GUIDELINES FOR THE MONITORING AND MANAGEMENT OF GROUNDWATER RESOURCES IN RURAL WATER SUPPLY SCHEMES

R Meyer

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by

R Meyer,
CSIR
Pretoria

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PREFACE

While there has been a general trend towards greater utilisation of local ground water resources, the National priority for meeting basic needs of especially rural communities has resulted in a much greater emphasis on the use of ground water as a water resource. As a result groundwater's role and importance has risen dramatically in the last few years. The Government White Paper on Community Water Supply and Sanitation (1994) has, as one of its main objectives, the provision for every household of a clean, safe water supply of at least 25 litres per person per day within 200 metres walking distance. Ground water, because of its widespread occurrence, albeit in relatively low yields and sometime lower quality standards, is ideally suited for this water supply situation particularly in the less densely populated areas. However, the large scale over-pumping and pollution of ground water in selected areas of the country, emphasizes the overall objective of sustainable development in terms of the Reconstruction and Development Programme (RDP), the improvement of general standards of ground water development practice, and lately also the more controlled form of management of this important resource in South Africa.

This document is based on a research project funded by the Water Research Commission to develop a strategy and guidelines for the management of especially rural ground water resources. Implementation of these guidelines will allow communities to monitor different properties of their ground water resource with the objective to identify at an early stage if the sustainability of the resource is threatened. Implementation and adherence on a wide scale to the guidelines will hopefully bring greater uniformity in the monitoring of ground water on a national scale, which will not only be to the benefit of the community, but also to the authorities in managing the water resources of the country more efficiently.

This document is a first draft submitted to the WRC. The WRC, regional offices of the Department of water Affairs and Forestry, and interested parties are requested to comment on the procedures outlined in the document and to make suggestions and recommendations for its improvement. Once the contents is finalised, it is suggested that DWA&F take ownership of the document and distribute it widely for implementation in mainly rural ground water abstraction schemes. However, its use should not be seen to be restricted to these users of ground water, but is can and should be used widely by for example, farmers, municipalities, industries using ground water for their activities and others with an interest in responsible management of their ground water resources.

A document of this nature can never he final. Users of the guidelines provided in the following pages are requested to comment on their experience in the implementation of the techniques and to make suggestions about how the procedures can or should be changed or improved in order to provide better management of ground water. Comments will he most welcome and should be forwarded to the Water Research Commission.

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1. INTRODUCTION AND PURPOSE OF THE GUIDELINES

The White Paper on Water Supply and Sanitation Policy for South Africa released by the Department of water Affairs and Forestry in 1994, the provision of sustainable water and sanitation services to the entire population of South Africa is identified as a primary goal of the Government. Coupled to this the Department also committed itself to water resource management and that this will receive specific attention. This guideline intends to specifically focus on the management of one of the many water resource management issues, namely that of the ground water resources utilised by many rural communities. However, ideas and principles of ground water management as expressed in this report, can equally well be applied in many other areas where ground water resources are utilised.

Ground water management is often focused on the long term sustainability of the resource in terms of quantity or yield. The White Paper, however, states very clearly that the resource quality measures that will be implemented in the context of the larger scale water management residing in the Catchment Management Agencies (CMAs). In addition to the general guidelines for water management, the White Paper identifies two provisions dealing specifically with ground water. These are that in future all new boreholes will have to be registered and that the development and use of ground water resources must be carried out in the context of an adequate *catchment management plan*, based on an understanding of the sustainable yield of the local ground water resources. Objectives of the Water Services Act, Act 108 of 1997, include monitoring, gathering of information on water resources on a National scale and the management of these resources.

In many of the more remote areas it is unlikely that water reticulation schemes distributing surface water from large impoundments will ever be installed because of low population density (and therefore relative low demand), high cost of implementing such schemes and a lack of surface water sources. In these cases the emphasis will be on the exploitation of ground water resources. Large sections of the country can be regarded as being semi-arid and cyclical droughts are common in some parts of the country.

The more remote areas are often also areas with a low ground water potential, but still relatively high population densities . This coupled with the semi-arid nature of many of these areas and the prevailing cyclical droughts, will lead to increasing demand on ground water as the water resource to cater for an expected increasing demand from the rural population. These are often also areas of low rainfall and where limited recharge to aquifers takes place.

At present, many rural communities rely on ground water as their sole source of supply. In addition, ground water often provides a basis for economic activity in some areas as irrigation water. Water demands of the population in these areas may have to be satisfied by ground water resources which may eventually lead to over-exploitation of the already limited water resources. It is a well established phenomenon that once a community has access to a water supply to meet their basic demands, the demand steadily increases because of higher living standards, increasing irrigation requirements, more and improved sanitation requirements, etc. All of this increases the risk of increasing the demand above the levels of sustainability and natural recharge.

It is unlikely that sophisticated management systems at community level will in future be affordable to be implemented, but nevertheless, some form of voluntary 'control' over the use of ground water resources is required at this level. If over-exploitation of these already limited water resources occurs, irreversible damage can be done to the sustainability of ground water resources in selected areas which will in turn affect the development of the community negatively. All these indicators highlight the importance of proper management of the country's water resources and in particular its valuable ground water resources.

The Department of Water Affairs and Forestry has embarked on a long term national ground water monitoring project. This will include both ground water quality and water level monitoring. However, this programme is primarily focused on background monitoring in aquifer systems that are not necessarily under stress, and does not focus on the smaller user, such as rural communities.

There is therefore a distinct need to manage the ground water resources of the more remote areas through a carefully designed and managed monitoring procedure. With this guideline an attempt is made to put structures in place to perform monitoring at community level, as well as guide the local Water Committee or the Water Service Provider in the basic water management practices by assisting in the design and implementation of an affordable, community driven ground water monitoring and information collection system from which a management scheme will be developed to ensure sustainable water supply to the community over the long term and create a feeling of ownership of the resource. The emphasis is on self management by the community by involving them in the process.

2. THE NEED FOR GROUND WATER MANAGEMENT AND MANAGEMENT GUIDELINES

2.1 What is understood by *"Ground water management"?*

Although ground water is a renewable resource, the availability of it is also influenced by climatic patterns. As with other renewable resources, demand can exceed supply, and therefore some form of control or management of the use of the resource should be in place, to ensure long term access by users. Management does not imply that users are guaranteed to have access to unlimited quantities of the resources at all times, but rather that under normal circumstances, users will be ensured of a specified minimum quantity at all times. It must however, also be realised that South Africa, being located in a region with vastly different rainfall conditions, periods of extreme climatic conditions do occur, and that even with the best intentions, there may be times when even these minimum standards of supply cannot be met.

Four different levels of ground water management exist: regional, national, provincial and local. These guidelines focus on the local or community level, but several of the concepts discussed here apply equally well to the other levels.

Regional, national and provincial ground water management would typically address the management of ground water within southern Africa, and South Africa and provinces in particular, and would address issues like the establishment of regional and national ground water information systems and ground water monitoring networks, aquifer characterization, exchange of information between countries, capacity building and institutional framework and the development of minimum common standards for ground water development and management.

Ground water management at a local scale (community, rural, etc.) scale on the other hand would typically focus on the monitoring of key ground water parameters, and the interpretation of these data, with the aim of guaranteeing a sustainable resource to be used for mainly domestic purposes (small scale and volumes), and limited use in local industries and/or agriculture.

2.2 Why ground water monitoring and management is required

Four primary reasons why ground water should be monitored and managed are identified:

- To prevent the ground water resource (aquifer) from being over-utilised. If an aquifer is over-pumped a long term depletion of the ground water resource can result throughout the entire aquifer.
- To prevent that ground water of a lower quality is drawn into the area of influence of the production/abstraction borehole. If abstraction from a borehole is too high, ground water of a different quality due to for example, contact with different rock types or depositional environments, can be drawn towards the abstraction point.
- To prevent ground water contamination from surface sources such as pit latrines, waste disposal areas, kraals and dipping tanks, or other underground sources.
- To optimise individual borehole pumping rates. If individual borehole pumping rates are too high, a localized depletion of ground water results. Energy is also wasted, since the pumping head is unnecessarily high; and if the water level in the borehole is drawn down to the pump intake, a combination of air and water will be pumped.

The first three items above are not only important with respect to maintaining the water resource for human consumption, but also to protect aquatic ecosystems which could be dependent on ground water sources.

2.3 The need for management guidelines

The primary aim of these guidelines is to ensure a sustainable supply of water to rural communities. This applies specifically to communities who totally rely on ground water as a their water source.

The management of ground water, is unlike surface water, made more difficult mainly because the source is not visible. Other factors which contribute to this situation are that the recharge or "inflow" to the ground water storage volume, cannot be measured directly. The managers of ground water therefore have to rely on the monitoring of a number of parameters from which deductions can be made about not only the immediate availability of the resource, but also to predict the sustainability of the resource for a specified period, typically a few months to a year.

In order to ensure that this information is available to the decision makers, a set of structured information collection and interpretation guidelines should be in place. This will further assist in the establishment of uniform ways of information collection and recoding, and also prevent that unnecessary information is collected.

As it is not always possible for the Water Service Provider or the Department of Water Affairs and Forestry to respond immediately to requests from rural communities when water supply problems are experienced, these guidelines are also intended to allow the Water Committees of communities to recognise early warning signs that problems water quantity and quality may be experienced in the short term. By recognising these signs, precautionary measures can be taken to prevent serious problems, and the Service Provider or other authorities can be made aware of potential problems in future. This will allow more time to plan and institute remedial measures if required.

By allowing the Water Committees to at least do the first level of management of their water resource, will require that the members of the Water Committee and others interested members of the community, to become better educated about ground water. These awareness programmes will serve an educational purpose and will increase the general awareness of the importance of ground water to the community. Ground water awareness programmes are not included in these guidelines and should ideally be developed by geohydrologists with input from social scientists with experience in rural community education programmes.

3. GROUND WATER AS A RESOURCE

3.1 Its occurrence and place in the hydrological cycle

Ground water is often perceived to occur in underground streams and lakes. Although this form of ground water does occasionally occur, it is not he general way in which ground water is found underground. Ground water is in most cases simply filling open spaces between sand or rock grains and in fractures and fissures in rocks. These openings or pores in rocks are more frequently found at shallower depths and therefore ground water exploitation is predominantly from the upper approximately 100 m of the earth's surface. The ratio of open space to the total volume of a rock, is referred to as the porosity. The porosity determines the amount of water that can be stored underground. Where these openings have formed simultaneously with the deposition, these pores are termed primary openings or primary porosity. In unconsolidated sand and gravel deposits, the porosity can be as high as 40% in selective cases. When these deposits are buried, the pores are reduced in size due to the compaction by the weight of the overlying layers and through cementation with elements dissolved in water percolating through these pores, and the primary porosity is reduced and can at times be completely destroyed. At a later stage in the geological history these rocks are often subjected to forces within the earth, resulting in fractures and fissures forming in these rocks. Openings formed in this way can also store ground water, and are referred to as secondary porosity. In South Africa, more than 80% of our ground water resources occur in fractured rocks.

Ground water is usually in motion, flowing under the force of gravity to lower areas where it may discharge as a spring, or to a stream or to the ocean. If water is to move freely through a rock, openings (pores) must be interconnected, and must be large enough that wall friction does not greatly impede the flow. When water can move through a rock, the rock is said to be permeable. The rate of flow is determined by the hydraulic gradient and the ease by which water can move (referred to as the permeability) through the pores and other openings in the rock. Generally this rate of flow is expressed in metres per year.

The water filled opening underground constitute a "reservoir" of water referred to as an aquifer. Aquifers often have natural boundaries, and specific recharge and discharge areas.

3.2 Recharge

The predominant source of ground water is rain water percolating into the ground. Other sources are streams, snow and water stored in large reservoirs at surface. Some of the water infiltrating is consumed by plants, some evaporates from the upper soil layers, a small percentage is held onto the soil grains by capillary forces, and the surplus percolates downward and reaches the zone where all pores are saturated with water. This upper level of water formed by the saturated pores, is referred to as the water able. Below this level all pores are filled with water.

Ground water is that fraction of precipitation or snow that reaches the zone of saturation after seeping through the soil or through stream beds. This amount of water is referred to as the ground water recharge (or replenishment). In South Africa the amount of recharge typically is less than 15% of annual rainfall. Ground water recharge is part of the hydrological cycle illustrated in **Figure 1**.

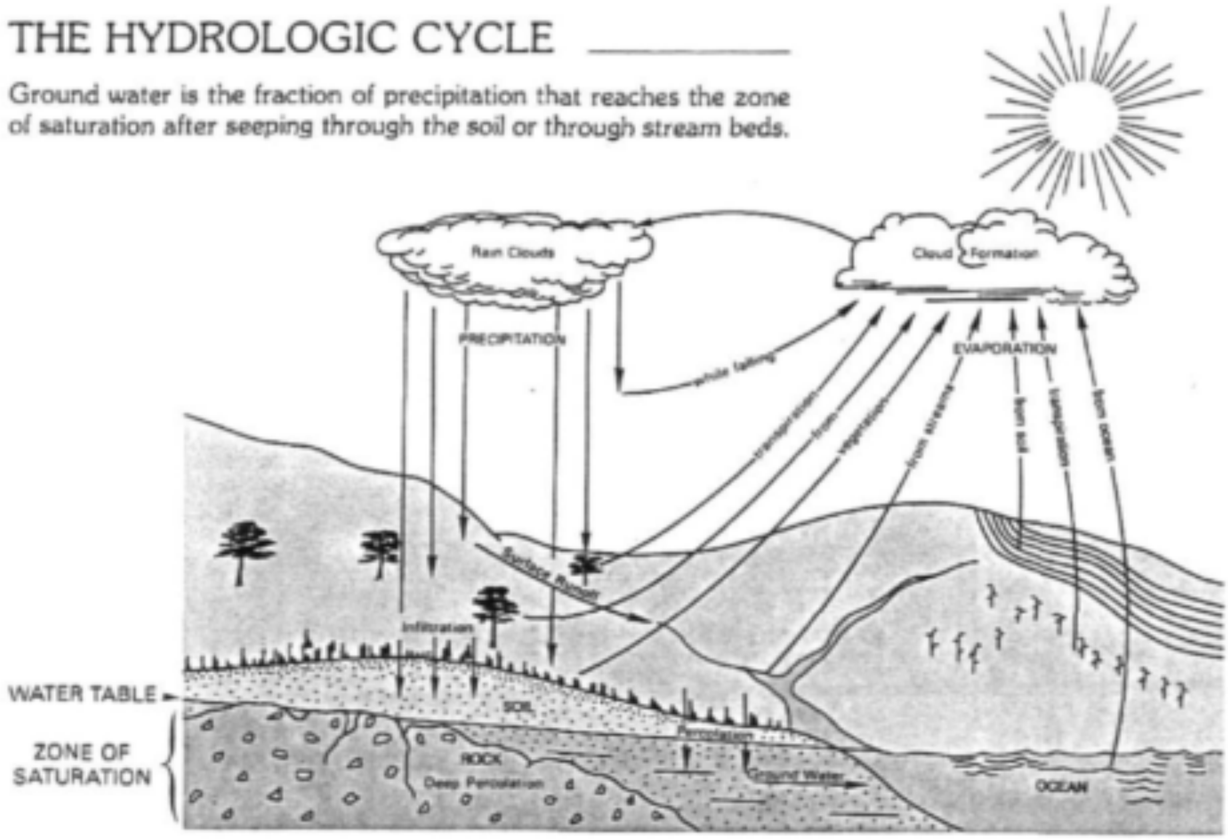

Figure1: The hydrological cycle (from American Institute of Professional Geologists publication: Ground water, issues and answers, 1985).

3.3 *The use of ground water*

Ground water resources are exploited all over South Africa. The strategic importance of the resource is controlled predominantly by the availability of water supplied from surface water resources. It is therefore clear that in the more arid areas of the country, such as parts of the Northern Cape Province, the Karoo and Northwest Province, and areas which are difficult to be service by surface water supply schemes (including many rural communities and farmers), ground water has a vital role to play in terms of water supply for domestic, industrial and agricultural purposes. As ground water is often the only available source of water in these regions, responsible management of the resource is required.

The most common way of abstracting ground water is by installing pumps into boreholes. Another common way of harvesting ground water is by collecting water seeping from springs, which occur where the ground water level reaches the ground surface.

3.4 Ground water quality, contamination and protection

Ground water nearly always contains more mineral matter than nearby surface water, although they both originate from precipitation. The reason for this is that water passing through the soil dissolves large amounts of carbon dioxide formed by soil bacteria, thereby producing a weak carbonic acid solution. Where soluble chloride and sulphate compounds are present, as in arid climates, they are also dissolved in the infiltrating water. Ground water quality various significantly across the country and is largely controlled by the geological conditions.

Contamination is a serious threat to our ground water resources in South Africa. Because of the often strategic nature of these resources, ground water should be protected from any forms of contamination. Typical sources of contamination are large industrial concerns such as found in the chemical industry, mining, pit latrines, waste disposal sites, cattle kraals, and the uncontrolled dumping of waste in the country side.

Protection from contamination is a very important phase of ground water management; as a ground water source which becomes polluted, is in most cases extremely difficult (and sometimes virtually impossible) to restore to its original quality. Protection from pollution is therefore done at best at the source of the pollution, through for example the reduction in the production of waste, the proper disposal of waste in designated and well designed waste disposal areas far removed from aquifers of which the water is used for domestic and agricultural purposes, restricting the uncontrolled release of contaminated effluent into streams and onto land surfaces, etc.

3.5 Management

It should be clear from the above discussion that the amount of ground water available will differ according to the geological conditions. Further it should be well understood that ground water is not available in unlimited quantities and depends greatly on rainfall patterns and intensities. Droughts therefore do not only affect surface water conditions negatively, but also the ground water resources. In the interest of the many users of ground water in the country, the uncontrolled use of ground water and disposal of waste and waste water, should therefore not be allowed. Managing the use of ground water resources therefore becomes very important, especially where it is the only readily available source of water.

Management of ground water basically consists of two components: managing the quantities and quality of ground water. These guidelines attempt to address these two aspects of ground water management as they apply to the use of ground water mainly for domestic purposes and on a limited scale for industrial and agricultural development in rural communities.

3.6 Ground water as a renewable water resource for rural water supply

There are many areas in South Africa where it would be impractical to develop water supply schemes using only surface water. Reasons for this include the high cost of the infrastructure to supply relatively small volumes of water over large distances (economy of scale and low population densities), the lack of surface water in certain regions of the country and high maintenance costs. In the majority of these cases ground water resources provide the only alternative to this situation. These conditions often apply to rural communities. As was stated before, the availability of ground water in unlimited quantities and of acceptable quality everywhere in the country, cannot be guaranteed. However, ground water is not to be regarded as being of a lower standard as surface water. It must be stressed that ground water resources, especially those in the more remote areas of the country are largely unpolluted and the availability and quality (salt content) is the result of natural processes only. Where certain elements are present in concentrations above those that are recommended for domestic use, treatment of the water to an acceptable level, can be achieved at reasonable costs.

4. STRATEGY FOR GROUND WATER MANAGEMENT

4.1 What should be monitored, how and at what frequency?

Structures are to be in place within the communities to regularly monitor the following parameters:

- water level depth
- volume of water abstracted from each borehole;
- rainfall;
- water quality;
- water consumption, and
- borehole pump operating schedules.

4.1.1 Water level depth

The water level of an aquifer fluctuates as a result of natural conditions and a due to the abstraction of water from it. These fluctuation can be compared to the changes observed in surface water dams, where levels will rise due to the inflow of water from rivers after heavy rains, and will decline when the use and evaporation of water exceeds that of the inflow. In this case the management of the water resource or volume of water, is done by carefully observing the water level in the dam. A decline in the water level can be allowed to proceed to certain predetermined levels, before control measures of varying degree are implemented. By monitoring the ground water levels over time, exactly the same result is achieved. By measuring the fluctuations of ground water levels, different management options can be implemented.

Monitoring of water levels and water consumption depends on the borehole construction and pumping equipment installed in the borehole. However, what is important is that the measuring technique is easy to use, mechanically sound, tamper proof, easy to install and does not require sophisticated technology to capture the water level data (for example pressure transducers that record automatically at predetermined intervals and store the data electronically for downloading later). Target accuracy for water level measurement is 10 mm. Both these parameters should preferably be measured and recorded at least weekly, but local conditions may dictate that more frequent measurements are required.

Various methods are available for the measurement of water levels in boreholes. Reasonably low cost measuring tapes equipped with an electric contact mechanism activated when in contact with water, are commonly available in South Africa and are the preferred way of measuring water levels for rural ground water management purposes.

4.1.2 Volume abstracted and consumed

The installation of in-line water flow meters is not common practice on most existing water supply boreholes. This would be the preferred and recommended way of recording the volumes of water pumped on a daily basis. The installation of an in-line flow meter should be compulsory when new production boreholes are installed and equipped. Lacking these facilities, at least monthly, but preferably weekly, tests should be made of the pumping yield at each abstraction borehole. This should be done by using a container of fixed volume (25 or 200 litre drums for example) and recording the time required to fill this container of known volume. A prerequisite for this method of measurement is that a valve system is installed at the well head enabling the diversion of the water to the measuring facility. Target accuracy for volumes of water abstracted should be set at less than 5% of the daily volume pumped.

In many community water supply schemes water is pumped from the borehole to some form of reservoir from where water is distributed in a reticulation system throughout the village. These reservoirs are often far away from the production borehole and not visible. Pumping from the borehole is seldom controlled by the water level in the reservoir, with the result that reservoirs are often overflowing and water is wasted in this way. It would therefore also be advantageous to monitor the consumption of water from the reservoir by installing an in-line flow meter at the outlet pipe.

By measuring both the borehole abstraction and consumption volumes, efficiency and cost effectiveness of the pumping operation can be optimised.

It is recommended that borehole yield and water consumption should be measured and recorded on a weekly basis.

4.1.3 Rainfall

The importance of rainfall in supplying the recharge to the aquifer was discussed earlier. The monitoring of rainfall therefore constitutes an important component of ground water management. Low cost rain gauges are to be installed at all boreholes used for community water supply. Where boreholes are close to each other, fewer rain gauges will be sufficient. Rainfall is to be recorded on a daily basis. If the data collection process is likely to be unreliable, then a cumulative rainfall sampler as the one described by Murray and Dindar (1998) could be used. The cumulative rainfall sampler has a dual purpose in that it can be used to measure rainfall volume as well as to collect a composite rainfall sample. The storage capacity of the sampler is large enough to hold an entire year=s rainfall. This allows rainfall measurements to be taken over an extended period without the risk of losing data. The rain gauge/sampler is designed to keep out insects and other organic matter. This ensures that the sample is not organically contaminated and can be used for the determination of chloride concentration in rainfall or for selective isotope analyses. The advantage of this, with respect to ground water management, is that groundwater recharge estimates can be obtained using these data.

