DESCRIPTION OF CATCHMENTS AND METHODOLOGY

By JJ Lambourne & TJ Coleman

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WATER RESEARCH COMMISSION

EFFECTS OF URBANIZATION ON CATCHMENT WATER BALANCE

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ABSTRACT

The water balance study was undertaken on two adjacent catchments in Sandton, Transvaal. This report contains both descriptions of the physical characteristics of the catchment from a hydrological point of view and the instrumentation used in the study.

The catchments have an areal coverage of 75ha, the one being a suburban township with stands with areas of 1000m2, and the other, a field used for cattle grazing. Both catchments are situated on homogeneous granites, with later stage doleritic dyke intrusions. The surface layers of the granite base rock have been denuded to produce decomposed granitic strata. The complexity of this basal rock structure yields difficulty in determining the groundwater status of the catchments. There are thin soils characteristic of granite parent material, except in channels and at the base of the catchments where deep clay soils can be identified.

Instrumentation to measure the primary inputs and outputs of the water balance were installed in the catchments. Measurements of rainfall, runoff from the catchments, borehole water levels, sewer outflow, domestic water consumption, and basic meteorological were undertaken. The basic meteorological parameters were used to estimate the Maximum Evaporation. Locally manufactured electronic data loggers were used to capture the data onto both EPROM and RAM storage devices. The transfer from older analogue (chart) based instrumentation to electronic media was not without problems. It was concluded that no completely satisfactory method of data capture in the field can be found.

WATERVAL CATCHMENT

SUNNINGHILL SUBURBAN CATCHMENT

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CHAPTER 1. INTRODUCTION

1.1 General

The process of urbanisation often leads to marked changes in the hydrological response of catchments. The most dramatic changes that become evident are increases in storm runoff rates and volumes. These increases are due mainly to increased proportions of impervious areas coupled with more efficient drainage systems.

Less dramatic, but warranting equal attention, is the general deterioration in storm water quality from urban catchments. High levels of nutrients and dissolved salts and a high oxygen demand result in eutrophication and a decline of fish life in receiving waters and a degradation of aquatic life in general.

Total evaporation (Evapo-Transpiration) is necessarily affected by urbanisation. Stripping the vegetation and denuding ground surfaces to make way for urban growth decreases the potential for total evaporation while the converse could be true in some residential areas where an increase in vegetation has occurred.

In addition to effects on the hydrological regime by virtue of the changed physical nature of the catchment, direct man-induced changes must also be considered. For instance, the import of water into urbanised catchments in the form of piped water supply creates an artificial input into the system in the hydrological sense while sewer outflows create an artificial output.

To adequately assess the impact of urbanisation on a catchment, the effects on the entire water balance of that catchment should be considered. While qualitative assessment of the changes in a catchment's water balance can be arrived at more or less intuitively, a quantitative assessment would require a great deal of input.

1.2 Purpose and Methodology of Research Project

The main objective of the research is to determine the effects of urbanisation on catchment runoff. Rather than simply comparing rainfall and runoff to assess the effects of urbanisation on the overall hydrological regime, the effects of urbanisation on the total catchment water balance should be studied. In this way the actual mechanics involved in producing the changes in runoff due to urbanisation can be determined. Computer models, based on physical laws and using measured parameters can then be developed to model storm water runoff.

A widely used method for determining changes in the hydrological response of a catchment due to land use changes is the use of paired catchments (Lindley et al, 1988). This method requires two similar catchments, one urbanised and the other natural. However in order to correlate the two catchments, records are required for both catchments for a reasonable period before the urbanisation of the urbanised catchment. Further extensive records would have to be gathered for the period after urbanisation to determine the effects of urbanisation. The natural catchment serves as a control so that effects on runoff of parameters other than urbanisation can be determined.

This approach is unlikely to be able to be used as urban development takes many years before the services are installed and decades before the catchment is fully urbanised. A different method therefore had to be adopted for this study. Initially the approach being used was to compare two hydrologically similar catchments, one urbanized and the other undeveloped, over a common time period. The difference in runoff however may not be solely due to urbanisation and in order to distinguish between the different effects a distributed parameter runoff model based on physical laws and using measured parameters will be used. In this way, provided the model is verified, the difference in the behaviour of the two catchments due to urbanisation can be determined. Recently a third catchment was instrumented which will be developed in th(near future. This catchment will provide data both before and after urbanisation.

Initially the two catchments chosen for this research project were Waterval and Sunninghill. Both catchments are located in Sandton, north of Johannesburg, and are situated alongside each other sharing a common water divide (fig 1.1). The catchments have similar topographical features and soil types and they should experience similar rainfall and antecedent moisture conditions. The Waterval catchment is undeveloped and is likely to remain so for some time. The Sunninghill catchment has undergone urbanisation over the past five years and about 90% of the plots have been developed. The third catchment is situated adjacent to the Waterval catchment (Fig. 1.2) and exhibits similar characteristics to the Waterval catchment.

The more important parameters of interest in both catchments are:

- rainfall
- water supply
- ground water inflow
- storm runoff
- sewer outflows
- total evaporation
- infiltration
- changes in ground storage

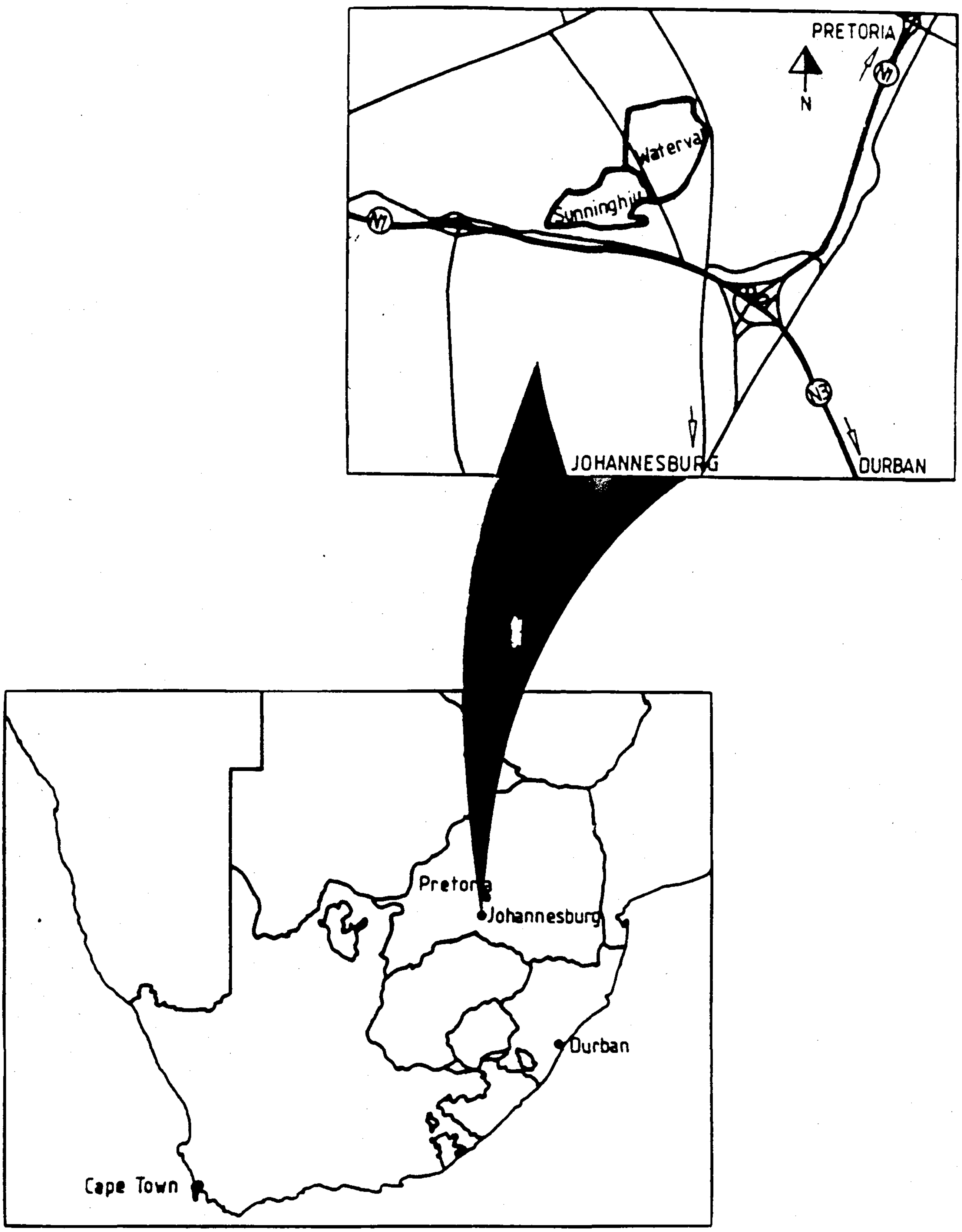


Figure 1.1 - Locality Map

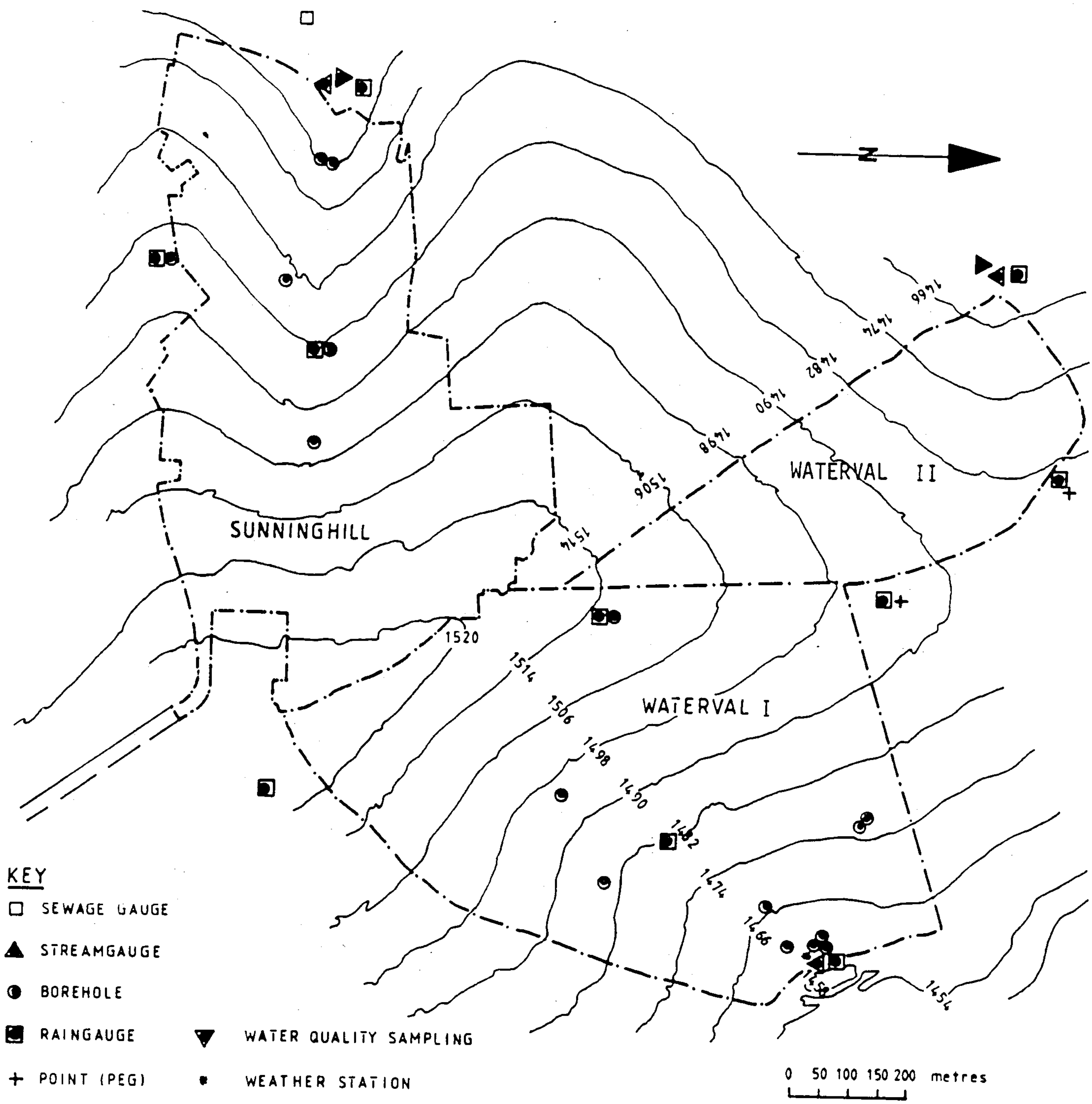


Figure 1.2 - Structure of Adjacent Catchments

The first three parameters listed comprise the total input to the catchment while the next four parameters comprise the water output. The difference between the total input and output will be the change in subsurface water storage.

In order to study the water balance of the catchments, the Water Systems Research Group of the University of the Witwatersrand established a monitoring programme in 1986. Of the above parameters rainfall, water supply, storm runoff, and changes in groundwater storage have been monitored. This report describes the instrumentation used in the monitoring programme and gives a general description of the geology, geomorphology, vegetation, land-use, and topography of the catchments.

CHAPTER 2. DESCRIPTION OF CATCHMENTS

2.1 Background

The Johannesburg-Pretoria area lies on a dome of granite base material that has been exposed on the Kaapvaal craton. A regional geological investigation of this dome has been undertaken by Anhaesser (1973) which shows the catchments lying on a transitional zone between the relatively homogeneous granites in the south and the inhomogeneous gneisses and migmatites in the north. One can therefore expect the geology to vary over the two catchments. The rocks that can be expected are fairly homogeneous granites, with later stage mafic dolerite dyke intrusions as well as scattered granite tors and outcrops.

Barker (1986) reported that the catchments lie within the region of South Africa affected by the African period of planation. The severity of this denudation produced deeply weathered rock profiles in which both ferruginous laterite and locally developed bauxite have been developed. Subsequent upliftment followed by further denudation has led to the typical Kyalami Land System. All the catchments display the characteristics of this land system which are smooth, relatively flat surfaces with localised hard rock exposure in the form of tors.

2.2 Waterval Catchment I & II

2.2.1 General

The catchments have an area of 75 ha and 32 ha respectively and are situated on a farm on the northern border of the Johannesburg metropolitan area (fig 1.1). There are still indications of previous agricultural activity and some grazing of cattle is still allowed. One of the catchments slopes evenly from west to east with a fall of 50m over approximately 800m, the other slopes east to west. There are no defined watercourses and sheet flow with concentrations of flow in rills and cattle tracks have been observed during heavy rainfall. Cutoff trenches at the bottom of the catchments converge the storm runoff onto a streamgauge where the flow is measured. A contour map of the area showing the positions of the boreholes, raingauges and streamgauge is presented in figs 2.1 and 2.2 for the two catchments respectively.

A small area of the Waterval catchment I is used by Eskom for houses and a sub-station. These developments take up an estimated 5% of the catchment area and therefore do not detract from the rural nature of the catchment.

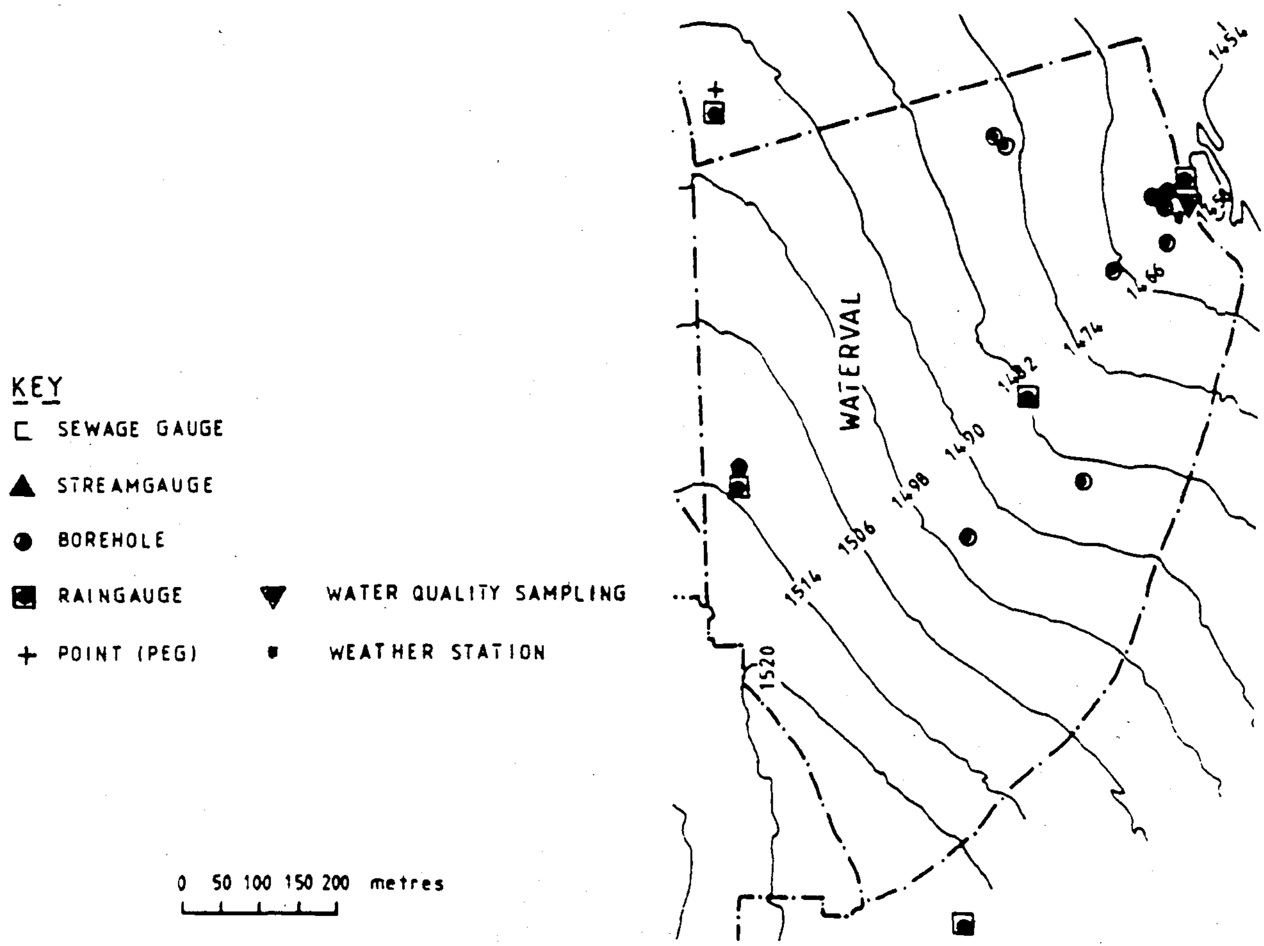


Figure 2.1 - Waterval Catchment I

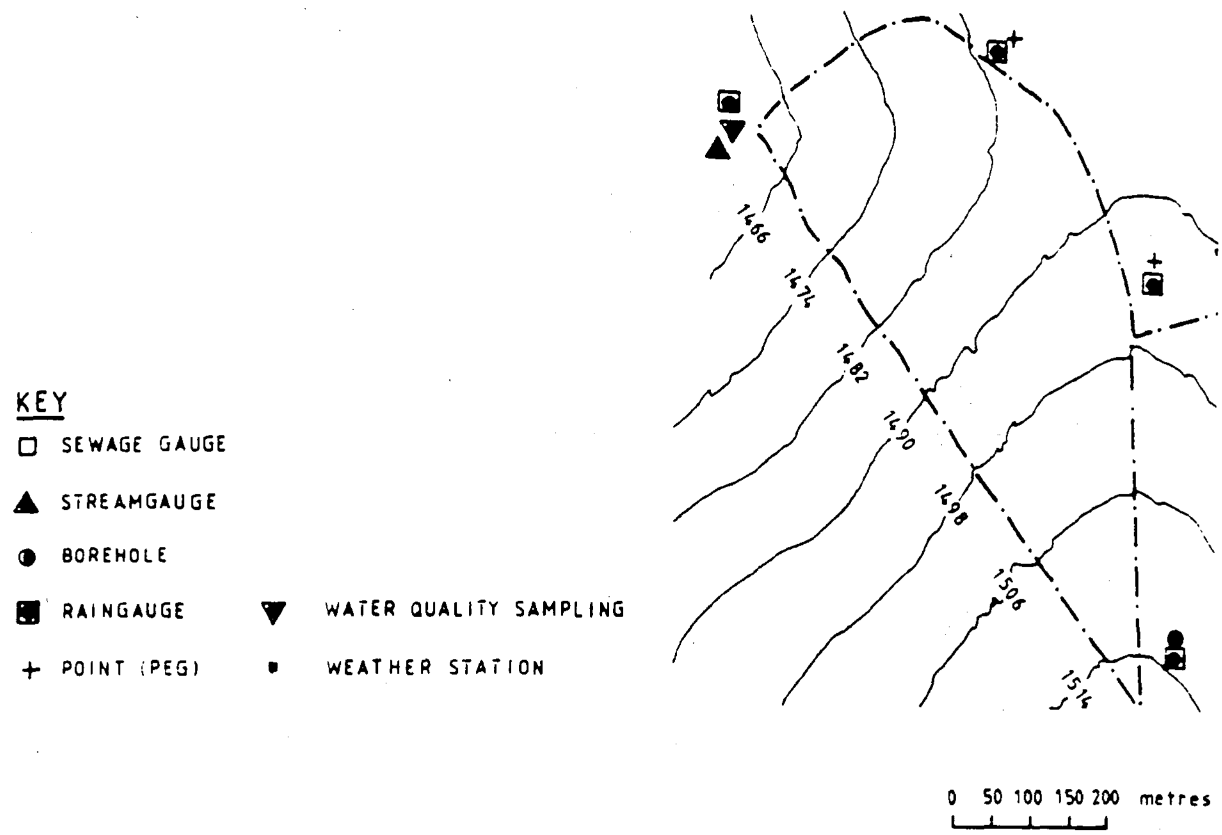


Figure 2.2 - Waterval Catchment II

2.2.2 Geology and Geomorphology

Mony (1988) undertook a study of the catchment by air photo interpretation, as well as resistivity, and magnetometer analyses to assess the geohydrological characteristics of the catchment. This analysis revealed a fairly large magnetic anomaly in the lower north eastern corner of the catchment (line 1 fig 2.3). A magnetometer traverse inferred a fairly large linear dyke feature which could be considered to be the lower boundary to the movement of groundwater out of the catchment. A further magnetic anomaly at the top south western section of the catchment is considered to be a similar intrusive event (line 2 fig 2.3). These two events are considered to have caused a complex arrangement of secondary dykes radiating along joint and fault zones. These zones are considered to be filled with various pegmatitic, gneissic, and doleritic material. Resistivity traverses carried out show that aquifers do exist along and parallel to the lineations mapped from the air photo analysis.

