.24	38.22
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	5	<5	<5	<5	5
SODIUM (Na)	mg/l	6	7	7	4	47	68	19	7	8	10
POTASSIUM (K)	mg/l	2	2	3	2	2	3	2	2	2	2
CALCIUM (Ca)	mg/l	59	25	34	12	62	86	87	29	21	42
MAGNESIUM (Mg)	mg/l	30	36	23	9	36	78	36	16	31	14
NITRATES+NITRITES (N)	mg/l	3	9.8	8.9	.4	9.5	6.1	1.2	4	7.8	1.5
NITRITES-NITROGEN (N)	mg/l	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
SULPHATES (SO-4)	mg/l	38	27	5	4	48	229	81	4	35	25
ORTHO-PHOSPHATES (P)	mg/l	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
CHLORIDES (Cl)	mg/l	21	29	14	4	32	171	39	11	27	6
ALKALINITY (CaCO-3)	mg/l	217	117	125	64	256	172	240	121	97	149
CHEM.OXYGEN DEMAND	mg/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
BORON (B)	ug/l	128	72	79	86	96	84	100	110	60	53
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	7	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	<25	<25	66	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	<25	217	<25	<25	39	222	<25	<25	989	<25
IRON (Fe)	ug/l	<25	38	<25	104	<25	<25	60	44	84	149
FLOURIDE	ug/l	<100	<100	115	<100	115	<100	530	<100	<100	150
TOTAL COLIFORMS (per 100 ml)		387	2990	550	367	1043	4700	1620	19	2610	1430
FAECAL COLIFORMS (per 100 ml)		10	49	0	4	52	120	39	1	24	1
STANDARD PLATE COUNT (per ml)		10640	1453	87	810	310	6280	750	263	763	940
LAB No.		2751	2750	2752	2753	2754	2736	2748	2738	2749	2747
O-18 ISOTOPE TESTS		-2.52	-2.98	-4.63	-5.09	-3.6	-.5	-3.06	-4.83	-4.34	-4.82
		-2.4		-4.72			-.55			-4.49	-4.8
				-4.72							

TABLE M4 : OCTOBER 1989 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		2	8	15	36	56	62	67	69	73	78
SUBURB CODE		MEYER	QUEENS	CONSTANT	WILGLEN	CAPITAL	DORANDIA	PTA. N	ANNLIN	MAGALIES	E. LYNNE
MUNICIPAL WATER QUALITY											
LAB.No.		6399	6389	6391	6434	6387	6430	6432	6395	6401	6397
TURBIDITY (NTU)		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
pH		7.7	7.6	7.6	8.2	7.5	7.6	7.7	7.5	7.5	7.8
ELEC.CONDUCTIVITY (mS/m)		33.4	36.9	27.4	32.2	26.9	27.4	25.3	25.5	25.2	32.1
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	11	23	12	20	19	11	12	13	28	22
POTASSIUM (K)	mg/l	1	3	2	3	3	3	3	3	1	3
CALCIUM (Ca)	mg/l	34	31	33	27	27	24	27	27	27	27
MAGNESIUM (Mg)	mg/l	6	8	4	7	5	5	5	4	4	6
NITRATES+NITRITES (N)	mg/l	.5	.6	.6	.4	.7	.9	.7	.7	.6	.5
NITRITES-NITROGEN (N)	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SULPHATES (SO-4)	mg/l	21	21	13	21	16	15	14	16	21	19
ORTHO-PHOSPHATES (P)	mg/l	.4	.4	<0.2	.3	<0.2	<0.2	<0.2	<0.2	<0.2	.4
CHLORIDES (Cl)	mg/l	19	21	15	18	16	13	11	13	17	19
ALKALINITY (CaCO-3)	mg/l	92	107	95	93	98	82	80	90	91	109
CHEM.OXYGEN DEMAND	mg/l	7	7	7	8	9	14	9	9	9	8
BORON (B)	ug/l	480	215	429	75	166	52	50	137	75	108
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	7	<5	<5	<5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	<25	28	<25	<25	<25	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	428	413	436	106	117	350	<25	<25	<25	124
IRON (Fe)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
FLOURIDE	ug/l	464	510	471	488	493	540	488	414	364	457

TABLE M4 (CONT) : OCTOBER 1989 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		84	87	88	92	98	100	102	107	111	112
SUBURB CODE		MOUNT.V	CLAREMNT	PTA.GARD	MOUNT.V	WESPARK	GROENKLF	EASTWOOD	WATERKLF	ELARDUSP	WINGATEP
MUNICIPAL WATER QUALITY											
LAB.No.		6403	6405	6393	6418	6422	6426	6420	6424	6428	6416
TURBIDITY (NTU)		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
pH		7.5	7.7	7.4	7.5	7.9	7.7	7	7.9	8.1	8.6
ELEC.CONDUCTIVITY (mS/m)		25.5	27	25.5	26.9	24.9	23.5	80.8	32.2	24.5	23.9
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	24	15	14	14	12	13	17	22	11	14
POTASSIUM (K)	mg/l	<1	3	3	3	3	3	<1	3	3	3
CALCIUM (Ca)	mg/l	26	29	28	28	26	29	71	30	26	27
MAGNESIUM (Mg)	mg/l	4	4	4	5	5	5	44	8	3	3
NITRATES+NITRITES (N)	mg/l	.7	.6	.6	.7	.7	.4	11.1	.4	.5	.6
NITRITES-NITROGEN (N)	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SULPHATES (SO-4)	mg/l	25	22	14	20	14	15	64	20	13	17
ORTHO-PHOSPHATES (P)	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	.3	<0.2	<0.2
CHLORIDES (Cl)	mg/l	17	15	13	15	11	12	53	18	12	15
ALKALINITY (CaCO-3)	mg/l	98	90	88	87	74	83	247	98	82	84
CHEM.OXYGEN DEMAND	mg/l	8	7	8	7	12	7	<5	8	9	8
BORON (B)	ug/l	115	91	131	73	88	105	135	119	115	106
CHROMIUM (Cr)	ug/l	42	<25	<25	<25	42	<25	42	28	<25	33
CADMIUM (Cd)	ug/l	<5	<5	<5	<5	7	<5	5	12	<5	<5
COPPER (Cu)	ug/l	<25	<25	<25	<25	28	<25	72	<25	72	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	69	<50	83	56	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	50	76	44	244	89	350	5850	420	450	139
IRON (Fe)	ug/l	1689	<25	<25	<25	<25	<25	400	<25	<25	<25
FLOURIDE	ug/l	336	329	464	400	396	368	279	347	382	436