4.1.4 Water quality

Water quality testing should be compulsory for every borehole used for the supply of potable water to a community. Ground water quality in general does not change over short periods of time and therefore a high frequency of extensive chemical testing is not usually required. What is, however, of greater importance is the bacteriological contents of the water. Bacteriological contamination of drinking water can have serious health implications for the users. Samples for bacteriological analysis need to be taken more regularly and submitted for routine microbiological tests. It is recommended that water samples be taken and analysed for their chemical composition and bacteriological contents according to the protocol listed in **Table 1**.

Table 1: Analytical requirements

Sampling point		Frequency	Test/analyse for
Well head tap	**Storage tank/Reservoir**		
Y	Y	Weekly	Electrical conductivity (EC)
Y		Quarterly	EC, pH, NO_3, Cl, Na, Ca, K, Mg, F, COD
	Y	Annually	Abbreviated SABS 241-1999 specification (includes microbiological and chemical analyses)
	Y	Bi-monthly	Microbiological (*E. coli*,, Total plate count, total coliforms)

A range of commercially available products and test kits to detect indicator organisms in drinking water have been evaluated for possible use by communities. These include self-contained membrane filtration test devices and DST (Defined Substrate Methodology) based methods (Millipore, undated; Genthe and Du Preez, 1996). It would appear that none of these use too sophisticated instrumentation that could not be acquired and operated by a community.

4.1.5 Borehole pump operating schedules

Where boreholes are not equipped with in-line flow meters, it is important that accurate pump operating schedules are kept. The switch-on and switch-off times are to be recorded daily, and together with the weekly borehole yield measurement, the volume of water pumped from each borehole daily can be calculated.

4.2 Recording of monitoring information

Information recording protocols for the recording of daily or weekly water levels (before pump switch-on and at pump switch-off), daily switch-on and switch-off time, daily volume pumped and water quality where appropriate, are supplied to each pump operator according to the example in Appendix A. Instructions on the recording of data on these sheets is to be given to each operator and constant checks should be made to ensure correct measurements are taken and that these are recorded accurately on the data sheets.

4.3 Data recording

Data recording protocols for the recording of weekly water levels (before pump switch on and at pump switch off), daily switch and switch off time, daily volume pumped and water quality where appropriate, are supplied to each pump operator according to the examples provided in Appendix A. Instructions on the recording of data on these sheets is to be given to each operator and constant checks should be made to ensure correct measurements are taken and that these are recorded accurately on the data sheets.

5. PRESENTATION AND ANALYSIS OF MONITORING DATA

5.1 Data presentation techniques

Where in the case of a surface water impoundment structure, the water holding capacity is well known, it is not as easy to determine this in the case of ground water. The degree to which the level can be allowed to drop, also effects the economics of the water supply scheme as it may be come uneconomical to pump from great depths.

Perhaps the most important issue that needs to be attended to in the development of a ground water management system for a rural community, is displaying the ground water, rainfall, abstraction and water consumption levels in such a way that the community can easily understand it. It is clear that some form of process control methodology should be included in the analysis of data, whether it be rainfall, water levels or consumption.

In **Figure 2** a process control chart, which is essentially a plot of data over time, is illustrated by using water level information as an example. The basic principle behind these charts is the continued assessment of data describing some process, to monitor when the process goes "out of control". This methodology can be transferred to ground water management, by applying it to the assessment of data representing for example, the ground water level, rainfall, quality or consumption of water from an aquifer.

Using historical data, two control limits are set up for the data representing the system. These are the Upper Control Limit (UCL) and Lower Control Limit (LCL). The control chart then allows the user to not only monitor when a system actually goes out of control (by moving outside the predefined limits), but also when it moves alarmingly close to the limits (thus providing an early-warning system).

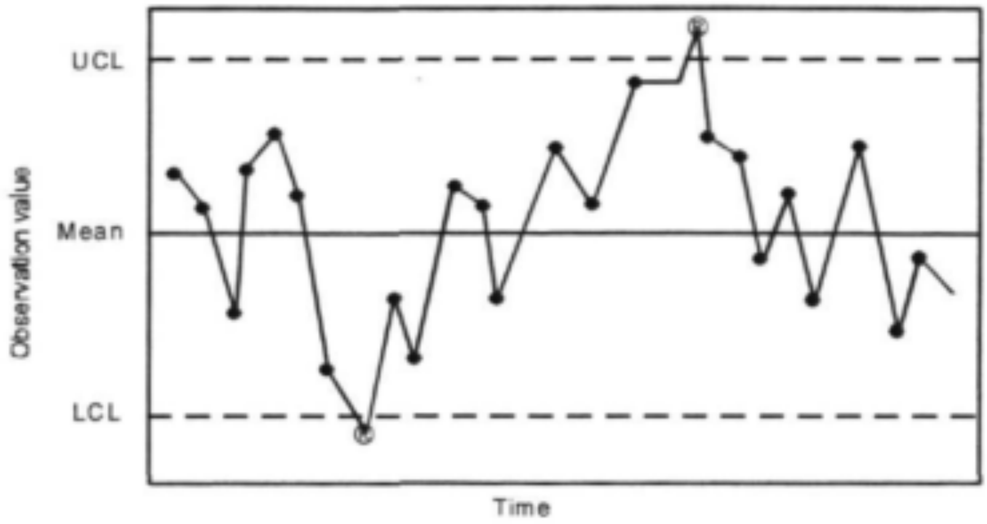

Figure 2: Water level fluctuation over time to illustrate the process control concept. In this example two observations which fall outside the control limits (UCL: upper control limit and LCL: lower control limit), thus indicating "out of control" states at these times.

Another possible method involves analyzing the general trends in the ground water level and borehole yield to provide information for the management of the system. In particular, the relation between the slope and water level slope (**Figure 3**) can be used effectively in ground water management.

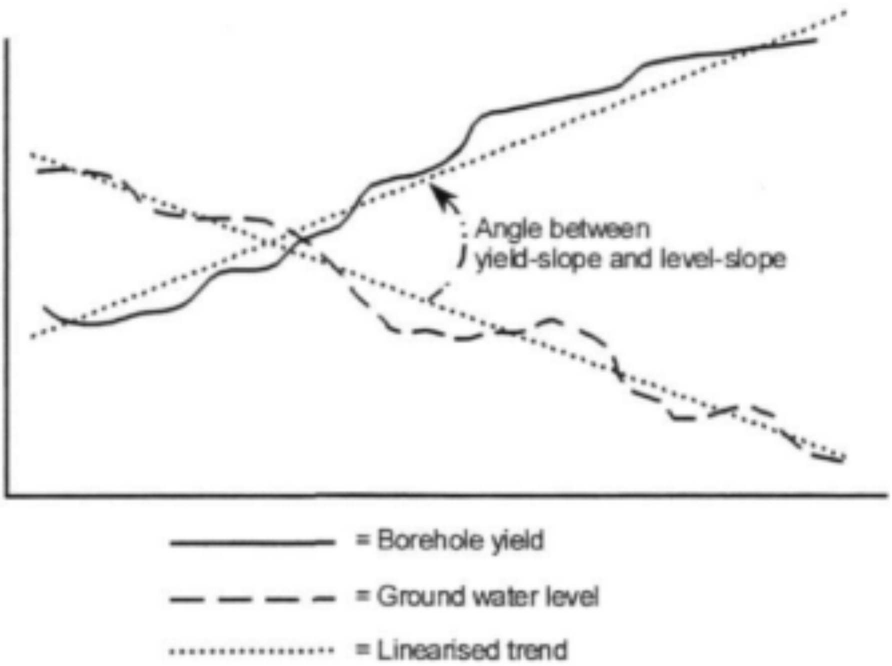

Figure 3: Graph illustrating the angle between trend in borehole yield and the trend in ground water level.

5.2 Ground water levels

From a scientific point of view, the obvious means of displaying ground water level information would be using a graph, with the months represented on the horizontal axis, and the water level on the vertical axis. Such a graph, initially containing only the long term average reference water level, can be prepared in the beginning of the year by the Village Water Committee and displayed in a public place, for example the Community Centre. Every month the actual water level measured for that month can be added to the graph, so that everyone can see what the state of their ground water resource is compared to the average of previous years.

A possible extension to the basic graph-concept would be to divide the area above and below the graph into a number of separate zones, representing different "warning levels". This is similar to the previously referred to process control methodology. The zone directly around the line representing the average reference water level can for instance be coloured yellow (indicating caution), while the area above the yellow zone can be coloured green (indicating a safe state), and the area below the yellow zone can be coloured red (indicating real danger). This is shown in **Figure 4**.

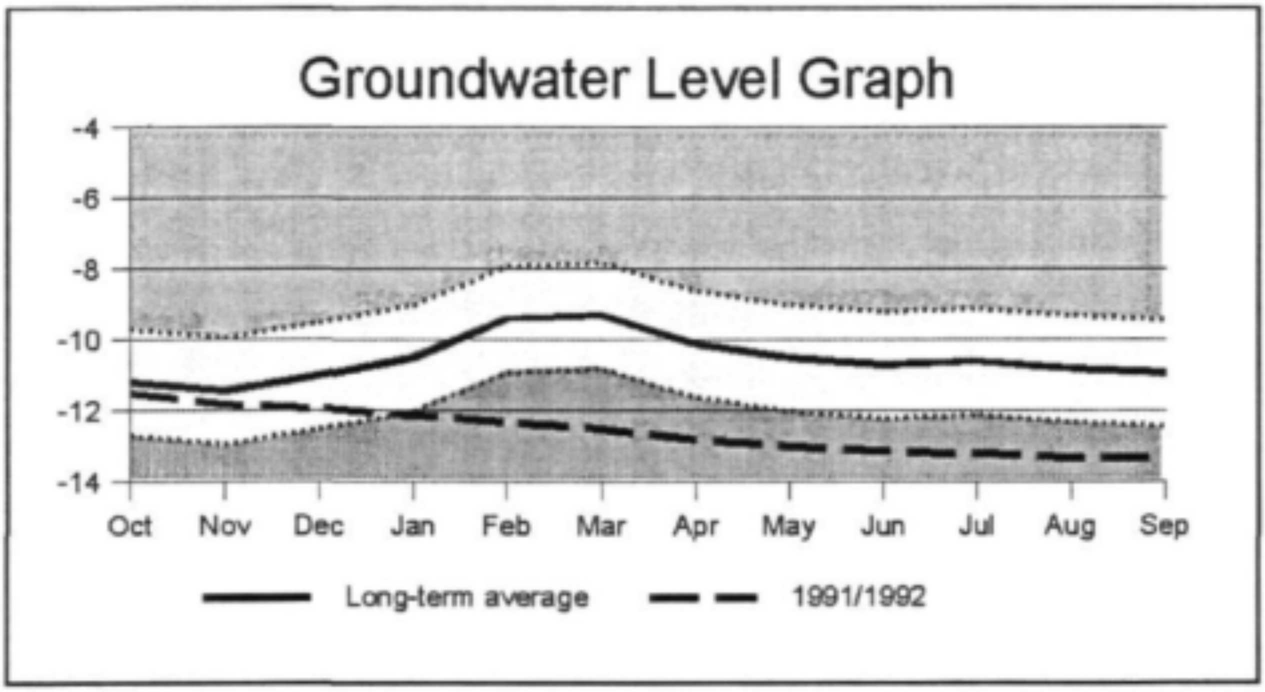

Figure 4: Ground water level graph, showing the long-term average water level together with the ground water level for a specific year to indicate the condition of the resource compared to the average.

If the new value for a current month is plotted, this new point will then be in either the green, the yellow or the red portion of the graph. It can then be explained to the community that as long as they remain in the green zone, they have adequate water available, and have nothing to be concerned about. If they are in the yellow band, things are still going reasonably well, and while there is no reason to panic, they have to ensure that they don't increase their water consumption drastically. If, however, they find that they are moving into the red section of the graph, they should realize that they may potentially have a serious problem at hand with their water resource. If this happens, they should therefore do their best to use less water wherever possible, to try and conserve their ground water resource. If they do manage to use less water than usual, the situation should not worsen too quickly, and if substantial rains occur, they should find that within a few months the water level indicator should move back into the yellow zone.

Using the colour zone system described above should help in making the community understand what is happening in the ground water system. In this way they only need to see if the water level is in the green, yellow or red area, and thereby understand whether they have a ground water problem or not.

5.3 Rainfall

The importance of rainfall as being the main source of ground water recharge has been explained earlier. It is clear that using only water level as a means of measuring the condition of the ground water resource may not be representative enough of the actual situation. There may for example be times where the rainfall is much lower than average, but that this low rainfall period has not yet been reflected by the water level record. In such a case, the water level graph may indicate a situation of no concern, and there is no need for water conservation measures. However, by continuing to use water according to the normal pattern, consumption exceeds recharge. This low recharge condition will only show on the water levels graphs a few months later.

A similar problem can occur if the water level is very low (i.e. in the red zone) while good rainfall has occurred. The ground water graph may then indicate that there is a water shortage, while the real situation may simply be that the recent rain fall has not yet had a chance to impact on the water levels. For these reasons, it is crucial that rainfall figures are also taken into account in the community-level ground water management system. When incorporating rainfall into the system, it should be kept in mind, that the envisaged ground water management system ideally *has to be run by the rural community themselves,* which requires that the message has to be conveyed to the community in an easily understandable manner.

A possible way of incorporating rainfall into the system, without significantly increasing its complexity, would be to simply add some rainfall level display mechanism to the water level display discussed earlier (without attempting to incorporate any complex interaction between rainfall and ground water level in the system). This rainfall level display should in some way indicate to the community whether the rainfall in their catchment area is above or below average. One way of doing this would be to use a graph similar to the ground water graph, where the current monthly rainfall figures are plotted against the long term average monthly rainfall figures. Unlike the ground water levels, however, rainfall figures can be highly variable, meaning that for a specific month the rainfall may be far below average, while the next month's rainfall may far exceed the average. For this reason it would be very difficult for the community to see how the rainfall for the season, or for the year to date, compares to the average. Such a graph would therefore not be very useful.

A better way of displaying rainfall figures would be by using cumulative rainfall. In a cumulative rainfall graph, the rainfall for each new month will be added to the total for the year up to that point, and this cumulative sum will be plotted for each month. Similarly, a cumulative graph for the long term average rainfall can also be plotted. A comparison between the rainfall of the current year and the average rainfall of previous years then becomes much clearer. In a cumulative graph the user simply has to see which graph is the "highest". If the cumulative rainfall graph for the current year lies above the cumulative average rainfall graph, it means that more rain than average has fallen to date for the current year, and visa versa. **Figure 5** is an example of a cumulative rainfall graph for a rainfall station in the Northern Province. In this figure it is clear that the 1991/92 rain fall indicates a drought condition when compared to the average cumulative rainfall trend as the cumulative rainfall was for the first 7 months of the season below the cumulative minimum, and only during the last 5 months reached the cumulative minimum.

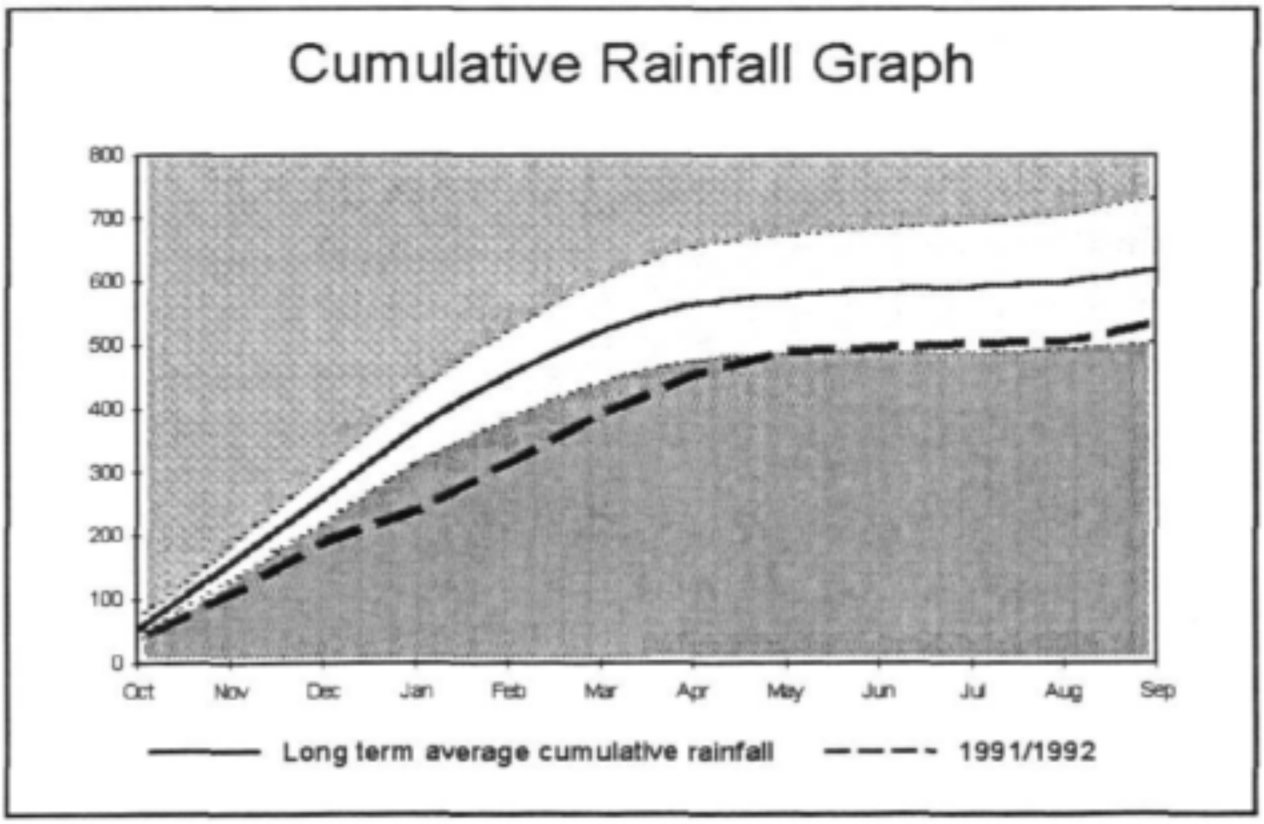

Figure 5: Cumulative average monthly rainfall for the Nebo District, Northern Province.

5.4 Water abstraction/consumption

It was indicated earlier that ideally both water abstraction from a borehole, and the water consumption of the community should be monitored. As in the case of ground water levels and rainfall, water abstraction from a borehole and the consumption figures can be also be displayed best by means of a graph. However, the important factor is not so much the comparison of current water abstraction/consumption figures with historical trends, but rather this graph should be an indicator of the community's response to the message displayed by the ground water level and rainfall indicators. If the ground water resource is managed successfully, the water consumption graph should be an indicator of the community's response to these indicators. In this case the water consumption graph should mimic ground water level graph, i.e. it should decrease when water levels start dropping, and increase again when the water level returns to a "safe" level. The water abstraction/consumption is also expected to show a seasonal variation, due to changing needs during different seasons. Abstraction/consumption can also be illustrated by means of cumulative graphs (**Figure 6**).

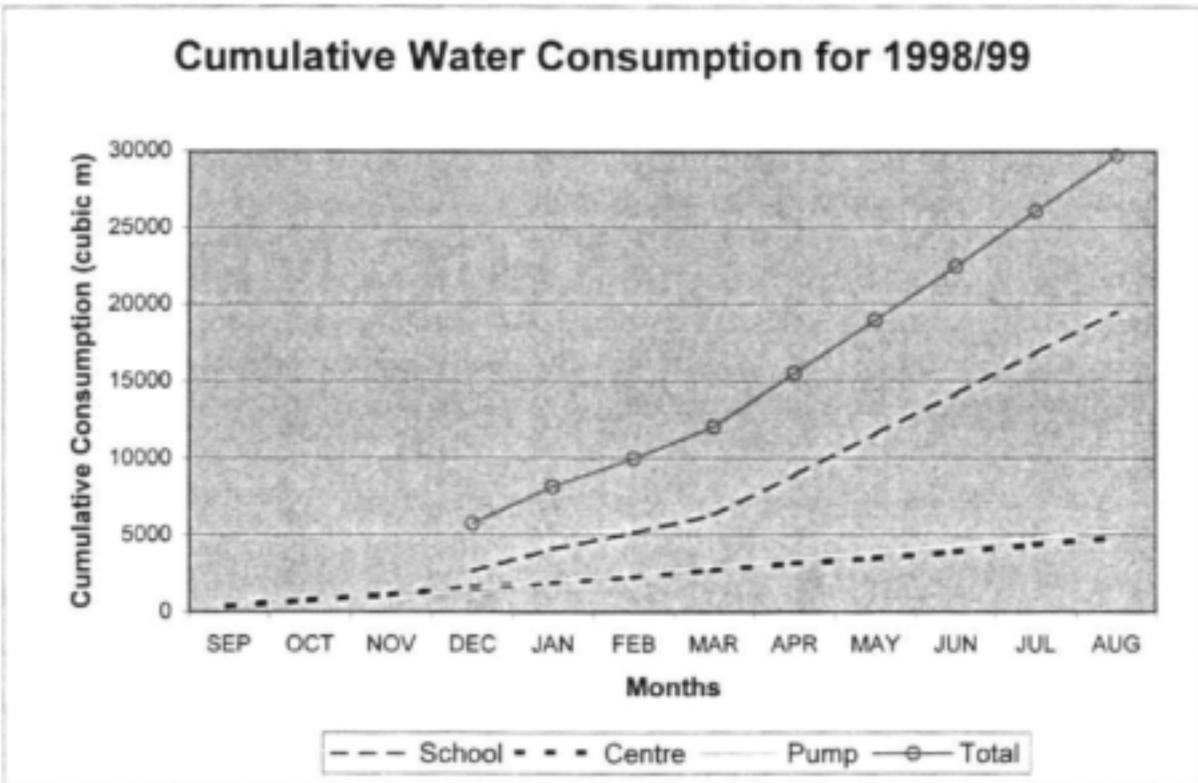

Figure 6: Cumulative water consumption at the three monitoring boreholes.