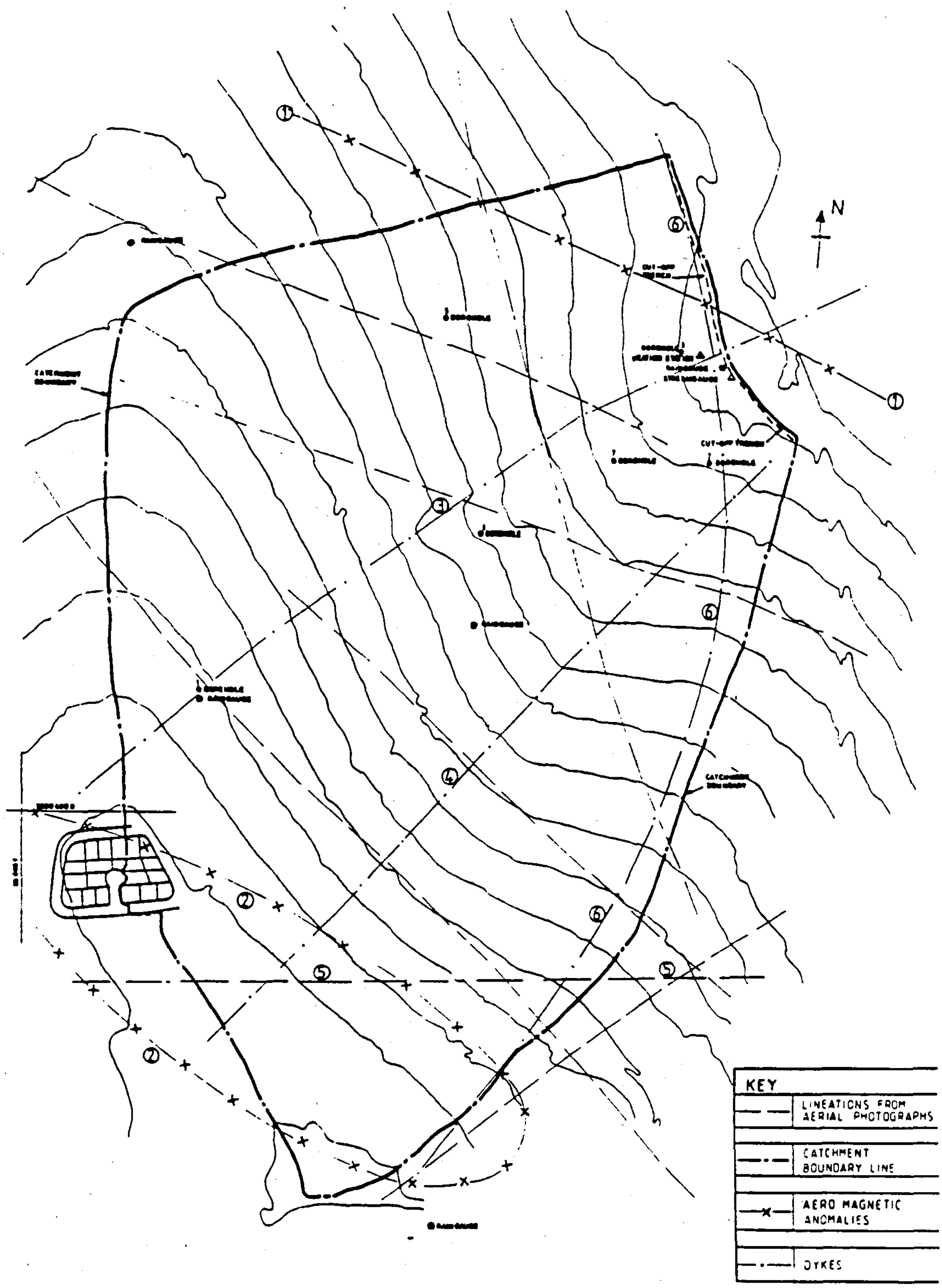


Figure 2.3 - Waterval - Aerial Analysis of Geology - after Mony (1988)

As a result of this study of the catchment, Mony proposed a division of the catchment into 3 geohydrological units (fig 2.3). The first area is bounded by the catchment boundary in the north and the lineament line 3 and is considered a composite mixture of predominantly granite and apalitic material with a fairly deep decomposition zone. The second area south east of area 1, bounded by lineament lines 3, 4, and 6, has a similar material composition to area 1 but with a shallower decomposition zone. The third area, bounded by lineament lines 4, 5, and 6, is considered to have a much more clay type soil cover as a result of surface wash from the Megawatt Park area which is considered to be mafic in composition.

A further geophysical study was undertaken on the catchment using vertical electrical soundings (VES) and electromagnetic (EM) methods. These surveys were designed to investigate the soil profile of the decomposition zone rather than to pick up any faults or joint systems in the basement granites. As most earth materials are essentially insulators, the electrical methods of investigation are best suited to groundwater studies as the subsurface waters act as the electrical circuit. For the Schlumberger VES, a battery powered 4 Watt CSIR resistivity meter was used. The positions of the sounding sites are shown on fig 2.4. These soundings provide information on the vertical stratification in the electrical properties which are a direct indication of the water present. This method is however time consuming and fc: this reason VES results were coupled with an EM survey of the catchment to give a more extensive and cost effective cover of the catchment. The EM method also used the earth's electrical properties but differs from the electrical method in that electromagnetic wave propagation is used. A Geonics EM-34 instrument was used with measurements being made in both the horizontal and vertical coplanar modes with a coil separation of 40 m. The positions of the 4 traverses are shown in fig 2.4. A fifth traverse was attempted in the Megawatt Park area in the south of the catchment but the background noise caused by an electrical sub-station prohibited its execution.

The VES are of the H-type which are typical granite terrain signatures. These H-type curves represent a resistive surface layer underlain by a more conductive layer which in turn overlies a considerably more resistive rock layer. Towards the bottom of the catchment in the vicinity of the dam an A-type response curve was obtained. This indicates a two layer system where conductive overburden overlies a very resistive layer. In fig 2.5 the results of the VES are summarised by a contour map of the total conductivity thickness product (ms). The results of the EM traverses are also summarised by a contour map of the total conductivity thickness product (ms) shown in fig 2.6. These results are for the horizontal dipole mode as the vertical dipole mode results proved to be far to noisy for any meaningful assessment which probably indicates later inhomogeneities.

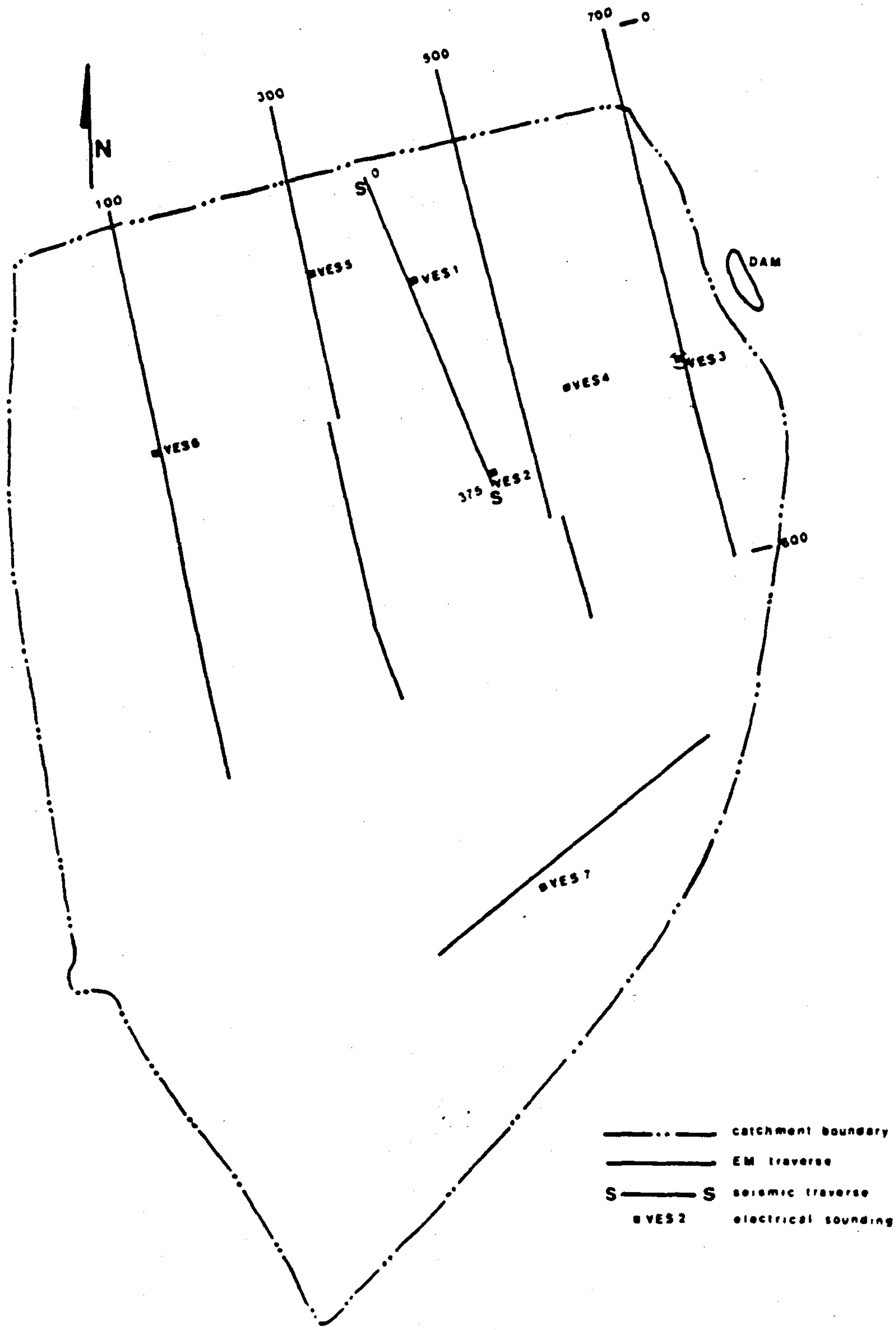


Figure 2.4 - Waterval - VES sites and Em Transverses

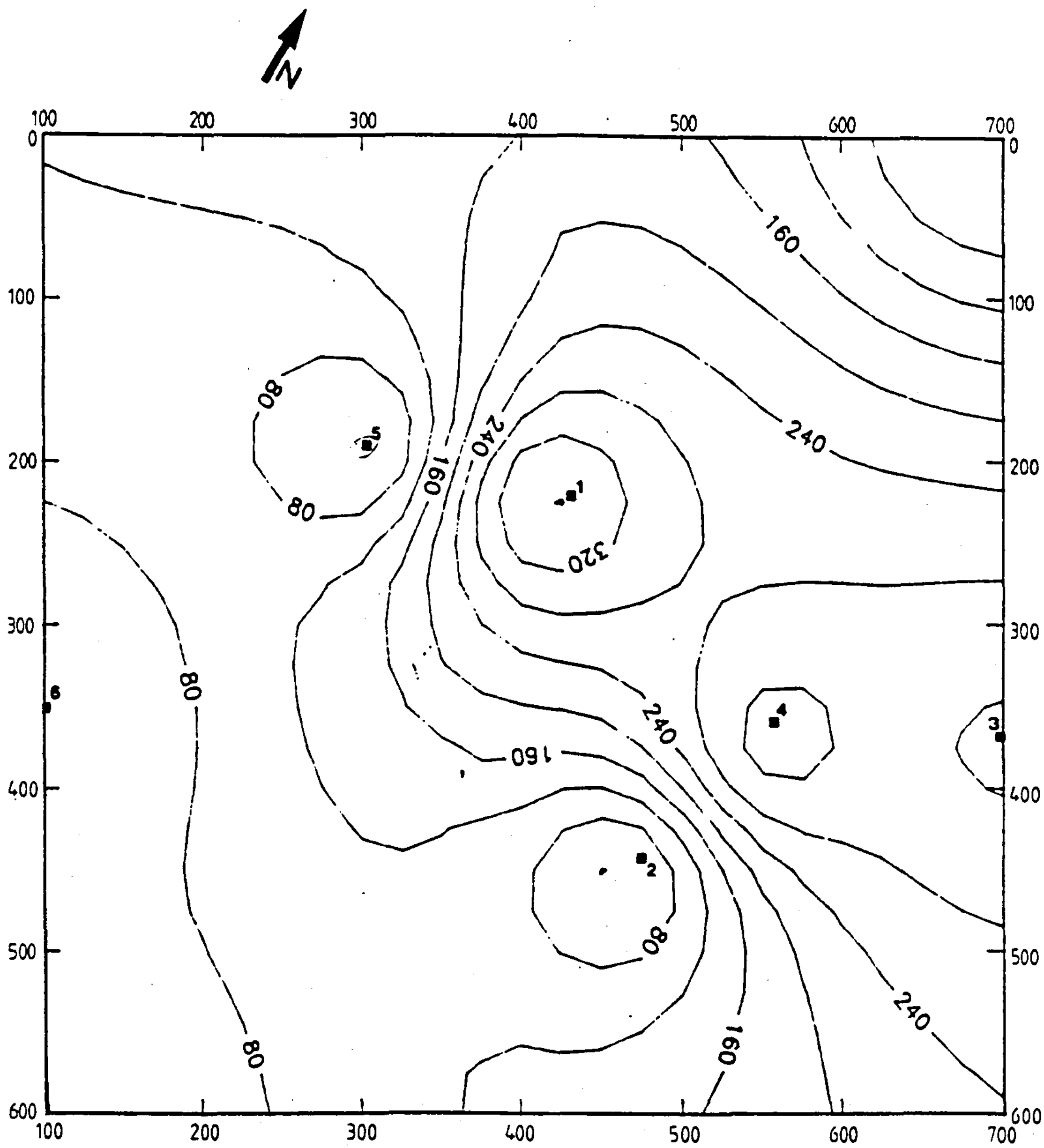


Figure 2.5 - Waterval - Contour Map Interpolated from VES

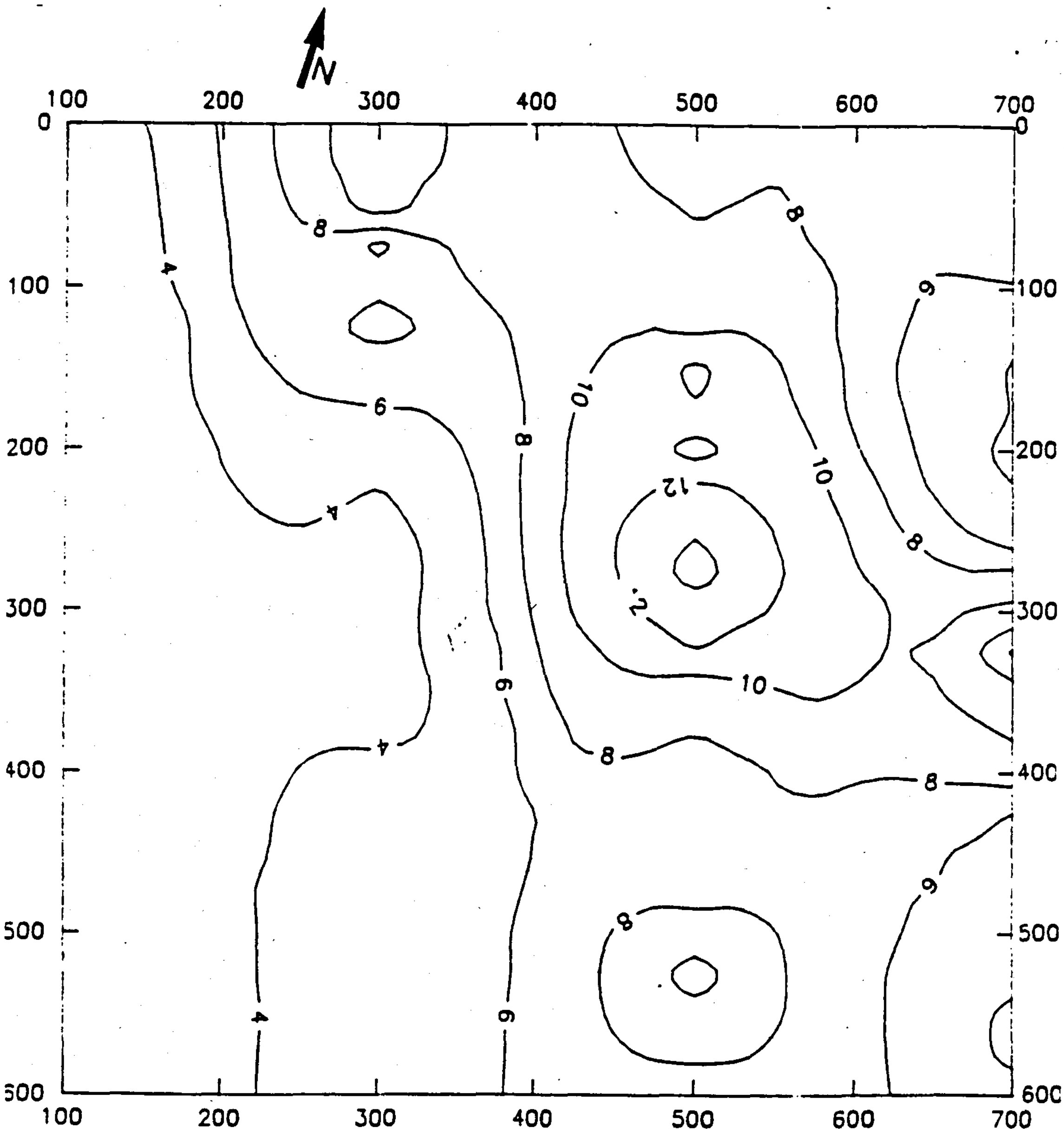


Figure 2.6 - Waterval - Contour Map Interpolated from EM

Due to the different methods used and system responses, the absolute values of the conductivity thickness product depicted on the contour maps differ. However the trends displayed are the important features and the contour maps produced by the EM method and the VES method support each other in that both show a trend of high conductivity thickness product starting in the east of the catchment and going in a north westerly direction towards the centre of the grid.