TABLE B4 : OCTOBER 1989 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		2	8	15	36	56	62	67	69	73	78
SUBURB CODE		MEYER	QUEENS	CONSTANT	WILGLEN	CAPITAL	DORANDIA	PTA. N	ANNLIN	MAGALIES	E. LYNNE
BOREHOLE WATER QUALITY											
LAB.No		6398	6388	6390	6433	6386	6429	6431	6394	6400	6396
TURBIDITY (NTU)		<0.2	<0.2	<0.2	10	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
pH		6.8	7	6.7	6.8	6.9	7.3	7.1	6.9	7.1	7.2
ELEC.CONDUCTIVITY (mS/m)		37.5	53.6	21.2	22.3	40.7	65.3	49.8	38.8	18.8	77.9
COLOUR (mg/l Pt)		<5	<5	<5	15	<5	<5	<5	<5	<5	<5
SODIUM (Na)	mg/l	13	18	5	4	9	7	7	9	14	42
POTASSIUM (K)	mg/l	2	<1	<1	<1	<1	1	1	2	3	1
CALCIUM (Ca)	mg/l	23	47	20	28	35	59	36	31	12	58
MAGNESIUM (Mg)	mg/l	17	25	8	7	19	31	24	19	8	28
NITRATES+NITRITES (N)	mg/l	.2	3.3	.2	<0.2	8.9	2.6	6.7	6	.4	5.2
NITRITES-NITROGEN (N)	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SULPHATES (SO-4)	mg/l	21	31	12	11	24	31	23	9	7	26
ORTHO-PHOSPHATES (P)	mg/l	.3	<0.2	.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CHLORIDES (Cl)	mg/l	9	25	9	9	25	21	31	14	6	34
ALKALINITY (CaCO-3)	mg/l	138	188	80	86	104	241	125	130	87	267
CHEM.OXYGEN DEMAND	mg/l	<5	5	<5	<5	<5	5	<5	<5	<5	<5
BORON (B)	ug/l	122	166	188	<50	133	50	56	133	64	157
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
CADMIUM (Cd)	ug/l	<5	7	<5	12	5	<5	<5	<5	<5	<5
COPPER (Cu)	ug/l	<25	33	<25	<25	<25	<25	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
MANGANESE (Mn)	ug/l	72	<25	72	356	33	<25	<25	<25	<25	<25
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	<25	202	131	639	1144	<25	78	<25	<25	98
IRON (Fe)	ug/l	<25	<25	<25	644	<25	<25	<25	<25	<25	<25
FLOURIDE	ug/l	740	563	1590	329	464	409	390	393	307	464
STANDARD PLATE COUNT (per ml)		506	129	10	6	85	500	127	136	143	450
TOTAL COLIFORMS (per 100 ml)		3	407	0	0	17	353	87	15	88	197
FAECAL COLIFORMS (per 100 ml)		0	92	0	0	9	2	21	2	30	62

TABLE B4 (CONT) : OCTOBER 1989 TEST RESULTS (DIVISION OF WATER TECHNOLOGY)

BOREHOLE NUMBER		84	87	88	92	98	100	102	107	111	112
SUBURB CODE		MOUNT.V	CLAREMNT	PTA.GARD	MOUNT.V	WESPARK	GROENKLF	EASTWOOD	WATERKLF	ELARDUSP	WINGATEP
BOREHOLE WATER QUALITY											
LAB.No		6402	6404	6392	6417	6421	6425	6419	6423	6427	6415
TURBIDITY (NTU)		<0.2	<0.2	<0.2	1	<0.2	<0.2	<0.2	<0.2	<0.2	4
pH		6.6	7.3	6.2	6.8	7.3	6.4	7	6.8	5.4	6.6
ELEC.CONDUCTIVITY (mS/m)		99	69.2	14.1	50.1	36.6	24.7	80.1	23.5	8.8	12.5
COLOUR (mg/l Pt)		<5	<5	<5	<5	<5	<5	<5	<5	<5	10
SODIUM (Na)	mg/l	14	15	5	10	12	6	18	5	3	15
POTASSIUM (K)	mg/l	3	3	<1	1	<1	<1	<1	<1	1	<1
CALCIUM (Ca)	mg/l	58	79	10	34	40	14	72	16	3	9
MAGNESIUM (Mg)	mg/l	49	20	5	24	14	16	43	14	3	4
NITRATES+NITRITES (N)	mg/l	7.6	.5	2	9.8	1.7	2	11.9	2.2	.4	.3
NITRITES-NITROGEN (N)	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	.1	<0.1	<0.1	<0.1
SULPHATES (SO-4)	mg/l	88	61	8	39	17	11	62	6	5	12
ORTHO-PHOSPHATES (P)	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CHLORIDES (Cl)	mg/l	54	39	9	29	6	18	55	9	4	9
ALKALINITY (CaCO-3)	mg/l	188	187	36	101	141	70	237	87	27	55
CHEM.OXYGEN DEMAND	mg/l	<5	<5	<5	6	<5	<5	<5	<5	<5	<5
BORON (B)	ug/l	117	124	97	77	88	126	119	65	92	104
CHROMIUM (Cr)	ug/l	<25	<25	<25	<25	28	<25	<25	42	<25	<25
CADMIUM (Cd)	ug/l	<5	<5	5	<5	7	12	<5	7	<5	5
COPPER (Cu)	ug/l	<25	<25	<25	<25	<25	47	<25	<25	<25	<25
LEAD (Pb)	ug/l	<50	<50	<50	<50	69	<50	69	69	<50	<50
MANGANESE (Mn)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	1040
NICKEL (Ni)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
ZINC (Zn)	ug/l	252	211	317	33	128	689	633	283	78	103
IRON (Fe)	ug/l	<25	<25	<25	<25	<25	<25	<25	<25	300	822
FLOURIDE	ug/l	279	464	364	293	340	306	264	306	326	364
STANDARD PLATE COUNT (per ml)		710	263	13	96	42	310	163	3330	66	923
TOTAL COLIFORMS (per 100 ml)		15300	3180	4	170	276	50	400	635	37	383
FAECAL COLIFORMS (per 100 ml)		47	1500	1	1	0	2	1	11	4	22

ADDENDUM TO MAIN REPORT

Estimating the annual quantity of groundwater abstracted in the Pretoria municipal area and its effect on municipal water consumption

by

N J Van der Linde and C Elphinstone

RESEARCH INTO GROUNDWATER ABSTRACTION IN RESIDENTIAL AREAS :

ESTIMATING THE ANNUAL QUANTITY OF GROUNDWATER ABSTRACTED IN THE PRETORIA MUNICIPAL AREA AND ITS EFFECT ON MUNICIPAL WATER CONSUMPTION

by

N.J. Van der Linde

and

C.D. Elphinstone

ABSTRACT

This report deals with the investigation of the effect of groundwater usage on municipal water consumption. The number of properties with boreholes in the Pretoria municipal area is estimated and the difference in the consumption of municipal water for a sample of properties with and a sample of properties without boreholes is examined. The average daily and yearly reduction in municipal water usage due to ground water usage is estimated.

INTRODUCTION

The main aim of the project is to assess the quantity of water abstracted daily and annually from private boreholes in Pretoria in relation to the quantity of water supplied by the municipal water supply system.

A procedure to compare the amount of water used externally by properties without boreholes (ie. the difference in municipal water usage for properties with and without boreholes), with the amount of water used externally by properties with boreholes, was implemented in the Pretoria municipal area.

A sample of properties with boreholes in the Pretoria municipal area was chosen. Borehole and municipal water usage was monitored on the chosen properties. A sample of municipal water readings for properties without boreholes was provided by the municipality. Readings from the municipal and borehole water meters were taken near the beginning of each month. The figure was converted to an average daily measurement of water usage for the previous month in kilo–liters.

From the data the following estimates were calculated :

1. The proportion of residential properties with boreholes is 0.3749 with a 95% confidence interval given by 0.297 and 0.453. (see Table 1)

2. The average daily amount of borehole water and municipal water used on a property with a borehole are 1.78 kl and 0.82 kl respectively. (see Tables 2 and 3)

3. The average annual quantity of groundwater abstracted from private boreholes is 20 063 Ml. (see Table 4)

4. The average daily amount of municipal water used on a property without a borehole is 1.04 kl. (see Table 5)

5. The average daily reduction in municipal water usage for a property with a borehole is 0.21 kl. (see Table 6)

6. The average daily and yearly reduction in municipal water sales due to groundwater usage are 6439 kl and 2350 Ml/year respectively. (see Table 7)

ESTIMATING THE PROPORTION OF RESIDENTIAL PROPERTIES WITH BOREHOLES.