To determine the volume of wasted water, a graph of the difference between pumped volumes (as recorded by the in-line flow meter at the pump) and the volume of water consumed (as recorded by the in-line flow meter at the reservoir outlet) should be constructed. The target level for this graph should be a horizontal line at a y-axis level of 0. A horizontal line at y=0 may also mean that demand exceeds supply.

6. MANAGING QUANTITY AND QUALITY

6.1 Starting a monitoring and management programme

The borehole and rainfall monitoring and consumption information displayed in **Figures 4 to 6** forms the basis to decide whether any management actions are required. The management techniques described in this document, are based on knowing at least some historical information of how water level conditions and rainfall patterns have changed with time. However, at the start of a management programme, it is unlikely that this information will be available for the particular borehole(s) where the management actions are required. It is therefore recommended that the rainfall record(s) of a nearby rainfall recording station(s) be used to construct the graph indicating the cumulative monthly minimum, average and maximum rainfall. The longer the period for which rainfall information is available the better. To determine the zones on either side of the average required for deciding whether some form of management is required, a value of one standard deviation around the mean is added or subtracted from the monthly average values.

A similar technique should be used to construct the initial water level fluctuation graph with time. It may, however, be more difficult to obtain the necessary information to do this as historical records and the density of monitoring stations in South Africa are rather limited. As in the case of the rainfall records, it is recommended that the closest water level monitoring stations are used for this purpose. These should preferably be located on the same geological formations as the borehole(s) where management is required.

The next step in the programme is to ensure that the ground water abstraction system that supplies a community with water (typically one to three boreholes), is properly equipped for monitoring. The minimum requirements are access to each borehole to measure the water level, and an in-line flow meters to record the volumes pumped. As alternative to an in-line flow meter, a take-off point with the necessary valves is required to measure the yield of the borehole from time to time. In addition the storage reservoir(s) should also be equipped with in-line flow meters to record water consumption.

6.2 Monitoring actions

It will be the task of the Village Water Committee, or in cases where these are not functional, the Water Service Provider, to nominate or appoint a person to be in charge of the monitoring. The logical choice would be the pump operator. He will have to be trained in the measurement and recording of water levels, volume of water abstracted, rainfall, water consumption, electrical conductivity of the water, and the collection of samples for chemical and microbiological analyses. Monitoring information to be recorded on the forms provided in **Appendix A** of this document. The frequency at which the different monitoring actions are to be done, are shown in **Table 2** below.

Table 2: Monitoring requirements

		Frequency	Monitoring point	Recording units	Recording accuracy
Water level		Weekly	Borehole	metre (m)	m
Abstraction rate		Weekly	Borehole	cubic metre (m^3)	m^3
Consumption		Weekly	Reservoir	cubic metre (m^3)	m^3
Rainfall		Daily	Borehole	millimetre (mm)	millimetre
Electrical conductivity		Weekly	Borehole	milliSiemens/metre (mS/m)	1 mS/m
Time pumped		Daily	Borehole	hours (hr)	hour
Water quality sampling	Chemical	Quarterly	Borehole & reservoir	mg/l	Variable
	Microbiological	Quarterly	Borehole & reservoir	counts/100 ml	Variable

Monitoring of the water level is to be done before the pump is activated (this is referred to as the static water level) and again just before the pump is shut down. In both cases the pump switch on and switch off time is to be recorded. It is recommended that borehole yield and water consumption rates are measured on the same day. It is also good practice to always do the measurements on the same day of the week. It is further recommended that the weekly static water level (before pump switch on) be measured after, according to the weekly pumping schedule, the longest period of no pumping has occurred. For example, if no pumping is done on Saturdays and Sundays, it is recommended that the static water level is measured on Monday morning just before the pump is switched on. This will allow the water level to return to its true rest level.

Rainfall is also to be recorded at the same time every day, preferably at say 08h00 every morning.

6.3 Displaying the monitoring information

It is proposed that the water level and rainfall monitoring information is displayed in two different ways:

(i) Both water level and cumulative rainfall can be plotted according to the method explained in Section 5 (**Figures 4 and 5** respectively) where these parameters are plotted and compared to the long term average and within the maximum and minimum allowable fluctuations (provided these are already available). In **Figure 7** an example from the Northern Province is shown illustrating the cumulative rainfall as measured at an abstraction borehole.

(ii) When the water levels measured before switch on and shortly before pump switch off, as well as the difference between the two values, are plotted against time, the three lines (water level before switch on, water level before switch off, and difference between the two levels) should ideally remain horizontal. As an example of this way of displaying the water level information from measurements on a borehole in the Northern Province used for community water supply is shown in **Figure 8** below.

7. INTERPRETING THE MONITORING INFORMATION (WITH EXAMPLES)

Whether graphs or any other type of display are used to indicate the current ground water and rainfall status of a particular catchment area, it is still required to determine where the cut-off points between the different "safety zones", i.e. the red, yellow and green zones, should be. These zones are used to indicate to the community whether they are in a safe situation as far as their ground water resources are concerned, or if there is need for alarm. Once these levels have been selected, and are used as management guidelines, these will have an influence the community's water consumption, and therefore it is important that they are chosen with care. On the one hand, the community should not be lulled into a false sense of security, but at the same time the zones should not warn the users of impending danger if this is clearly not the case.

Ideally, the calibration of the different zones should be based on the following information:

- the size of the catchment area;
- the historical water consumption patterns in the community;
- the historical ground water levels in the area; and
- the historical rainfall figures in the area.

This information is, however, unlikely to be available in all cases where the guidelines have to be established, and therefore assistance in defining the boundaries of the "safety" zones should be obtained. It is recommended that the Directorate Geohydrology of DWA&F should be approached for this information.

Historical records of the water level fluctuations and rainfall are the most likes ones to be available. Calibration of the range of the "safety" zones will therefore in most cases be based on the standard deviations in the long term behaviour of these two parameters. In the case of the ground water level graph, the different zones are determined by the monthly average water levels, and the standard deviation of the annual ground water level. The size of the different zones are therefore kept constant for every month (as shown in **Figures 4 and 6**). The following rules can be used to determine the boundaries for the different colour zones.

Below (Ave - Std dev):	*Red zone*
Between (Ave - Std dev.) and (Ave - Std dev/2):	*Changing from red to* [illegible]
Between (Ave - Std dev/2) and (Ave + Std dev/2):	[illegible]
Between (Ave + Std dev/2) and (Ave + Std dev):	*Changing from* [illegible] *to green*
Above (Ave + Std dev):	Green zone

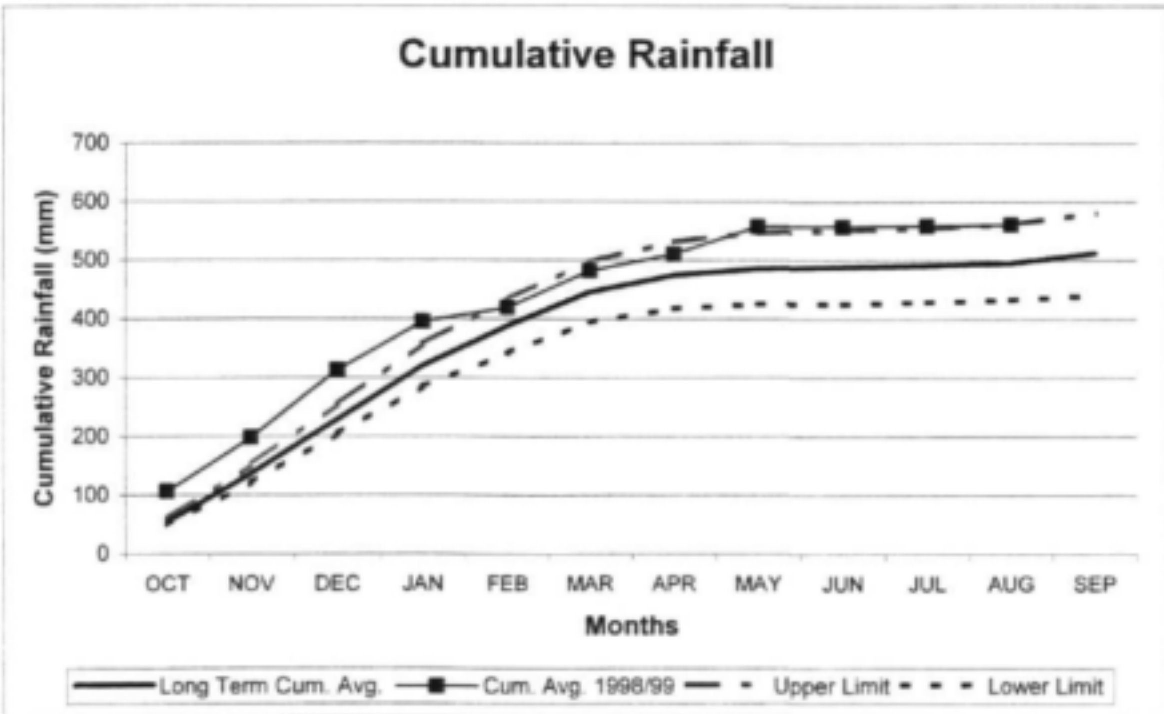

Figure 7: Cumulative average monthly rainfall for the Nebo district.

In the case of the long term rainfall, the situation is more complex. Since use is made of cumulative rainfall, the bounds on the different zones have to widen as the year progresses, to allow for the cumulative effect.

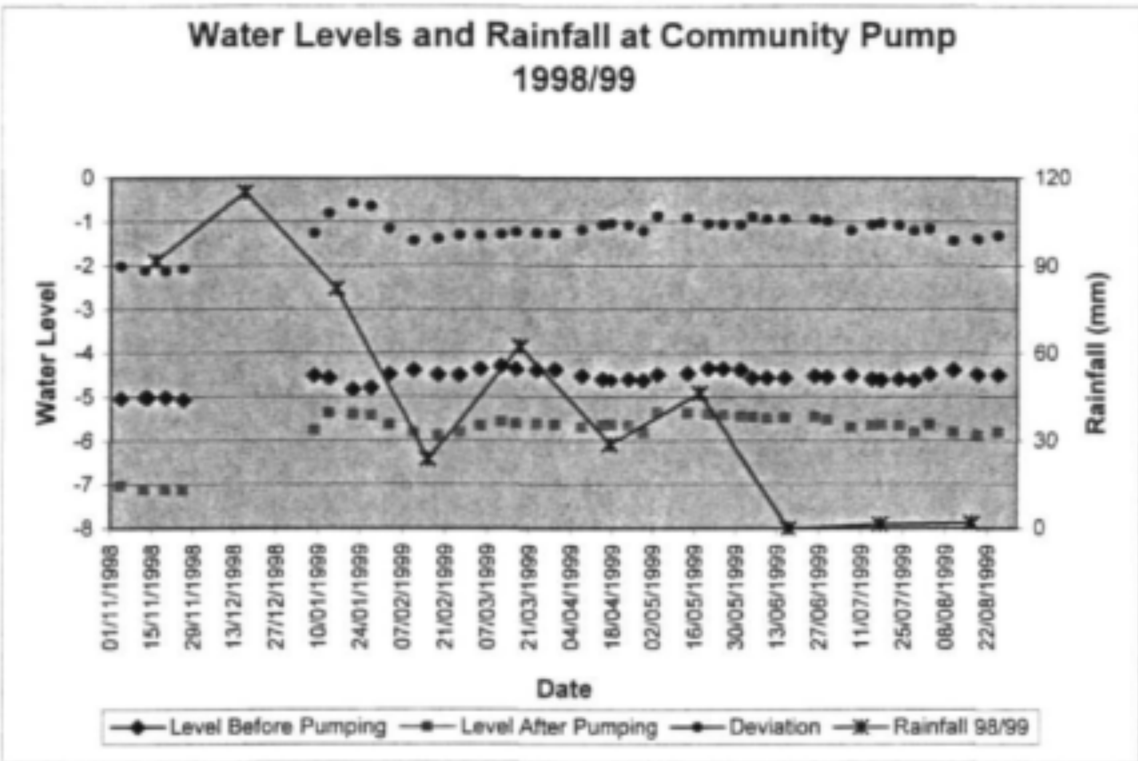

Figure 8: Water level and rainfall record at the Nebo Community borehole for 1998/199.

An example where this technique has been applied to rainfall data from the Northern Province is shown in **Figure 7** below. example of the alternative way of displaying the data illustrating the concept of "parallel lines" for water level before and after pumping, as well as the difference in water levels is shown in **Figure 8**. Despite the local fluctuations on these lines, the average slope of all three lines is basically the same. This illustrates that the aquifer is not being over-pumped and that the pumping rate is within the boundaries of the annual recharge and natural inflow/outflow conditions of the aquifer system.

GLOSSARY OF TERMS FREQUENTLY USED IN GROUND WATER RELATED PUBLICATIONS

Anion: An electrically positively charged ion.

Aquifer: A rock formation that contains sufficient saturated permeable material to yield significant amounts of water to boreholes or springs.

Capillary water: Water held in small openings in rock or soil by capillary force.

Cation: An electrically negatively charged ion.

Cone of depression: The depression in the water table or potentiometric surface caused by the withdrawal of water from a borehole/well.

Drawdown in a borehole: The vertical drop of the water level in a borehole caused by pumping.

Electrical conductivity (EC): The ability of water to conduct electricity (expressed in milli-Siemens per metre (mS/m)).

Evapotranspiration: The combine loss of water by evaporation from water and soil surfaces and through the transpiration of vegetation.

Fracture: Any break in a rock owing to mechanical failure caused by compressional or tensional forces.

Geohydrology: That branch of hydrology that deals with subsurface water, i.e. both water in the unsaturated and saturated zones. Also used interchangeably with hydrogeology.

Gradient, hydraulic: The change of pressure head per unit distance from one position to another in the aquifer.

Ground water: Water in the zone of saturation of a rock or unconsolidated formations. Synonyms: underground or subterranean water.

Ground water level: The water level in a borehole or well penetrating the zone of saturation and from which no water is being withdrawn. (Synonym: static water level or rest water level).

Head: Pressure, expressed as the height of a column of water that can be supported by the pressure.

Hard rock: A compact rock that lacks primary porosity.

Hydraulic conductivity: The rate of flow of water through a unit cross section of soil or rock, under unit hydraulic gradient.

Hydrogeology: see Gohydrology.

Hydrologic cycle: All movement of water in its liquid, gaseous and solid phases, in the atmosphere, on the Earth's surface, and below the ground surface.

Hydrology: The science that deals with continental water on or below the Earth's surface.

Ion: An electrically positively or negatively charged particle into which salts are dissociated when dissolved in water.

Permeability: In a general sense, it refers to the ease with which water will pass through a porous media under a potential gradient. More specifically it is the volume of water that discharges from a unit area of an aquifer under the unit hydraulic gradient of in unit time (expressed in units of m^3/m^2 /d = m/d).

Porosity: The property of soil or rock of containing interstices. Porosity is not to be confused with *storage coefficient*. *Primary porosity* refers to porosity formed at the time when the soil or rock was formed. *Secondary porosity* refers to interstices that were formed by processes that affected the rock after they were formed, for example fractures.

Recovery of a pumped borehole: When pumping from a borehole or well ceases, the water level rises (recovers) to approximately the static level.

Secondary porosity: see Porosity.

Saturated zone: Zone below the water table where all interstices are filled with ground water.

Static water level: see Water level.

Storage coefficient: Also referred to as *Storativity*. The volume of water that an aquifer releases from storage per unit surface area of aquifer per unit change in head. The storage coefficient of an unconfined aquifer corresponds to the specific yield.

Surface water: Water on the surface of the Earth.

Unconfined aquifer: Water bearing strata containing water that is in direct contact with the atmosphere through open spaces.

Unsaturated zone: That part of porous strata which the voids are occupied by air and water. In an unconfined aquifer this zones is above the water table.

Water table: The upper surface of the zone of saturation, or the imaginary surface below which all openings are filled with water. On this surface the pressure is equal to atmospheric pressure.

Water resources: The volume of replenishable water available in an area, whether on the surface or in underground strata, coastal outflow, and abstracted over a catchment area.

APPENDIX A

EXAMPLES OF FORMS THAT CAN BE USED FOR RECORDING MONITORING INFORMATION

GROUND WATER LEVEL AND PUMPING LOG SHEET (No flowmeter installed)

Borehole No:.............................Locality:...............................Operator:...........................Month/Year:......................./20....

Day no.	Date	Water level before start of pump	Time pumping starts	Water level before pump switched off	Time pump is switched off	Hours pumped	Discharge rate (l/s)	Volume pumped (m^3/day)	Electrical Conductivity (mS/m)	Rainfall (mm/day)
1										
2										
3										
4										
...										
...										
...										
29										
30										
31										
					TOTAL		TOTAL		TOTAL	

Record of water samples collected for analysis:

Date collected: ....

Collected by: ....

Laboratory submitted to : ....

Analysis requested: Chemical ☐ Microbiological ☐

GROUND WATER LEVEL AND PUMPING LOG SHEET (Flow meter installed)

Borehole No: ....Locality: ....Operator: ....Month/Year:................................./20....

Day no.	Date	Water level before start of pump	Flow meter reading before pump is switched on	Time pumping starts	Water level before pump switched off	Time pump is switched off	Hours pumped	Discharge rate (l/s)	Volume pumped (m^3/day)	Electrical Conductivity (EC) (mS/m)	Rainfall (mm/day)
1											
2											
3											
4											
...											
...											
...											
29											
30											
31											
						TOTAL		TOTAL		TOTAL	

Record of water samples collected for analysis:

Date collected: ....

Laboratory submitted to : ....

Sample collected by: ....

Analysis requested: Chemical ☐ Microbiological ☐

GUIDELINES FOR THE MANAGEMENT OF RURAL GROUND WATER RESOURCES

Final Report

Submitted to the Water Research Commission on the project

Development of guidelines for the management of rural ground water resources

by

R Meyer, G le Roux and M Dindar

CSIR

Pretoria

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EXECUTIVE SUMMARY

The Department of Water Affairs and Forestry, has in its White Paper on Water Supply and Sanitation Policy for South Africa, identified the provision of sustainable water and sanitation services to the entire population of South Africa as being of prime importance to the Department (DWA&F,1994). In a follow-up White Paper on a National Water Policy for South Africa, the Department stated that water resource management will be one of the fundamental aims that will receive specific attention (DWA&F, 1997c). This Water Research Commission (WRC) project is an attempt to address one of the many water resource management issues, namely that of the ground water resources utilised by mainly rural communities. However, ideas and principles of ground water management as expressed in this report, can equally well be applied in many other areas where ground water resources are utilised.

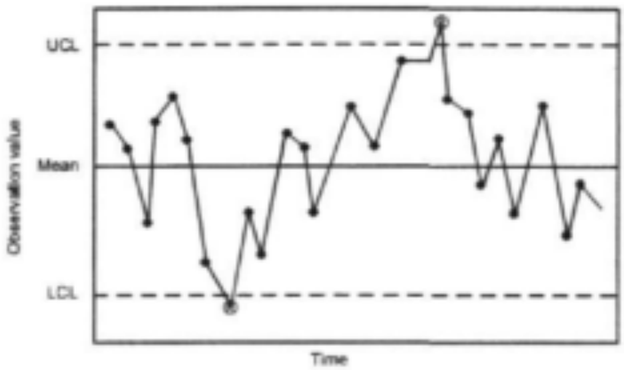
The ultimate aim of this project is to develop guidelines for monitoring and management of ground water resources in local communities who are largely dependent on the long term sustainability of the ground water resource. The main aims as stated in the contract with the WRC were to:

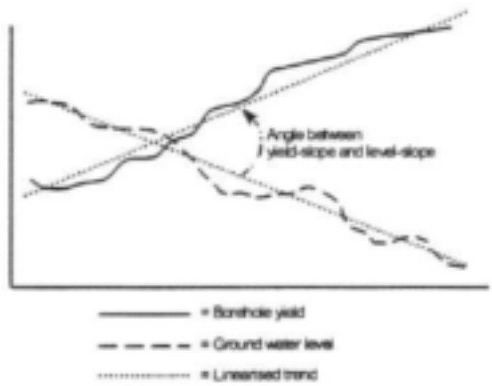
- Identify the appropriate issues that are important in creating an awareness in rural communities of the importance of ground water
- Identify those geohydrological parameters that are of importance for proper management of rural ground water resources.
- Develop guidelines as to how these parameters can be obtained through involvement of the user community including the documentation of data collected by the community.
- Improve knowledge of local and regional ground water resources in order to provide a sound basis for sustainable water supply management.
- To create a reliable network for the collection of dynamic hydrogeological, water quality and abstraction data that will provide a baseline.
- Develop a set of guidelines for analysing the data collected to be implemented by the user community.

The report is divided into six chapters. **Chapter 1** provides background information on ground water management issues especially as these pertain to the rural communities. It also describes ground water management in general and lists a number of problems associated with the South African scene. The need for ground water monitoring and management is discussed as well as the objectives of the project. **Chapter 2** describes the methodology adapted to fulfil the requirements of this project. Issues that require attention as part of proper management of the country–s ground water resources are listed and discussed. Training of pump operators to perform the monitoring and awareness programmes to educate the community of ground water aspects also form part of this chapter. The monitoring requirements and the roles and responsibilities of al the role players in the management of ground water resources are addressed in **Chapters 2** and **3**. **Chapter 4** the data analysis techniques are described, followed by the description of the pilot study conducted on a number of boreholes supplying water to the community of Phokwane and Nebo in the Northern Province in **Chapter 5.** In the final chapter of the report **Chapter 6**, the main conclusions and some recommendations are listed. The results of this study and the lessons learnt have also been compiled in a Guideline document where the principles for ground water management are explained and the techniques described in this report are discussed. This guideline can form the basis for a Department of Water Affairs and Forestry initiative to implement a ground water management procedure in communities reliant on ground water for their water supply.

During the first part of the project different techniques were proposed for the display of ground water monitoring information. In order to test these, a monitoring programme was implemented in Phokwane, a village in the Northern Province which is totally dependent on ground water for its water supply. The display of monitoring information was to be such that a clear message about the conditions of the aquifer were portrayed to the community in a way that was easily understandable. Further, by monitoring a few as possible parameters, sufficient information had to be collected to already arrive at some meaningful conclusions that would assist in the management of the resource. It was concluded that by measuring the water level response to pumping, rainfall, water quality and the abstraction and/or consumption volumes, the basic graphs for first level ground water management could be achieved.