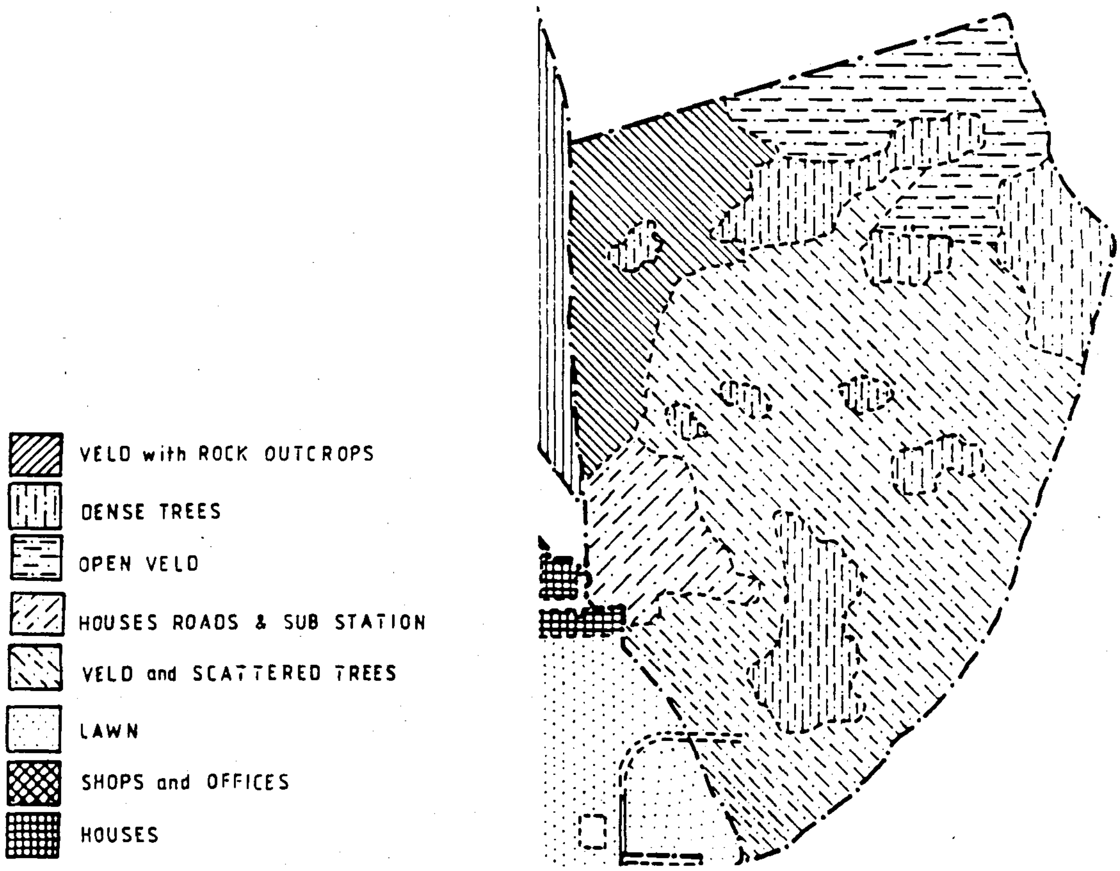
The EM survey shows that the catchment is largely reliefless except for the north westerly trend of high conductivities. This implies that the basement granite profile is fairly homogeneous. The VES survey showed that the decomposition zone above the basement granite is essentially a two layer system with the upper layer thickness varying between 1.6 and 2.0 m while the second layer varies between 8 and 16 m. Anomalies however do occur in the second layer in the region of VES 1 where the depth is 48 m and towards the bottom of the catchment near the dam in the region of VES 3 where the basement granite is 2.5 m from the surface.

The borehole logs given in Appendix A substantiate the results of the geophysical survey. The soil towards the top of the catchment is a fairly uniform decomposed granite sand over the full depth of the soil profile. Further down the catch ıent the clay content increases in the upper layer of the soil until in the region of the dam a clay layer of up to 4.5 m in depth has been recorded. The second layer remains a coarse decomposed granite sand with fragments of granite of 5-10 mm in size occurring in the interface zone between the basement granite and the decomposed material.

The compartments proposed by Mony are supported to a certain extent by the geophysical survey. However the greater depths of decomposition in compartment 1 are in a localised area in the region of VES 1 and borehole 5 rather than over the whole compartment. Unfortunately the geophysical survey does not cover the southern part of the catchment in the Megawatt Park area. The borehole logs in this area show a different geology in that the basement granites are covered by a shallow decomposed zone of approximately 3.5 m depth.

2.2.3 Vegetation cover and Surface Soil Information

A vegetation survey was carried out using aerial photographs and site investigations. The results of the survey are presented in map form in figure 2.7. An estimated 50% of the catchment is open veld area and this is situated in the northern part of the catchment. This part of the catchment is also characterised by scattered boulders or tors. A further 30% of the catchment is covered by veld and scattered trees which occur mainly in the southern part of the catchment. The areas of dense trees comprise 15% of the catchment and



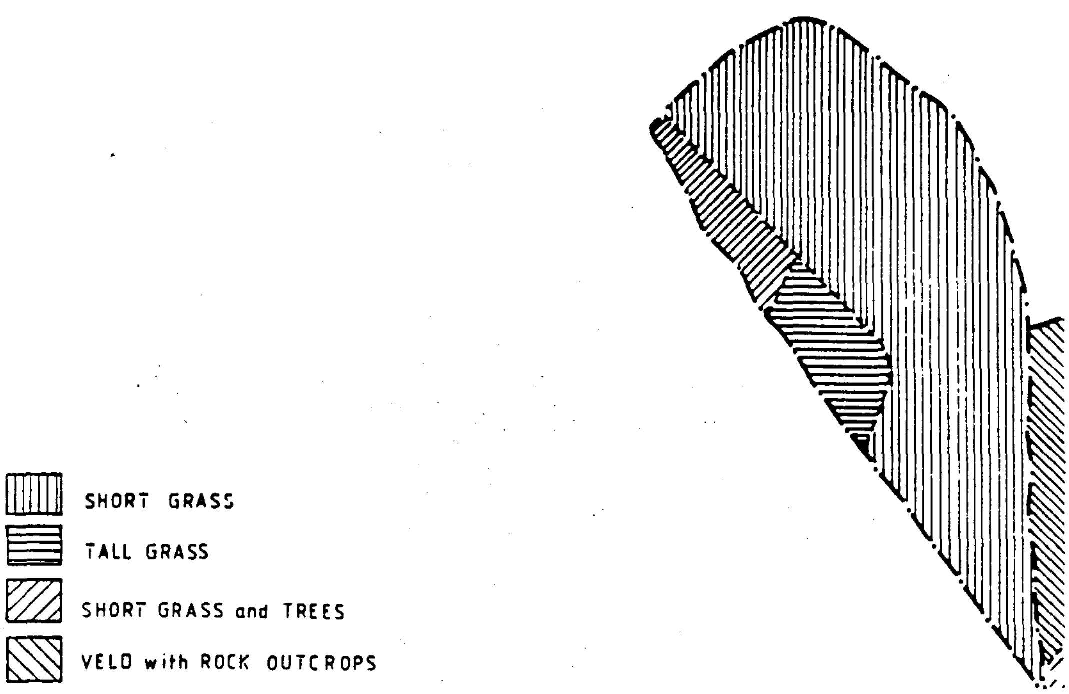


Figure 2.7 - Waterval - Vegetation Information

consist of large black wattle and eucalyptus trees. These trees are underlain by sparse grass and sandy patches. The remaining 5% of the catchment consists of the Eskom housing project and sub-station.

An example of typical veld and tree conditions is presented in Figure 2.8.

Figure 2.8 - Waterval - Typical Veld and tree conditions

There is a borrow pit almost in the centre of Waterval I which was probably used to provide material for the dam wall. In addition a small dam possibly used for cattle watering is situated close by. This dam has been breached and is therefore dry most of the year. The catchment has a relatively smooth surface and is well covered with grass showing no signs of erosion although the catchment is traversed by numerous car tracks and cattle paths. At the bottom end of catchment I is an area of gully erosion which is depicted in figure 2.9.

In order to get more information on the infiltration characteristics of the surface soil horison the work of Rawls et al (1983) was used. After analysing the soil water characteristic data of some 1200 soils, Rawls et al were able to provide estimates of total porosity, effective porosity, wetted front capillary pressure, and hydraulic conductivity based on the United States Department of Agriculture (USDA) classification of a soil (Soil Conservation Service, 1975).

Grading analyses were carried out on 17 samples taken at depths from 50-500 mm below ground surface. The results of the gradings were used to define zones

Figure 2.9 - Waterval - Gully Erosion

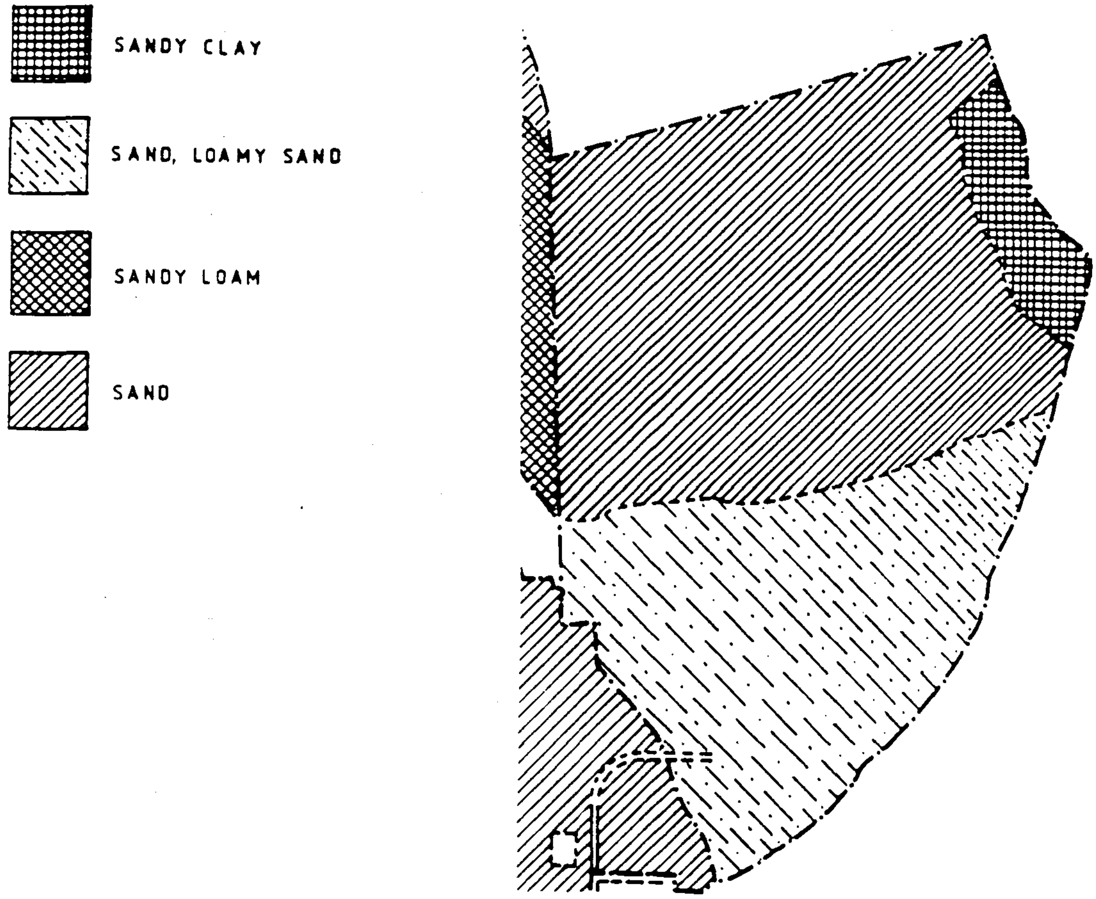
of similar surface soils which are shown in figure 2.10. Due to the sparcity of the data these areas can only be regarded as estimates. The infiltration parameters for the different zones are given below in Table 2.1.

Table 2.1 Infiltration Parameters

Soil Classification	Porosity		Capillary Pressure (cm)	Conductivity (cm/h)
	Total	Effective		
Sand	.437	.417	4.95	11.78
Loamy Sand	.437	.401	6.13	2.99
Sandy Clay	.430	.312	23.90	0.06

2.2.4 Soil Types

The Department of Agriculture and Water Supply in Pretoria have published a series of memoirs and maps of soil types which cover the areas of these catchments. From the map covering the region it was established that the soil catena was Bb1. This information also produces the predominant soil types for that particular catena. There are four different classes dependent on the slope; namely, summit or crest, intermediate slope, flood plain or bottom of slope, and base of slope. The soil types with their corresponding % of occurrence and hydrological parameters are given in Tables 2.2a to 2.2d.



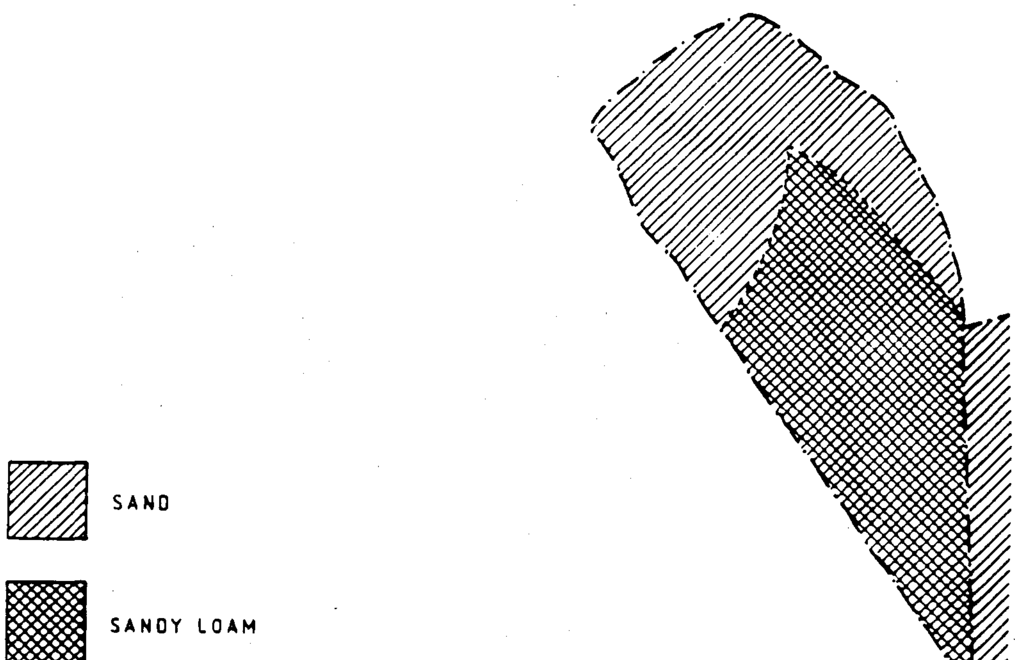


Figure 2.10 - Waterval - Soils Information (Engineering Classification)

Table 2.2a - Soil Type Information - Summit/crest							
Soil Types		%	Depth (mm)	Clay % (A)	Clay % (B)	Texture	SCS Group
Glenrosa	Gr15	20	300-400	12	-	SLm	Bx
Avalon	Av26 \	15	400-600	18	20	SClLm	Bx
Ruston	Av16 /					SClLm	Bx
Newcastle	Av25 \	10	400-600	12	12	SLm	A/Bx
Wolweberg	Av15 /					SLm	Ax
Msinga	Hu26 \	20	400+	25	30	SClLm	A
Hutton	Hu16 /					SClLm	A
Bontberg	Hu25 \	10	400+	12	12	SLm	A
Kyalami	Hu15 /					SLm	A
Doveton	Hu27	5	400+	27	40	SCl	A/B
Sandvlei	Wa31	10	400-600	12	9	SClLm	B/Cxx
Klipfontein	Ms11	5	200-400	12	-	SClLm	Cxx
Wesselsnek	Gc25 \	5	400-800	18	18	SLm	A/Bxx
Delmas	Gc15 /					SLm	A/Bx

Table 2.2b - Soil Type Information - Intermediate Slope							
Soil Types		%	Depth (mm)	Clay % (A)	Clay % (B)	Texture	SCS Group
Rock		5					
Glenrosa	Gr15	20	300	12	-	SLm	Bx
Avalon	Av26 \	10	400-600	18	20	SClLm	Bx
Ruston	Av16 /					SClLm	Bx
Newcastle	Av25 \	10	400-600	12	12	SLm	A/Bx
Wolweberg	Av15 /					SLm	Ax
Msinga	hu26 \	5	400+	25	30	SClLm	A
Hutton	Hu16 /					SClLm	A
Bontberg	hu25 \	5	400+	12	12	SLm	A
Kyalami	Hu15 /					SLm	A
Sandvlei	Wa31	15	400-600	12	9	SClLm	B/Cxx
Klipfontein	Ms11	15	200-400	12	-	SClLm	Cxx
Vaalsand	Lo31	10	400-600	12	9	SLm	Cxx
Wesselsnek	Gc25 \	5	400-800	17	17	SLm	A/Bxx
Delmas	Gc15 /					SLm	A/Bx

Table 2.2c - Soil Type Information - Bottom of slope							
Soil Types		%	Depth (mm)	Clay % (A)	Clay % (B)	Texture	SCS Group
Sandvlei	Wa31	30	400-600	12	9	SClLm	B/Cxx
Vaalsand	Lo31	40	400-600	12	9	SLm	Cxx
Slangkop	Kd15	10	400-500	17	49	SClLm	C/Dxx
Sibasa	We13	20	300-400	12	38	SCl	Dx

Table 2.2d - Soil Type Information - Base of slope							
Soil Types		%	Depth (mm)	Clay % (A)	Clay % (B)	Texture	SCS Group
Slangkop	Kd15	50	400-500	17	49	SClLm	C/Dxx
Sibasa	We13	20	300-400	12	38	SCl	Dx
Dundee	Du10	30	>1200	12	-	SLm	B/C

The x and double x codes in the SCS group refer to some interflow potential and high interflow potential respectively. It is interesting to note that interflow will play a large part in the hydrological regime of the catchment. Also there is a significant clay fraction present in the soils found in the area.

2.3 Sunninghill Catchment

2.3.1 General

The Sunninghill catchment is situated to the west of the Waterval catchment and shares a common boundary for a short distance (see fig 1.1). The catchment area also measures 75 ha and slopes from east to west with a fall of 50 m over a distance of about one kilometre. This catchment has a well defined watercourse flowing through a park area in the center of the catchment. A contour map of the catchment showing the boreholes, rain, stream and sewage gauges is presented in fig 2.11.

2.3.2 Geology and Geomorphology

The Sunninghill catchment is largely developed and the natural surface has been altered which makes geological investigation very difficult. The urbanisation of the catchment has made a geophysical investigation of the catchment impossible. Use therefore was made by Mony of aerial photographs, and limited resistivity and magnetometer traverses to identify two geohydrological areas which are shown in fig 2.12. The lower boundary of area 1 is lineament line 4 which a magnetometer traverse indicated could be a dolerite intrusion which is likely to be variable in composition and permeability.

From the borehole logs, the soil profile varies in depth from 1,5 m in the region of borehole BS4 to the order of 2,2 m at the bottom of the catchment in the region of boreholes BS2 and BS3. As in the case of the Waterval catchment the surface soil horison varies from sandy hillwash material to an alluvium with higher silt and clay contents along the watercourse.

2.3.3. Land-use, Vegetation and Surface soil information

Urban development started in the catchment in about 1983. The township was layed out with 120 erven. Of the 120 eleven of the erven were earmarked for commercial and townhouse developments. Only one commercial stand remains empty. All but 3 of the remaining erven set aside for houses have been developed. The erven for houses are of the order of 1500 m^2. The estimated impervious area on the developed housing erven is 25%. There is an office block, shopping center, garage with associated parking facilities. These areas have greater areas of paving than the housing developments with an estimated 50%-60% impervious area. Approximately 25% of the catchment is covered by impermeable surfaces. The roads are all tarred and a piped stormwater reticulation system exists (fig 2.13). Most of the developments are walled in so the surface runoff is concentrated along driveways or at low points.