Method

The Pretoria municipal area was divided into 9 strata. Field workers were sent into each of the strata and a number of clusters of properties were sampled and a record made of whether the property had a borehole or not. For each stratum we know the total number of properties in the stratum and the number of properties in each sampled cluster. The proportion of properties with boreholes in each sampled cluster was calculated.

This sampling technique is known as stratified cluster sampling. The theory requires that a sample be obtained by dividing a population into strata, dividing each stratum into variable sized clusters, randomly selecting a number of clusters in each stratum and sampling each unit in the chosen clusters. In the technique applied to the Pretoria municipal area the strata were defined a priori but the clusters were only chosen and defined by the enumerators at the time of the survey ie. the sizes of the unsampled clusters were never explicitly defined.

Consider a population of size N, divided into h strata of size N_h. Suppose that the h^{th} stratum has been divided into M_h clusters of different sizes, the i_{th} cluster being of size N_{hi} and $N_h = \sum_{i=1}^{Mh} N_{hi}$. Let $\overline{N}_h = \frac{Nh}{Mh}$ be the average number of elements per cluster in the h^{th} stratum. Let r_{hi} be the proportion of erven with boreholes in the i_{th} cluster.

Suppose a sample of n_h clusters is drawn randomly from the M_h clusters in the h_{th} stratum, then an unbiased estimate of the proportion for the h_{th} stratum, $\hat{p}_h$ is given by

$$\hat{p}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{N_{hi} r_{hi}}{\overline{N}_h}$$

with variance $\hat{V}(\hat{p}_h)$ given by

$$\hat{V}(\hat{p}_h) = \frac{M_h n_h}{M_h} \times \frac{1}{n_h} s_b^2.$$

s_b^2 is given by

$$s_b^2 = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} \left[\frac{N_{hi} \; r_{hi}}{\overline{N}_h} - \hat{p}_h \right]^2 .$$

An estimate of the population proportion P is given by

$$\hat{P} = \frac{\Sigma \; N_h \; \hat{p}_h}{N}$$

with variance $\hat{V}(\hat{P})$ given by

$$\hat{V}(\hat{P}) = \Sigma \frac{N_h^2}{N^2} \hat{v}(\hat{p}_h).$$

Because we do not know the average cluster size for each stratum we need to estimate this value. The average cluster size was estimated by the average size of the sampled clusters in each stratum.

Results

The estimates of the number of properties with boreholes are given in Table 1 for all strata as well as a combined estimate for the whole area.

A $100(1-\alpha)\%$ confidence interval for the proportion is

$$\bar{P} \pm z_{\alpha/2} \sqrt{\hat{V}(\hat{P})} .$$

A 95% confidence interval is

$$\text{Probability}[0.2965 < P < 0.4533] = 0.95.$$

ESTIMATING THE AVERAGE DAILY AMOUNT OF MUNICIPAL WATER AND BOREHOLE WATER USED ON A PROPERTY WITH A BOREHOLE

Method

Over a period of two years, monthly readings of borehole water and municipal water usage were recorded for a fixed number of properties in the Pretoria municipal area. From this data a mean daily value is calculated with its associated variance. The sample arithmetic mean is an unbiased estimate of the true population mean.

A daily mean for each year is calculated by weighting the daily means for each month according to the sample sizes.

Let x_i be a daily average for month i.

Then X, the daily average for the year is given by

$$X = \left(\sum_{i=1}^{12} n_i x_i \right) / \left(\sum_{i=1}^{12} n_i \right).$$

An estimate of the variance is obtained by pooling the monthly variance:

$$VAR(X) = \left(\sum_{i=1}^{12} (n_i - 1) \ var(x_i) \right) / \left(\sum_{i=1}^{12} n_i - 12 \right).$$

The standard error of the mean is

$$STDE(X) = \sqrt{VAR(X) / 12}.$$

Results

Monitoring of 106 properties with boreholes took place over a period of 24 months. The analysis was performed on residential properties only and although readings were obtained from certain non–residential properties eg. churches, flats, nurseries and schools, they were excluded from the analysis. Where no data was available the property was excluded from the analysis for that particular month which accounts for the differences in sample size for some months.

Graphs of the average municipal and borehole water usage on properties with boreholes are given in the appendix. The graphs cover the two year period 1988–1989. Also included are barcharts showing the distribution of borehole and municipal water usage.

The average daily quantity of borehole water used on properties with boreholes for each month of the year for the years 1988 and 1989, and the yearly estimates are given in table 2.

The average daily quantity of municipal water used on a property with boreholes for each month of the year for the years 1988 and 1989, and the yearly estimates are given in Table 3.

ESTIMATING THE TOTAL ANNUAL QUANTITY OF GROUNDWATER ABSTRACTED FROM PRIVATE BOREHOLES

Method

Let $\hat{X}_1$ be the estimate of X_1, the average daily quantity of groundwater abstracted from a private borehole.

Let $\hat{X}_2$ be the estimate of X_2, the number of properties with boreholes in the Pretoria municipal area.

Then $\hat{W} = \hat{X}_1\hat{X}_2$ is the estimate of W, the total daily quantity of groundwater abstracted from private boreholes in the Pretoria municipal area.

The variance of $\hat{W}$, $V(\hat{W})$ is given by

$$\begin{aligned} V(\hat{W}) &= E(X_1^2X_2^2) - \{E(X_1X_2)\}^2 \\ &= E(X_1^2)*E(X_2^2) - \{E(X_1)\}^2*\{E(X_2)\}^2 \\ &= \{V(X_1)+[E(X_1)]^2\}\{V(X_2)+[E(X_2)]^2\} - \{E(X_1)\}^2*\{E(X_2)\}^2 \end{aligned}$$

where $V(X_i)$ is the variance of X_i.

The estimate $\hat{G}$, of G, the total annual quantity of groundwater abstracted from private boreholes is

$$\hat{G} = 365 \times \hat{W}$$

with variance of $\hat{G}$, $V(\hat{G})$ given by

$$V(\hat{G}) = (365)^2 \times V(\hat{W}).$$

Results

The estimates of the total annual quantity of groundwater abstracted from private boreholes for each month of the years 1988 and 1989 and the yearly totals are given in Table 4.

The average daily and yearly quantity of groundwater abstracted from private boreholes can be estimated as 54 968 kl/day and 20 063 Ml/year respectively.

ESTIMATING THE AVERAGE DAILY AMOUNT OF MUNICIPAL WATER USED ON A PROPERTY WITHOUT A BOREHOLE.

Method

From a sample of municipal meter readings, the mean of municipal water usage is estimated. The yearly means and variances are calculated in the same way as the yearly estimates for properties with boreholes.

Results

The average daily quantity of municipal water used on properties without boreholes for each month of the year for the years 1988 and 1989, and the yearly estimates are given in Table 5.

A graph of municipal water usage on properties without boreholes is included in the appendix.

ESTIMATING THE AVERAGE DAILY REDUCTION IN MUNICIPAL WATER USAGE FOR PROPERTIES WITH A BOREHOLE.

Method

We assume that if a property has a borehole then all borehole water is used externally and all municipal water is used internally. If a property does not have a borehole then municipal water is used internally and externally. Therefore the difference in municipal water usage between properties with and properties without boreholes is the amount of extra municipal water that a property would use if it did not have a borehole ie the external water usage on properties without a borehole.

Let $\hat{X}$ be the estimate of X, the average municipal water usage for properties without boreholes.

Let $\hat{Y}$ be the estimate of Y, the average municipal water usage for properties with boreholes.

Let Z be the mean external water usage by people living on properties without boreholes.