The graphical display of this information used two basic techniques to illustrate changes in the aquifer conditions. These are illustrated with the two graphs below:

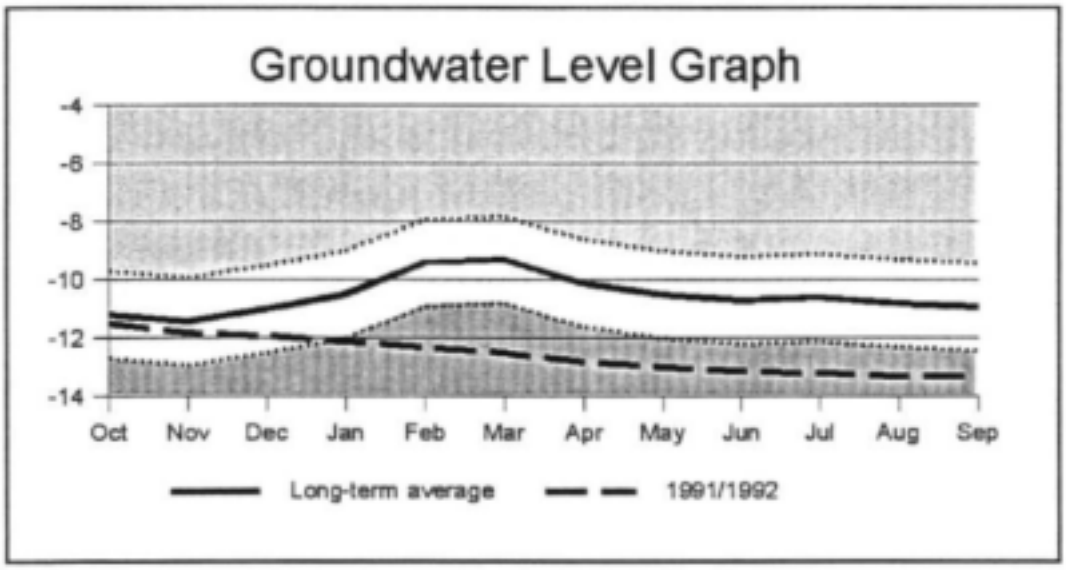




The left hand graph illustrates the principle of an upper and a lower control limit around a mean value. These are the bounds within which for example the water level is allowed to fluctuate without the need for any management actions to be implemented. By establishing these ranges from historical data, control on pumping from the aquifer can start immediately. In most cases the historical information is not available and first has be built up. The right hand graph illustrates a technique whereby the pumping yield can be optimised. By minimising the angle between the borehole yield and water level response to the pumping, the borehole can be pumped at a sustainable rate.

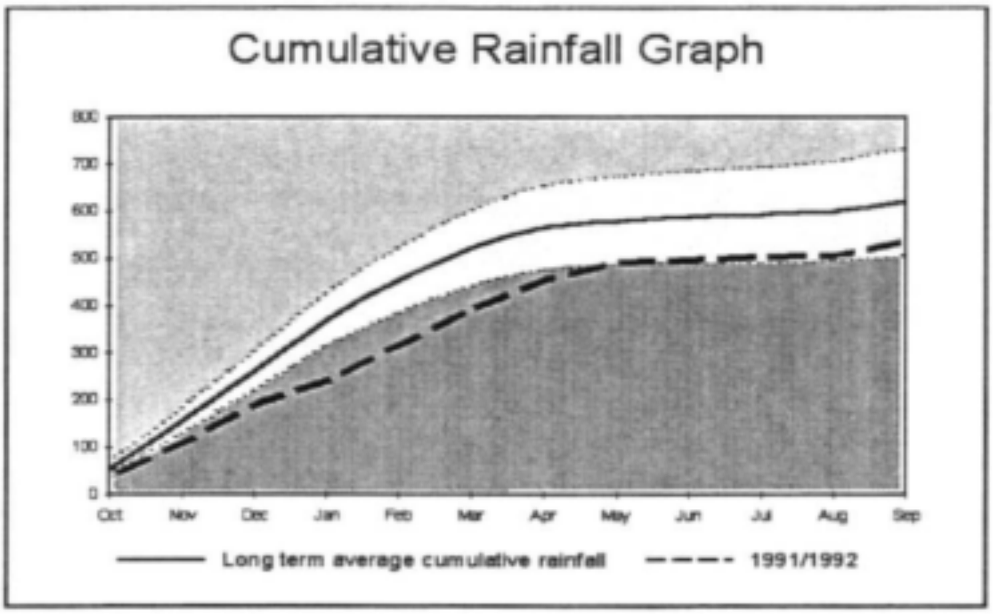
Different ways to graphically display the monitoring information was also investigated. It appears, however, that the normal x-y type graphs best illustrate the response of the different monitoring parameters to pumping.

Long term records of natural water level variations with the effect of pumping superimposed thereon, can be used to establish the monthly average water level over a hydrological cycle. To determine the range within which water levels will be allowed to fluctuate without management intervention, typically one standard deviation around the mean can be used. The annual water level fluctuations, typically measured and displayed at weekly intervals, is then compared to this long term record. An example of such a long term water level graph, showing the upper and lower limit around the mean (one standard deviation), as well as the water level for one specific year is shown below. Here it can be seen that up to approximately January the water levels still remained within the predetermined minimum level, but thereafter, due to a prolonged drought and the associated increase in water consumption, water levels continued to decline and remained below the minimum recommended level. This clearly illustrates a case where some form of management or intervention in water abstraction is required. As long as water levels remain in the green or yellow zones, there is no need for intervention.



Historical rainfall information is displayed in a similar way. In this case it is recommended that the monthly average rainfall is displayed as a cumulative monthly curve as displayed below. Similar to the water level information, the maximum and minimum ranges are established by allowing one standard deviation variation on either side of the mean. This figure illustrates that the cumulative rainfall over the period up to about May, is far below the monthly average and between May and September it just reaches the minimum allowable range. By comparing the two graphs, it is clear that the below average rainfall correlates with the similar decline in water level observed.

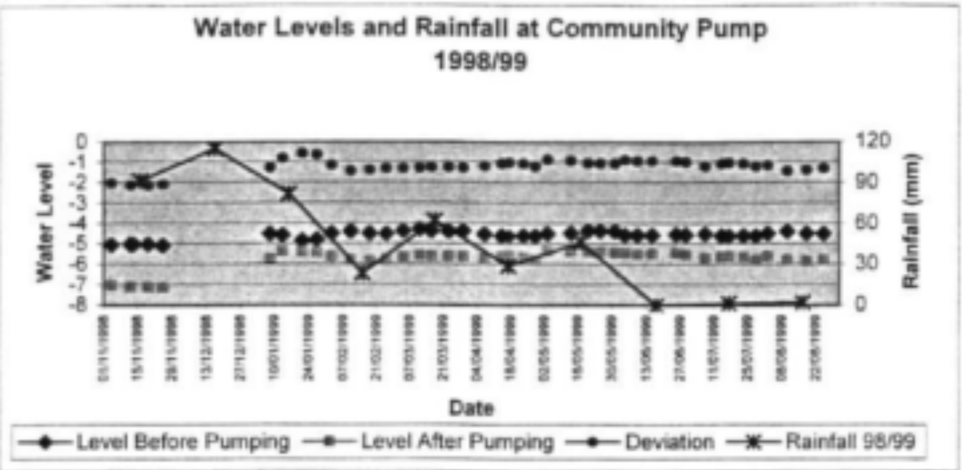
The other two parameters that should be monitored are water abstraction (or consumption) and quality. Water abstraction or consumption can be more easily controlled than water quality. In most cases water quality changes are not related to the cyclical changes in water level or rainfall, which are mainly a manifestation of different climatic conditions. Nevertheless, quarterly chemical and microbiological analyses are recommended, supported by weekly measurements of electrical conductivity as an early warning mechanism for possible changes in water quality.

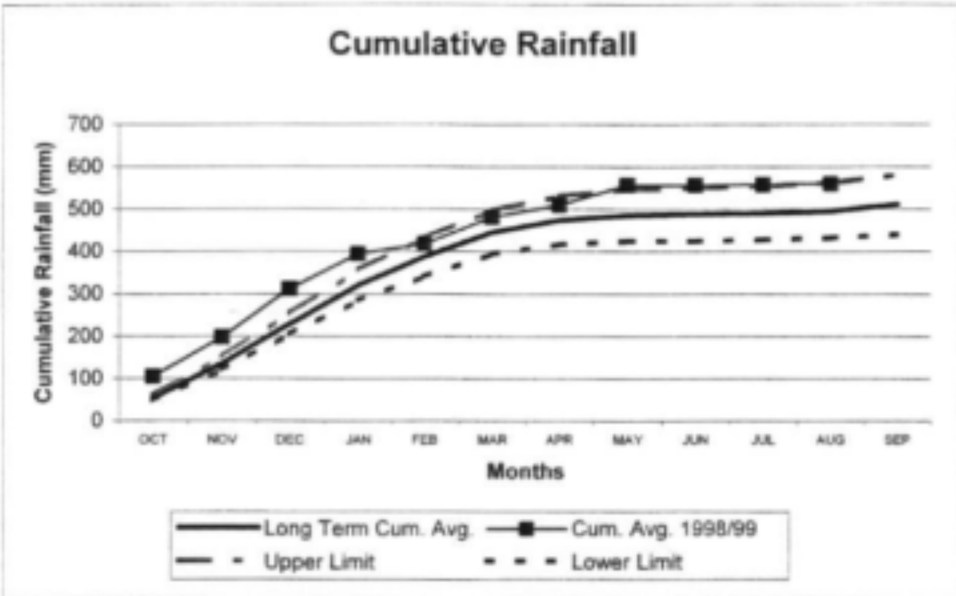


The pilot study at the village of Phokwane near Nebo in the Northern Province, illustrated a case where the aquifer was not put under any stress by the current pumping. This resulted in almost no variation in the water level pattern over the monitoring period of close to one year. No records for any of the three boreholes used to supply this village with water were available and it would appear that either no long term pumping tests were conducted beforehand to establish sustainable pumping rates, or that a very conservative abstraction rate was chosen.

In cases like these it is recommended that both the water level before pumping starts, the water level just before pump switch off, and the difference between these two measurements are displayed on a x-y graph. Should these three lines be parallel or near parallel, it indicates that the aquifer is not stressed nor is there a need for intervention in the pumping schedules or adjusting the pumping rate. If the aquifer is stressed, the lines will deviate from the horizontal position, indicating a degree of over pumping. Once this situation arises the previously mentioned way of displaying the information should be used for management purposes. In this situation, the minimum range within which the water levels need to remain are required. This situation is displayed below in the data collected during the pilot study at Phokwane.

The pilot study at Phokwane was conducted during a period of higher than average annual rainfall. This is illustrated by the cumulative rainfall graph for the hydrological year 1998/1999. The higher than average rainfall may also have played a role in the water level patterns observed in the previous graphs and contributed to a situation where no management intervention is required.





Although monitoring information was only available for a one year period, a number of important lessons were learnt. Several conclusions and recommendations for the implementation of future ground water management programmes in rural communities could be derived. These can be summarized as follows:

- Through the monitoring of only four fundamental geohydrological parameters, water level, rainfall, discharge and water quality, sufficient information can be collected to prepare time series graphs of these parameters which can be used for ground water management.
- A number of different and easily understandable graphical display techniques have been proposed which can be used to visualize the behaviour of the aquifer for different abstraction and rainfall conditions. It was found that the normal x-y type plot best illustrates the aquifer conditions.
- A disadvantage of most ground water management programmes is the lack of historic ground water monitoring information. Management of ground water schemes will continuously improve as longer time series of monitoring data become available.

- It is also important to keep the community responsible for the management of the ground water resource interested in the management programme during this period while building a longer term data set which is crucial for the proper management of the ground water resource in future.
- From the short record of monitoring information collected during the pilot study at Phokwane, it would appear that, despite all three boreholes situated in the same geological environment, each borehole reacts differently to pumping. In some cases there appears to be a lag of a few months between rainfall events and the water levels responding to such events, whereas, at one of the three monitoring boreholes no lag could be observed.
- A monthly cumulative rainfall plot is very informative and can be used to provide a first indication of whether sufficient recharge is occurring and whether the aquifer is over or under exploited. By using the rainfall information of nearby rainfall recording stations, maximum and minimum monthly cumulative rainfall curves can be constructed which can be used as a guideline as to whether ground water recharge would occur in a specific season or not. As soon as a rainfall record for a number of years is available, this will replace the data from the surrounding stations. In this regard it is recommended that cumulative rainfall measurement instrument be installed at each borehole used in the monitoring programme.
- It is also clear from the monitoring programme that unless the abstraction rate from a borehole is such that the aquifer is placed under stress from time to time, the monitoring data is of little use. In such cases the monitoring and management of the resource is actually not required.

The following recommendations for community based ground water management programmes are made:

- To ensure reliable monitoring data, frequent visits to the pump attendants are required to attend to problems. This is especially important in the beginning when the monitoring crew are still uncertain about their role in the management programme.
- For each pump operator, a backup operator, trained to perform the monitoring functions, should be available. This will ensure that no gaps occur in the monitoring datasets.
- It is important that reliable geohydrological information of all the boreholes forming part of the monitoring network is available. It is critical to know what the sustainable yield of each borehole is in order to be able to pump the borehole at maximum sustainable yield.
- By pumping at the maximum yield but for shorter periods, the aquifer is put under more stress, an managing becomes easier.
- It is recommended that cumulative rainfall monitoring equipment be installed at all ground water monitoring schemes.
- From a management point of view, it is preferable to have information on consumption rather than abstraction volumes.
- All boreholes should be equipped with in line flow meters to measure volumes pumped.

- For each community where ground water management programmes are to be implemented, a survey of water needs and demands and average expected water consumption is required. The survey should also include a hydrocensus.
- The limited water quality tests done in the pilot study indicate that a large proportion of the high nitrate concentrations in ground water close to rural, communities, can be attributed to the sanitation systems used. Therefore water samples should be taken regularly to monitor the nitrate concentration in ground water used in rural villages.
- Despite the fact that the sanitation systems are the main source of high nitrate concentrations in ground water, the microbiological quality of the water was found to be acceptable.
- Each pump operator should also be issued with a portable EC meter and instructed to measure EC on a weekly basis. He should further also receive training in the measurement of EC and the correct way to collect samples for chemical and microbiological analyses.

Based on the experience gained during this project, a guideline document in which the process of ground water management through the monitoring of a few basic geohydrological parameters is described, was compiled. In this document the requirement s for the management of ground water in especially rural communities are explained step by step. It is hoped that this document will form the basis for a management strategy implemented under the supervision and control of the Department of Water Affairs and Forestry.

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Development of guidelines for the management of rural ground water resources

The Steering Committee responsible for this project consisted of the following people:

Mr AG Reynders	Water Research Commission
Mr H Maaren	Water Research Commission
Dr CG Green	Water Research Commission
Mr K Pietersen	Water Research Commission
Mr R A Titus	University of the Western Cape
Mr C J Haupt	Water Systems Management
Dr AA Shaker	University of the North
Mr B Aleobua	Department of Water Affairs and Forestry
Mr S Marais	Department of Water Affairs and Forestry
Ms J Evans	Department of Water Affairs and Forestry
Ms L Colvin	Department of Water Affairs and Forestry
Mr M Mosia	Water Research Commission (Committee Secretary)
Ms U Wium	Water Research Commission (Committee Secretary)

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CHAPTER 1: INTRODUCTION, THE NEED FOR GROUND WATER MANAGEMENT AND OBJECTIVES

1.1 *Introduction and motivation for the project*

The Department of Water Affairs and Forestry, has in its White Paper on Water Supply and Sanitation Policy for South Africa, identified the provision of sustainable water and sanitation services to the entire population of South Africa as being of prime importance to the Department (DWA&F,1994). In a follow-up White Paper on a National Water Policy for South Africa, the Department stated that water resource management will be one of the fundamental aims that will receive specific attention (DWA&F, 1997c). This Water Research Commission (WRC) project is an attempt to address one of the many water resource management issues, namely that of the ground water resources utilised by many rural communities. However, ideas and principles of ground water management as expressed in this report, can equally well be applied in many other areas where ground water resources are utilised.

Although the White Paper addresses water in general, several of the remarks can be equally well read in the context of ground water resources. Statements made in the introduction to the White Paper, highlight the aims of the current WRC project. Some examples are:

"In a region of growing demands on a limited resource, the increasing scarcity of water could result in devastating conflicts and catastrophes.";

"The development of our society, our growing population, and the legitimate demands of the disadvantaged majority for access to that most crucial natural resource - water - have placed new demands on what is, although renewable, a limited resource that can easily become polluted or over-used."; and

"It is time to extend our ingenuity in another direction. Water conservation programmes may be far better investments than financing new dams, new tunnels and pumping stations, new weirs and pipelines. Conservation programmes may both increase water supply, ... and manage demands."

Ground water management is often focused on the long term sustainability of the resource in terms of quantity or yield. The White Paper, however, states very clearly that the resource quality measures that will be implemented in the context of the larger scale water management residing in the Catchment Management Agencies (CMAs). In addition to the general guidelines for water management, the White Paper identifies two provisions dealing specifically with ground water. These are that in future all new boreholes will have to be registered and that the development and use of ground water resources must be carried out in the context of an adequate catchment management plan, based on an understanding of the sustainable yield of the local ground water resources.

A long term and ambitious project pursuing the need of providing a minimum standard of water supply to the approximately 12 million people in South Africa without adequate water supply for their basic needs is currently underway. This goal is often easier to achieve in the metropolitan areas through the supply from surface water sources (for example in the Gauteng area Lesotho Highlands Water, Vaal Dam and Sterkfontein Dam) and distributed through existing distribution system operated by Water Boards (Rand Water, Umgeni Water, Municipalities, and others). In many of the more remote areas it is unlikely that water reticulation schemes distributing surface water from large impoundments will ever be installed because of low population density (and therefore relative low demand), high cost of implementing such schemes and a lack of surface water sources. In these cases the emphasis will be on the exploitation of ground water resources. Large sections of the country can be regarded as being semi-arid and cyclical droughts are common in some parts of the country.

The more remote areas are often also areas with a low ground water potential, but still relatively high population densities (for example certain parts of what was previously known as Lebowa and Venda, and certain parts of the Northwestern Province, are underlain by low yielding aquifers in a granitic and gneissic environment). This coupled with the semi-arid nature of many of these areas and the prevailing cyclical droughts, will lead to increasing demand on ground water as the water resource to cater for an expected increasing demand from the rural population. These are often also areas of low rainfall and where limited recharge to aquifers takes place. Refer in this respect to the National Hydrogeological Map published by the WRC (Vegter, 1995).

At present, the majority of rural communities rely on ground water as their sole source of supply. In addition, ground water often provides a basis for economic activity in some areas as irrigation water. Water demands of the population in these areas may have to be satisfied by ground water resources which may eventually lead to over-exploitation of the already limited water resources. It is a well established phenomenon that once a community has access to a water supply to meet their basic demands, the demand steadily increases because of higher living standards, increasing irrigation requirements, more and improved sanitation requirements, etc. All of this increases the risk of increasing the demand above the levels of sustainability and natural recharge.

It is unlikely that sophisticated management systems at community level will in future be affordable to be implemented, but nevertheless, some form of voluntary 'control' over the use of ground water resources is required at this level. If over-exploitation of these already limited water resources occurs, irreversible damage can be done to the sustainability of ground water resources in selected areas which will in turn affect the development of the community negatively. In a 1996 publication of the World Bank on South Africa's water resources and the management thereof, a warning is given that South Africa's already poor water supply situation may worsen even further if unfavorable climatic changes should arise from global warming (World Bank, 1996).

All these indicators highlight the importance of proper management of the country's water resources and in particular its valuable ground water resources.

Management of rural ground water resources in a South African and African context has been addressed by a number of authors in the past (Balek, 1993; Bannermann and Ayibotele ,1984; Cameron-Clark, 1993; Foster, 1984; Jacobson and Haupt, 1993; Knott and McDonald, 1983; Lewis and Chilton, 1984; Muller, 1993; Wurzel, 1993).

In a paper describing the experiences of ground water management in Africa Balek (1993) states that effective ground water management is a prerequisite condition for the sustainable development in Africa. He argues that proper ground water management is an efficient tool in the restoration and conservation of the African environment and that sustainable development itself does not guarantee environmentally and socio-economically sustainability unless the whole community, district or region equally share the benefits of the development. Effective ground water management consists of i) constraints and problem analysis, ii) search for adequate technical solutions, iii) institutional measures, and iv) capacity building programmes. Under the technical solutions he lists that all ground water utilisation should be based on adequate inventories, long-term assessment of the needs and impact on the ground water resources on a regional and national level should be conducted, all pollution sources are to be identified, and the relation between ground water exploitation and the environment should be established beforehand. This is similar to the concept of the ground water component in the "water reserve" as described in the new South African National Water Act, Act No. 36 of 1998. In this report the term "sustainable development" is used not only in the context of sustainable development of the water resource, but also to the socio-economic development of the community.

Cameron-Clark (1993) describes the importance of basement aquifers in South Africa for water supply to rural communities and emphasizes the importance of monitoring and storing of basic data requirements such as rainfall, water consumption, water level fluctuations and water quality. He is also of the opinion that the maintenance of the quality of the resource should be a responsibility at local level.

Jacobson and Haupt (1993) describe the advantages of conjunctive use of surface and ground water in rural areas in times of severe drought and identify a number of lessons learnt from emergency drought relief programmes. Muller (1993) identified the critical role that ground water plays in many rural situations in South Africa and that the adaptation of on-site sanitation systems may become a constraint in future on the use of ground water in these areas. He stated that if the full potential of the resource is to be exploited, an institutional framework within which the exploitation of ground water can be addressed is to be established.

Wurzel (1993) concludes that the success or failure of rural water supply and sanitation in Africa is very much in political hands and that it is up to those working in the field to recognize that they have the dual role of promoting both the technical aspects as well as the social awareness at all levels.

With the new National Water Act (Act 36 of 1998) and the increasing demands on ground water, there is an urgent need to collect data and information which can be used in longer term planning and management of the ground water resources in a manner that will be economically feasible and sustainable. Monitoring of the country's water resources, including ground water, receives specific attention in the White Paper (DWA&F, 1997c). In this regard the Department has embarked on a long term national ground water monitoring project. This will include both ground water quality and water level monitoring. Although this has been ongoing for many years (DWA&F, 1995), the programme is being extended to cover the entire country. However, this programme is primarily focused on background monitoring in aquifer systems that are not necessarily under stress, and does not focus on the smaller user, such as rural communities.