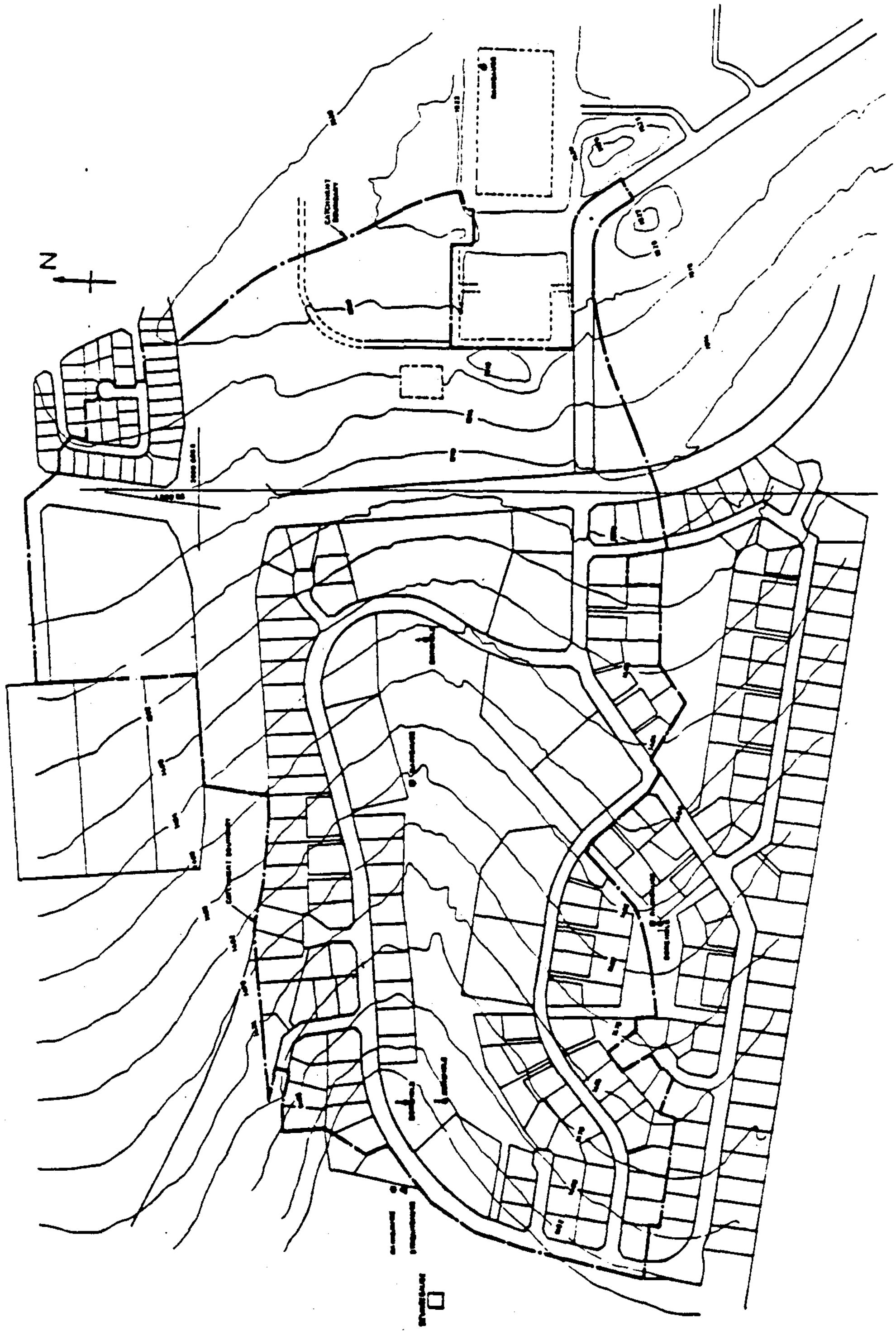


Figure 2.11 - Sunninghill Park Catchment

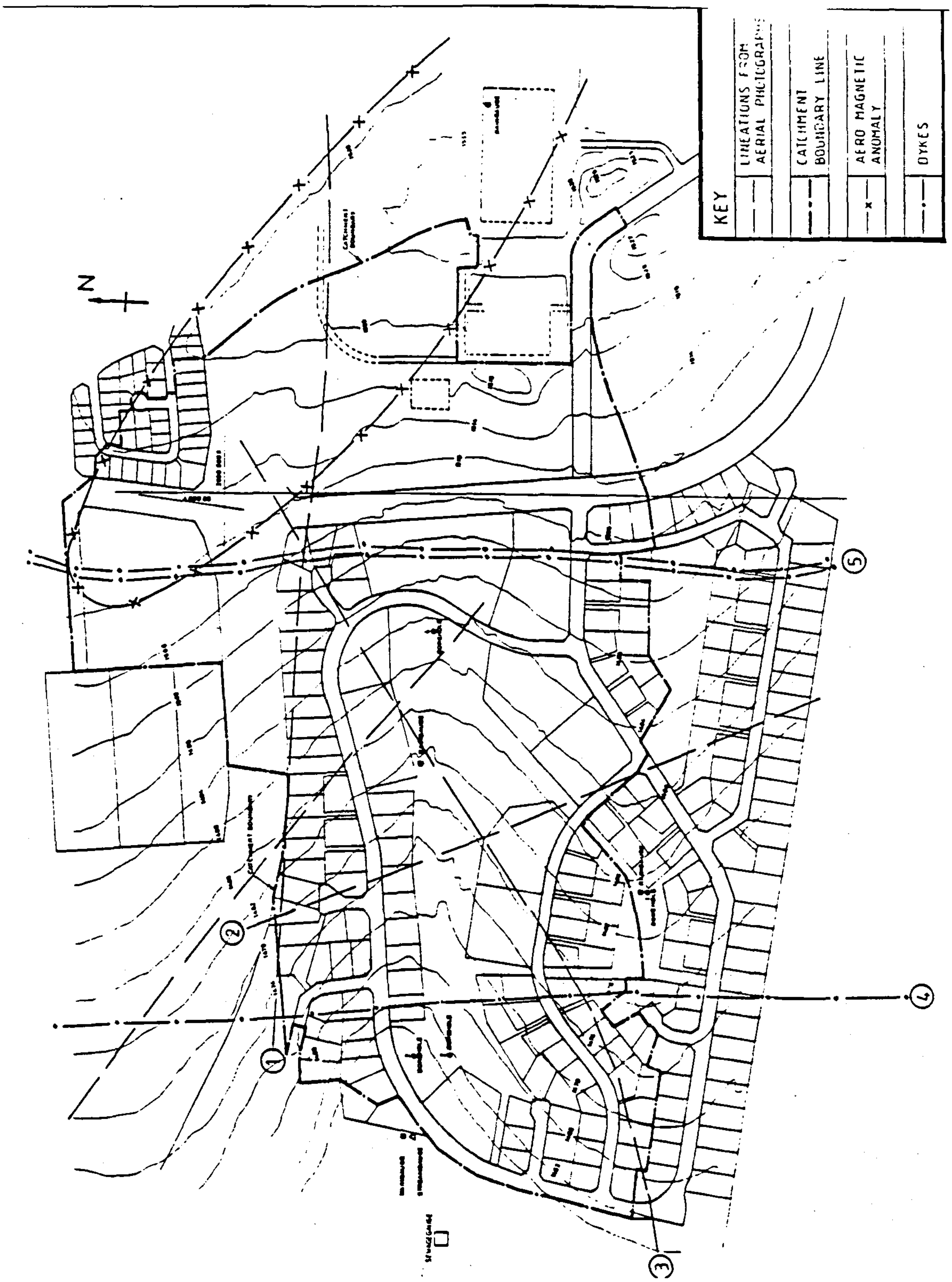


Figure 2.12 - Sunninghill - Aerial Analysis of Geology

Figure 2.13 - Sunninghill Stormwater Reticulation

The water course runs down the middle of the catchment through a park area. A vegetation survey was carried out on the catchment and the results are presented in fig 2.14. In the central park area kikuyu grass has been planted along the banks of the watercourse. Trees have also been planted in this area and some of the original tree areas have been preserved. At the top of the catchment lies Megawatt Park, Eskom's office complex, which is surrounded by lawns which are shown in fig 2.14. At the bottom of the catchment just above the road in the region of boreholes 2 and 3 is a marshy area.

Grading analyses were carried out on 9 samples taken from various points in the catchment. The results of the analyses were used to classify the soils according to the USDA soil classification methods. Areas of similar soil were then demarcated and are shown on fig 2.15. The area along the watercourse was found to be loamy sand and while the rest of the catchment surface soils were classified as sand. Using the results of the work by Rawls et al the infiltration parameters presented in Table 2.3 were obtained for the soils.

Table 2.3 Infiltration Parameters

Soil Classification	Porosity		Capillary Pressure (cm)	Conductivity (cm/h)
	Tota .	Effective		
Sand	.437	.417	4.95	11.78
Loamy Sand	.437	.401	6.13	2.99

2.3.4 Soil Types

The discussion of soil types that is presented in Section 2.2.4 is equally applicable to the Sunninghill Catchment.

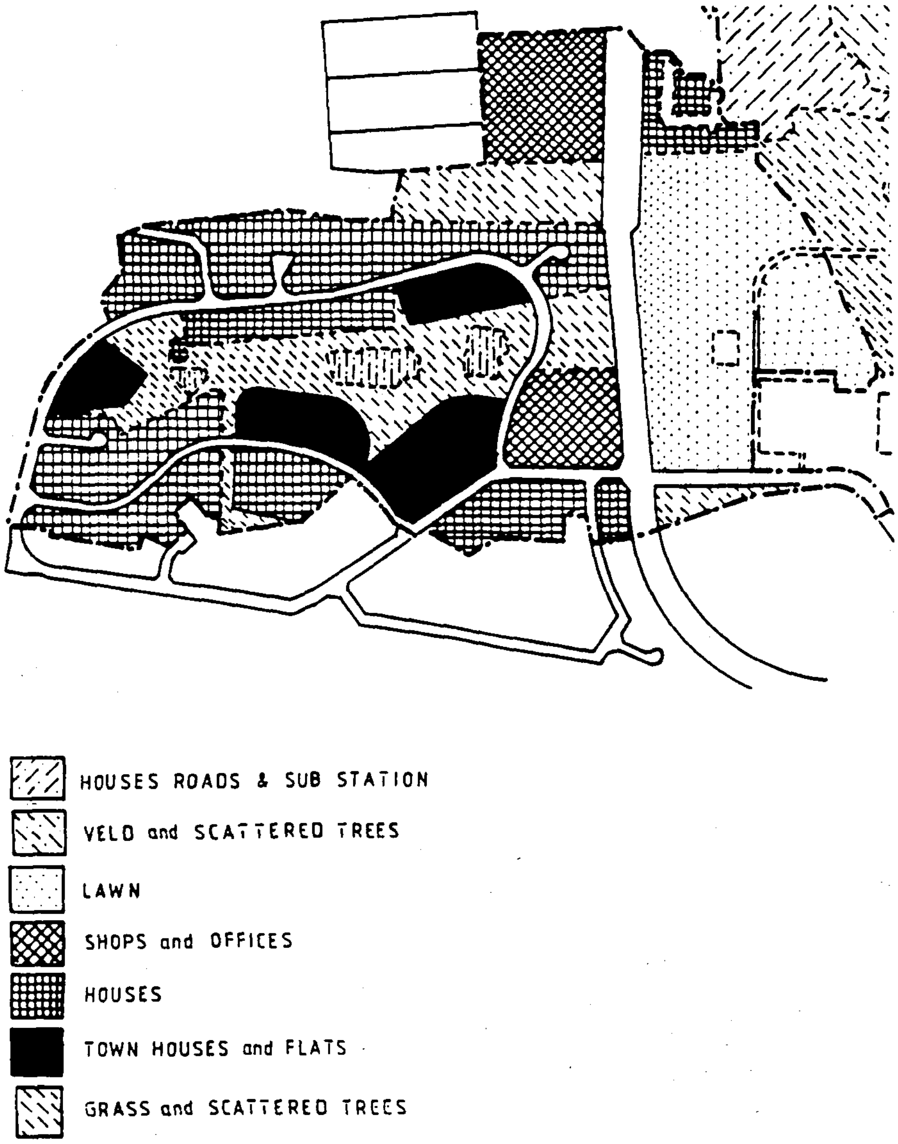


Figure 2.14 - Sunninghill - Land-Use Information

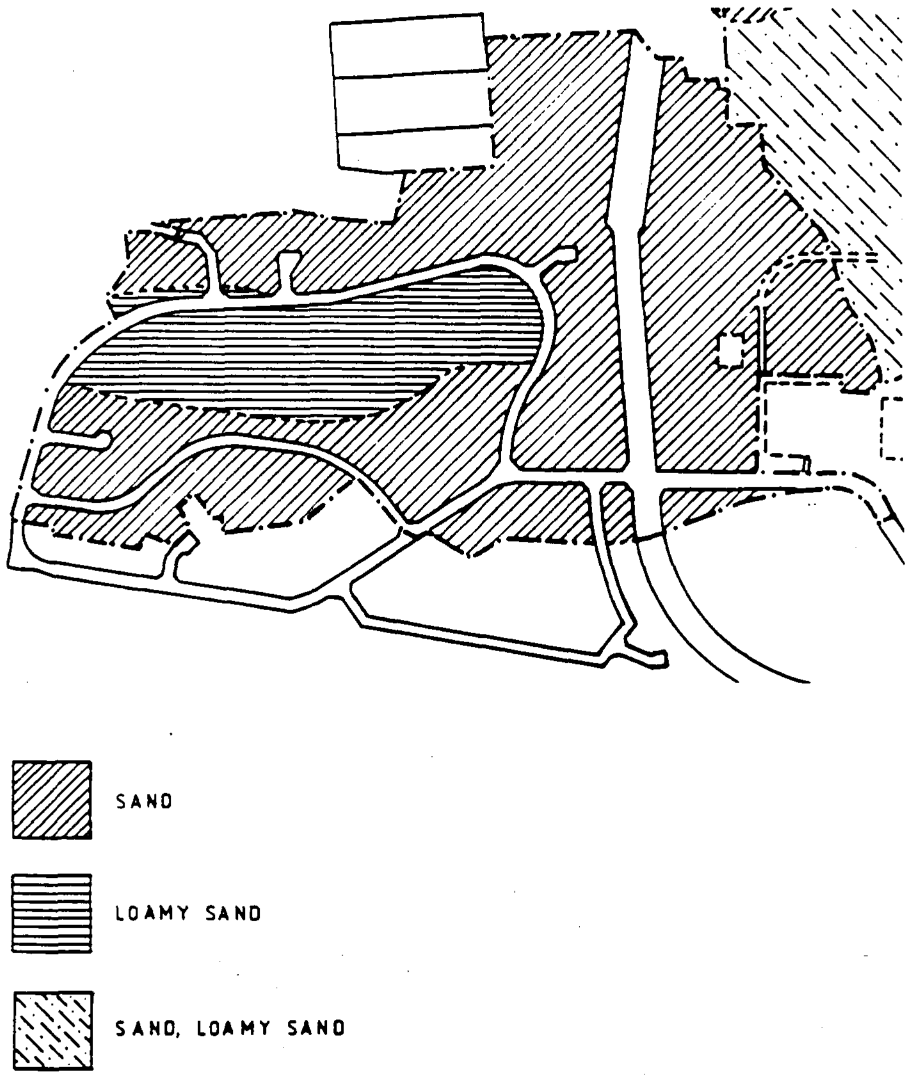


Figure 2.15 - Sunninghill - Soil Information (Engineering soil Categories)

CHAPTER 3 DATA COLLECTION AND ASSOCIATED PROBLEMS

3.1 General

The Water Systems Research Group has for some years been involved in hydrological data collection programmes as part of ongoing research under contract to the Water Research Commission.

Precipitation, streamflow and to a lesser extent stormwater runoff quality data have been collected from two urbanized catchments since 1982. These catchments comprised Montgomery Park and Hillbrow which were described in a report by Stephenson, Green and Lambourne (1986). In these instances, use was made of chart recorders in conjunction with syphon-type or tipping-bucket raingauges and pressure-bubble water depth recorders.

It was found that some of this equipment required excessive technical maintenance, particularly the instrumentation with many moving parts. For example, the clockwork mechanism on the pressure-bubble depth recorders and on the drum chart recorders required continual maintenance. Workshop repairs of the pressure diaphragm in the bubble recorder was necessitated on a few occasions. Minor other technical problems were experienced such as gas leaks in the ›ressure-bubble recorders, sticking of the float in the syphon raingauges and lever arm repairs on the drum chart recorders. Such minor problems, while easy to rectify, nevertheless often resulted in the loss of potentially valuable data.

It was therefore decided that for the present contract, use would be made of electronic data logging equipment, as it was presumed that electronic equipment would be more efficient and therefore cost effective as well as being trouble free. With the rapid development of electronic systems for data collection, one particular system was chosen at the time. The MCS system was initially chosen (a locally made product) since field trials proved its efficiency and it was cost-effective. This data logger still forms the majority of instrumentation systems in the field.

3.2 Instrumentation

Requirements for logging equipment in both Sunninghill and Waterval catchments varied owing to the presence of urbanised communities within the Sunninghill catchment. Rainfall sites were optimised to give a complete coverage of both catchments. A description of the equipment used in all catchments is presented. The data loggers used to record the data are common to all sites and catchments and hence a separate section will be devoted to explanation of these systems.

The map of the catchments presented in Chapter 1 (figure 1.2) shows the sites of the instrumentation. Instrumentation sites in the Sunninghill Catchment were chosen given the constraint of the zoning of the separate areas of the township. Raingauges and boreholes in this case could only be situated in the green belt regions.

3.2.1 Waterval Catchment I & II

The various parameters which were measured are listed below.

- Rainfall
- Runoff
- Groundwater (borehole levels)
- Meteorological parameters

3.2.1.1 Rainfall

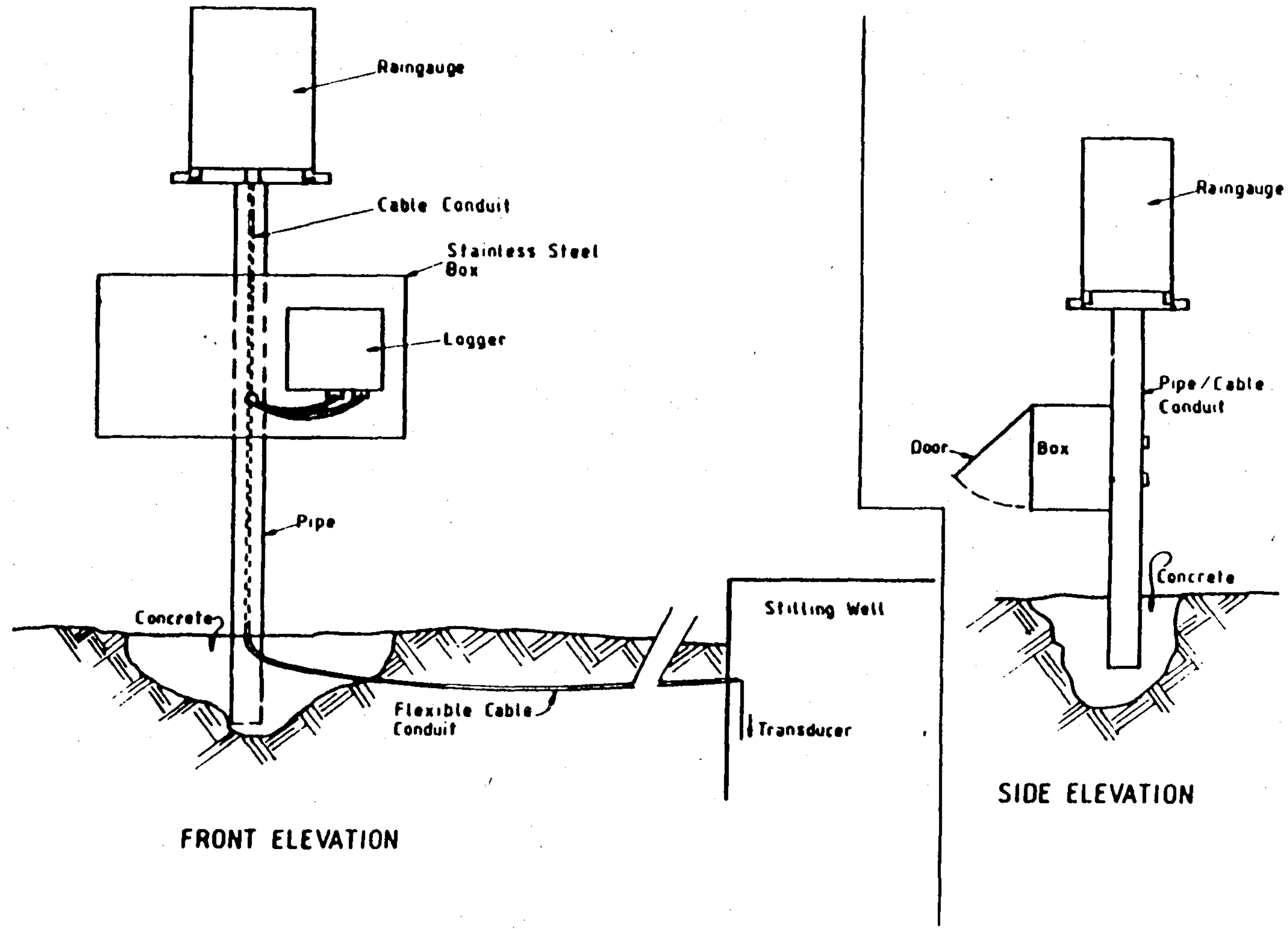
Six tipping-bucket raingauges were installed to give an acceptable cover of the Waterval catchment. A seventh gauge can be used in analysis although technically it is within the bounds of the Sunninghill catchment.