Then Z can be estimated by $\hat{Z}$ given by

$$\hat{Z} = [\ \hat{X} - \hat{Y}\ ]$$

with variance of $\hat{Z}$, $V(\hat{Z})$ given by

$$V(\hat{Z}) = [\ V(\hat{X}) + V(\hat{Y})\ ]$$

where $V(\hat{X})$ is the variance of $\hat{X}$

and $V(\hat{Y})$ is the variance of $\hat{Y}$.

Results

The estimates of external water usage on properties without boreholes for each month of the years 1988 and 1989 are given in Table 6.

A graph of external water usage on properties without boreholes is included in the appendix.

ESTIMATING THE AVERAGE DAILY AND YEARLY REDUCTION IN MUNICIPAL WATER SALES DUE TO GROUNDWATER ABSTRACTION.

Method

Let N be the total number of erven in the Pretoria municipal area.

Let $\hat{P}$ be the estimate of P, the proportion of households with boreholes.

Then T, the total number of erven with boreholes can be estimated by $\hat{T}$ given by

$$\hat{T} = N \times \hat{P}$$

with variance of $\hat{T}$, $V(\hat{T})$ given by

$$V(\hat{T}) = N^2 \times V(\hat{P})$$

where $V(\hat{P})$ is the variance of $\hat{P}$.

The estimated average daily reduction in municipal water usage, $\hat{R}$ is given by

$$\hat{R} = \hat{T} \times \hat{Z}$$

with estimated variance, $V(\hat{R})$, given by

$$V(\hat{R}) = [\ \hat{T}^2 \times V(\hat{Z})\ ] + [\ \hat{Z}^2 \times V(\hat{T})\ ] + [\ V(\hat{T}) \times V(\hat{Z})\ ].$$

Results

The total number of properties with boreholes, T is estimated as

$$\hat{T} = 80\ 536 \times 0.3749 = 30\ 193$$

with variance

$$\mathrm{var}(\hat{T}) = (80536)^2 \times 0.0016 = 10\ 377\ 676.$$

A $100(1 - \alpha)\%$ confidence interval for the total, T, is

$$\hat{T} \pm z_{\alpha/2} \sqrt{\operatorname{var}(\hat{T})} \ .$$

A 95% confidence interval is

$$\text{Probability} \ [\ 23879 < T < 36507\ ] = 0.95.$$

The average daily reduction in municipal water usage due to groundwater abstraction is given in Table 7.

CONCLUSIONS AND RECOMMENDATIONS

The estimated loss of revenue to the municipality caused by the use of municipal water for external use being replaced by the use of borehole water is based on the value of

6 899 kilo–liters per day for 1988

5 977 kilo–liters per day for 1989.

This would imply an equivalent total loss for the year equal to the value of

2 518 135 kilo–liters for 1988

2 181 605 kilo–liters for 1989.

The above are point estimates of the daily and yearly reduction in water sales due to groundwater abstraction from private boreholes. The variances attached to these values are large because of the large variance on the estimate of the daily water usage per property. This variance can be reduced by increasing the size of the sample.

For the above analysis a sample of approximately 98 properties with boreholes was used. The total number of properties with boreholes in the Pretoria municipal area was estimated as 30 193, implying a sample proportion of approximately 0.3%.

A sample of approximately 439 properties without boreholes was used. The total number of properties without boreholes in the Pretoria municipal area was estimated as 80 536 – 30 193 = 50 343, implying a sample proportion of approximately 0.9%.

If the sample proportion for each sample is increased to between 1–5 %, the variances will be greatly reduced.

From the methods used in this study it can be assumed that it is not necessary to know the amount of borehole water used on properties with boreholes in order to calculate the reduction in municipal water sales. It is sufficient to have the municipal water readings and to know whether the property has a borehole or not. Meters do not have to be installed to measure borehole water usage.

However it can be argued that the loss in sales to the municipality is much greater in reality. If a property acquires a borehole, the study indicates that there will be a reduction in municipal water use of approximately 0.21 kl/day, however this is replaced by a groundwater abstraction of 1.78 kl/day. This leads to the conclusion that at least during the period of the study, the supply of municipal water for external usage was severely constrained by a combination of availability and price.

TABLE 1

THE PROPORTION OF PROPERTIES WITH BOREHOLES IN THE PRETORIA MUNICIPAL AREA

STRATUM	DESCRIPTION	NUMBER OF ERVEN	SAMPLE SIZE	AVERAGE CLUSTER SIZE	PROPORTION WITH BOREHOLES	VARIANCE
1	NORTH-WEST	4344	471	117.75	0.5542	0.0061
2	CENTRAL-NORTH	5243	401	133.67	0.4956	0.0189
3	CENTRAL-WEST	7430	539	107.80	0.3386	0.0259
4	CENTRAL	16181	1399	116.58	0.6004	0.0034
5	CENTRAL-EAST	12624	1160	96.67	0.1940	0.0202
6	SOUTH-WEST	5803	865	144.17	0.2254	0.0081
7	CENTRAL-SOUTH	10800	1167	97.25	0.3907	0.0247
8	SOUTH-EAST	12304	1485	114.23	0.3538	0.0074
9	FAR SOUTH-WEST	5807	533	106.60	0.1079	0.0041
TOTAL	PRETORIA	80536	8020		0.3749	0.0016

TABLE 2

ESTIMATED AVERAGE BOREHOLE WATER USAGE IN KILO-LITERS/DAY PER PROPERTY
(standard errors of the means appear in brackets)

MONTH	NO. OF SAMPLES		MEAN	
	1988	1989	1988	1989
JAN	66	98	2.5220 (0.1997)	2.2306 (0.1721)
FEB	91	98	2.4177 (0.1895)	0.5210 (0.0610)
MAR	97	98	1.2745 (0.1321)	2.2799 (0.1633)
APR	98	98	1.4837 (0.1101)	1.1924 (0.1088)
MAY	98	98	1.9122 (0.1437)	1.3461 (0.0961)
JUN	98	96	1.4159 (0.1116)	0.8656 (0.0802)
JUL	98	97	1.5846 (0.1132)	1.5017 (0.1172)
AUG	98	98	2.5001 (0.1669)	2.4363 (0.1566)
SEP	98	97	2.0875 (0.1430)	3.3257 (0.2165)
OCT	98	98	1.6679 (0.1095)	2.4009 (0.1706)
NOV	98	96	2.4254 (0.1493)	1.1853 (0.0882)
DEC	98	95	1.1672 (0.0878)	1.2688 (0.1195)
ANNUAL AVERAGE			1.8504 (0.1360)	1.7152 (0.1327)
AVERAGE			1.7828 (0.0399)	

TABLE 3

ESTIMATED AVERAGE MUNICIPAL WATER USAGE IN KILO-LITERS PER DAY PER PROPERTY WITH A BOREHOLE
(standard errors of the means appear in brackets)

MONTH	NO. OF SAMPLES		MEAN	
	1988	1989	1988	1989
JAN	66	98	0.7593 (0.0480)	0.8529 (0.0647)
FEB	91	98	0.6953 (0.0441)	0.7604 (0.0545)
MAR	97	98	0.7970 (0.0694)	0.8230 (0.0538)
APR	98	98	0.7256 (0.0506)	0.8985 (0.0845)
MAY	98	98	0.7617 (0.0514)	0.8042 (0.0535)
JUN	98	97	0.7721 (0.0533)	0.8046 (0.0532)
JUL	97	98	0.7761 (0.0523)	0.8497 (0.0607)
AUG	98	97	0.8476 (0.0598)	0.9282 (0.0630)
SEP	97	97	0.8433 (0.0597)	1.0282 (0.0808)
OCT	98	98	0.8202 (0.0586)	0.9582 (0.0867)
NOV	98	97	0.9097 (0.0820)	0.8844 (0.0714)
DEC	98	96	0.7431 (0.0510)	0.8280 (0.0682)
ANNUAL AVERAGE			0.7890 (0.0570)	0.8683 (0.0662)
AVERAGE			0.8286 (0.0616)	