There is therefore a distinct need to manage the ground water resources of the more remote areas through a carefully designed and managed monitoring procedure. This project relates to the design and implementation of an affordable, community driven ground water monitoring and collection system from which a management scheme will be developed which will secure a water supply to the community over the long term and create a feeling of ownership of the resource. The emphasis is on self management by the community by involving them in the process. An information transfer mechanism to keep proper record of the data is also proposed. In this way this information can be used by for example the DWA&F in order to compile the greater picture on overall water resources and consumption for different sources of the country and for long term planning purposes.

1.2. Ground water management and the need for it

Four different levels of ground water management are identified; regional, national, provincial and local. Although this project focuses on the lowest level, namely the local or community level, the others will be touched on briefly.

1.2.1 Regional ground water management

In the past regional projects focused on surface water but coordination on ground water has been lacking despite the overwhelming use of ground water in the region. The management of ground water within the Southern Africa region for sustainable development thereof in the region, is being addressed by a programme driven by SADC (Groundwater Consultants, 1998). This programme which is described in a draft final report addresses issues like the development of

- a regional ground water information system;
- the compilation of a regional ground water monitoring hydrogeological map and atlas;
- establishment of a regional ground water monitoring network;
- regional ground water resource assessment and aquifer characterization;
- the collaboration and exchange of information between SADC countries;
- the establishment of a regional training and research institute;
- capacity building and institutional framework,
- and the development of minimum common standards for ground water development

1.2.2 Ground water management at a national and local scale

Extensive investigations and characterization of South Africa=s hydrogeological environment has already been achieved over the years. In terms of the issues listed above, South Africa is already far advanced in a number of these and will continue to address the remaining issues with time. A national ground water monitoring network is being established currently including about 400 monitoring stations where ground water is being sampled at a six monthly frequency for macro-element analysis. Several years of chemical data are now available and the information is being evaluated currently (Simonic, DWA&F project in progress). A national ground water level monitoring network, comprising of about 300 autographic water level recorders and the measurement of an additional approximately 1000 open boreholes, where water levels are being monitored regularly, has been in place for many years and is also constantly expanded.

1.2.3 The need for ground water management

Murray and Dindar (1998) identified four reasons why ground water should be monitored and managed:

- To prevent the aquifer from being over-pumped. If an aquifer is over-pumped a long term depletion of the ground water resource can result throughout the entire aquifer.
- To optimise individual borehole pumping rates. If individual borehole pumping rates are too high, a localized depletion of ground water results. Energy is also wasted, since the pumping head is unnecessarily high; and if the water level in the borehole is drawn down to the pump intake, a combination of air and water will be pumped.
- To prevent poor quality ground water from entering the aquifer. If abstraction from the aquifer is too high, poor quality ground water from further afield can be drawn into the aquifer.
- To establish whether the ground water is being contaminated from surface sources such as pit latrines, animal kraals and dipping tanks.

Items 1, 3 and 4 above are not only important with respect to maintaining the water resource for human consumption, but also to protect aquatic ecosystems which could be dependant on ground water sources. The National Water Act (Act 36, 1998), recognises a "Reserve", which includes "the quantity and quality of water required to: i) satisfy basic human needs and ii) protect aquatic ecosystems".

1.2.4 Practical problems identified in the management of South Africa's ground water resources

During the compilation of the details pertaining to the sections dealing with ground water to be included in the new National Water Act, a task team was appointed to develop a range of options that would provide for the practical implementation of the Water Law principles. The outcome of the work of the task team is documented in a WRC report by Lazarus (1997).

They identified four inter-related components to be addressed in the formulation of a national ground water management and regulatory framework;

- the formulation of a coherent national ground water policy;
- the development of a broad enabling legal framework which gives effect to the national ground water policy;
- the development of practical procedures for the implementation of the national ground water policy; and
- the development of scenarios to be included in national water legislation and associated regulations.

Lazarus and his team concluded that there are 12 fundamental practical problems experienced by the water managers and other experts involved in the management of ground water in South Africa (Lazarus, 1997). Some of these have already been addressed in follow up actions by the Department of Water Affairs and Forestry. These are (with some follow-up actions included):

1) Absence of a ground water management policy which lays down norms and standards to guide regional and local ground water management practices (This has been addressed by the first edition of a DWAF document entitled "Policy and Strategy for Groundwater Quality Management in South Africa" forming part of the DWA&F "Water Quality Management Series", DWA&F, 2000);
2) There is a lack of an efficient information retrieval system (the National Ground Water Database is currently revised and the registration process of boreholes and ground water users is in place);
3) Absence of an institutional structure that promotes the effective ground water management at local, regional and national level (This will form part of the responsibilities of Catchment Management Agencies);
4) There is a bias towards surface water in water quality management policies and strategies with the resultant lack of coherent ground water quality management strategies;
5) there is an absence of clear and effective regulation of subterranean water control areas;
6) There is an absence of strategies to involve the private sector and communities in the regulation and management of ground water resources;
7) There is a lack of professionalism in the ground water industry;
8) There is an absence of an effective conflict resolution mechanism to resolve disputes between competing users concerning over-abstraction or interception of ground water resources;
9) There is an absence of clear policy and strategies to ensure protection of the resource itself (This aspect has already been partly addressed by the DWA&F document by Xu and Braune,1995, A guideline for ground water protection for the Community Water Supply and Sanitation Programme);
10) There is a lack of effective monitoring and control systems regulating ground water abstraction and the need for a licensing system (This is being implemented

currently);

11) There is insufficient attention to the interaction between sanitation and ground water systems and addressing the potential conflict between ground water quality management and sanitation provision (see Xu and Braune, 1995); and

12) The distinction and separation of ground water management from surface water management stemming from the legal distinction between public and private water is not clear.

1.3 Objectives of the project

In the preceding paragraphs some background information and a rationale for ground water monitoring and management is explained. The level at which this project is addressing ground water management is at that of the community who are either totally or to a large extent dependant on ground water as their only supply of potable water and cannot rely on extensive assistance from provincial or national government agencies.

The ultimate aim of this project is therefore to develop guidelines for monitoring and management of ground water resources in local communities who are largely dependent on the long term sustainability of the ground water resource. As originally listed in the contract with the Water Research Commission these aims will be achieved by conducting the following steps:

- Identify the appropriate issues that are important in creating an awareness in rural communities of the importance of ground water as their (only) water resource.
- Improve knowledge of local and regional ground water resources in order to provide a sound basis for sustainable water supply management.
- Identify those geohydrological parameters that are of importance for proper management of rural ground water resources.
- Develop guidelines as to how these parameters can be obtained through involvement of the user community including the documentation of data collected by the community.
- To create a reliable network for the collection of dynamic hydrogeological, water quality and abstraction data that will provide a baseline and later, a platform for the continuous assessment of the impacts of ground water abstraction.
- Develop a set of guidelines for analysing the data collected to be implemented by the user community. This will included ways to transfer the negative as well as positive consequences to the community of the responsible or irresponsible utilisation of the resource.

Health aspects related to water supply, although not specifically addressed in the original stated objectives, were also be addressed during the project. From the preceding paragraphs it should be clear that ground water management is a complex task and involves a broad spectrum of activities. As such the results from this project is will only contribute in a small way to the overall national ground water management strategy. Nevertheless, it is believed that it forms an important component of this strategy and one that, from a community point of view and in the context of providing a sustainable supply of water to local communities, is of great importance.

CHAPTER 2. METHODOLOGY ADOPTED AND MONITORING REQUIREMENTS

There are two broad aspects of ground water management; the technical aspects which deal with information system and databases, resource assessment , mapping and monitoring while the other wider aspect of overall integrated ground water management extends to policy, legal framework, socio- economics, training as well as financing and economics. In this study the emphasis is on the technical aspects of the collection, monitoring, interpretation and archiving of relevant ground water information, in order to achieve ground water management on a local community level

2.1 Methodology followed

The project was planned in four phases; i) Identification and investigation phase; ii) design phase; iii) implementation and education phase, and iv) reporting phase.

2.1.1 Phase 1: Identification and investigation phase

Identification of the issues involved in the management and control of low demand and low yield aquifer systems was the initial step in this project. These were identified through brain storming sessions involving the research team and important role players from DWA&F, Provincial Governments, NGO's, local communities involved in rural water supply and individuals.

Of relevance is the scale at which ground water management schemes have to be designed and implemented. After consultation with the stakeholders, it was concluded that a broad scale of users needs to be catered for. This will typically be a from a small consumer group like villages with one borehole supplying say 100 people, to villages, residential suburbs or small towns with say 5 000 inhabitants relying on several boreholes. From discussions with the communities and other role players, it was concluded that the best approach would be a form of voluntary 'control' of the ground water resources.

2.1.2 Phase 2: Design phase

Monitoring systems were designed for the monitoring and recording of water levels, abstraction rates, rainfall and water quality, etc. on a community level by involving the local community water committees and officials of the Department of Water Affairs and Forestry responsible for pump operation and maintenance.

Different methods to analyse and present the data in a format that is easily understandable to the community were developed. These are then used as the basic management tools, and preferably are such that the communities and the local Water Committees can apply these in self controlling and management of their ground water resources.

2.1.3 Phase 3: Implementation and education phase

The third phase was an implementation phase during which a pilot study was initiated where the monitoring methods were implemented in a community which is totally dependent on ground water for their water needs. During this phase a limited hydrocensus of the area was conducted, pump operators were trained to perform the different monitoring functions, the local Water Committee and the community were made aware of the importance of monitoring their water consumption, protecting the aquifer from contamination and eventually managing it themselves.

During this period a data set of water levels, volume abstracted, pumping periods and rainfall was collected and analysed according to the methodologies developed in Phase 2.

The education programme should also focus on aspects such as that ground water, although replenished from time to time, still remains a limited resource, replenishment usually is slow, the dangers of pollution, and the steps that can be taken to prevent pollution. They also have to be made aware that there are periods during which ground water resources can become overstressed (concept of 'ground water droughts') and that the ultimate aim of the local ground water management programmes is to overcome these drought periods successfully. During these information sessions it is also important that the pump operators, who are responsible for data collection, are made aware of the importance of recording data accurately and diligently.

Ultimately, geohydrologists and other technical staff associated with provincial structures, CMAs, or consultants appointed by and acting on behalf of these authorities, should be responsible of the overall and proper management on a larger scale of the data collection, analysis and recommendation resulting for the monitoring programmes. At times when the local management of the ground water resource impacts on the regional ground water situation, officials of the National Department of Water Affairs and Forestry, should become involved in assisting and advising on the management on a larger scale.

2.1.4 Phase 4: Report compilation and the development of guidelines for the management of ground water resources at community level

The final phase of the project consisted of the compilation of the final report on the project and the writing of draft guidelines for the development and implementation of community based practical ground water management procedures and methodologies. These draft guidelines should be seen as a first attempt to the compilation of a more extensive set of guidelines, perhaps leading to protocols, that will eventually cater for a wide variety of situations that can be expected in community based water supply schemes based on ground water resources. It is proposed that these guidelines be circulated to staff of the Department of Water Affairs and Forestry actively involved in ground water based community water supply schemes for comment. This will ensure that practical experience already gathered during the implementation and management of such schemes can be included in the guidelines. Similarly, the large number of consultants and NGOs involved in ground water based water supply schemes, should be consulted to harness their experience. It is intended that some of the management techniques developed during this project will be implemented during the current Norwegian Government funded ground water management project operating in selected villages in the Eastern Province, Kwazulu-Natal and the Northern Province. Last but not least, cognizance must be taken of indigenous knowledge collected by local communities over many decades, on ground water management practices. This aspect applies especially where natural springs are supplying in part of the water requirements.

2.2 Issues to be addressed for the proper management of rural ground water resources

The most important aspects that require consideration during the development of programmes for the management and community based ground water resources are listed below. This is a generic list and should be adapted depending on the application. High yielding aquifers with a relatively low demand are to be treated different from a low yield aquifer on which a high demand is placed. These aspect are especially important when customizing the guidelines for a specific community.

Table 1: List of issues to be addressed for the proper management of the rural water resources

Management and information gathering functions	Requirements and Issues	Responsibility and Linkages
Community related aspects	Size of community. Water requirements and demands including future requirements. Type of borehole infrastructure (hand pumps, generator driven, submersible pumps, etc). Water consumption patterns. Has a Water Committee been established? Will community controlled monitoring and management programmes be accepted and who will be responsible? Ground water education within the community. What assistance/cooperation can be expected from the community and or the authorities (e.g. DWA&F)? What approval is required to work in the community (induna, local authority, etc.)	**Responsibilities:** Provincial Department responsible for Community and Infrastructure development. Community Development Officers **Linkages to:** Water Services Development Programmes/Water Service Providers
Monitoring of geohydrological variables	Water levels [1)] Borehole yield [2)] Water quality [1) & 2)] Water consumption [1)] Pumping record; hours pumped /day/week [1)] Rainfall recording [1)] Recording of monitoring data [1)] Format of data captured [2)] Monitoring frequency [2)] Responsibility for interpreting the data [2)]	**Responsibility:** [1)] Locally trained pump operators [2)] Geohydrologist **Linkages to:** Regional DWA&F Offices, CMAs, Consultants
Monitoring equipment	Design and installation Safety and reliability of measurement	**Responsibility:** Geohydrologists **Linkages:** Regional DWA&F Offices, CMAs, Consultants

Table 1 (cont.): List of issues to be addressed for the proper management of the rural water resources

Management and information gathering functions	Requirements and Issues	Responsibility and Linkages
Transfer of information	To local/regional/provincial/national level? Responsibility for data archiving. What format is required? Type of information required. Data analysis. What is the aim with the analysis? How should data be analysed (manually or electronic)? If manually, what techniques are to be used , and if electronic, what software is recommended? How should data be displayed for decision taking?	**Responsibility**: Geohydrologists in consultation with Service Providers and DWA&F. **Linkages:** Service Providers
Management	Who will guide decision taking in the community? On what basis will decisions be taken? How will decisions be communicated to community? Level of decision taking.	**Responsibility:** Water Committee in consultation with geohydrologist when required. **Linkages**: Water Service Providers

2.3 Education and training

In order to enhance the quality of participation by the community, a basic ground water education and awareness exercise is vital. In this regard close cooperation with the DWA&F and their national ground water education initiatives have to be maintained. If a ground water education programme is in operation in the region or Province, close links have to be maintained with such programmes. Based on the outcome of the education phase, the data capturing protocol may need refinement in order to suite the specific requirements of the community.

2.3.1 Objectives

The ultimate aim of the education process would be to increase awareness of the local Water Committee, other leaders in the community, pump operators, children and the community in general, to the nature of their ground water resource and the need for proper management of the resource. A further aim would be to equip pump operators and selected individuals with the skills necessary for the monitoring, data analysis and decision taking phases of the project. It will, however, not be an objective of this training to turn participants into geohydrologists or geohydrological technicians. This service is to be provided by the Regional Office of the Department of Water Affairs and Forestry, Catchment Management Agencies, consultants and others specifically appointed for these tasks.

The participation of the local secondary school in the monitoring and management project can also be explored. In this regard class projects could be defined that will fit into the monitoring programme, for example the responsibility for rainfall monitoring, or to perform limited data analysis. Again, in the case of the school participating, the project would seek to link up with other existing education programmes of say the DWA&F.

For community based ground water monitoring programmes to be implemented and run successfully, the concept of "Acceptance and ownership in the community" has to be accepted by the community. For this concept to be successfully implemented it will be of great importance that the community be made aware of and understand some important principles and requirements of the programme, for example:

- why ground water is important to them and why it should be protected and managed;
- some basic principles of ground water occurrence (hydrological cycle, ground water as a limited resource with limited yield, recharge is slow process, etc.);
- why they are asked to perform certain tasks on a regular basis;
- what the aim of the project is;
- why it is important for them to do the tasks allocated to them and ensure for reliable information to be collected; and
- what benefit they will ultimately have in managing their water supply.

They should also be made aware of the difference in monitoring for health reasons, and monitoring for determining long term trends in the behavior of the aquifer. With regard to the health aspects, close consultation with the Sanitation Sub Directorate in DWA&F and the Department of Health is recommended.

Unless the cooperation of the community in this regard is received, it would be difficult to successfully achieve the objectives of the project. Mogane (1990) and Mogane-Ramahotswa (1992a, 1992b) compiled a series of articles to assist in the community-based management of water supply services. Although not specifically referred to, the management practices described in these articles focus almost exclusively on surface water resources, but the guidelines described here can be used to good advantage in the community-based management of ground water resources. The community will also require more basic information on the principles of ground water. Unless this can be achieved, the management of the resource will be even more difficult.

2.3.2 Approach, techniques and current initiatives

A number of initiatives to increase awareness of the occurrence and importance of ground water as a resource to local communities in South Africa have recently received attention (Toens *et al*, 1993; Toens *et al*, 1995, DWA&F, 1996). The project referred to by Toens *et al.* (1993) educating the youth of the Northern Cape Province to protect their ground water resources in areas where potable water is scarce, so as to ensure a sustainable and clean source of water, was reported to be very successful. In order to combat the misunderstandings of ground water issues within the communities, a ground water education and environmental awareness programme was initiated. The approach followed was to target the school children and teachers and consisted of a series of lectures and competitions (Visser *et al.* (1995). The lectures covered topics such as the water cycle, aquifers, the concept of ground water as an exhaustible resource, common causes of contamination and methods to prevent contamination and how to conserve water. Different competitions were designed where student participation was invited. These varied from colouring in of line drawings for the lower Grade pupils, to models and compositions for the more senior Grades.

DWA&F (1996), in their draft document outlining criteria for the development of ground water resource development for the community water supply and sanitation programme, recognises the need for education in rural communities. They identify capacity building and training as essential to the success of any ground water resource management initiative. The objective would be to develop at least: (i) an awareness of the importance of local ground water resources to the community, and (ii) a sense of responsibility for the operation, maintenance and protection of the local ground water supply source. They admit that this would require the presentation locally of informal education sessions and the attendance by designated responsible community members of technical training courses.

The approaches referred to in the literature are often of a general nature and need to be adapted for each specific community depending on its own needs.

2.3.3 Role players

Consultation with as wide as possible a spectrum of people involved in the education of the broad subject of water in the rural communities is of critical importance. This may be achieved through the involvement of officials from the Department of Water Affairs and Forestry, NGO's, education departments, consultants, and others. During May 1996 a Unit tasked with developing a Ground Water Training/Awareness Building/Extension Programme was established in the Directorate Geohydrology of the DWA&F to address these issues. According to the White Paper (1994) this task will eventually be fulfilled by the National Community Water and Sanitation Training Institute. In the interim, however, this task will fall into the integrated efforts of the aforementioned Unit and the Social Development Consultant(s) appointed to each ground water development project (DWA&F, 1996).

In essence these training programmes must seek to secure the full involvement of the community in a ground water resource development project through the establishment of a capacity within the community to: (i) understand, (ii) operate, (iii) maintain, (iv) monitor and (v) manage the source(s) of its water supply. The monitoring and management capacities will apply to the ground water resource itself. Before these issues can be addressed, however, it will be necessary to consider the level of technical sophistication of the water supply system (DWA&F, 1996).

2.4 Monitoring requirements

2.4.1 Introduction and background to the development of management techniques

The accurate and continued monitoring of various parameters is obviously crucial to the success of a ground water management project. Unless reliable measurements are recorded, no meaningful analysis of the information can be done, and thus no predictions of the behavior of the aquifer are possible. For each specific site a monitoring protocol needs to be designed taking into account the level of ground water related education achieved in the community and the complexity of the ground water environment. As mentioned earlier, a clear distinction should be made between monitoring for health reasons and monitoring with the aim of managing the resource in terms of sustainability. Health related monitoring will often be to address issues on impacts on the shorter term, whereas water level monitoring has long term implications.

2.4.2 Parameters to be monitored

Structures are to be in place within the communities to regularly monitor the following parameters:

- water level;
- water consumption;
- water quality;
- rainfall; and
- borehole pump operating schedules.

In Chapters 4 and 5 of this report it is explained how these parameters are used in the data analysis for management of the resource. DWA&F (1997a) list a similar set of parameters in their document "*Criteria for Groundwater Resource Development for the Community Water Supply and Sanitation Programme*".

2.4.3 Monitoring techniques

Water level

Monitoring of water levels and water consumption depends on the borehole construction and pumping equipment installed in the borehole. However, what is important is that the measuring technique is easy to use, mechanically sound, tamper proof, easy to install and does not require sophisticated technology to capture the water level data (for example pressure transducers that record automatically at predetermined intervals and store the data electronically for downloading later). Target accuracy for water levels is 10mm and for water consumption it should be set at less than 5% of the daily volume pumped. Both these parameters should preferably be measured and recorded daily, but local conditions may be such that this can be extended to a weekly recording.

Various methods are available for the measurement of water levels in boreholes. A low cost portable water level measuring device involving a pressure gauge, bicycle pump and air tank connected to a permanently installed small diameter plastic tube in the borehole, has been described by Strangeways (1984). This device has been specifically designed for village wells by the UK Overseas Development Administration (ODA), but it is not known how widely this instrument is used. However, reasonably low cost measuring tapes equipped with an electric contact mechanism activated when in contact with water, are commonly available in South Africa and are the preferred way of measuring water levels for rural ground water management purposes.

Volume abstracted

The installation of in line water flow meters is not common practice on most water supply boreholes. This would be the preferred and recommended way of recording the volumes of water pumped on a daily basis. Lacking these facilities, at least monthly, but preferably weekly, tests should be made of the pumping yield at each abstraction borehole. This should be done by using a container of fixed volume and the time measured to fill this container of known volume. A prerequisite for this method of measurement is that a valve system is installed at the well head enabling the diversion of the water to the measuring facility.

Rainfall

Low cost rain gauges are to be installed at all boreholes used for community water supply. Where boreholes are close to each other, fewer rain gauges will be sufficient.. Weekly cumulative rainfall to be recorded. If the data collection process is likely to be unreliable, then a cumulative rainfall sampler as the one described by Murray and Dindar (1998) could be used. The cumulative rainfall sampler has a dual purpose in that it can be used to measure rainfall volume as well as collect a rainfall sample. The storage capacity of the sampler is large enough to hold an entire year's rainfall. This allows rainfall measurements to be taken over an extended period without the risk of losing data. The rain gauge/sampler is designed to keep out insects and other organic matter. This ensures that the sample is not organically contaminated and can be used for chloride or isotope analysis. The advantage of this, with respect to groundwater management, is that groundwater recharge estimates can be obtained using these data. The sampler has recently been developed by the CSIR in Stellenbosch (J Weaver, pers. comm.).