The gauges used are 200 cm^2 orifice, 0.2 mm capture Japanese instruments which have proved reliable on other catchments (i.e. Montgomery Park and Hillbrow). They contain a filter for particle removal. A reed switch which is activated by the tipping action moving a magnet across the reed switch which results in a pulse of current. Rainfall is monitored continuously and the number of tips within 5 minute periods are logged. The digital input data loggers' internal counter increments by one each time a tip occurs.

These instruments, in common with all tipping bucket systems will measure medium to high intensity rainfall events. Low intensity storms will not be measured accurately owing to the amount of water that has to be captured to enable the bucket to tip. Very high intensity rainfall events (in excess of 150mm/hr have found to drown the system).

The raingauge instrument is mounted on a three cornered plate. Each of the corner bolts can be raised or lowered to ensure the level of the instrument is correct. The plate is welded to a galvanized hollow pole which is concreted into the ground. The height to the rim of the raingauge is 1,25m. The cables from the raingauge pass down through the pole and enter the logger cabinet which is bolted onto the pole. The maintenance of the instrument can therefore be carried out in situ. A fence of 1,5 x 1,5m surrounds the installation. A photograph of a raingauge site is shown in figure 3.1 and the drawing specifications of the raingauge and installation details are shown in figure 3.2. It was interesting to note that the design withstood a veld fire as indicated in figure 3.3.

Figure 3.2 - Schematic of Raingauge Installation



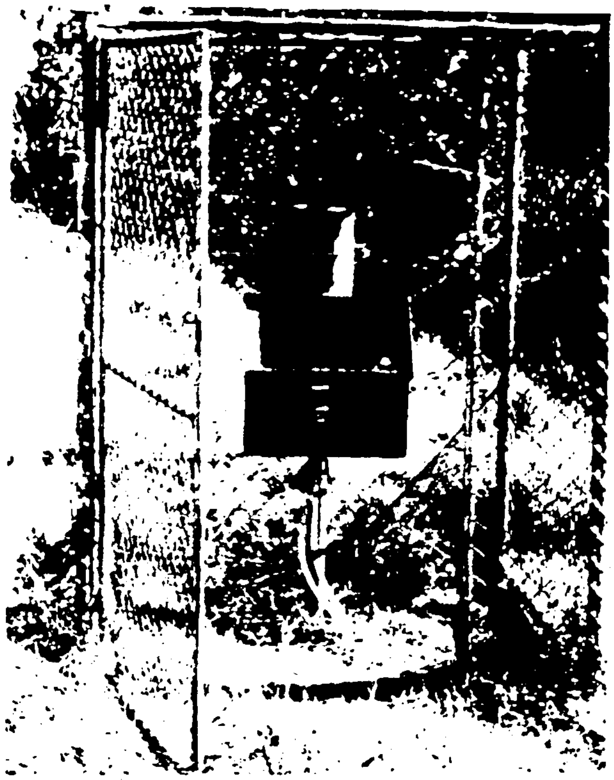


Figure 3.1 - Photograph of Raingauge site

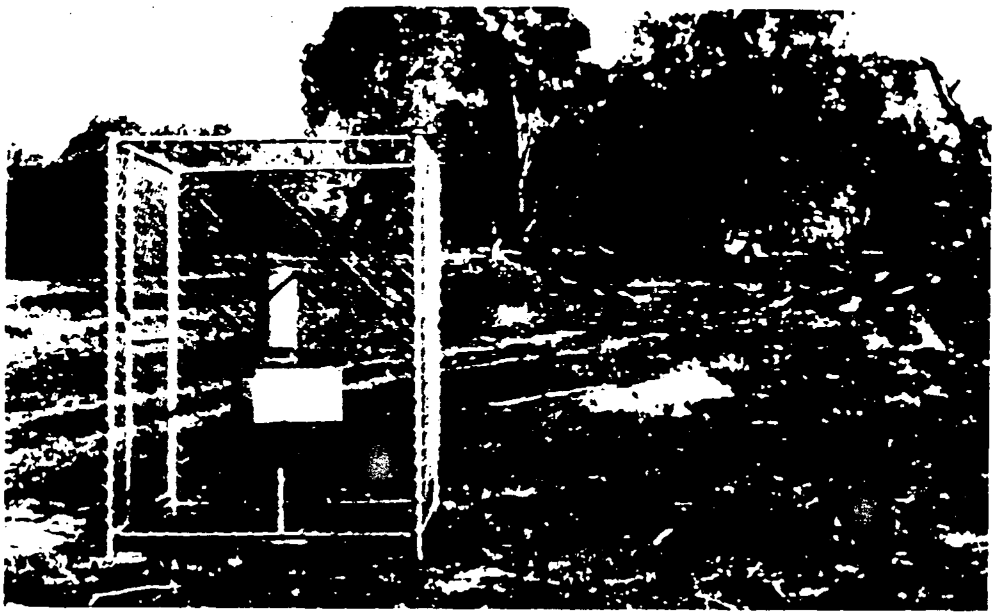


Figure 3.3 - Waterval - Installation copes with veld fires

3.2.1.2 Runoff

The Waterval catchments have no well defined water course present. The Waterval I catchment can be approximated by a converging surface topography. The bottom of the catchment forms the side of a farm dam. To enable surface runoff that enters the dam to be measured, two cut-off channels were constructed. A flat plate v-notch weir was used as a control structure. A 1 on the principle of a strain gauge, thus a measurement of the pressure (and hence depth) of water above the sensor can be made. This particular instrument has a very low temperature sensitivity compared with other pressure transducers (e.g. WIKA). In fact the MCS data loggers used have a greater Analogue to Digital conversion error than the sensor errors. The sensor is powered by 10 volts and produces an analogue signal of between 20 and 50 mV (dependent on the calibration of each instrument). The voltage is directly related to the depth of water in the stilling basin.

The stage readings are converted to discharge using a rating table. A graph of the rating table is presented in figure 3.6. As the stilling basin is dry during periods between rainfall events, and the actual depth over the weir, even during a storm, is low, it was not possible to calibrate the rating table by conventional means. The weir plate was manufactured to designated specifications and hydraulic equations used to determine the discharge at various stage levels. As the catchment is small (0,75 km^2), the monitoring time interval is kept to the smallest possible (in this case 5 minutes). To optimise site allocation within the catchment; a raingauge was installed within cable distance of the weir. Thus the same construction as the rainfall capture sites, of logger box and fencing could be erected.

The streamgauge at the outlet of the Waterval II catchment comprises a flume and earthworks. The earthworks form a cut-off channel to collect the runoff from the overall catchment. The flume is a 2,7m long cut throat flume with a 800mm throat width. The flume was designed according to the criteria set out by Strogerboe et al (1972). The maximum capacity of the flume is 1,8 cumecs. The depth of flow through the flume is measured with a new enhanced WIKA transmitter with a range of 0-2,5m. The transmitter is housed in the floor of the flume and will therefore be subject to extreme temperature variations which would affect the transmitter readings. For this reason a galvanized sheet cover was installed on the flume to shade the transmitter thereby limiting the large temperature variations. The depths were logged at 2 minute intervals on a DDS IDLE 816 logger powered by a solar panel.

In order to examine the quality of the stormwater runoff, a tank having a volume of 2m^3, was constructed on the side of the flume. Stormwater is diverted from the end of the flume by means of a flow splitter into the tank. The splitter diverts approximately 0,1% of the runoff volume to the tank. (See figure 3.7).

3.2.1.3 Groundwater (Borehole levels)

A series of boreholes were drilled at places recommended by the geologists' reports. The depth of each of these holes varied from 25 to 40 metres dependent on the position that water was encountered. The top few metres of metre high stilling well, just upstream of the weir was constructed to enable the water level to be measured. A concrete apron upstream of the weir acts as a catch-point for the water being conveyed in the cut-off channels. Photographs of the weir site are presented in figures 3.4 and 3.5.

Figure 3.4 - Waterval Weir - Downstream Apron

Figure 3.5 - Waterval Weir - Catch Apron and Logger Site

The measurement of stage in the stilling basin was accomplished using a pressure transducer, which was suspended in the well. The particular instrument was imported from the U.K. as at the time suitable locally made instruments were not available. The instrument (produced by DRUCK Ltd) works

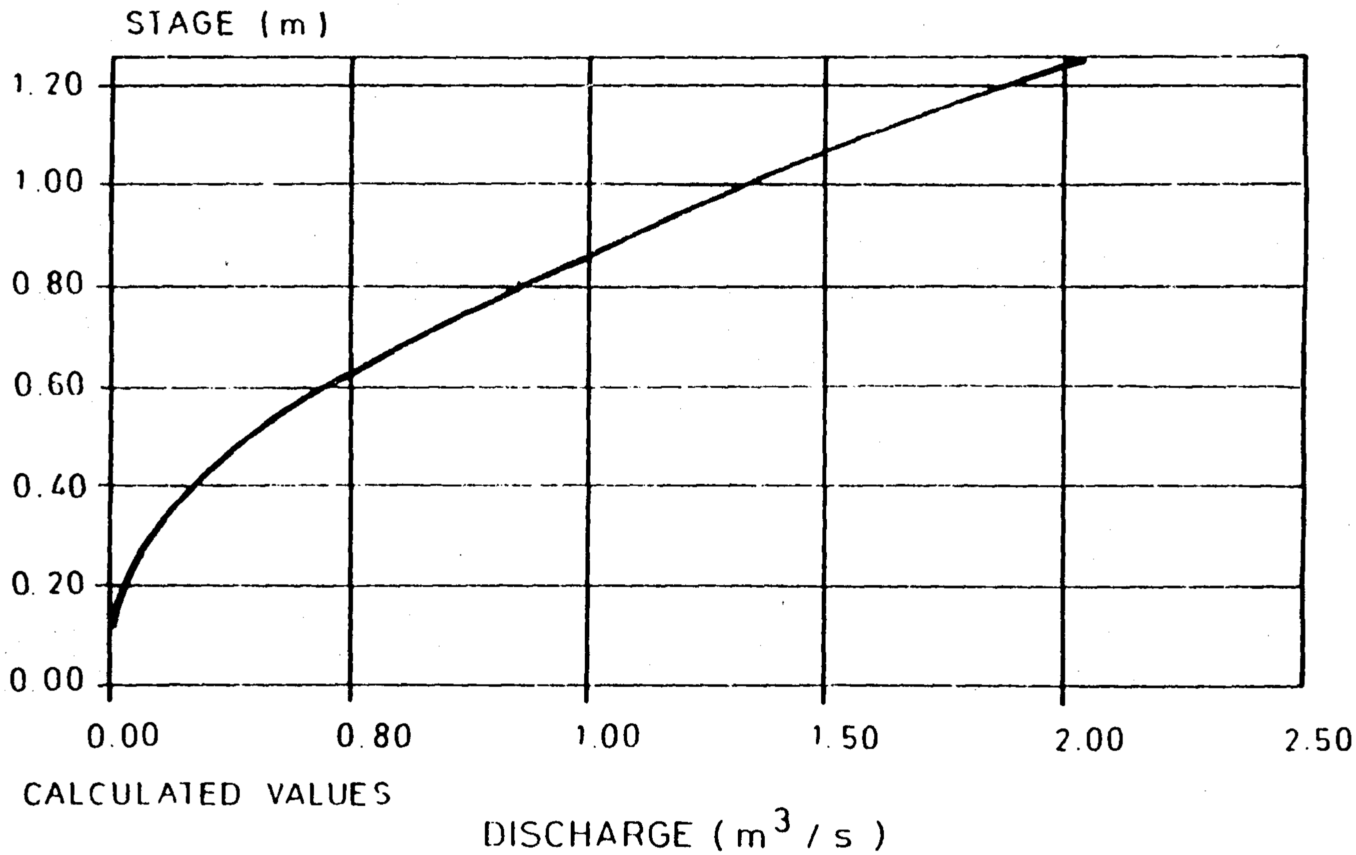


Fig. 3.6 - Waterval Weir I - Stage-Discharge Relationship

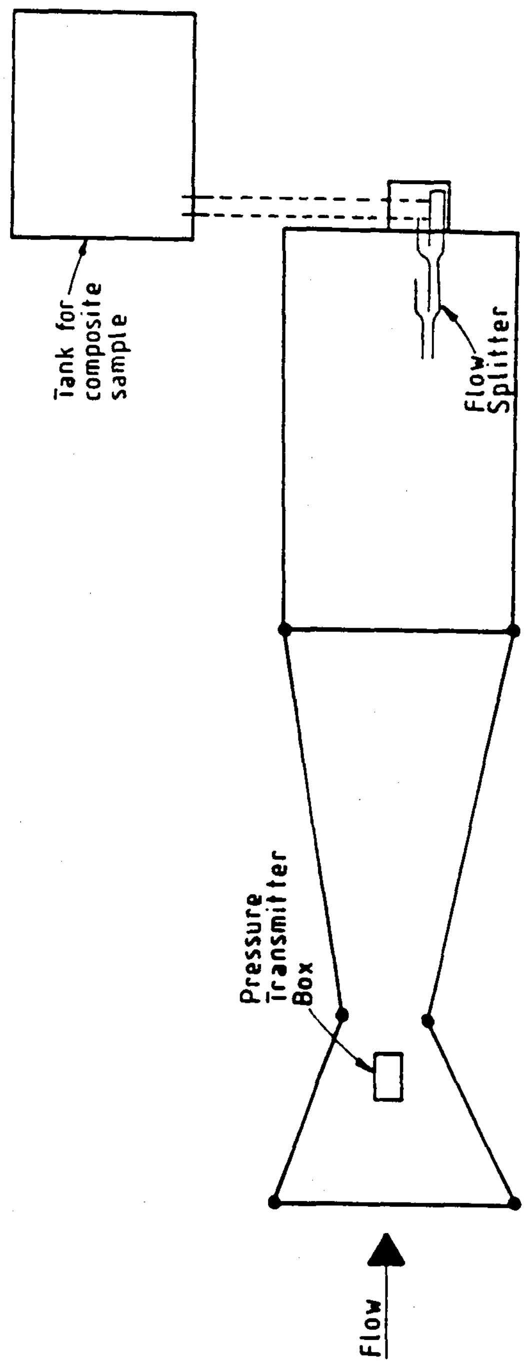


Figure 3.7 - Plan of Waterval Catchment II Weir Structure

the hole were cased to prevent subsidence in the dry material near to the surface. A cap was placed on top of the hole to prevent uncontrolled access to the hole. The water level in each of the boreholes was measured on a weekly basis using a simple resistance probe. Out of the original 10 boreholes only 8 are at present operational; one had a very high clay content and the drill bit jammed thus allowing a clay slurry to enter the hole, and the other had the casing removed by persons unknown.

3.2.1.4 Meteorological parameters

So as to quantify other aspects of the hydrological cycle, (i.e. evaporation) a series of sensors were employed to measure these parameters. An automatic weather station was then installed to meet these requirements. A list of parameters measured is given below.

Temperature
Wind speed
Wind direction
Solar radiation
Barometric pressure
Relative humidity
Potential evaporation

A site was designated and the instruments arranged within a security fence. Room is available within the weather station demarcation to carry out small infiltration studies on a long term basis. As an existing water pump tower was available, an extension bracket was attached to the top of the mast. The sensors were then attached to the tower with cables to the recording box at the base of the tower. A photograph of the weather station site is presented in fig. 3.8.

Temperature

A MC Systems temperature sensor using a DC analogue output was installed. This sensor is only powered at the time a reading is taken, thus saving battery power. The range of the instrument is between -10 and 50 degrees celsius. The instrument is housed in an aspirated shield to prevent direct sunlight affecting the measurements. The instrument was attached to the wind pump tower at a height of 1,5 metres. The measurement of temperature is undertaken every 30 minutes.

Wind Speed

A Windess model V-02 wind speed instrument or anemometer (cup type) was installed on the other piece of the U shaped bracket (along with the wind vane). The sensor was of digital type, which produces a series of pulses during a fraction of a revolution. These series of pulses are counted by the

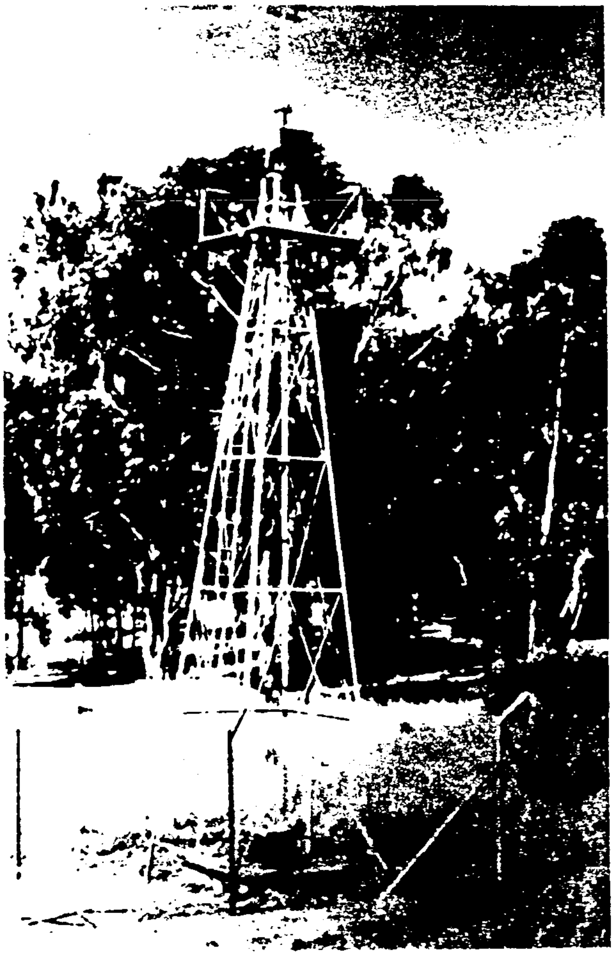


Figure 3.8 - Waterval I - Weather Station

data logger during a finite period of time and hence the speed of rotation may be calculated. The instrument is able to measure wind speeds of up to 20 metres a second. Whilst the pulses are transmitted on a continuous basis, the calculations of the wind speed are averaged over 30 minutes. High frequency wind speeds (gusts) are therefore not measured.

Wind Direction

A Windess Model D-02 wind vane installed at the top of the tower on a dual U shaped bracket was used to measure wind direction. A potentiometer within the wind vane provides a variable voltage that is measured by the logger. The MCS data logger has the facility to determine 'cross-over' (when the vane passes through 0 to 360 degrees) when averaging wind direction measurements. Wind direction measurements are taken every minute and averaged over 30 minutes.

Solar Radiation

Three different types of solar radiation can be measured; namely global, direct and diffuse radiation. In general terms global radiation is commonly measured, which comprises both direct and diffuse radiation. A hemispherical glass covering a thermopile is used as a sensor and the voltage measured is then directly proportional to the solar radiation in Watts per m^2. The sensor has to be positioned so that a minimal amount of radiation is lost as a result of vegetation and buildings. The amount of radiation is calculated every 30 minutes. The solar radiation instrument can also be used to estimate the number of hours of sunshine during the day. Diffuse radiation (not direct sunlight) contributes less than 20% of the total global radiation. The range of the instrument is 12 (moonlight radiation) to 1200 W per m^2.

Barometric Pressure

The barometric pressure was measured for completeness. Apart from frontal systems, there are no rapid changes in pressure recorded in this area. Half hourly average estimates of pressure were calculated from the measurements. The average barometric pressure is 835 mbar.

Relative Humidity

This parameter is perhaps one of the most difficult to measure effectively. A MC Systems relative humidity sensor was installed in the same position as the temperature sensor. The sensor produces a 0 to 1 V analogue signal which can be calibrated to 0 to 98% relative humidity. The sensor is switched on and off by the data logger so as to save battery power. Averaged values of relative humidity are stored every 30 minutes. The instrument is encased within an aspirated shield to prevent the effects of direct sunlight on the sensor. Relative Humidity instrumentation is noted for its poor drift characteristics.

Potential Evaporation

Potential evaporation may be measured through application of an evaporation pan. An American standard Class A-galvanised iron pan was used. The water within the tank had to be treated with a chlorine tablet to prevent algae forming. A potentiometer with a circular disk attached was used to measure the change in water level in the tank. A float mechanism attached to the disk controlled the movement of the potentiometer. The tank has to be filled up regularly by hand so that complete automation was not achieved. The electronics was found to be very temperature dependent and small scale evaporation was dwarfed by the noise of the instrument.