TABLE 4

ESTIMATED TOTAL QUANTITY OF GROUNDWATER ABSTRACTED FROM PRIVATE BOREHOLES IN THE PRETORIA MUNICIPAL AREA IN KILO-LITERS/DAY
(standard deviations of the means appear in brackets)

MONTH	BOREHOLE WATER USAGE 1988	1989
JAN	76148 (15816)	67349 (14502)
FEB	72998 (15343)	15731 (7687)
MAR	38481 (11775)	68837 (14301)
APR	44799 (11150)	36002 (10727)
MAY	57736 (13053)	40644 (10364)
JUN	42751 (11121)	26136 (9041)
JUL	47844 (11421)	45340 (11464)
AUG	75487 (14790)	73559 (14352)
SEP	63027 (13307)	100413 (17732)
OCT	50358 (11394)	72489 (14735)
NOV	73230 (14096)	35789 (9792)
DEC	35242 (9752)	38307 (11265)
ANNUAL AVERAGE	56508 (12752)	53428 (12164)
AVERAGE	54968 (12458)	

TABLE 5

ESTIMATED AVERAGE MUNICIPAL WATER USAGE IN KILO-LITERS PER DAY PER PROPERTY WITHOUT A BOREHOLE
(standard errors of the means appear in brackets)

MONTH	NO. OF SAMPLES 1988	NO. OF SAMPLES 1989	MEAN 1988	MEAN 1989
JAN	439	439	1.0246 (0.0339)	0.9633 (0.0380)
FEB	439	439	0.9447 (0.0324)	0.8854 (0.0265)
MAR	439	439	0.9611 (0.0343)	0.8883 (0.0223)
APR	439	439	1.0011 (0.0326)	0.8885 (0.0223)
MAY	439	439	0.9371 (0.0312)	0.8887 (0.0224)
JUN	439	439	0.9001 (0.0261)	0.9450 (0.0330)
JUL	439	439	1.1111 (0.0360)	1.0680 (0.0354)
AUG	439	415	1.0081 (0.0316)	1.2862 (0.0480)
SEP	439	439	1.0946 (0.0375)	1.4210 (0.0479)
OCT	439	439	0.9867 (0.0344)	1.2246 (0.0380)
NOV	439	434	1.1513 (0.0370)	1.0985 (0.0445)
DEC	439	439	1.0886 (0.0452)	1.2500 (0.0561)
ANNUAL AVERAGE			1.0174 (0.0344)	1.0663 (0.036)
AVERAGE			1.0418 (0.0352)	

TABLE 6

ESTIMATED AVERAGE REDUCTION IN MUNICIPAL WATER USAGE PER DAY PER PROPERTY WITH A BOREHOLE
(standard errors of the means shown in brackets)

MONTH	REDUCTION IN MUNICIPAL WATER USAGE 1988	1989
JAN	0.2653 (0.0818)	0.1104 (0.1028)
FEB	0.2495 (0.0765)	0.1250 (0.0810)
MAR	0.1641 (0.1037)	0.0653 (0.0762)
APR	0.2755 (0.0832)	-0.0100 (0.1068)
MAY	0.1753 (0.0826)	0.0844 (0.0758)
JUN	0.1279 (0.0795)	0.1404 (0.0862)
JUL	0.3349 (0.0883)	0.2183 (0.0961)
AUG	0.1606 (0.0915)	0.3580 (0.1111)
SEP	0.2513 (0.0972)	0.3928 (0.1287)
OCT	0.1666 (0.0930)	0.2664 (0.1246)
NOV	0.2416 (0.1190)	0.2142 (0.1159)
DEC	0.3455 (0.0963)	0.4220 (0.1243)
ANNUAL AVERAGE	0.2285 (0.0914)	0.1980 (0.1024)
AVERAGE	0.2133 (0.0969)	

TABLE 7

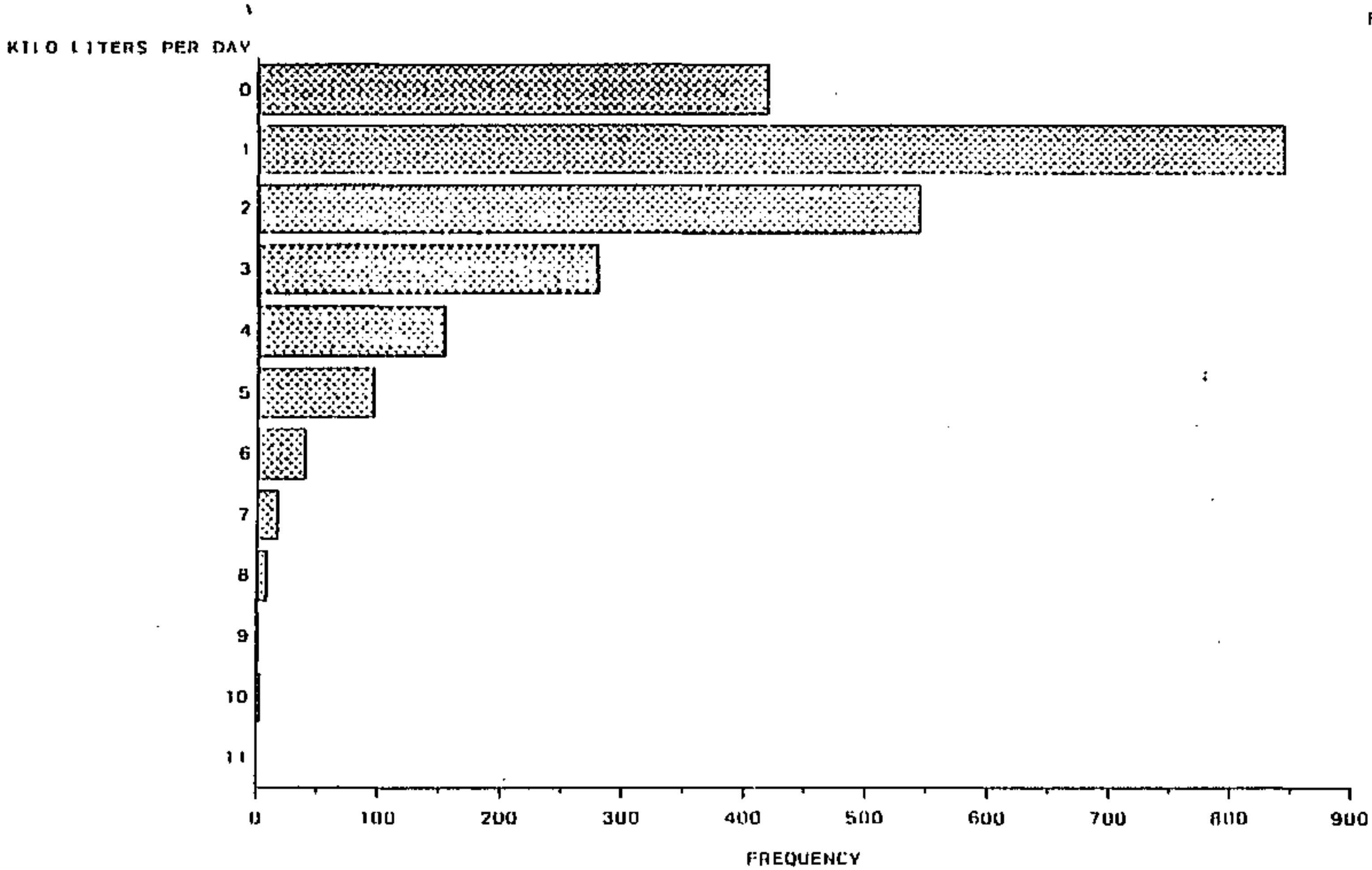
ESTIMATED TOTAL DAILY REDUCTION IN MUNICIPAL WATER USAGE
DUE TO GROUNDWATER USAGE FOR ALL PROPERTIES IN THE PRETORIA MUNICIPAL AREA
IN KILO-LITERS PER DAY
(standard deviations of the means appear in brackets)