Water quality

Water quality testing should be compulsory for every borehole used for the supply of potable water to a community. In general ground water contamination occurs over a relatively long period and therefore a high frequency of extensive chemical testing is not usually required. What is, however, of greater importance is the bacteriological contents of the water. Samples for bacteriological analysis need to be taken more regularly and submitted for the routine microbiological tests. It is recommended that water samples be taken and analysed for their chemical composition and bacteriological contents according to the protocol listed in **Table 2**.

Table 2: Analytical requirements

Sampling point		Frequency	Test for
Well head tap	Storage tank		
X	X	Weekly	Electrical conductivity (EC)
X		Quarterly	EC, pH, NO_3, Cl, Na, Ca, K, Mg, F, COD
	X	Annually	Abbreviated SABS 241-1999 specification
	X	Monthly	Microbiological (*E. coli*,, Total plate count, total coliforms)

A range of commercially available products and test kits to detect indicator organisms in drinking water have been evaluated for possible use by communities. These include self-contained membrane filtration test devices and DST (Defined Substrate Methodology) based methods

(Millipore, undated; Genthe and Du Preez, 1996). It would appear that none of these use too sophisticated instrumentation that could not be acquired and operated by a community. A nitrate concentration test using special sensitive paper strips which change colour depending on the concentration in the water, can be considered, but the resolution in terms of nitrate concentration is usually not sufficiently accurate.

2.4.4 Data recording

Data recording protocols for the recording of weekly water levels (before pump switch on and at pump switch off), daily switch and switch off time, daily volume pumped and water quality where appropriate, are supplied to each pump operator according to the example in Table 3. Instructions on the recording of data on these sheets is to be given to each operator and constant checks should be made to ensure correct measurements are taken and that these are recorded accurately on the data sheets.

Table 3(a) : Field data recording sheet for use by pump operators (no flow meter installed)

GROUND WATER LEVEL AND PUMPING LOG SHEET

Borehole No: .... **Locality:** .... **Operator:**........................ **MONTH/YEAR:**........................./ 20....

Day no.	Date	Water level before start of pump	Time pumping starts	Water level before pump switched off	Time pump is switched off	Hours pumped	Discharge rate (l/s)	Volume pumped (m^3/day)	Electrical Conductivity (mS/m)	Rainfall (mm/day)
1										
2										
3										
4										
...										
...										
...										
29										
30										
31										
					TOTAL		**TOTAL**		**TOTAL**	

Record of water samples collected for analysis:

Date collected: .... Laboratory submitted to : ....

Collected by: .... Analysis requested: Chemical ☐ Microbiological ☐

Table 3(b) : Field data recording sheet for use by pump operators (flow meter installed)

GROUND WATER LEVEL AND PUMPING LOG SHEET

Borehole No: .... **Locality: ....** **Operator: ....** **MONTH/YEAR: ..../ 20….**

Day no.	Date	Water level before start of pump	Flow meter reading before pump is switched on	Time pumping starts	Water level before pump switched off	Time pump is switched off	Hours pumped	Discharge rate (l/s)	Volume pumped (m^3/day)	Electrical Conductivity (EC) (mS/m)	Rainfall (mm/day)
1											
2											
3											
4											
...											
...											
...											
29											
30											
31											
						TOTAL		TOTAL		TOTAL	

Record of water samples collected for analysis:

Date collected: .... Laboratory submitted to : ....

Collected by: .... Analysis requested: Chemical ☐ Microbiological ☐

CHAPTER 3. ROLES, RESPONSIBILITIES AND INFORMATION REPORTING ROUTES

3.1 Roles and responsibilities in ground water monitoring and management

In the discussion document "Towards a framework for rural groundwater management" compiled by Murray and Dindar (1998), the role and responsibilities of the different stakeholders in rural ground water management are discussed in detail. Their recommendations are summarised in Table 4 below. They also make the point that since it is not possible to ensure a sustainable supply of ground water without ground water management, Water Services Authorities also have an interest in ensuring that ground water is managed. On the question *Whose responsibility should it be to set up these groundwater management systems?*, they argue that without an operational Catchment Management Agency in the area, the responsibility for ground water management should rest with the Water Services Authorities or with the regional DWA&F office. While the Water Services Authority may be involved in setting up ground water management systems, they cannot be responsible for prioritising the areas which require more stringent ground water management than others. This will need input from DWA&F's regional offices, since DWA&F is better equipped to identify the more vulnerable ground water sources. This responsibility will be with the Directorates Geohydrology and Community Water Supply and Sanitation.

3.2 Reporting routes

The hierarchy of reporting information on a wide variety of water related matters has not been finalised. The White Paper (1994) makes it clear that local communities are "..... *the point at which implementation, operation and maintenance of services will take place.*" It is intended that this function will be fulfilled at Local Government level through the offices of a Transitional Local Council (TLC) or a District Council representing a third tier agency (DWA&F, 1996). Each community within a district will have representation on these Councils through the offices of, amongst others, a Local Water Committee. Second tier agencies/institutions will include Water Boards and Provincial Governments, whilst Central Government, represented by its Department of Water Affairs and Forestry, will form the first tier institution. Within this institutional framework, other agencies such as NGOs and the private sector will occupy a niche supportive of and facilitating the activities associated with each of the three tiers of governance. DWA&F (1996) proposes that in regard to the Community Water Supply and Sanitation Programme, this framework can be reconstituted to involve: (1) an Activating Agency, (2) an Implementing Authority and (3) an Executive Agency.

DWA&F (1996) recognises that the sequence and structure of project activities will follow a logical progression from the initial recognition of water supply needs through to the eventual delivery of water to meet these needs. These activities can be grouped into three components: (1) project inception, (2) ground water resource development and (3) ground water resource management. Under the final activity items such as (i) data and information management, (ii) capacity building and training, and (iii) ground water protection are included. Ground water monitoring and management can easily be added to these activities. They further recommend that project data and information

Table 4: Proposed roles, responsibilities and information reporting routes

Institution/Authority	Responsibility
Village Water Committees and Water Service Providers	Must ensure that pump attendants collect ground water data and send the data to the District/Regional Councils or the Water Services Authority
Rural Councils	Rural Councils need not take on any water supply or management responsibilities, unless they have been appointed as Water Services Providers by the Water Services Authority.
District/Regional Councils and Water Services Authorities	Notify Village Water Committees or Water Services Providers that they (the VWC or WSP) are responsible for collecting and transferring groundwater data to the District/Regional Council or Water Services Authority. • Process this data into spreadsheet and GIS format. If the capacity to do this is unavailable, DWA&F Provincial or a consultant should be used. • Analyse the data or use DWA&F Provincial or a consultant. • Make groundwater management recommendations or use DWA&F or a consultant. • Ensure that the recommendations are adhered to. • Transfer all relevant data to DWA&F=s provincial office either directly or via the consultant who analyses the data. Recommendations: District/Regional Councils or Water Services Authorities should: • Act as conduits for groundwater data and management recommendations. • Fund the data analysis. Assist DWA&F in setting up localised groundwater management systems in the absence of Catchment Management Agencies.
Water Boards	Water Boards should only take on groundwater management responsibilities if District/Regional Councils lack capacity to perform groundwater management tasks and if Catchment Management Agencies have not yet been established.
Water User Associations	A water user association should not need to perform any groundwater management tasks, unless DWA&F's provincial or national offices , through the Minister or Director General, feels that this is necessary.

Table 4: Proposed roles, responsibilities and information reporting routes (cont.)

Catchment management Agencies	Catchment Management Agencies will become the institution responsible for the overall management of groundwater in their areas. This will probably include setting up a groundwater management system.
DWA&F Provincial/Regional Offices	Identify areas where groundwater management is most needed. • Set up localised groundwater management systems, unless Catchment Management Agencies have already done so. • Ensure that the pump attendant, Village Water Committee, Water Services Provider, Water Services Authority and District/Regional Council know their responsibilities with regard to groundwater management. • Ensure that the pump attendant, Village Water Committee, Water Services Provider, Water Services Authority and District/Regional Council have been properly trained with regard to groundwater management. • Monitor the state of the groundwater resources in the province. This should include monitoring groundwater management recommendations on key aquifers. • Collect and store groundwater data received from District/Regional Councils, Water Services Authorities, Water Boards, Catchment Management Agencies and consultants; and to update the National Groundwater Data Base.

must not only be documented in a technical report, but as much as possible of this data must also be captured in an approved electronic data base, which must be compatible with the National Groundwater Data Base (or a similar system such as the Dutch REGIS system which is currently implemented) operated and maintained by the Directorate Geohydrology of DWA&F.

In the 1996 document DWA&F does not elaborate on the ways in which management information should be captured and evaluated. It is suggested that the techniques and protocol presented in this report eventually be incorporated into the later editions of the excellent 1997 guideline document published by DWA&F. The draft "Guidelines document" on ground water management will be circulated to various offices of DWA&F and other interested parties for comment. The comments will be incorporated in the final version and could then be used as a DWA&F recommended guideline for community ground water management.

Figure 1 is taken from Murray and Dindar (1998) and sketches the proposed flow paths for the transfer of groundwater data and management recommendations from the pump attendant to a hydrogeologist and back. It also shows how this data can get to regional management institutions.

3.3 Ground water management and Integrated Catchment Management

DWA&F recognises that naturally occurring water can be effectively managed only within a catchment area - because of the need to account for all aspects of hydrological cycle (DWA&F, 1996b). This has resulted in the adoption of the philosophy of Integrated Catchment Management (ICM) which aims to combine environmental, economic and social issues which affect a catchment basin, into an overall management philosophy.

The development of ground water must therefore be carried out in the context of an adequate catchment management plan, based on an understanding of the sustainable yield of the local groundwater resources (DWA&F, 1997a). The determination of an aquifer's exploitation potential will in future take into account the estimates made of the ground water component of the water reserve.

The following points highlight how ground water management forms an integral part of Integrated Catchment Management:

- Ground water forms an integral part of the hydrological cycle and therefore an important part of Integrated Catchment Management.
- Ground water contributes to wetlands, springs and the base-flow of rivers.
- Ground water contributes to the sustainability of aquatic and associated ecosystems.
- Ground water quality has an impact on the type of agricultural and forestry activity practiced in the area.

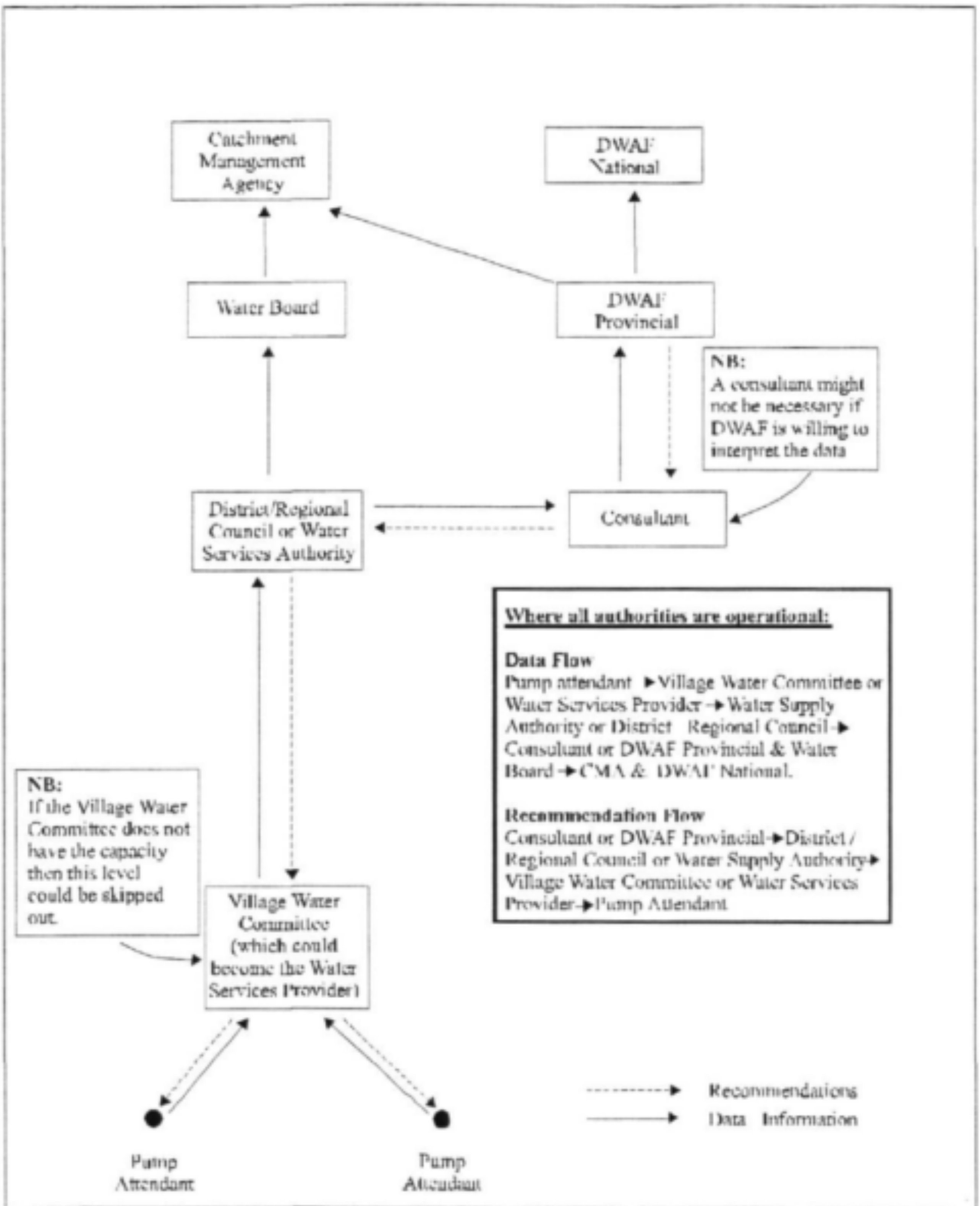


Figure 1: Proposed flow paths for the transfer of ground water information and data management recommendations

CHAPTER 4. DATA ANALYSIS AND MANAGING PRINCIPLES

4.1 Background to the development of management techniques

Effective data analysis, together with the illustrative and understandable presentation of the results to the decision makers and the community form an integral part of the development of appropriate ground water management techniques for rural communities. In developing these techniques the philosophy is to firstly develop visual aids that can be used by the community to manage their own ground water resources, and secondly to achieve a knowledge and understanding of ground water issues to a level which will assist them in realising why it is important to manage and protect ground water, and how to take appropriate action.

One of the aims in this project was to concentrate on developing techniques that are easily understandable visual displays of the current sustainable ground water yield (or demand) from the supply boreholes of the community relative to some pre-determined consumption guideline. The consumption guideline is based on existing knowledge of the aquifer behaviour and recharge estimates. These are then used as the first basic methods to assist in the communal management of ground water and should clearly indicate when supply problems can be expected in future.

Two approaches have been developed: 1) for those decision makers and community members that can be referred to in the sense of this report to be mathematically literate (i.e. that can read, write and understand data displayed in a graphical format; and 2) those that cannot read a graph. For the latter group the visual display techniques should be able to provide them with the same information.

Basic information on water consumption, water levels, depth and sustainable yield of boreholes, water demand and water quality has to be analysed in order to create some control system to identify changes in the ground water system, and in particular those that will have negative impacts on the community. Such changes may include dramatic increases in water consumption, decreases in ground water levels and, as an early warning system, changes in rainfall patterns. Through proper data analysis, including analysis by the community themselves, it should be possible to effectively identify situations where the levels of water consumption are threatening depletion or limited availability of the ground water source, so that corrective measures can be taken before it is too late. In this chapter graphical techniques to display the information of water levels, rainfall and consumption are described and it is shown how these can be used to the advantage of the community to manage their ground water supply.

4.2 Data requirements

The parameters listed below have been identified as being important for a ground water management system. These are divided into two groups, the first being the crucially important parameters, and the second being parameters which would provide useful additional information if they can be measured.

Table 5: Monitoring requirements

Parameter	Frequency of information required					
	Once off	Daily	Weekly	Monthly	Quarterly	Annually
Of critical importance:						
Geology	✔					
Ground water level			✔			
Sustainable borehole yield	✔					
Rainfall		✔		✔*		✔*
Water quality				✔**	✔**	✔**
Volume pumped		✔				✔*
Additional parameters:						
Regional rainfall				✔		✔*
"Blow yield"	✔					
Static water level	✔					

Notes: * Selected parameters only
** Cumulative values

If the above list of parameters can be measured at the requested intervals, data analysis should yield informative results, and therefore effective management of the local ground water system should be possible.

4.3 Factors influencing ground water management

In the management of ground water resources and at the level required for rural management schemes, there are four main factors that have to be taken into account, namely the ground water or potentiometric levels, rainfall, the use of the ground water resource and quality. Ground water levels, recorded on a weekly basis, can be used as an indicator of the current status of the ground water resource. If historical data is available on ground water levels, monthly averages can be calculated, and the current ground water level can be compared to these averages to see how the resource compares to the long-term average during any time of the year. Similarly, cumulative monthly rainfall needs to be recorded on a monthly basis. Knowing the current condition of the ground water resource through the measurement of the water levels, is not enough to ensure proper ground water management. In addition, some indication of how the ground water levels can be expected to change in the immediate future are required. To this end, it is vital that rainfall, which is the main source of ground water recharge, has to be measured and tracked well.

The third indicator that plays a role in ground water management is the level of ground water consumption by the community, i.e. the rate at which water from the storage is being abstracted.

Finally the ground water quality needs to be monitored. As shown in the table above, it is proposed that only key indicators of water quality are monitored at monthly and quarterly intervals, and that a full analysis is only conducted annually. Following the recommendations as published in the DWA&F document " Minimum standards and guidelines for ground water resource development for the Community Water Supply and Sanitation Programme" (DWA&F, 1997), it is recommended that the analyses be conducted as described in **Table 6**.

Table 6: Chemical analysis requirements

Sampling interval	Elements to be analysed for
Monthly	EC
Quarterly	EC
Bi-annually	EC, Nitrate, Microbial analysis
Annually	EC, pH, Calcium, Magnesium, Potassium, Sodium, Chloride, Sulphate, Nitrate, Fluoride, Total Alkalinity. Microbiological analysis (Faecal coliforms, *e. coli*)

4.4 Correlation of rainfall and water level response

As the techniques are not developed for any particular aquifer or region in the country, it was initially decided to take a selection of Department of Water Affairs and Forestry monitoring boreholes with long continuous water level records (>20 years if available) and compare these with rainfall records from nearby Weather Bureau rainfall stations. The objective was to determine whether a simple relationship between rainfall and water level response could be found that would provide an indication of the presence of a lag in the water level response (i.e. ground water recharge) of the aquifer. Should such a lag be present in any particular area, this had to be built into the rural ground water management technique.

In selecting the monitoring stations, reference was also made to the 1995 DWA&F publication "Inventory of ground water levels as recorded at operational ground water monitoring stations and possible correlations with causative monthly rainfall to December 1994". Mr E Van Wyk of the Directorate Geohydrology assisted in the selection of the monitoring boreholes for which information was extracted from the NGDB of DWA&F. The stations which were selected country wide and preferably on different geological terrains are listed in **Table 7**.

For the purpose of this project, management of ground water resources is not aimed at the short term, but rather on a longer, say annual period. Therefore, statistical analysis were performed on annual averages of water level and rainfall. Although some general correlations and trends are visible, and despite using different statistical ways to portray the data, no clear correlation was obvious that could be used in the design of the graphical management tools. A few examples of water level rainfall time series are shown in **Figures 2 to 4**.