Bosman (1986) showed that the potential evaporation as determined by an A-class pan is very dependent on the surroundings (i.e. vegetation). Also the state of the water and level within the pan will also influence the results. In light of this and other findings, it was decided to use the meteorological parameters determine an estimate of evaporation.

3.2.2 Sunninghill Catchment

The various parameters which were measured are listed :

- Rainfall
- Runoff
- Groundwater (borehole levels)
- Domestic Water Supply
- Sewer outflow

3.2.2.1 Rainfall

An array of four tipping bucket raingauges are used to estimate rainfall in the Sunninghill catchment. A further gauge used in the Waterval catchment may also be used to improve the areal estimate of rainfall.

Three of the gauges are the Japanese type as described in section 3.2.1.1 (raingauges used in the Waterval catchment), and the fourth is a version produced by MC systems (manufacturer of the data loggers).

This latter system is also a tipping bucket raingauge with 0,2 mm tip. The raingauge has a 203 mm diameter throat. The captured rainfall passes through a siphon arrangement prior to flowing into the available bucket. The instrument is of heavier construction (and hence significantly more expensive) and employs a Hall effect means of generating pulses. The maintenance of this instrument is made more difficult by the adoption of solid state technology.

Rainfall is monitored continuously and the number of tips within a five minute period is summated. These raingauges are all connected to MC systems dataloggers and utilize the same installation and fencing construction. However, the raingauge instrument which is situated on the roof of ESCOM's Megawatt Park complex is not fenced. The instrument lasted only four years until problems forced us to replace it with a Japanese type unit.

3.2.2.2 Runoff

The catchment is characterised by a defined channel. This channel is dry during periods with no rainfall. At the downstream outlet of the catchment a culvert beneath the road has been extended to provide a well-defined box channel. Within this length of concrete channel a V-notch crump weir has been constructed (by the Sandton Municipality) together with a stilling basin. Photographs of the installation are shown in figures 3.9 and 3.10. A raingauge site was chosen near to the weir so as to record both stage and rainfall on one logging system.

Initially a WIKA piezo-electric transducer was installed at the site. This graph of the rating table is presented in figure 3.11. The occurrence of small flows in the channel prohibit current meter calibration of the weir.

Although most of the channel is dry during inter-storm periods, sub-surface seepage is detected at the outlet of the catchment. This has proved to be a fairly constant flow even during dry periods.

3.2.2.3 Groundwater (borehole levels)

Five boreholes were drilled at sites within the catchment as suggested by the geological survey. These were obviously constrained by the nature of an urbanised catchment. The boreholes were drilled within the parkland areas. The water levels within the holes are measured on a weekly basis. One borehole is fitted with a DRUCK pressure transducer in order to measure the water level on a continuous basis. This borehole site is on the same site as a raingauge.

3.2.2.4 Water Supply

Being an urban catchment, a domestic water supply network exists within the catchment. Each of the 120 stands that are supplied has a water meter which is regularly read by the Sandton Municipality. The water reading is unfortunatel · every three months so an averaging procedure is used to estimate the monthly value. No instrumentation has been installed as the meters are the pre-existing property of the Municipality.

3.2.2.5 Sewer outflow

In an urbanised catchment an extra outflow (apart from runoff) can be measured. The sewer outflow as a result of man's influence on the catchment is a major factor in the overall water balance equation. There is one outflow pipe from the catchment. Since there was no previous installation for the measurement of sewerage, a new system had to be inaugurated. The system had to be installed in a standard size manhole without any modification to the flow path or the manhole itself.

An ultrasonic system was chosen as the best solution. The high moisture and corrosive effect of the manhole resulted in the locally produced equipment failing within a fortnight. A robust imported industrial ultrasonic sensor and associated equipment was then installed. Being an industrial sensor the power required by the instrument was 24V with a current drain of 20A/day. This necessitated the construction of an array of 4 solar panels, capable of charging four 12V car batteries. The 'sewerage' level in the pipe was measured every minute and averaged over 5 minutes. This averaging reduced the effect of the uneven surface of the 'fluid' in the pipe.

Figure 3.9 - Sunninghill Catchment - Crump Weir

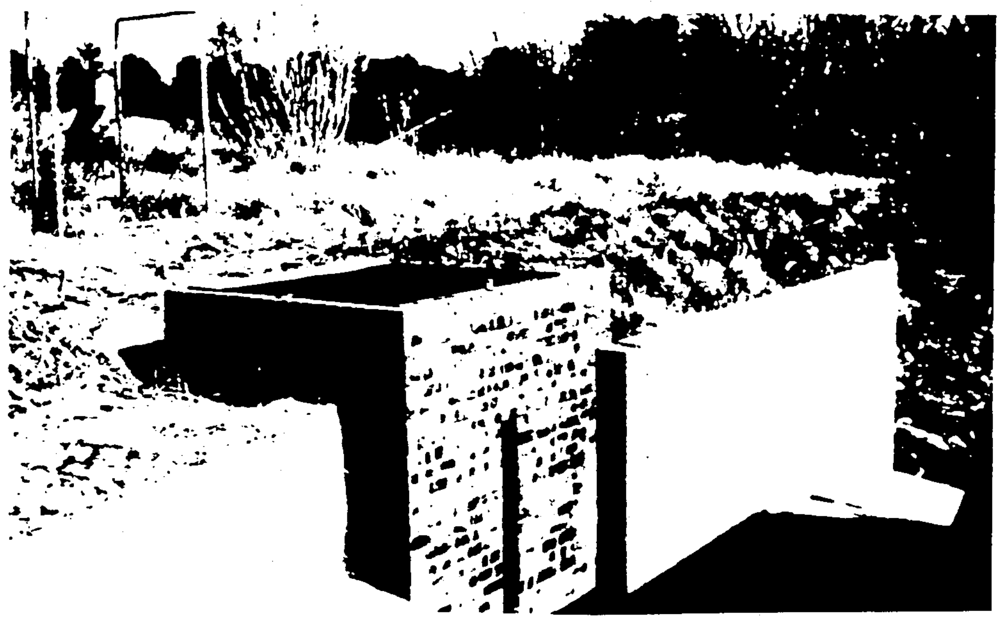


Figure 3.10 - Sunninghill Catchment - Stilling Well

instrument, however, proved very sensitive to temperature variations. This, combined with errors in the Analogue to Digital convertor of the MC systems data logger, resulted in the instrument being replaced by the DRUCK instrument. From 1990 onwards, the introduction of a water sampler at the gauge needed a relay to switch the sampler, thus a DDS logger and new enhanced WIKA were used.

As a result of the Crump weir being constructed under controlled supervision, rating tables prepared by the Hydraulics Research (UK) Ltd can be used. A

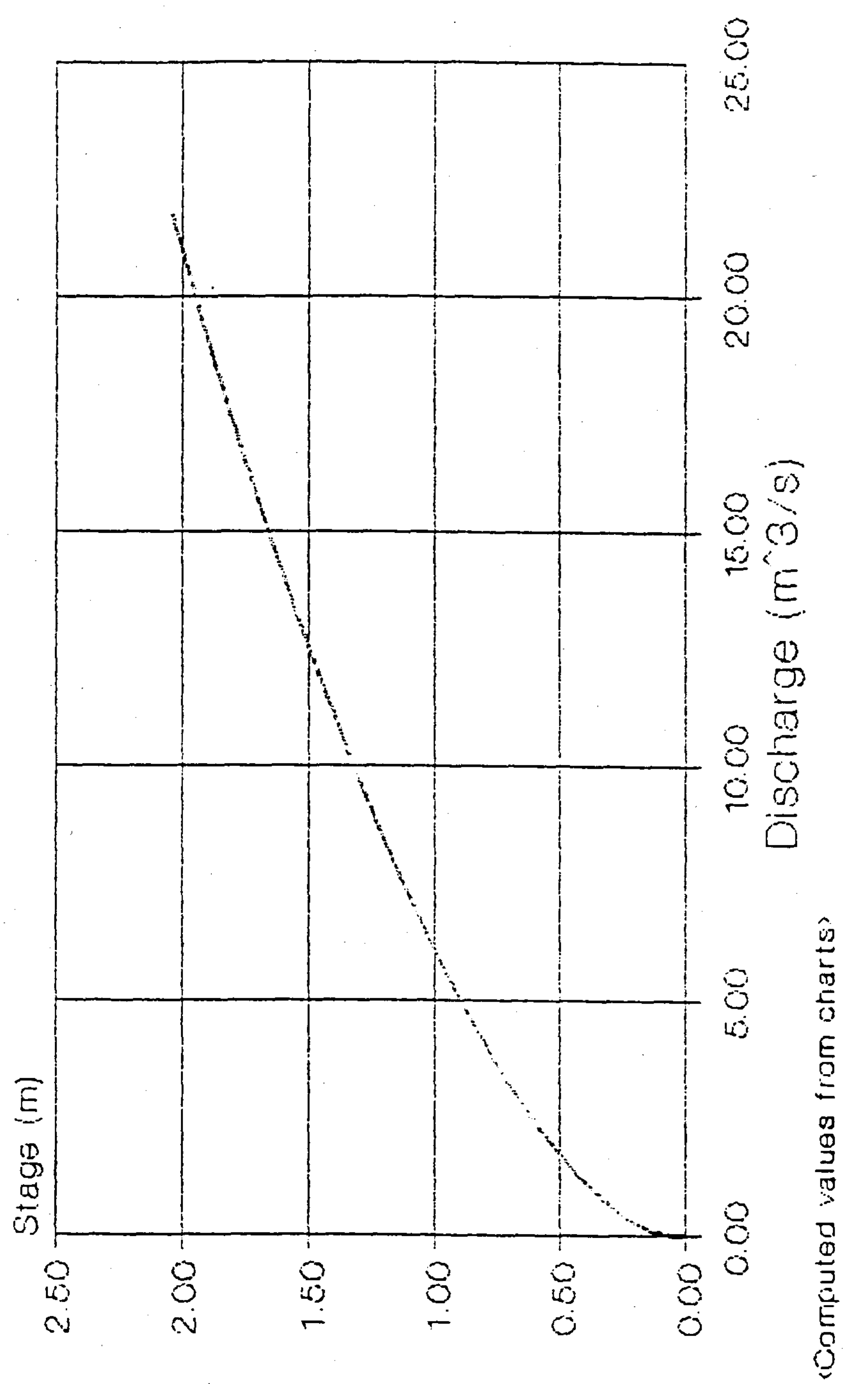


Figure 3.11 - Sunninghill Catchment - Stage-Discharge Relationship

The stage level is then converted to a discharge using a rating table compiled for the site. This table was calculated using hydraulic methods of fluids in conduits. A graph of the rating table is presented in figure 3.12.

3.2.3 MC Data Logger

It was decided to standardise on a single data logging system. After preliminary investigations and satisfactory testing, a data logger manufactured by MC Systems was accepted. A photograph of the logger is shown in figure 3.13. This logger comes in three models, namely a single analogue input, single digital input and multi-channel input. The latter system has eight analogue channels (numbered 1 to 8) and four digital channels (numbered 9 to 12).

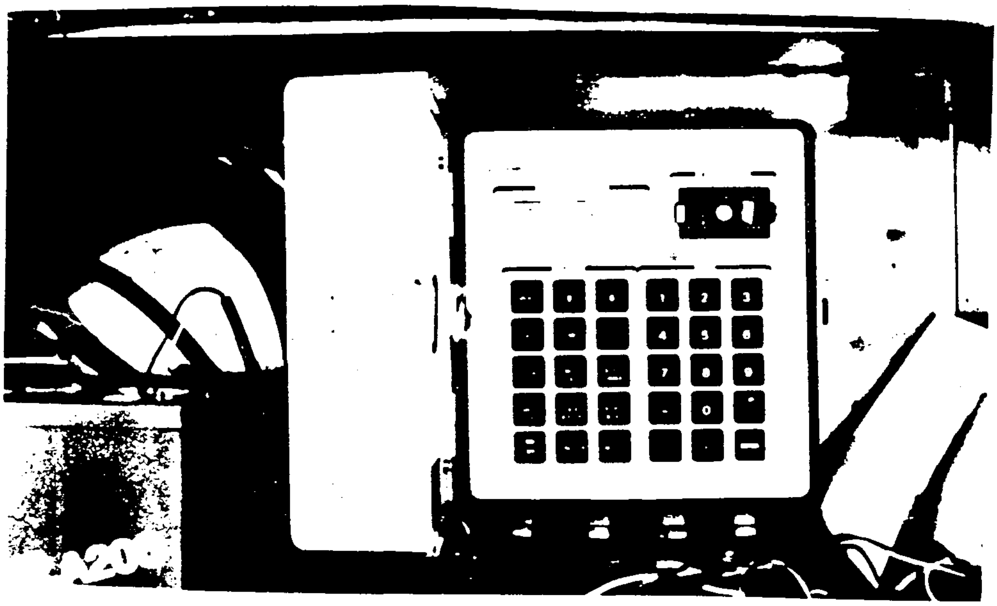


Figure 3.13 - MCS Data Logger

The logger is a compact, ultra low power CMOS microprocessor controlled recording system. The analogue to digital convertor is only able to resolve 8 bits (12 or 16 bits is the more common in other data loggers). This inaccuracy is especially noticeable with the water level measurement using the pressure transducers. The data logger also contains a real time clock, julian day register (a built-in conversion processor will accept calendar date information in DD MM YY format), station identifier register and an EPROM (Erasable Programmable Read Only Memory) module device.

The system is menu driven from a membrane keyboard and 16 digit alpha-numeric liquid crystal display. Half of the keys have a multiple operations. A graphic display of the keyboard is presented in fig 3.14.

The EPROM "chips" are downloaded using RS232 interface and MCS data Loader (Fig. 3.15).

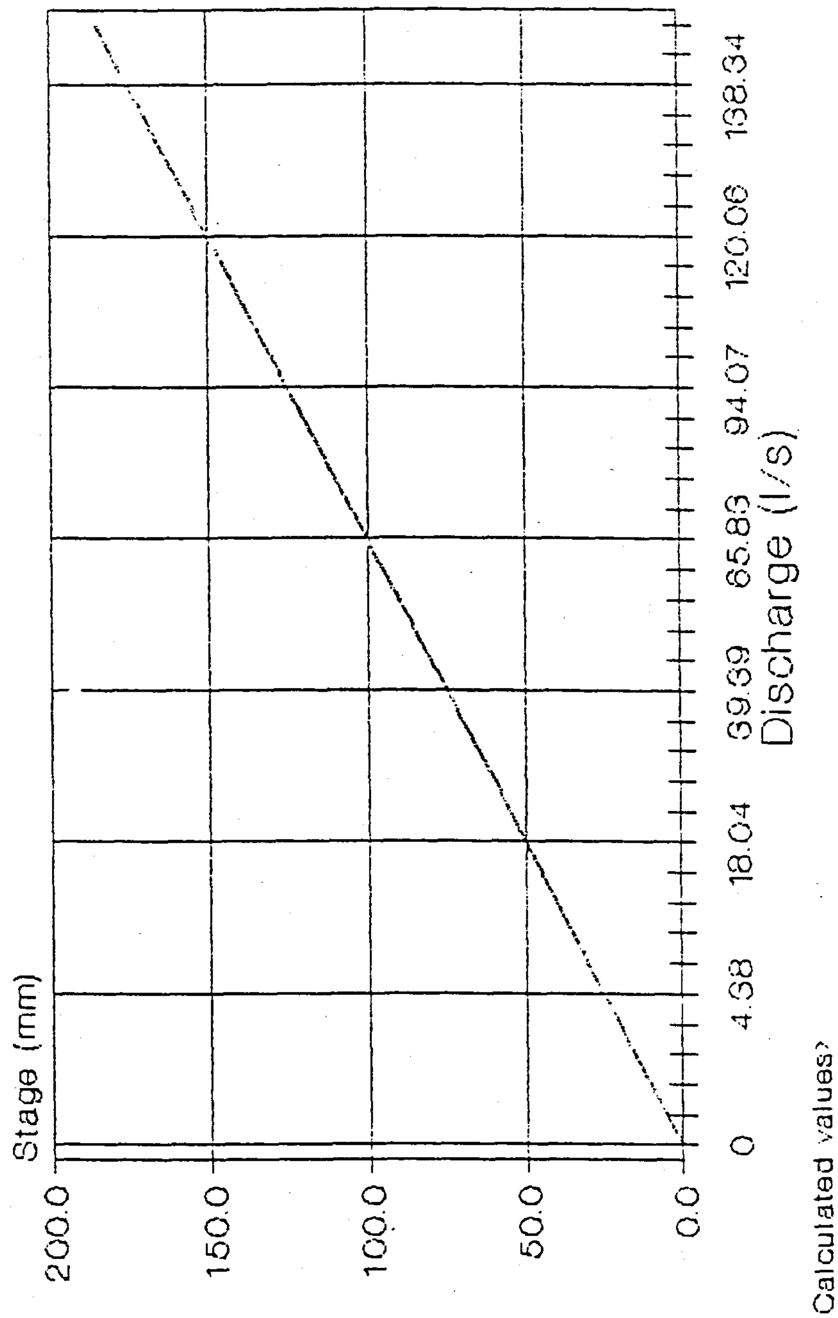


Figure 3.12 - Sunninghill Catchment - Sewage Rating Relationship

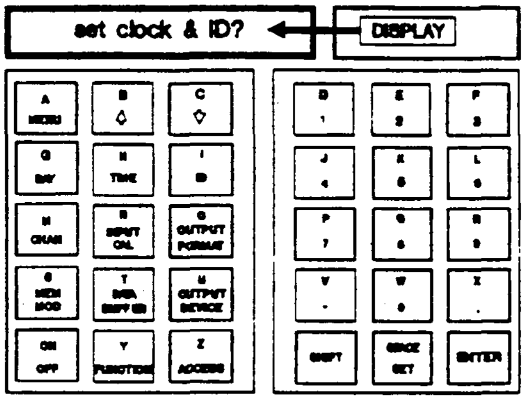


Figure 3.14 - MCS Data Logger Keyboard Display

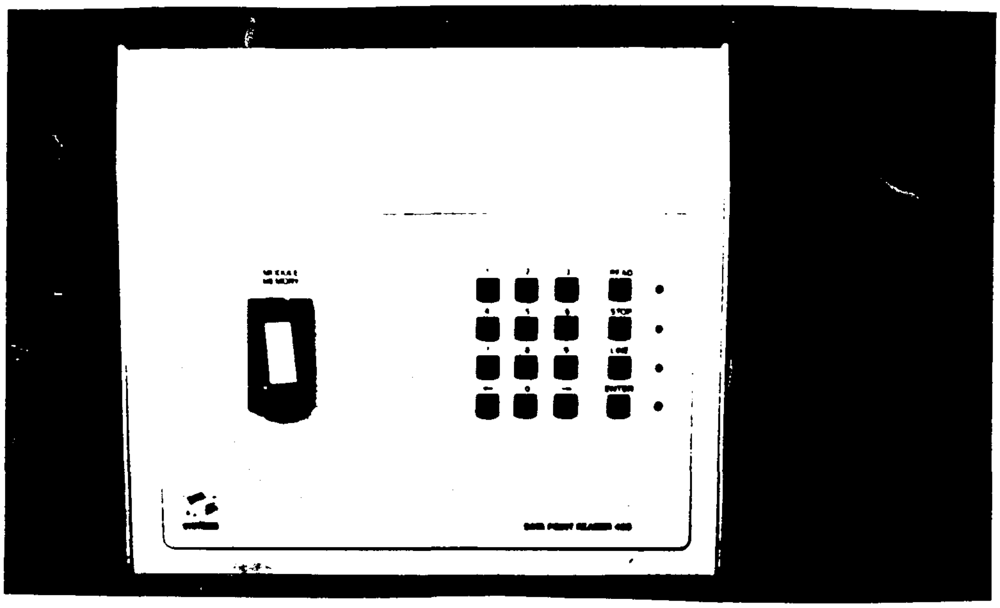


Figure 3.15 - MCS Data Downloading Device

3.2.4 DDS data logger

Towards the end of the contract when water quality sampling of the runoff was started, a second logging system which has the ability to trigger water quality samplers by means of electrical relays was used. The logger is the IDLE-318 manufactured by Digital Data Systems in Randburg. The logger has a real time clock and date system. The data is entered on 64kb RAM (random access memory) packs. The logger has the ability to declare an event once a user specified limit on a channel has been exceeded. The event will remain declared until the reading for that channel is lower than the specified limit. Once an event is declared a relay can be triggered. This feature of the logger is useful in setting off samplers once a depth limit has been exceeded.