MONTH	REDUCTION IN MUNICIPAL WATER USAGE 1988	1989
JAN	8011.44 (8726.37)	3334.68 (9742.05)
FEB	7532.32 (8436.74)	3774.77 (8651.23)
MAR	4955.08 (9792.36)	1973.01 (8384.53)
APR	8317.64 (8803.27)	-301.97 (9923.21)
MAY	5294.15 (8745.04)	2549.69 (8364.28)
JUN	3862.76 (8571.37)	4238.99 (8926.40)
JUL	10112.70 (9087.14)	6590.44 (9439.19)
AUG	4847.61 (9199.47)	10809.22 (10186.45)
SEP	7587.76 (9501.22)	11859.57 (10966.40)
OCT	5029.00 (9275.43)	8042.84 (10752.54)
NOV	7294.58 (10503.48)	6466.75 (10360.28)
DEC	10431.07 (9488.25)	12741.97 (10791.30)
ANNUAL AVERAGE	6899.77 (9209.35)	5977.84 (9737.51)
AVERAGE	6438.81 (9473.43)	

APPENDIX

DISTRIBUTION OF BOREHOLE WATER USAGE

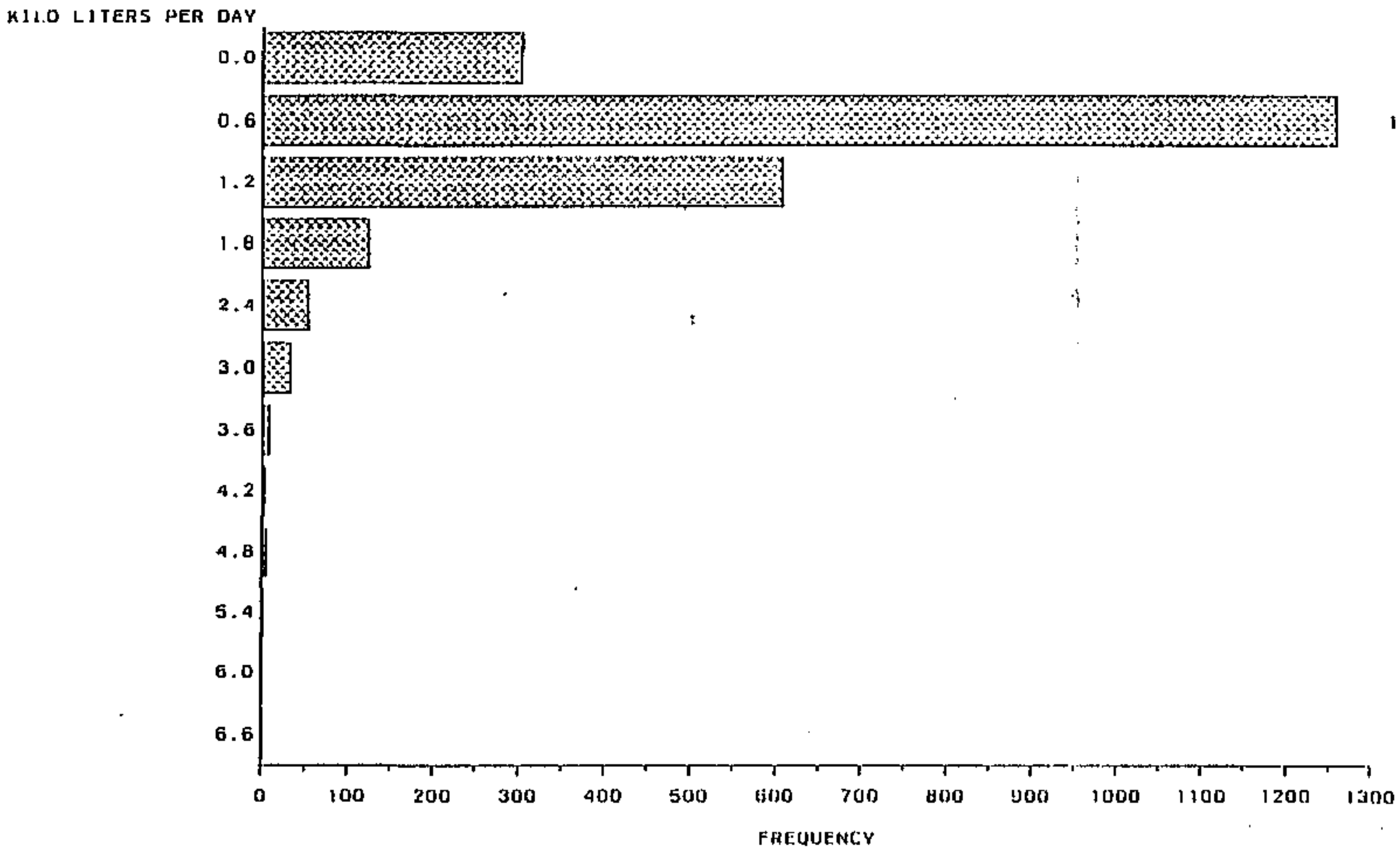
JAN [illegible] - DEC [illegible]



KILO LITERS PER DAY	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
0	418	418	17.42	17.42
1	843	1261	35.14	52.56
2	543	1804	22.63	75.20
3	279	2083	11.63	86.83
4	153	2236	6.38	93.21
5	95	2331	3.96	97.17
6	39	2370	1.63	98.79
7	17	2387	0.71	99.50
8	8	2395	0.33	99.83
9	1	2396	0.04	99.87
10	3	2399	0.13	100.00
11	0	2399	0.00	100.00