Table 7: Boreholes and rainfall stations used for ground water level/rain correlations

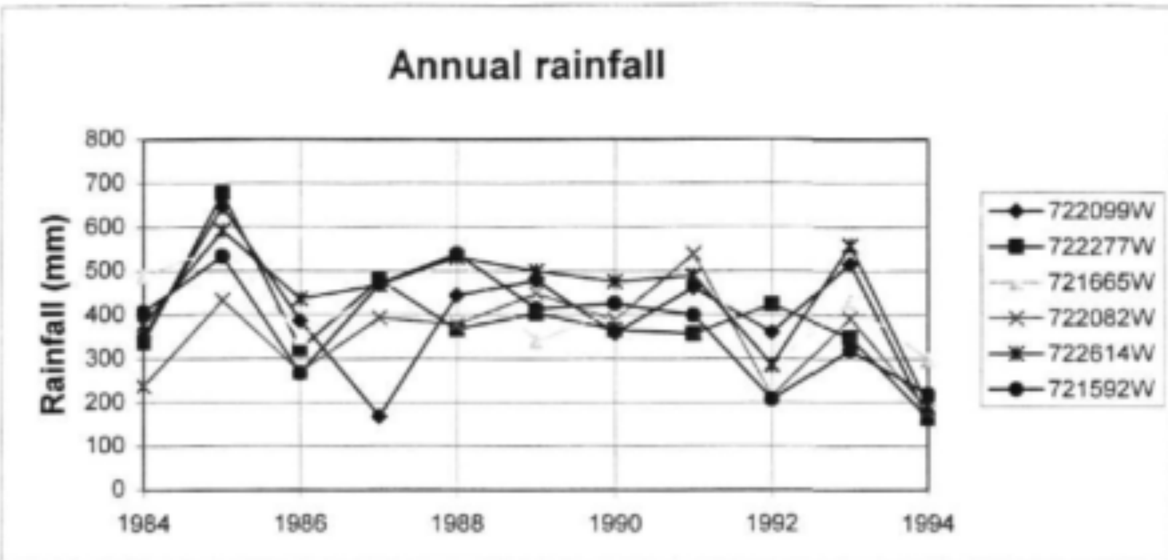
Geology	Borehole number (NGDB number)	Water level record length	Nearby rainfall stations
Granite	2329BA00002	1984 - 1997	722099W 722277W 721665W 722082W 722614W 72159W
Granite	2921AC00080	1978 - 1997	0251261A
Granite	2921AC00080	1969 - 1997	0157844W 0157874W
Bushveld norite	2724CB00007	1976 - 1997	587477W 587214W
Venterdorp lava	2625BB00030	1978 - 1997	508505W 472455W 471490W 471853W
Karoo	3023DB00014	1978 - 1997	170009W 169880W 170022W
Karoo	3222BC00136	1974 - 1997	0092369W 0092386W 70093W
Dolomite	2525DD00048	1975 - 1997	508649W
Dolomite	2627BD00038	1976 - 1997	475227W 475528W
Dolomite	2628BA00006	1985 - 1997	476666W 477309W

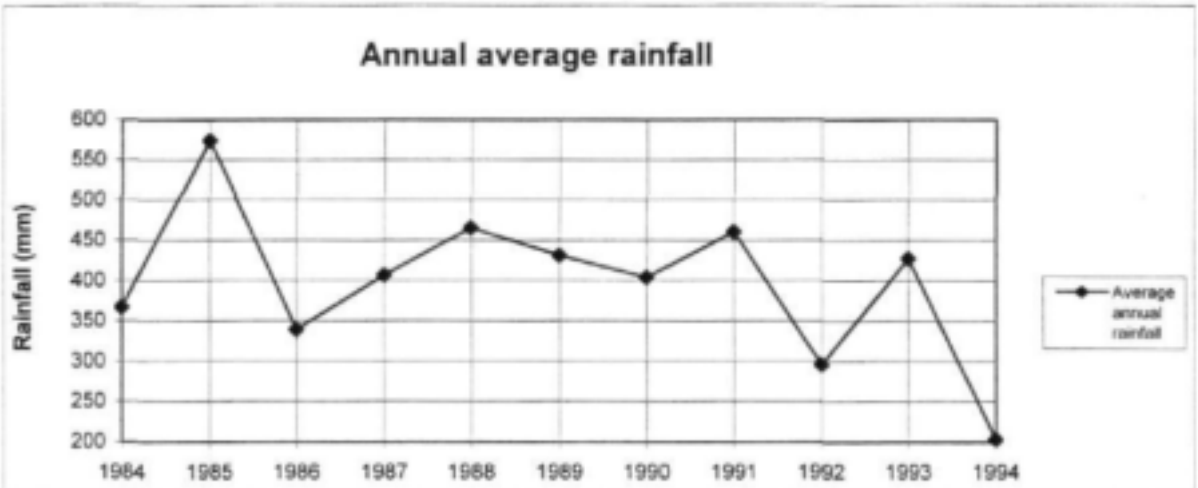
4.4.1 Ground water levels

Historical information on the ground water level at the pilot site (Nebo) is unfortunately not available and sufficiently long data sets will most probably not be available in the near future. To get past this problem, two possible approaches exist:

- *Obtaining information from nearby sites*

The first option was to obtain as much information as possible on ground water levels close to the pilot area. Should these indicate that the water levels are reasonably consistent, regional average water levels for the different times of the year can be calculated, and used as references at the pilot site. This option is advantageous in that it will provide reference





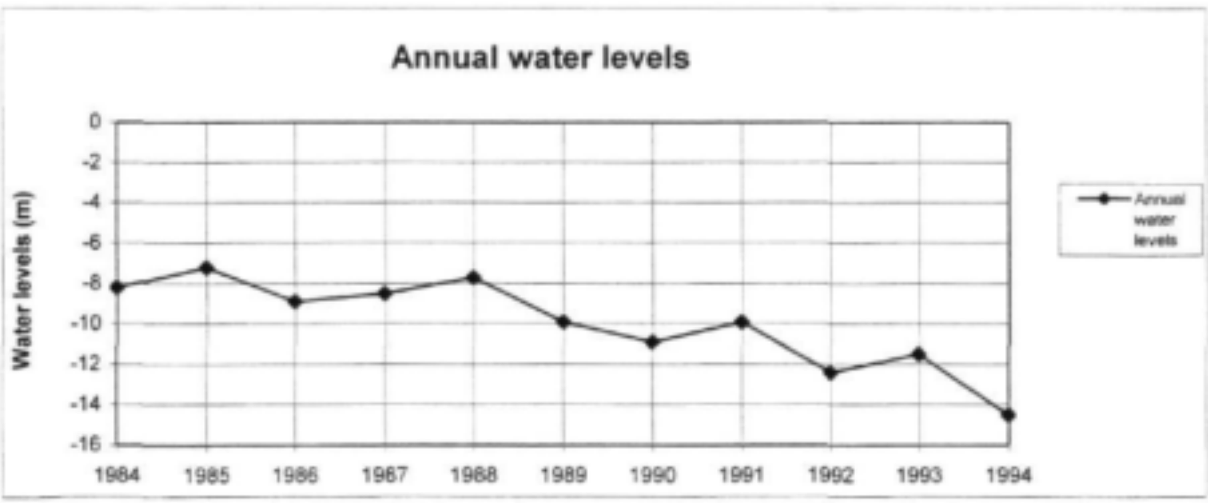
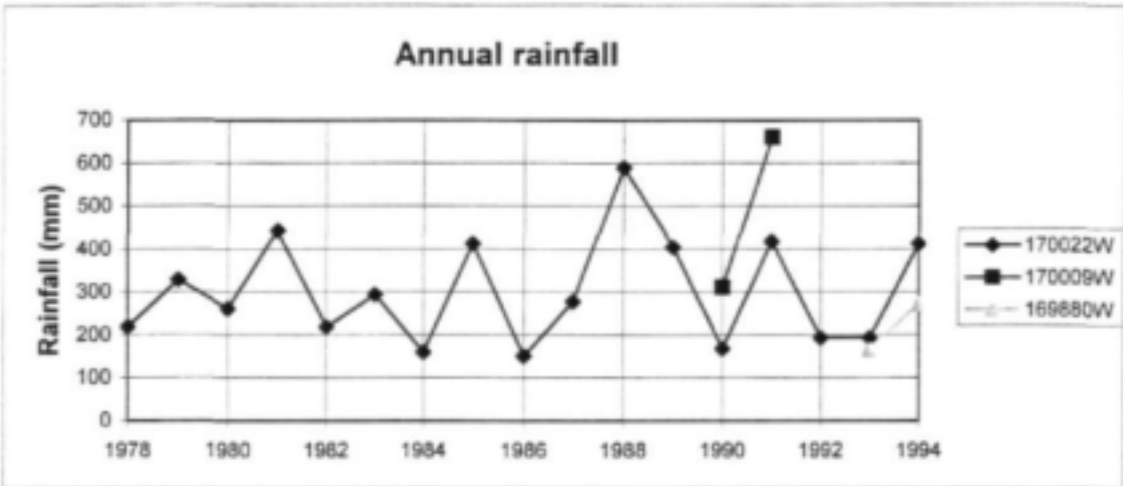
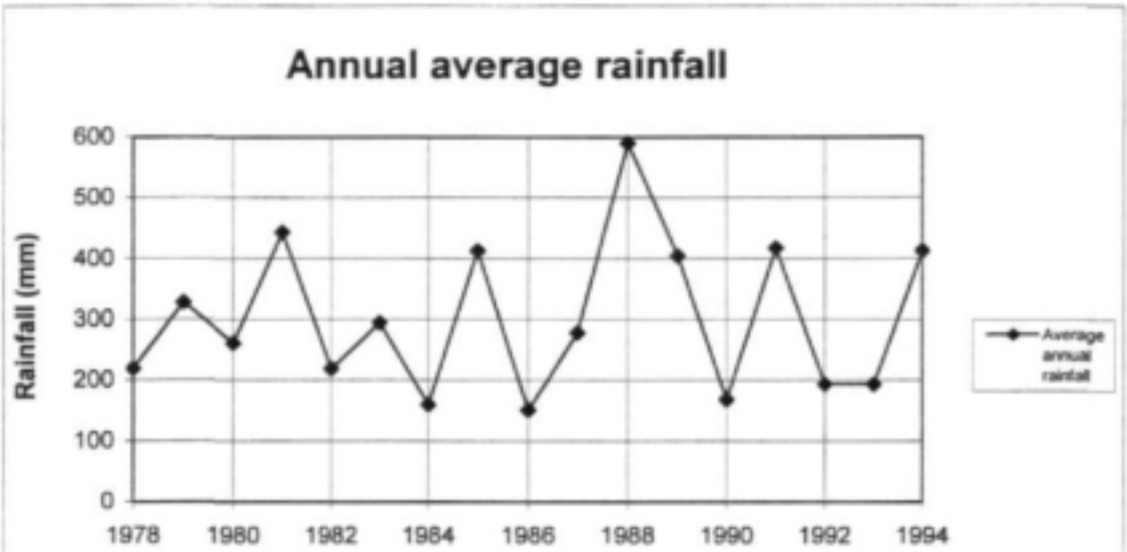


Figure 2: Annual ground water level for borehole 2329BA00002 and annual rainfall and average annual rainfall graphs for 6 rainfall stations in the vicinity of borehole 2329BA00002.





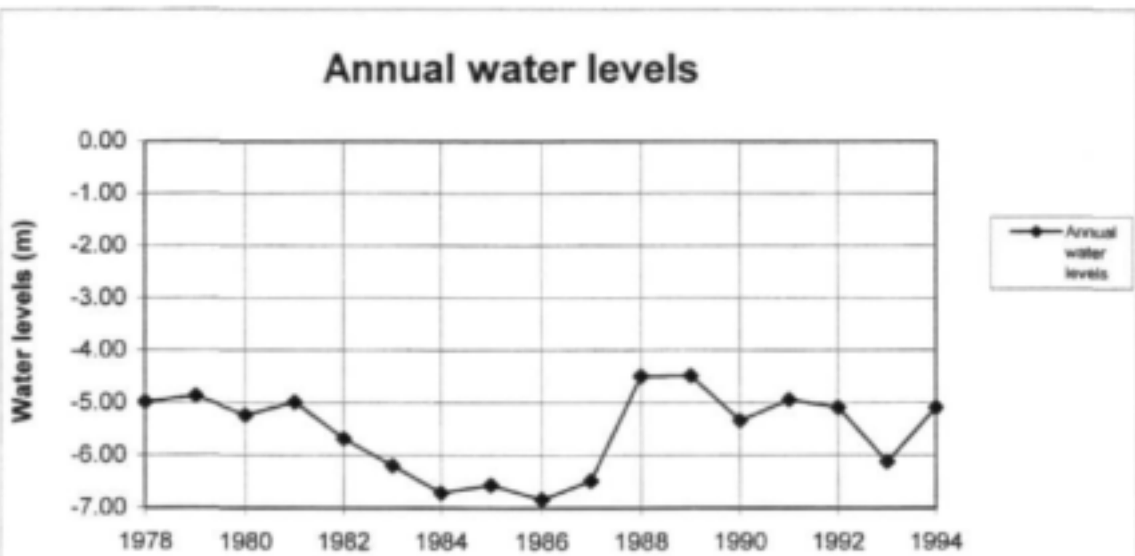
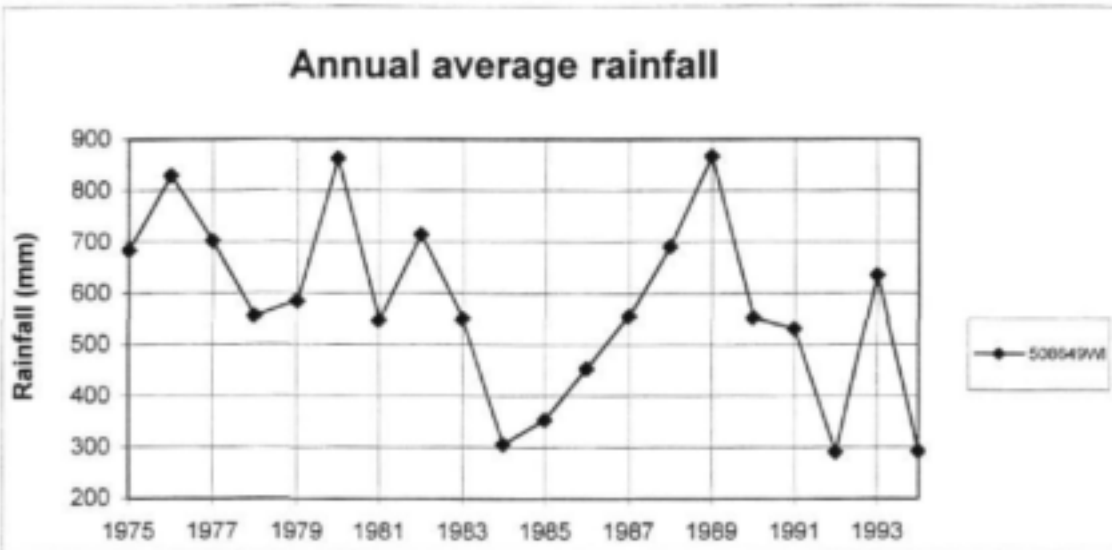


Figure 3: Annual ground water level for borehole 3023DB00114, and annual rainfall and average annual rainfall graphs for rainfall stations 170009W, 170022W and 169880W near borehole 3023DB00114.



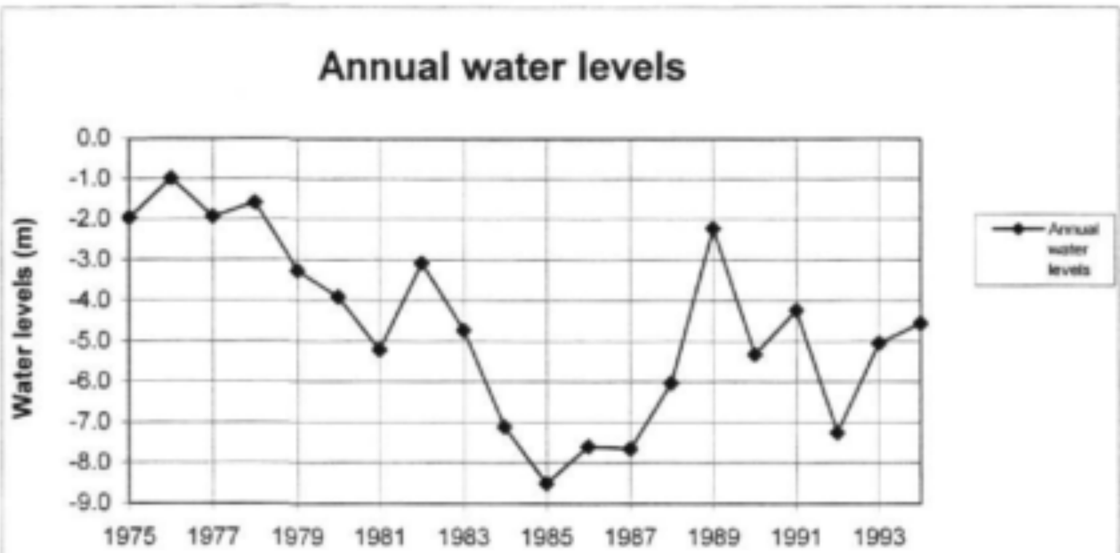


Figure 4: Annual ground water level for borehole 2525DD00048 and annual rainfall graphs for rainfall station 508649W near borehole 2525DD00048.

water levels from the outset of the management project. However, unless the geology and climatic conditions at the pilot site are similar to that of the surrounding areas, these levels may be misleading, and this may hamper effective ground water management at the pilot site.

- *Monitoring ground water levels for a year.*

As a second option, the ground water levels at the pilot site were monitored for the first year, thus providing a reference level for future ground water management. The levels for the first year can then be used as reference levels during the second year, the average of the first two years can be used in the third year, etc. Continuing with this process, a history of the ground water levels at the specific site can be built up, providing a better reference level against which to compare each new year's water levels. This option has the advantage of ensuring that the reference water levels are representative of the actual situation.

Since both the above options have clear advantages and disadvantages, it made sense to attempt to combine them, in order to obtain a better solution. Using average water levels from the surrounding region in the first year has the advantage that it provides immediate reference levels that can be used in ground water management. However, since it is not certain how accurately these levels represent the actual site, it would be crucial to also keep track of the actual recorded water levels at the site. These new, recorded levels can then be used from the second year onwards as reference levels.

4.4.2 Rainfall

Rainfall plays an important part in any ground water management system. Knowledge of rainfall behaviour can provide us with some predictive ability in terms of ground water management. If the lag between rainfall and aquifer recharge is known, rainfall figures can be used to predict expected future changes in ground water levels.

It is, however, difficult to obtain an accurate idea of the above-mentioned lag. The lag between rainfall and subsequent ground water recharge is very dependent on local conditions and geology, and since little historical data on ground water levels are available at the pilot site, the lag cannot be determined exactly for this site. The best option would therefore be to obtain a reasonable substitute estimate of the lag, by investigating the available data on rainfall figures and ground water levels for a site with similar geological features to the pilot site. The average lag for substitute sites can then be calculated, and applied to the pilot site with a reasonable level of confidence.

In cases where the ground water recharge lag of the aquifer is small, it makes sense to simply look at the current ground water level and the current rainfall levels when developing a basic ground water management tool. How these two variables can be displayed to the rural community in a way that is interactive and easy to understand, even when levels of mathematical literacy in the community may be low, will be addressed later in the report.

4.4.3 Water consumption

Cumulative volumes of water pumped/consumed have to be determine at least monthly. For the higher yielding boreholes in an area and therefore those from which abstraction figures are appreciably higher, actual pumping time has to be recorded, while consumption from small, individual boreholes can be extrapolated based on an average consumption (per household) over the study area.

Uncontrolled water consumption can have the effect of either temporarily or permanently exhausting the ground water resource. Some control on the consumption is therefore of vital importance in a ground water management system. When ground water and/or rainfall levels are significantly below average and this condition is maintained for a period of longer than a year, the community has to realise that they must cut down on their water consumption, in order to maintain their ground water resource until sufficient rainfall events will result in the necessary replenishment of the aquifer.

It should be stressed that the water consumption indicator has a different role to play in a ground water management system compared to the ground water level and rainfall level indicators. While ground water level and rainfall act as indicators of the current status of the resource, water consumption indicates the community's *response to* the status of the resource. The community has to be taught that, if ground water and/or rainfall levels are below average, they have to respond by lowering their usage levels accordingly, and that this response has to be kept up until the other indicators show that the resource has recovered significantly. Having a display indicating water consumption will allow the community to see how they are responding to the other indicators. If they are supposed to decrease their water consumption, and the water consumption indicator shows no decline, it will be clear that at least some members of the community are not responding as they should.

4.5 Display techniques

Perhaps the most important issue that needs to be attended to in the development of a ground water management system for a rural community, is displaying the ground water, rainfall and water consumption levels in such a way that the community can easily understand it. It is clear that some form of process control methodology should be included in the analysis of data, whether it be rainfall, water levels or consumption.

In **Figure 5** a process control chart, which is essentially a plot of data over time, is illustrated by using water level information as an example. The basic principle behind these charts is the continued assessment of data describing some process, to monitor when the process goes "out of control" (see Figure 5). This methodology can be transferred to ground water management, by applying it to the assessment of data representing for example, the ground water level, rainfall, quality or consumption of water from an aquifer.

Using historical data, two control limits are set up for the data representing the system. These are the Upper Control Limit (UCL) and Lower Control Limit (LCL). The control chart then allows the user to not only monitor when a system actually goes out of control (by moving outside the predefined limits), but also when it moves alarmingly close to the limits (thus providing an early-warning system).

Another possible method involves analyzing the general trends in the ground water level and borehole yield to provide information for the management of the system. In particular, the relation between the slope and water level slope (**Figure 6**) can be used effectively in ground water management.

4.5.1 Ground water levels

From a scientific point of view, the obvious means of displaying ground water level information would be using a graph, with the months represented on the horizontal axis, and the water level on the vertical axis. Such a graph, initially containing only the long term average reference water level, can be prepared in the beginning of the year by the Village Water Committee and displayed in a public place, for example the Community Centre. Every month the actual water level measured for that month can be added to the graph, so that everyone can see what the state of their ground water resource is compared to the average of previous years.

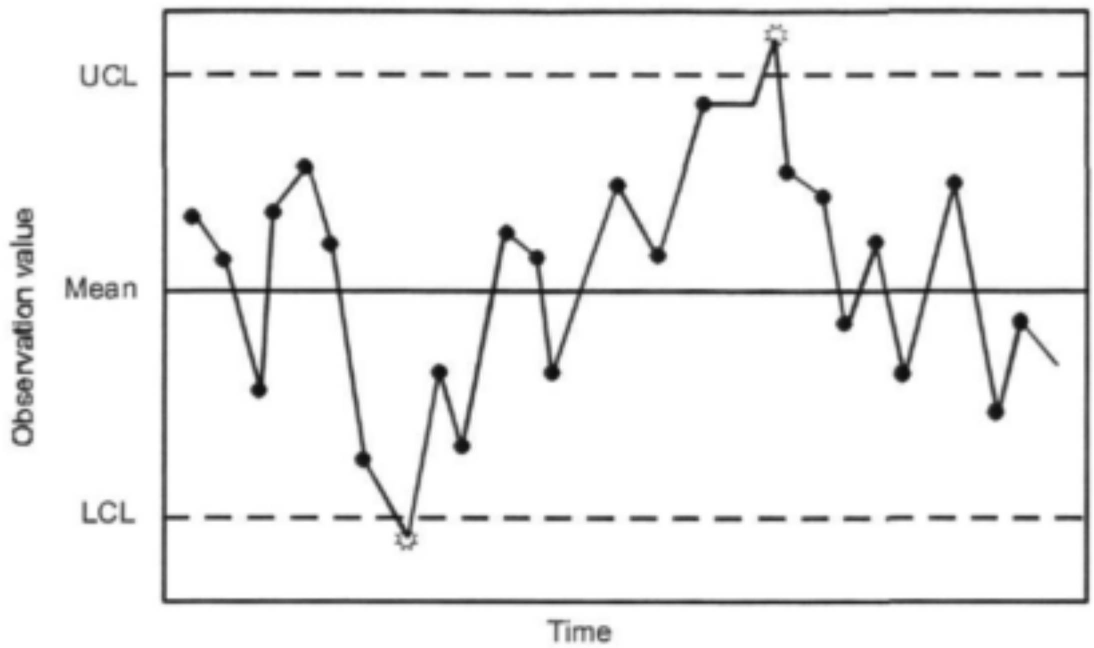


Figure 5: Water level fluctuation over time to illustrate the process control concept. In this example two observations which fall outside the control limits (UCL: upper control limit and LCL: lower control limit), thus indicating "out of control" states at these times.