3.3 Problems Encountered

3.3.1 Equipment Maintenance and Repairs

Although electronic data logging equipment contains no moving parts, repairs are nevertheless sometimes necessitated. Unfortunately, the sophistication of the instrumentation is such that these repairs can only be undertaken at the place of manufacture. On several occasions a data logger has ceased to function for no apparent reason. It is suspected that high static discharges due mainly to cold dry atmospheric conditions could be responsible for damaging the internal circuits.

The tipping-bucket rainguages all require regular cleaning, failing which the funnel outlets tend to block. It has also been observed that spider-webs cause the bucket mechanism to stick.

3.3.2 Power consumption

Owing to the nature of the research and the locations of the instrumentation, mains power could not be considered.

The data logger/tipping-bucket combination requires four standard torch batteries as power supply. The actual power consumption is however variable, depending on the severity and duration of rainfall. If no rainfall is experienced during a 24 hour period only the time and date are written to the EPROM (Erasable Programmable Read Only Memory) every midnight.

However, if more than .2mm of rain falls causing the bucket to tip, then the number of tips that occur during the selected time resolution period are converted to rainfall depth and this depth and time written to the EPROM. What this means essentially is that logging of data only occurs during periods of rainfall. As the chief source of power consumption is in actually writing the data onto the EPROM, it can be seen that the batteries will have a longer life during periods of no rain than during the wetter months. It has been found that the batteries for tipping-bucket/single channel data logger combination require replacing at approximately 6 week intervals during the rainy season.

In the case of pressure transducers, however, much more power is requred owing to the fact that the output from the transducers are continuous analogue signals which are logged at a selected time interval, irrespective of whether or not there has been any significant change in the magnitude of this signal. Unfortunately, the data loggers purchased are not capable of logging only those data outside a specified range of values. If such a facility were possible, then only data of interest would be recorded, with a consequent increase in battery life. Logging outside of predetermined limits is illustrated in Fig 3.16.

Rechargable dry-cell batteries are used to power the twelve channel data loggers and these need recharging at about two week intervals. One problem discovered relating to rechargable batteries is that over-discharging will shorten recharge life resulting in voltage fluctuations.

In general, the number or volume of batteries used with an electronic system is far greater than would be used with an equivalent chart system, due to the small band width of voltage that the CMOS circuitry in the data logger can handle.

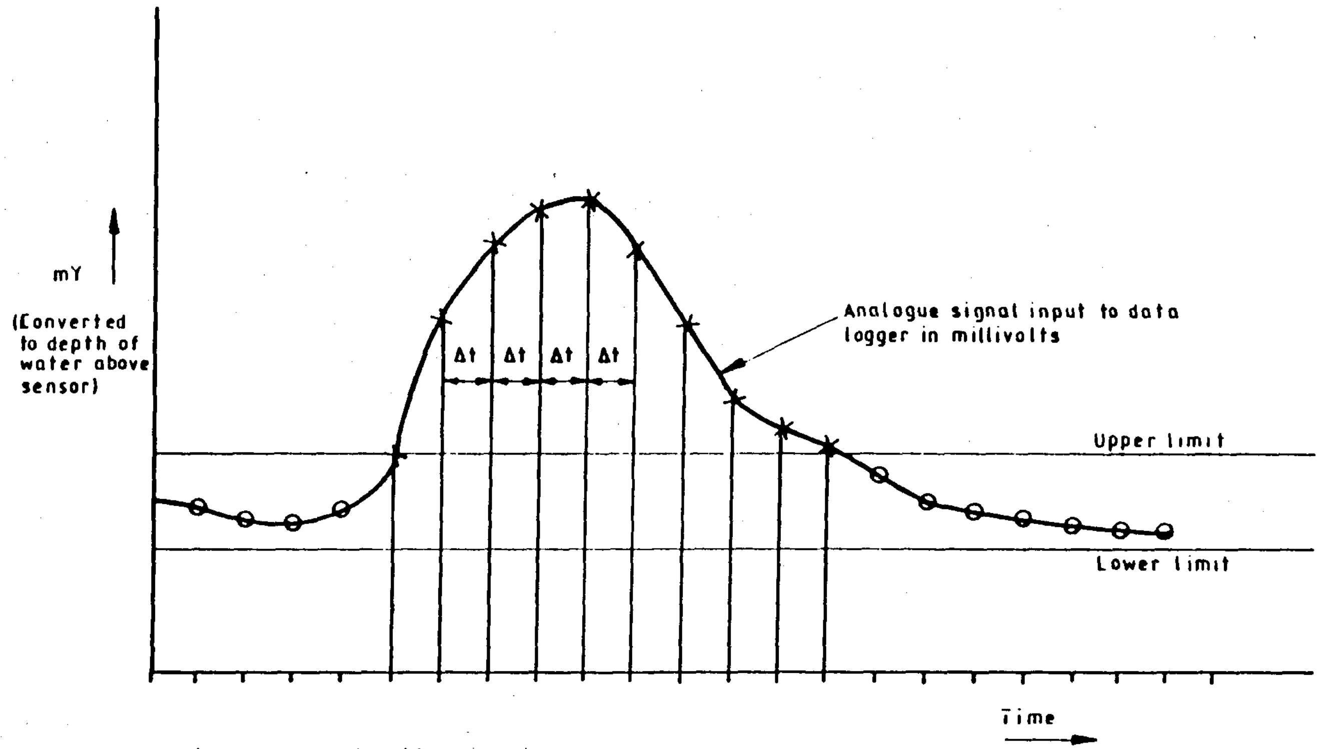
While the batteries as such do not present a problem, regular checking is required. It occurred on one occasion that the polarity of one of the torch batteries was reversed internally resulting in a week of valuable streamflow data being lost.

3.3.3 EPROM Capacity

Where a tipping-bucket raingauge is linked to a data logger, EPROM capacity does not usually represent a problem as data are only written to the EPROM during periods of rainfall. For example, a 16K EPROM can store up to 8000 data points, resulting in approximately 9 days of storage if date, time and precipitation depth are recorded every five minutes. This situation is however undesirable from the point of view recording fluctuations in water depth at stream flow gauging stations. If logging were possible outside a specified range, only data of interest would be stored and a 16K EPROM would last longer than 9 days. An added benefit would be that the resolution time step could then be reduced. For example, the Sunninghill catchment is reasonably steep with a main stream length of less than one kilometer, resulting in a short catchment response time. Thus a resolution time step of one minute would be more appropriate than the currently used time step of five minutes. If however a time step of one minute were adopted with continuous logging, the EPROM would reach full capacity after two days.

3.3.4 Familiarization and Training

The whole concept of electronic data collection and storage is different from that relating to the use of chart recorders, requiring re-training of



Δt Scanning / Logging time interval

Value scanned but not logged (within limits)

Value scanned and logged (outside limits)

Figure 3.16 - Logging outside pre-determined limits

personnel in the operation and maintenance of the equipment. While the operaton of electronic data logging equipment may seem more difficult in the initial stages, it becomes evident after a short while that this type of equipment is no more difficult to operate than the chart recorders used on previous contracts. Downloading the data stored on EPROMs is simpler and quicker than digitising charts and is also not prone to error.

Development of sophisticated software to download the data was however necessitated. Lambourne (1989) has developed a data management system which includes a facility for downloading data from EPROMs.

3.3.5 Vandalism

Vandalism has and apparently always will be a problem in data collection programmes of this nature. Fortunately, under the present contract the incidence of vandalism has been lower than that experienced under previous contracts.

3.4 Critical Appraisal

The change over from a chart/mechanical clockwork based data collection system has not been without problems. Some problems were anticipated (e.g. software development and personnel training) while others were totally unforeseen.

An attempt was made at the outset to draw on the experience of others involves in electronic data collection, but it became evident that only a few organizations had experience in this field. The learning process was therefore very much one of trial and error, and mistakes were made.

Hydrological data collection and data management requires sophisticated instrumentation and software if high quality data are expected. As Dent and Schulze (1985) correctly state, many design decisions resulting in expenditure of millions of rands are made on the basis of published hydrological data. Bearing these sentiments in mind, it seems pointless collecting hydrological data unless these data are of a good quality. It is considered in retrospect that the decision to opt for electronic data logging equipment was the correct one.

3.5 Summary

A description of the instrumentation and implementation procedures used in the Sunninghill Park and Waterval Catchments were presented. The rationale behind each instrument and the decision to opt for electronic data logging equipment was discussed.

The application of the newer technology in this environment and the failings of the equipment are critically appraised. It appears that even with the vast amount of equipment on offer, the designer of a catchment monitoring network is still faced with the problems that existed 10-20 years ago.

References

Anhaesser, C.R. (1973), "The Geology and Geochemistry of the Archaean Granites and Gneisses of the Johannesburg-Pretoria Dome", In Symposium on Granites, Gneisses and related rocks, Edited by L.A. Lister, Geological Soc. of South Africa, Special Publication No.3, pp 361-385.

Antoine, L., (1989), "Geophysical investigation of the Waterval catchment".

Barker & Associates, (1986), "Initial report : land use, geomorphology and geology of two adjacent catchments in Sunninghill Park and on an adjoining trust land farm, Waterval 54IR, Sandton, Transvaal".

Dent, M.C., and Schulze, R.E. (1985), "The hydrological data manager and digitisation in 1985 : Points to Ponder in the development of a new digitising system". Proceedings of the 2nd South African National Hydrological Symposium, Pietermaritzburg, September, pp 119-128.

Lambourne, J.J. (1989) "A User-friendly Hydrological Data-Management and Reporting System", Microcomputers in Civil Engineering, Vol. 4 , No. 1, March pp 1-8.

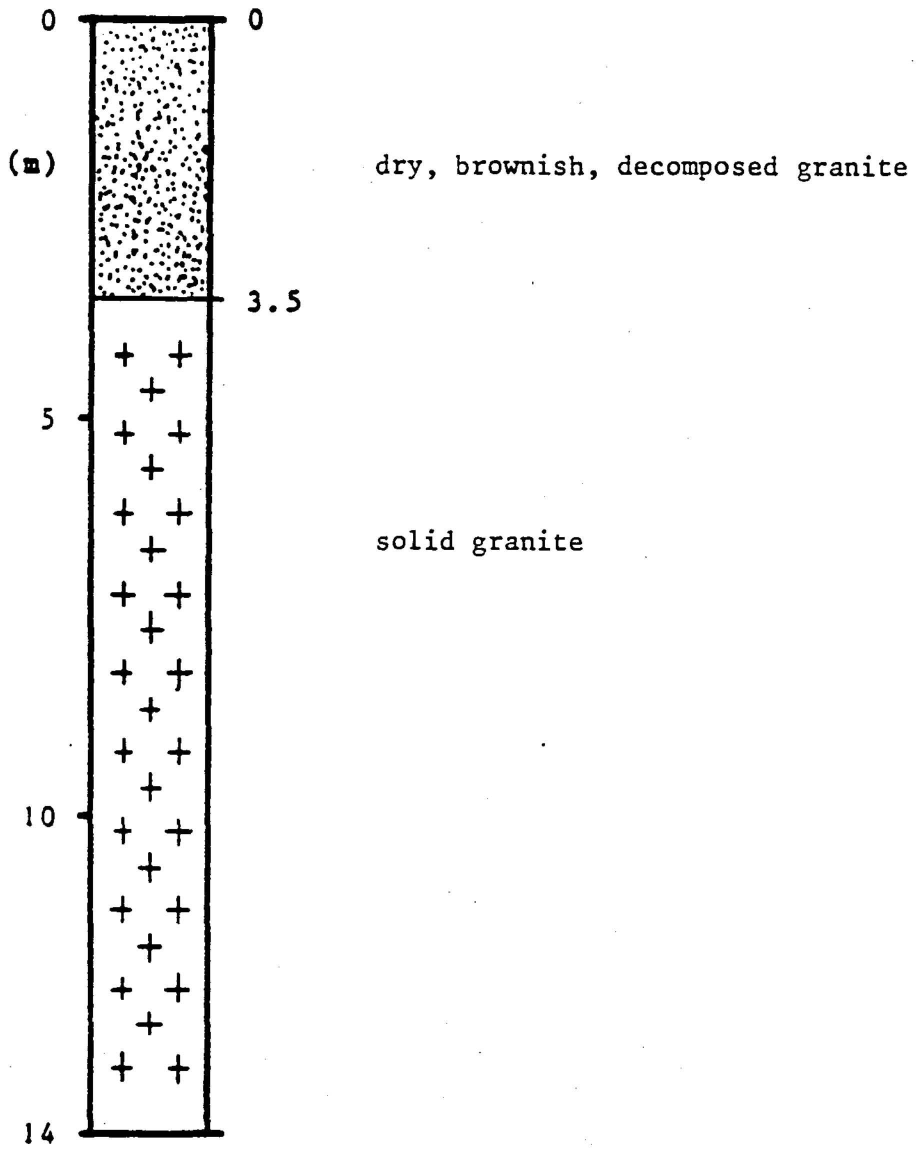
Lindley, A.S., Bosch, J.M., and van Wyk, D.B., (1988), "Changes in water yield after fire in fynbos catchment", Water S.A. 14(1), p 7-12.

Mony, P. (1988), "Proposal for the geohydrological assessment of two catchment areas near Megawatt Park, Sandton, and Halfway House, Midrand.

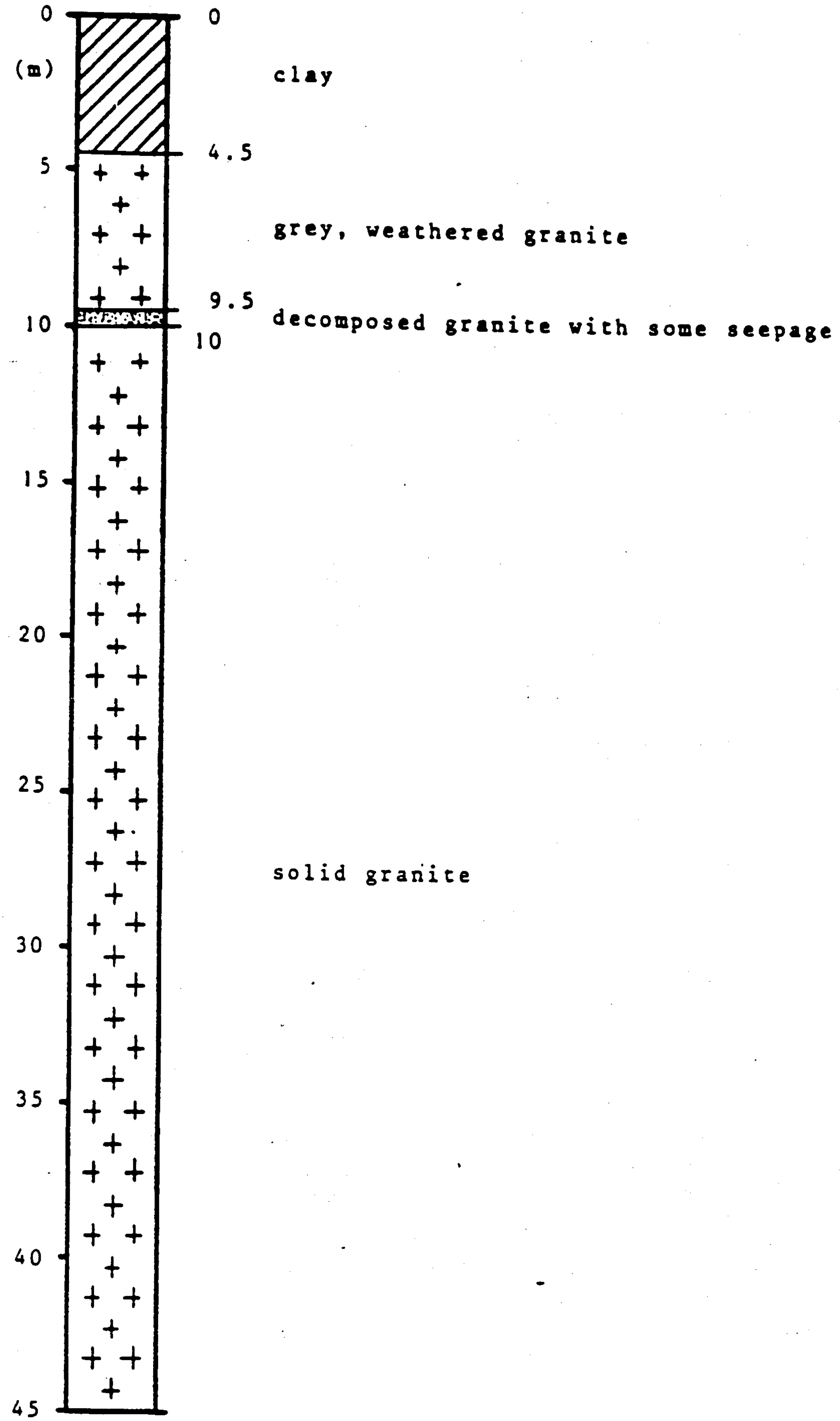
Rawls, W.J., Brakensiehn, D.L., and Miller, N. (1983), "Green-Ampt infiltration parameters from soil data", ASCE, Journal Hydraulics Division, Vol 109, No. 1.

Stephenson, D., Green, I.R.A., and Lambourne, J.J. (1986), "Urban Hydrology and Drainage : Review", Report to the Water Research Comiission by the Water Systems Research Group, University of the Witwatersrand, 15/1/86.

Strogerboe, Bennet, R.S., and Walker, W.R. (1972) " Generalised Discharge Relations for Cut-throat Flumes", Journal of Irrigation of Drainage, Proc ASCE.

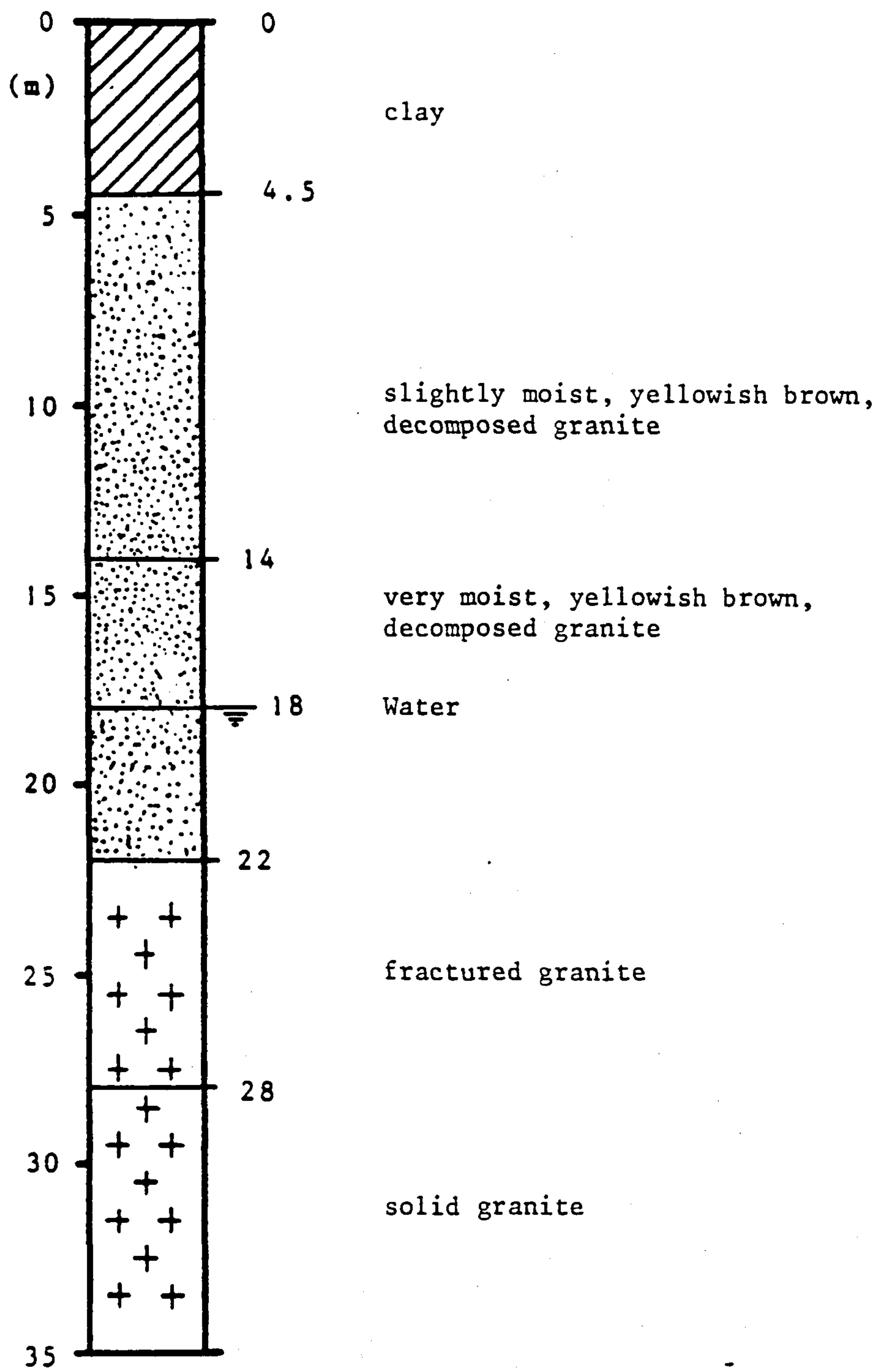


Borehole BW1 - Top Waterval catchment
- 2m Casing

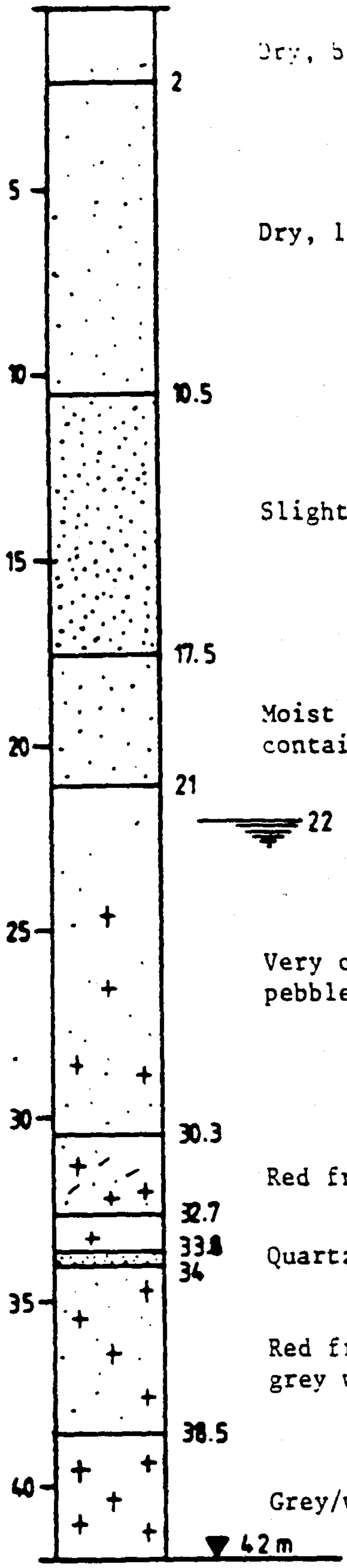


Borehole BW2 - Bottom Waterval catchment

- 1m Casing



Borehole BW3 - Bottom Waterval catchment, near windmill
- 3m Casing



Dry, brown coarse grained sand (possibly hillwash)

Dry, light brown coarse grained sand

Slightly moist, light brown coarse sand

Moist to wet, pinkish brown very coarse sand containing angular fragments of broken rock

Water

Very coarse sand with pink broken fractured granite pebbles.