DISTRIBUTION OF MUNICIPAL WATER USAGE

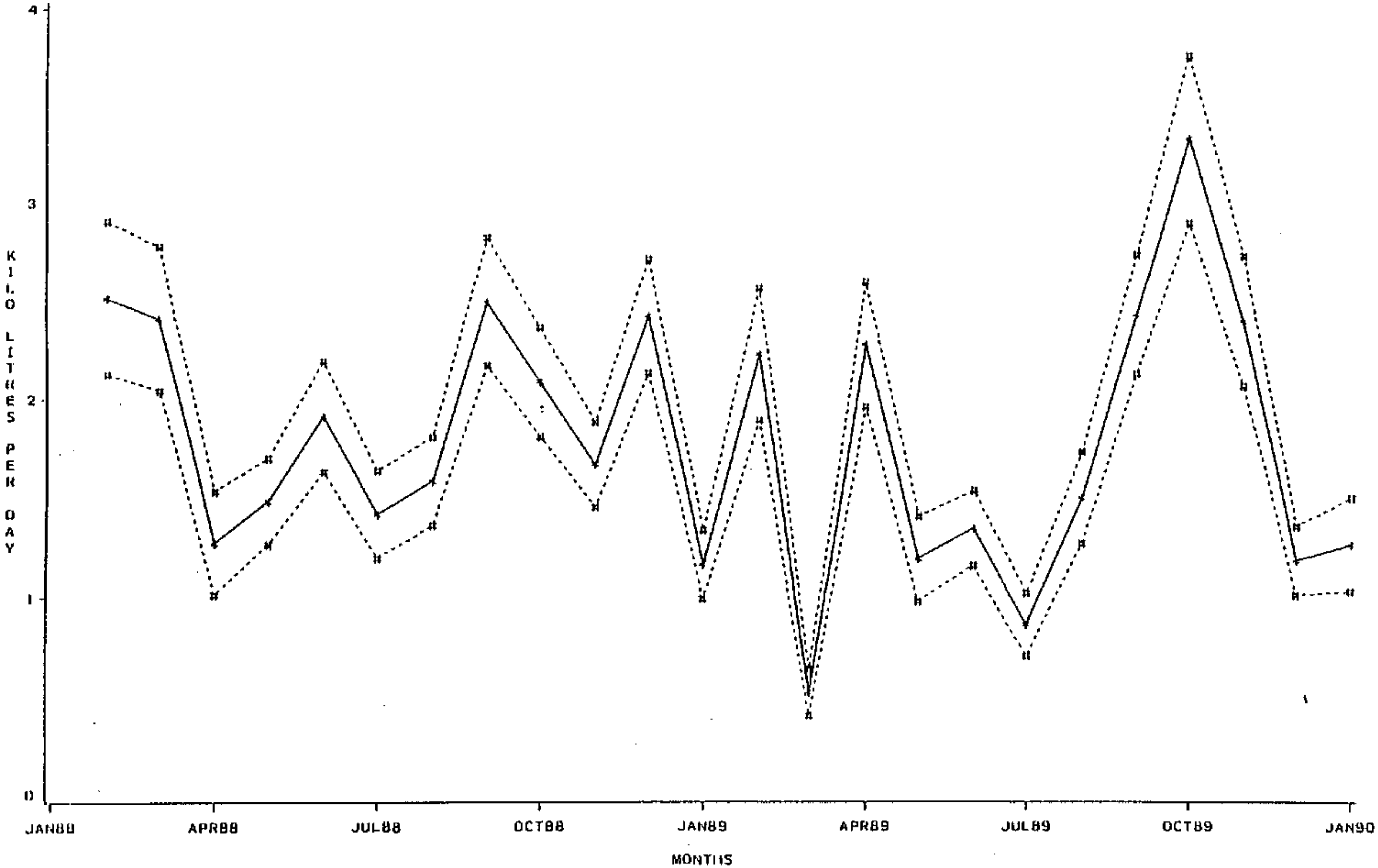
FOR PROPERTIES WITH BOREHOLES
JAN 1988 - DEC 1989



FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
303	303	12.63	12.63
1257	1560	52.38	65.00
608	2168	25.33	90.33
125	2293	5.21	95.54
54	2347	2.25	97.79
33	2380	1.38	99.17
8	2388	0.33	99.50
3	2391	0.13	99.63
5	2396	0.21	99.83
2	2398	0.08	99.92
1	2399	0.04	99.96
1	2400	0.04	100.00