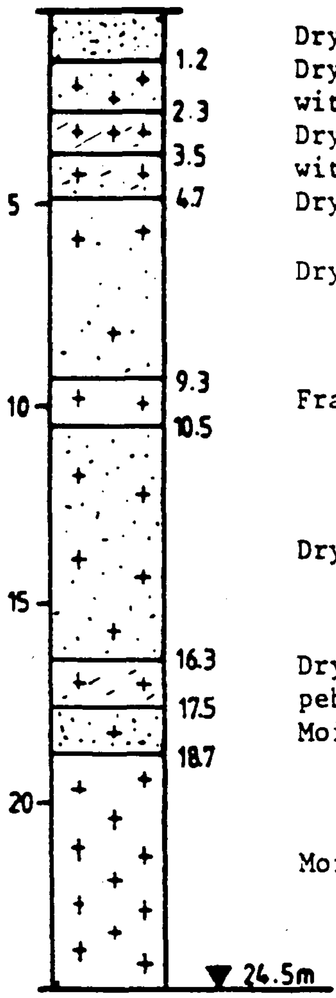
Red fractured granite

Quartz vein.

Red fractured slightly decomposed granite mixed with grey white fragments of fresh, broken granite.

Grey/white fresh granite

Borehole BW5 - Drilled 11 September, 1986
- Water encountered at 22m
- 7m casing



Dry, brown sand
Dry, grey/red fairly weathered coarse grained granite with large (10mm) pebbles
Dry, grey/red fairly weathered coarse grained granite with large (20 - 30mm) angular pebbles.
Dry, grey/red fine grained granite with angular pebbles.

Dry, light brown medium grained decomposed granite

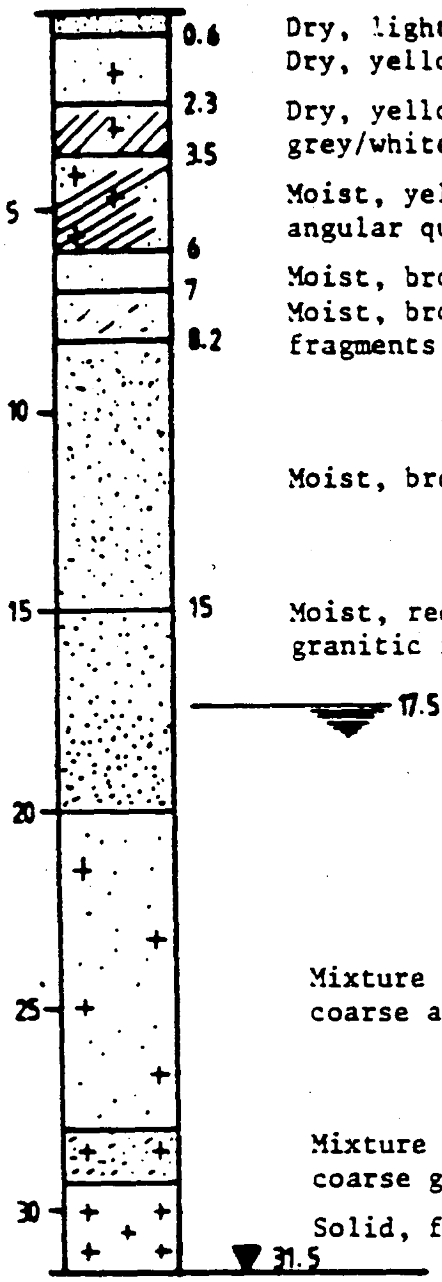
Fractured quartz pebbles.

Dry, light brown medium grained decomposed granite.

Dry, grey/pink weathered granite with angular quartzitic pebbles.
Moist, greenish/grey hard layer with rounded pebbles

Moist, grey slightly weathered solid granite

Borehole BW6	-	Drilled 1t September, 1986.
	-	NO WATER encountered, possibly due to close proximity of lots of bluegum trees.
	-	1m Casing.



Dry, light brown to grey clayey sand.
Dry, yellow, highly weathered granite.

Dry, yellow, highly weathered granite mixed with grey/white silty sand.

Moist, yellow, clayey silt matrix containing small angular quartzitic pebbles.

Moist, brown, silty sand with coarse fractions
Moist, brown coarse grained sand with pinkish quartzitic fragments.

Moist, brown, coarse grained sand (decomposed granite)

Moist, reddish, dark brown coarse sand with angular granitic fragments (approx. 1mm)

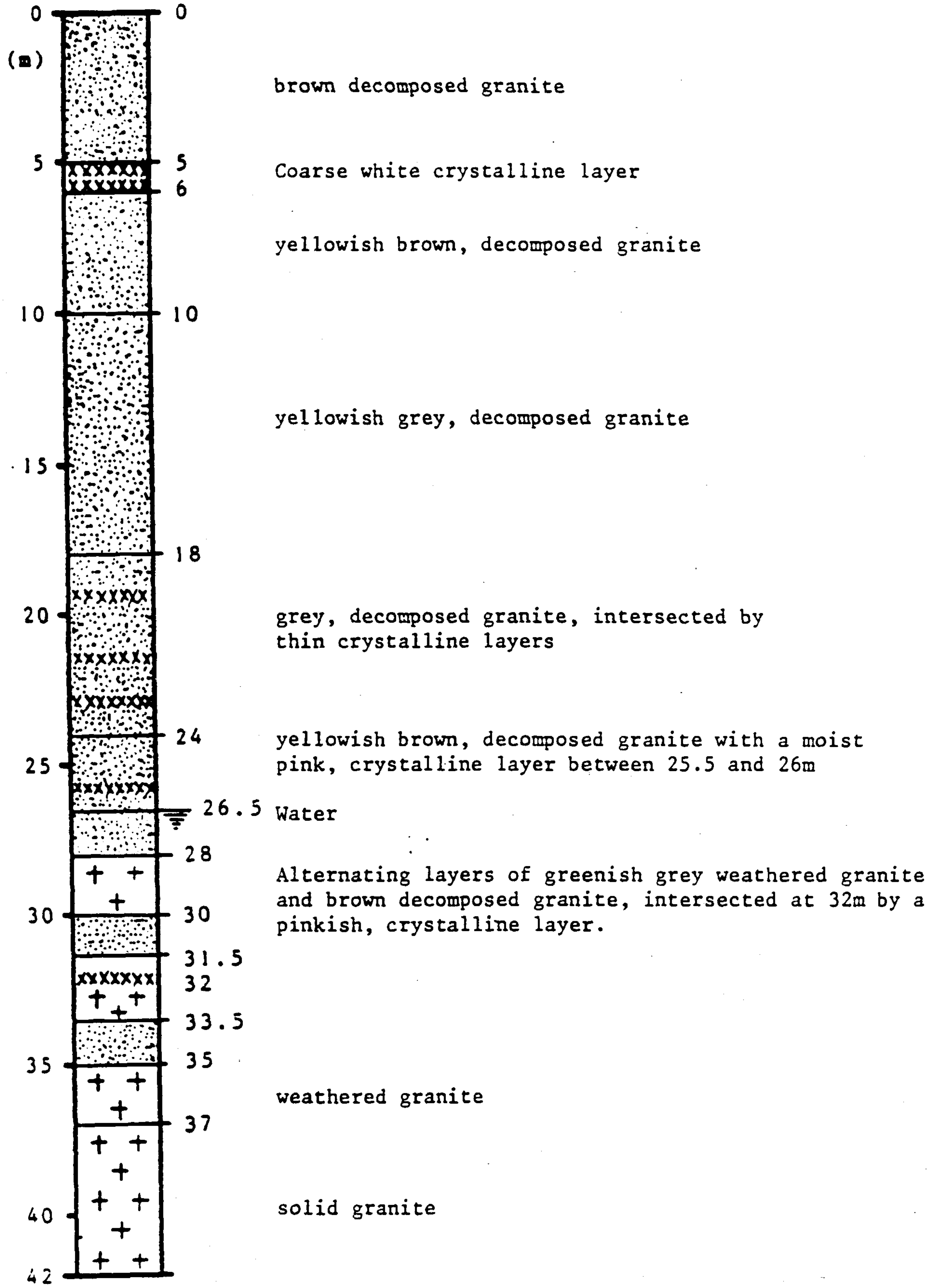
Water

Mixture of pinkish and grey/black granite fragments, coarse and fractured.

Mixture of pinkish and grey/black granite fragments, coarse grained.

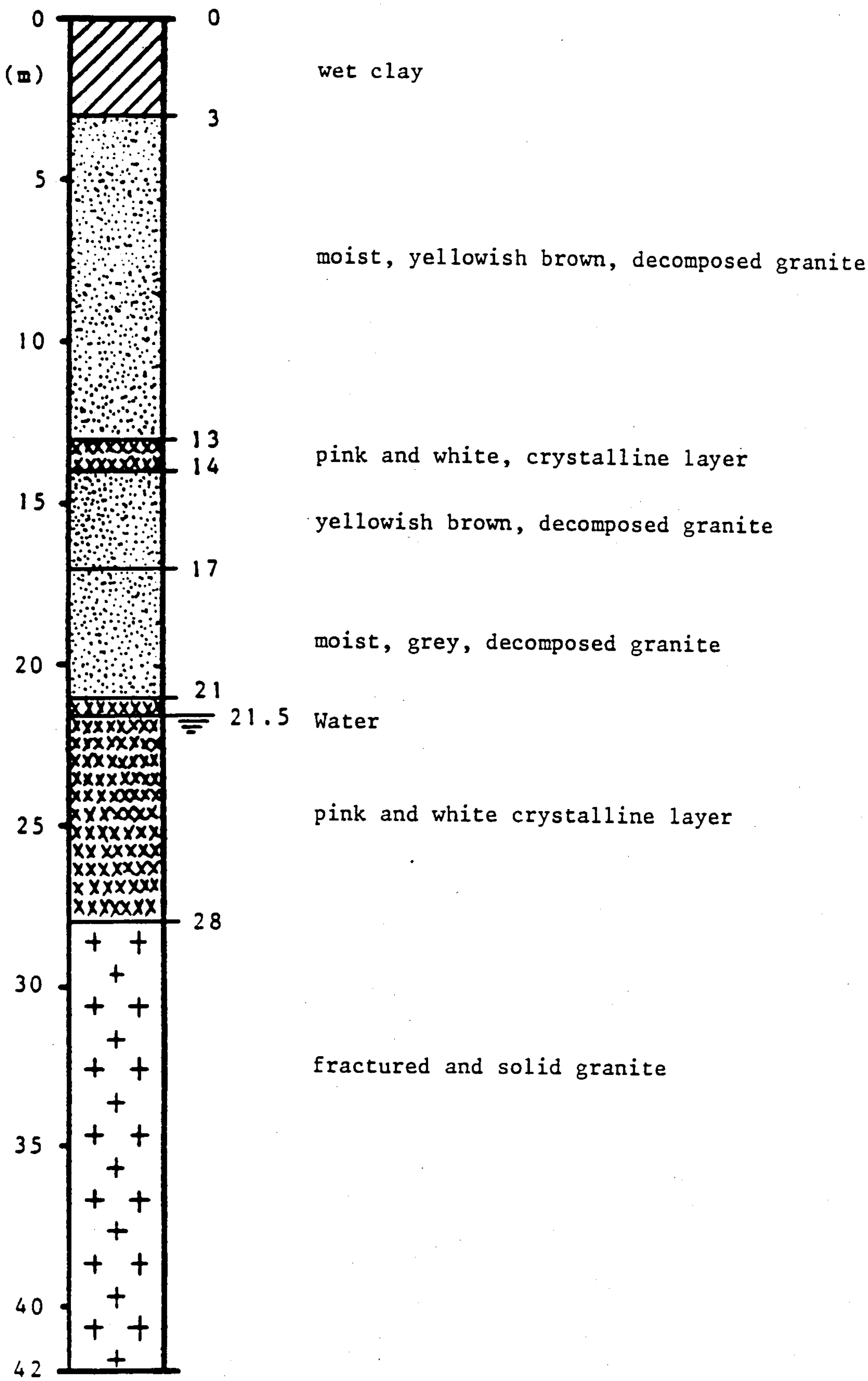
Solid, fresh, hard, pink granite.

Borehole BW7	-	Drilled 11 September, 1986.
	-	Seepage at 10,5m
	-	Water at 17,5m
	-	2m Casing.

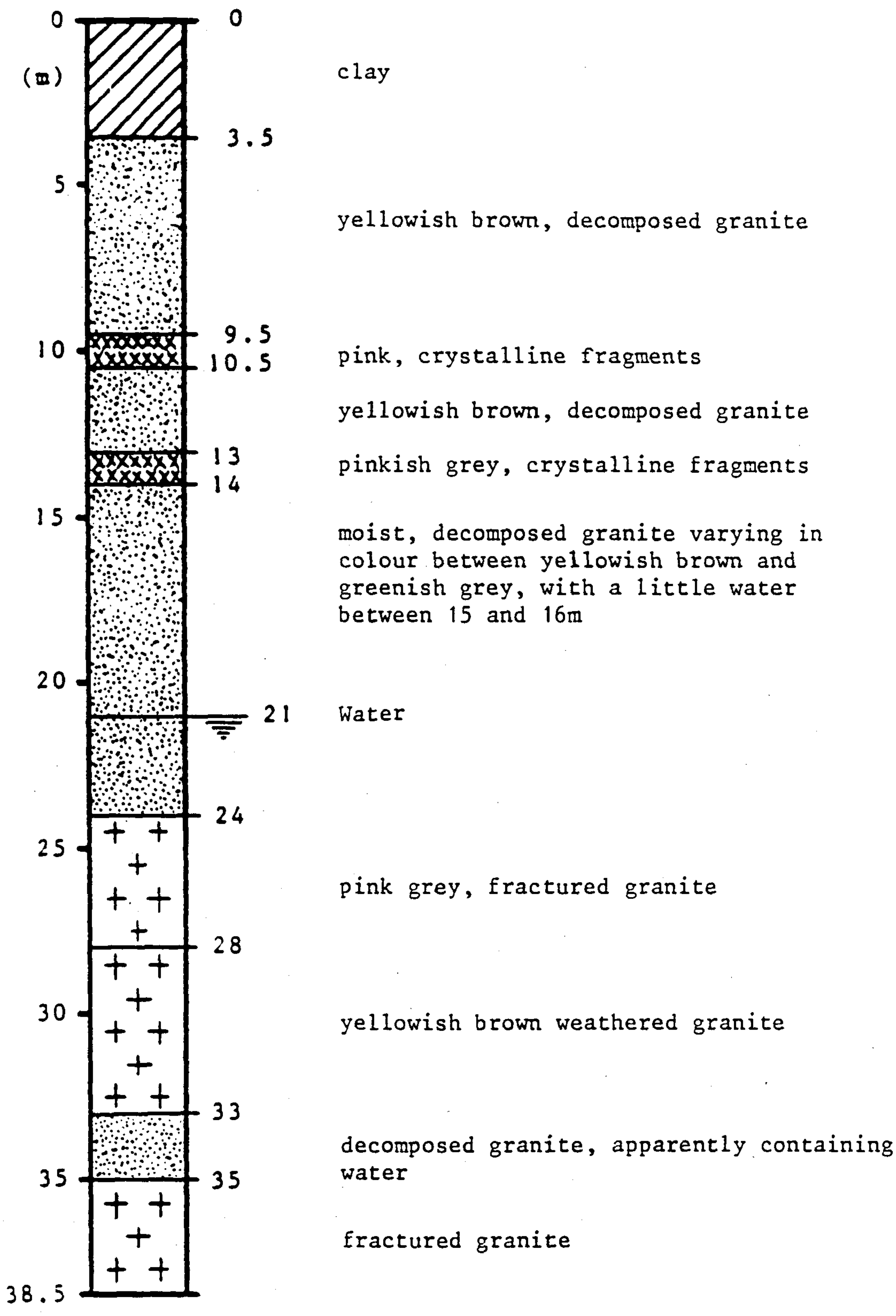


Borehole BS1 - Top Sunninghill catchment

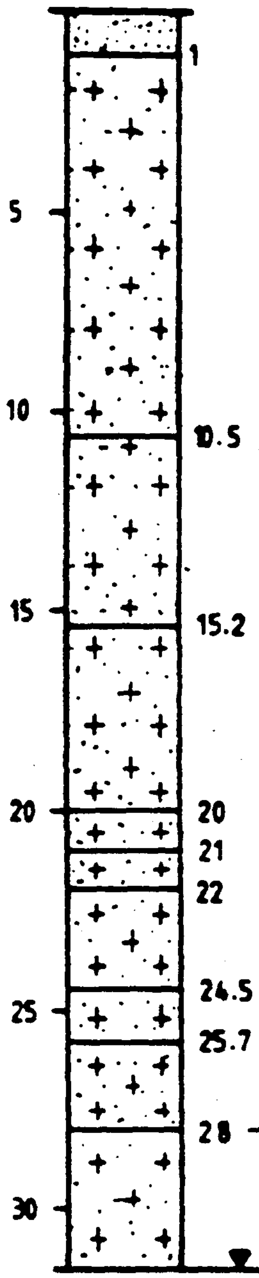
- 6m Casing



Borehole BS2 - bottom Sunninghill catchment
- 6m Casing



Borehole BS3 - Bottom Sunninghill catchment, near road
- 8m Casing



Dry grey/brown coarse sand

Dry light brown to greenish grey decomposed granite.

Dry grey/white decomposed granite with some angular grey particles.

Fresh, solid granite

Broken grey/white angular weathered granite

Grey/brown fine decomposed granite

Grey/green slightly decomposed fine grained granite

Grey/pink fractured weathered quartzitic angular granite particles.

Moist grey weathered granite with pink angular quartzite pebbles.

Water

Dark grey, coarse grained medium decomposed granite with pink angular fractions.

31.5

Borehole BS4 - Drilled 12 September, 1986.
- Seepage at 24.5
- Water at 28m
- 3m Casing