BOREHOLE WATER USAGE

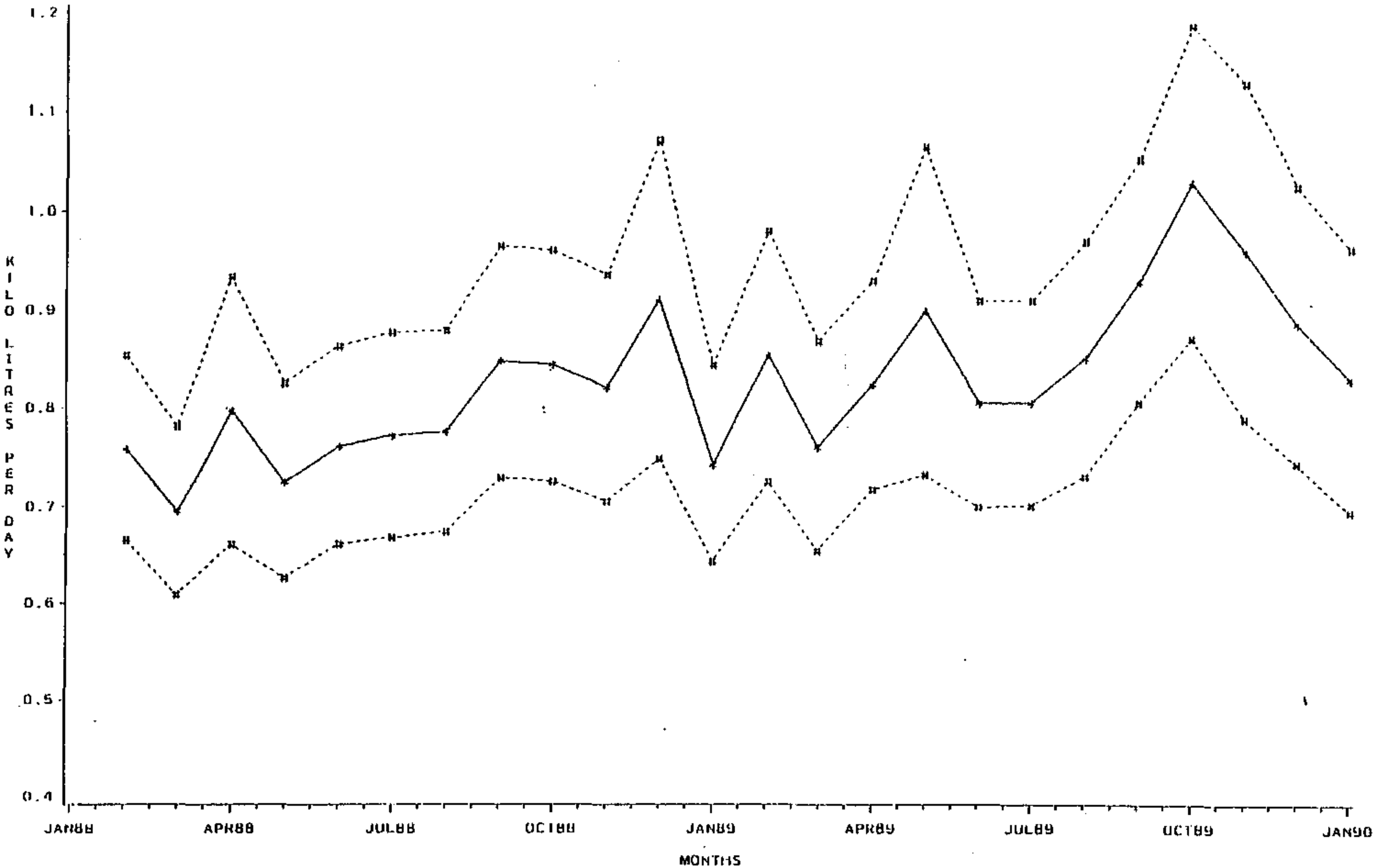
JAN 1988 - DEC 1989



* *MEAN VALUE*
# *95% CONFIDENCE INTERVAL*

MUNICIPAL WATER USAGE

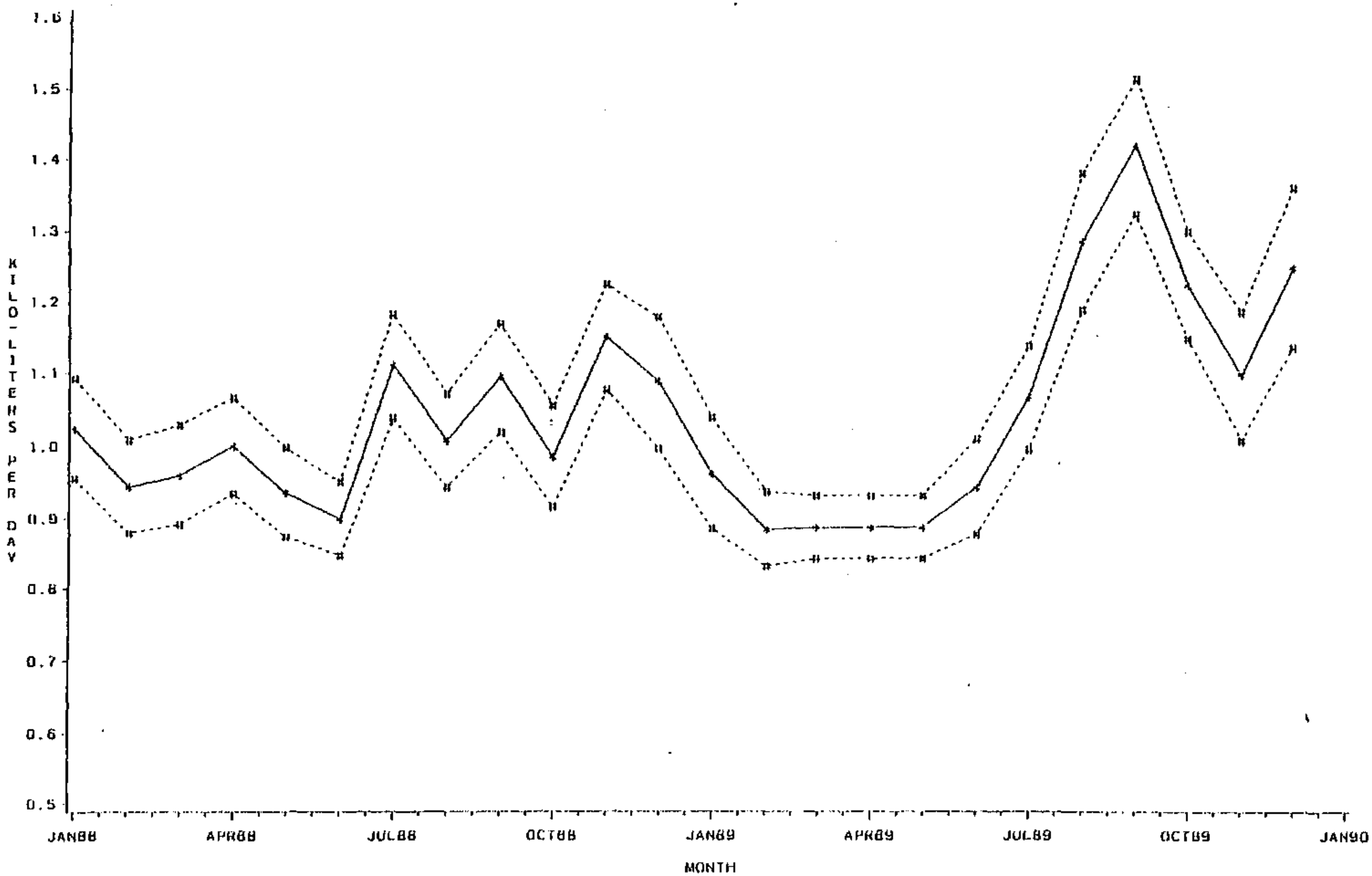
FOR PROPERTIES WITH BOREHOLES



** MEAN VALUE*
 # 95% CONFIDENCE INTERVAL

MUNICIPAL WATER USAGE

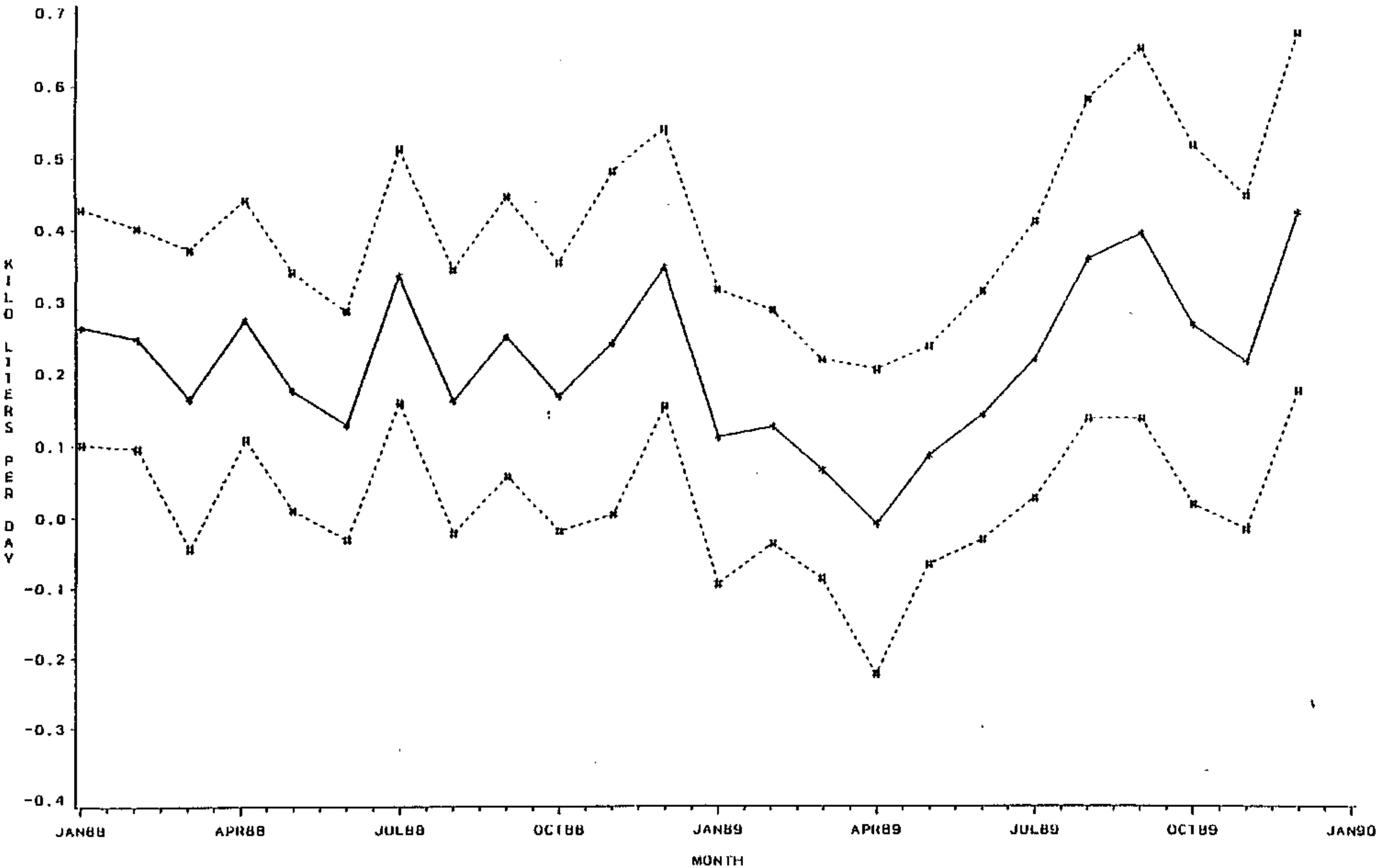
FOR PROPERTIES WITHOUT BOREHOLES



** MEAN VALUE*
 # 95% CONFIDENCE INTERVAL

REDUCTION IN MUNICIPAL WATER SALES

JAN 1988 - DEC 1989



** MEAN VALUE*
 # 95% CONFIDENCE INTERVAL