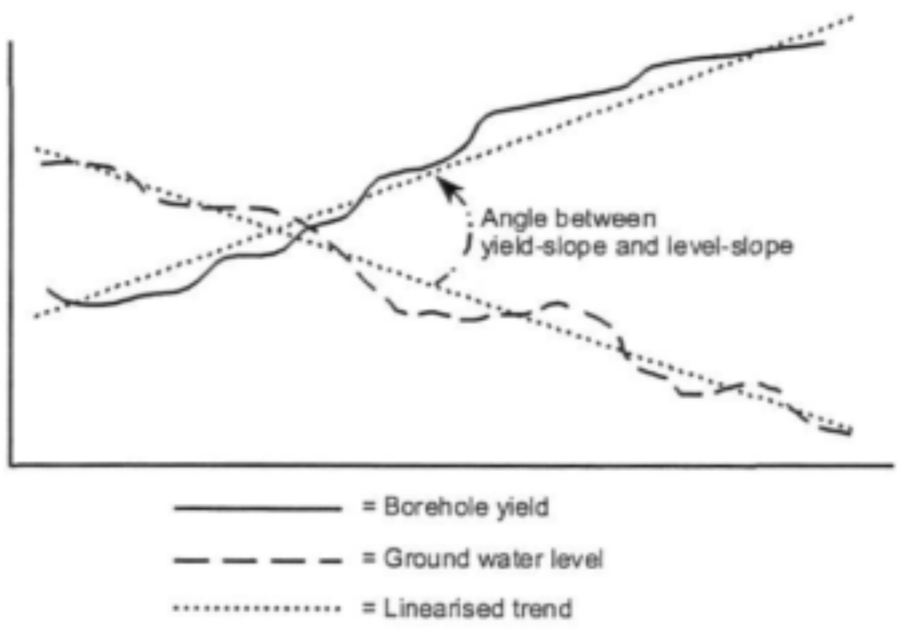


Figure 6: Graph illustrating the angle between trend in borehole yield and the trend in ground water level.

A potential problem with such a graph is that people may not be able to understand the graph, especially if there is a lack of mathematical or scientific literacy in the community. If this is the case, a graph will obviously have little significant impact.

A possible extension to the basic graph-concept would be to divide the area above and below the graph into a number of separate zones, representing different "warning levels". This is similar to the previously referred to process control methodology. The zone directly around the line representing the average reference water level can for instance be coloured yellow (indicating caution), while the area above the yellow zone can be coloured green (indicating a safe state), and the area below the yellow zone can be coloured red (indicating real danger). This is shown in **Figure 7**.

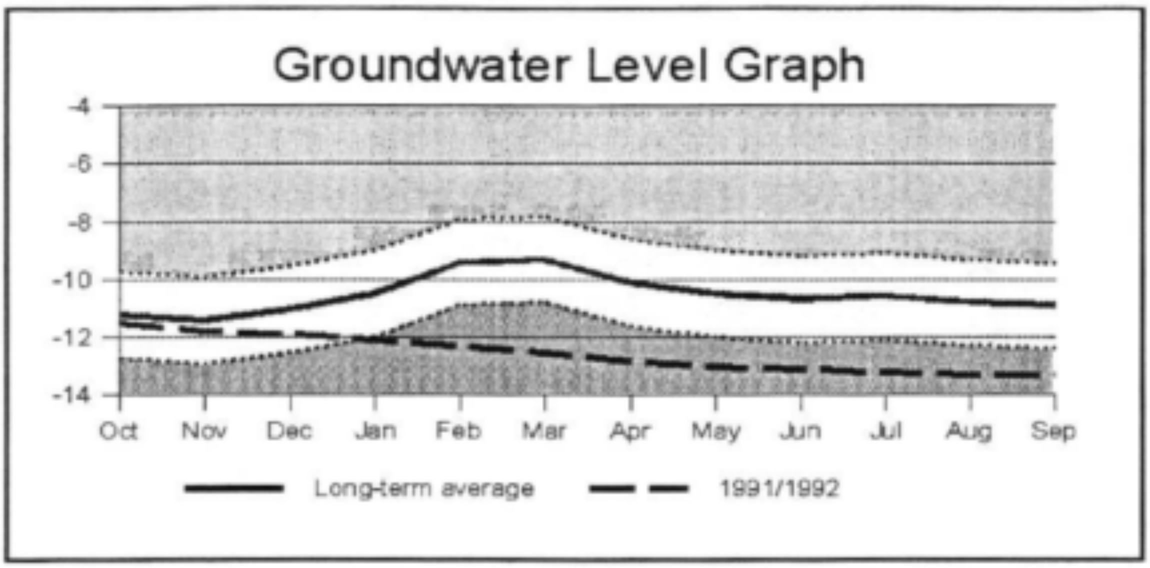


Figure 7: Groundwater level graph, showing the long-term average water-level together with the water level for a specific year, to illustrate the condition of the resource compared to the average.

If the new value for a current month is plotted, this new point will then be in either the green, the yellow or the red portion of the graph. It can then be explained to the community that as long as they remain in the green zone, they have adequate water available, and have nothing to worry about. If they are in the yellow band, things are still going reasonably well, and while there is no reason to panic, they have to ensure that they don't increase their water consumption drastically. If, however, they find that they are moving into the red section of the graph, they should realize that they may potentially have a serious problem at hand with their water resource. If this happens, they should therefore do their best to use less water wherever possible, to try and conserve their ground water resource. If they do manage to use less water than usual, the situation should not worsen too quickly, and if substantial rains occur, they should find that within a few months the water level indicator should move back into the yellow zone.

Using the colour zone system described above should help in making even illiterate members of the community understand what is happening in the ground water system. In this way they only need to see if the water level is in the green, yellow or red area, and thereby understand whether they have a ground water problem or not.

An alternative to the above paper-based graphic display would be to build a barometer- like device that can also be used to clearly display deviations from the average ground water levels (**Figure 8**).

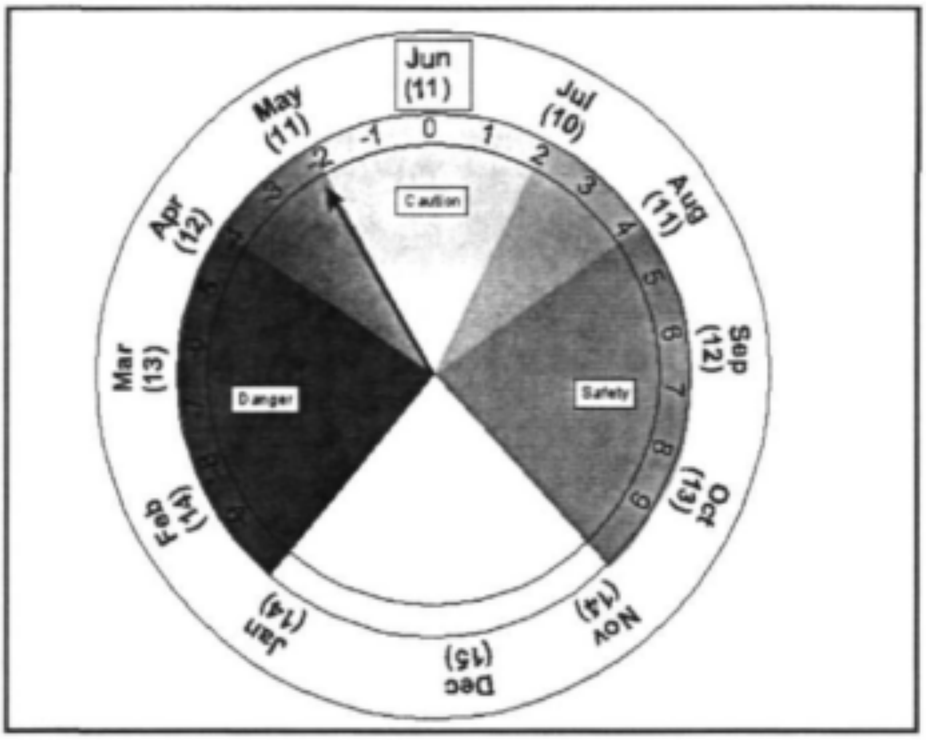


Figure 8: Barometer-type display for groundwater levels. In the real display, only a single month's values (In this case June) will be visible though the window in the front disk.

The above device will consist of two disks that can be rotated, with the one disk being placed directly in front of the other. The disk in the background will contain twelve entries written around its edge, representing the twelve months together with the long term average water level for each month. The disk in the front, on the other hand, has a square window cut out, through which a single entry from the back disk is visible. In addition, the front disk is also calibrated with positive and negative values, and has a dial which can be moved clockwise or counterclockwise to represent the amount by which the current month's water level is above or below the long term average. As in the case of the graphic display, the calibrated disk can also be divided into red, yellow and green sections, which have the same meanings as described earlier (i.e. if the water level is far below average, the dial would be in the red portion of the disc).

In the beginning of each new month, the back disk is rotated so that the entry for the previous month is visible through the window in the front disk. The dial on the front disk is then moved to represent the difference between the actual measured ground water level for that month and the long term average. For instance, if the long term average water level for the month of June is 13 m, and the measured water level is 14.5 m, this means that the current water level is 1.5 m below average, and so the dial is moved counterclockwise to -1.5 on the disk. Depending on the severity of the deviation, the dial will then point into a yellow or a red region as shown in **Figure 8**.

While both the above display mechanisms (the graph and the "barometer") are quite easy to understand, the final decision will be with the community to indicate which of the two they prefer. It may even be a good idea to use both displays - the barometer-display can help mathematically illiterate members of the community to understand the current ground water situation, while the graph has the advantage of including the history of the year-to-date, since the data for all past months remain on the graph. The graph-display also has the additional advantage of potentially being a mathematical educational tool for school children involved in the ground water management project.

4.5.2 Rainfall

Using only water level as a means of measuring the condition of the ground water resource may not be representative enough of the actual situation. It could, for instance, happen that very little rain fell during the previous months, but this has not yet had an effect on the ground water level. In such a case, the water level graph may show that everything is still going well, and that the community doesn't have to be concerned about starting to conserve water. If they then carry on using the water that is left in the aquifer at their normal consumption rates, and there is no "new" water to feed the aquifer, the consequence will be that, in the following months, the graph will suddenly start showing that they are in trouble. Apart from the fact that this would be an undesirable situation for the community to be in, it would have the further detrimental effect of weakening their trust in the water level graph: the graph indicated that everything was fine, and without any change in their behaviour it now suddenly shows their water resources are declining.

A similar problem can occur if the water level is very low (i.e. in the red zone) while good rainfall has occurred. The ground water graph may then indicate that there is a water shortage, while the real situation may simply be that the recent rain fall has not yet had a chance to impact on the water levels. For these reasons, it is crucial that rainfall figures are also taken into account in the community-level ground water management system. In the incorporation of rainfall into the system, it should be kept in mind, however, that the envisaged ground water management system ideally *has to be run by the rural community themselves,* which means It cannot include any complex mathematical modelling.

A possible way of incorporating rainfall into the system, without significantly increasing its complexity, would be to simply add some rainfall level display mechanism to the water level display discussed earlier (without attempting to incorporate any complex interaction between rainfall and ground water level in the system). This rainfall level display should in some way indicate to the community whether the rainfall in their catchment area is above or below average. One way of doing this would be to use a graph similar to the ground water graph, where the current monthly rainfall figures are plotted against the long term average monthly rainfall figures. Unlike the ground water levels, however, rainfall figures can be highly variable, meaning that for a specific month the rainfall may be far below average, while the next month's rainfall may far exceed the average. For this reason it would be very difficult for the community to see how the rainfall for the season, or for the year to date, compares to the average. Such a graph would therefore not be very useful.

A better way of displaying rainfall figures would be by using cumulative rainfall. In a cumulative rainfall graph, the rainfall for each new month will be added to the total for the year up to that point, and this cumulative sum will be plotted for each month. Similarly, a cumulative graph for the long term average rainfall can also be plotted. A comparison between the rainfall of the current year and the average rainfall of previous years then becomes much clearer. In a cumulative graph the user simply has to see which graph is the "highest". If the cumulative rainfall graph for the current year lies above the cumulative average rainfall graph, it means that more rain than average has fallen to date for the current year, and visa versa. Figure 9 is an example of a cumulative rainfall graph for a rainfall station close to Phokwane. In this figure it is clear that the 1991/92 rain fall indicates a drought condition as the cumulative rainfall was for the first 7 months of the season below the cumulative minimum, and only during the last 5 months reached the cumulative minimum.

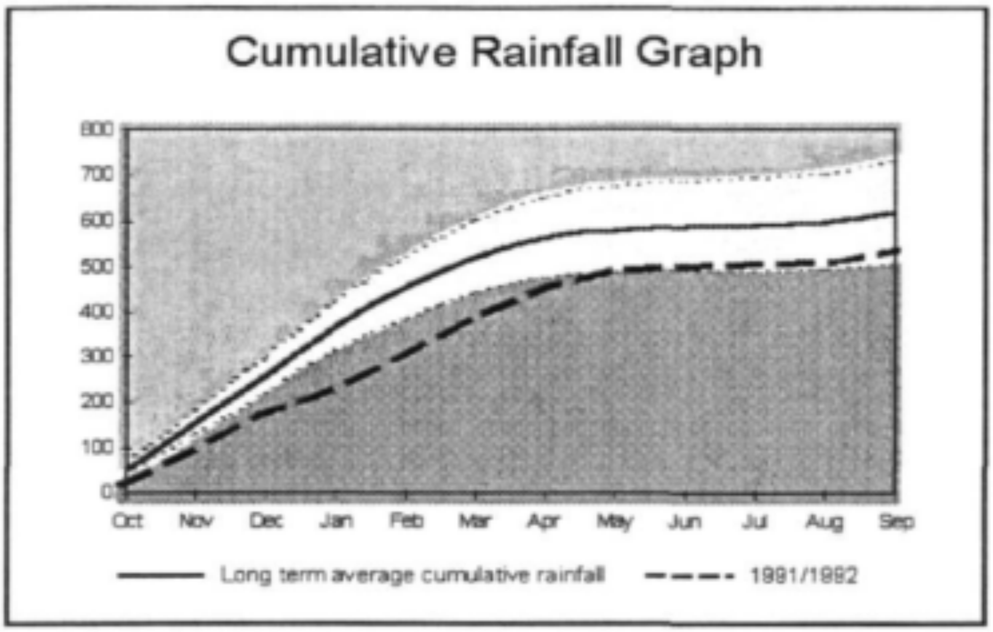


Figure 9: Cumulative rainfall graph, showing the long term average cumulative rainfall together with the cumulative rainfall for a specific year. This serves as an indication of the recharge potential of the groundwater system.

Yet another approach would be to again move away from the graph format for displaying the rainfall. As an alternative, the rainfall-to-date for the year can be displayed on a thermometer-type display, with the cumulative average monthly rainfall levels for the previous years used to calibrate the thermometer. Such a display is probably easier to understand, and it clearly shows whether the rainfall of the year is above or below average. An example of such a thermometer-type display is shown in Figure 10. An alternative and easily understandable method is to depict the status of the cumulative rainfall as the level to which a standard container (for example a 200 l drum) has been filled. The full container will represent a Anormal@ or Aaverage@ annual rainfall. The container can be calibrated on the side to show the average cumulative rainfall for the area.

Similar to the ground water display discussed earlier, it would be advantageous if the different colour zones (indicating different levels of safety) can be incorporated into the rainfall display. In the case of the cumulative graph this can again be done by simply having a yellow zone surrounding the long-term cumulative average rainfall graph, with a green zone above the yellow, and a red zone below. In the case of a cumulative graph, it should be kept in mind that the size of the yellow zone around the average graph should increase should increase as the year progresses, to allow for the effect of cumulative deviations.

In the case of the thermometer-display, incorporating the colour zones system is therefore somewhat problematic, since the positions of the colour zones will change vertically as the year progresses (it will move up each month) and also the yellow zone will widen each month. This can be accommodated by having twelve different cardboard inserts that can be replaced each month, so that the correct colour zones for each month are displayed.

4.5.3 Water consumption

As in the case of ground water and rainfall, water consumption can be displayed either by means of a graph, or by using some alternative display mechanism. In this case, however, the important factor is not so much the comparison of current water consumption figures with historical trends, but rather the water consumption graph should be an indicator of the community's response to the ground water and rainfall indicators. If the ground water resource is managed successfully, the water consumption graph should be an indicator of the community's response to the ground water and rainfall indicators. If the ground water resource is managed successfully, the water consumption graph should mimic ground water level graph, i.e. it should decrease as soon as water levels start dropping, and increase again when the water level returns to a "safe" level. The water consumption is also expected to show a seasonal variation, as a result of climatic variations. A water consumption graph can be constructed similar to the cumulative rainfall graph.

As an alternative to the above graph-format a ruler-type display (Figure 11), calibrated with a range of water consumption figures (ranging from the recommended minimum levels of 25 litres per person per day, up to some maximum level) can also be used. The display should include two indicators, one representing the long term average water consumption level, and the other indicating the water use of the last month (the "current state indicator"). For each new month, the display will indicate how far below/above average the past month's water consumption was, which will indicate whether the community is conserving or wasting water. If less water than average has been consumed, the current state indicator will be placed to the left of the long term average indicator, and if the current water use is above average, the current state indicator will be on the right.

4.6 Calibration of ground water and rainfall displays

Whether graphs or any other type of display are used to indicate the current ground water and rainfall status of a particular catchment area, it is still required to determine where the cut-off points between the different "safety zones", i.e. the red, yellow and green zones, should be. These zones are used to indicate to the community whether they are in a safe situation as far as their ground water resources are concerned, or if there is need for alarm. Once these levels have been selected, and are used as management guidelines, these will have an influence the community's water consumption, and therefore it is important that they are chosen with care. On the one hand, the community should not be lulled into a false sense of security, but at the same time the zones should not warn the users of impending danger if this is clearly not the case.

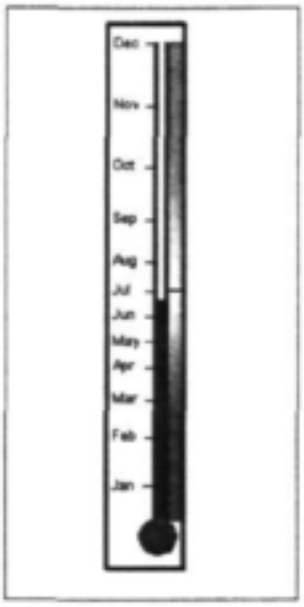


Figure 10: Thermometer type display for cumulative rainfall. The danger-level indicator shown in the figure applies to the month of July - a different indicator should be inserted for each month.

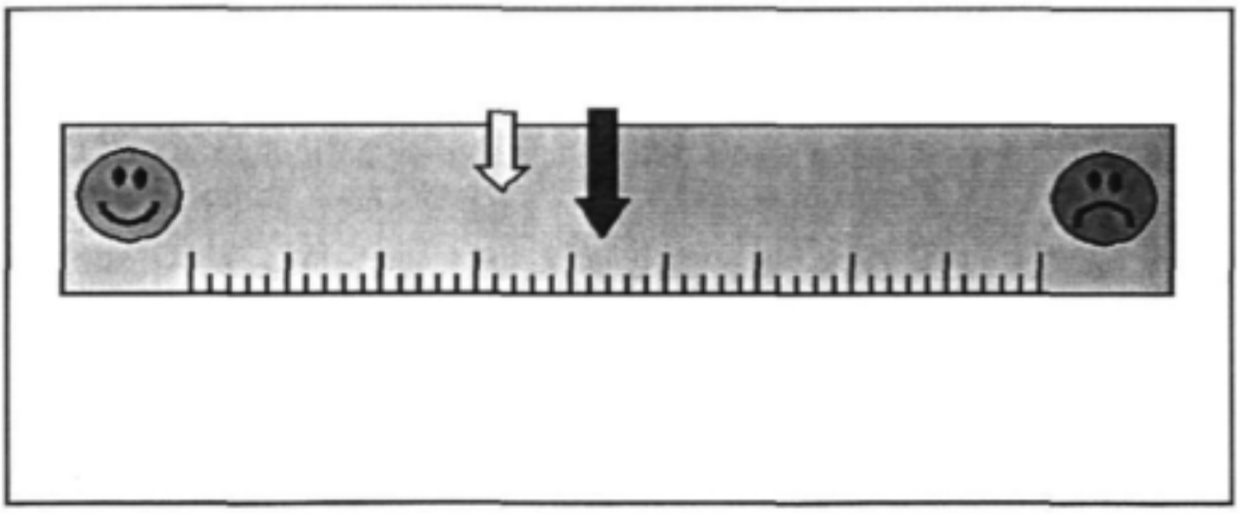


Figure 11: Ruler-type display showing current monthly water consumption (short arrow) compared to average monthly consumption (long arrow).

Ideally, the calibration of the different zones should be based on the following information:

- the size of the catchment area;
- the historical water consumption patterns in the community;
- the historical ground water levels in the area; and
- the historical rainfall figures in the area.

In these cases guidance should be given by Directorate Geohydrology of DWA&F by providing the best available estimate of ground water recharge for the catchment. For example, consider a ground water catchment or that part of the aquifer that would respond to rainfall recharge, with a surface area of say 25 00 ha (5 km x 5 km) and the average recharge from rainfall ranges from 20 to 30 mm/a. The average total volume of water replenishing the aquifer will be between 500 000 and 750 000 m^3/a. Therefore, should the size of the community dependent on that aquifer be say 20 000, the maximum average daily consumption should not exceed about 70 litres/person. This does, however, not allow a sufficient ground water reserve for below average rainfall years to ensure a steady water supply during years of drought, and the average daily consumption figure per head needs to be adjusted downward. However, this information needs to be determined for each rural aquifer management scheme individually.

Using the above information, the combined effect of water consumption and rainfall on the ground water levels can be calculated, which would provide us with accurate information on the effects that changes in water consumption may have on water levels, and when water levels are approaching dangerously low levels.

However, of the above four sets of data needed for accurate calculations, only the rainfall figures, and approximations of the ground water levels, are usually available. For this reason, it is impossible to base the calibration of the zones on actual aquifer behaviour. The best alternative is therefore to only consider the historical rainfall and ground water level information, and base the calibration of the zones on the standard deviations in the long term behaviour of the data.

In the case of the ground water level graph, the different zones are simply determined by the monthly average water levels, and the standard deviation of the annual ground water level. The size of the different zones are therefore kept constant for every month (as shown in Figure 8). The following rules can be used to determine the boundaries for the different color zones.

Below (Ave - Std dev):	*Red zone*
Between (Ave - Std dev.) and (Ave - Std dev/2):	*Changing from red to* [illegible]
Between (Ave - Std dev/2) and (Ave + Std dev/2):	[illegible] *zone*
Between (Ave + Std dev/2) and (Ave + Std dev):	*Changing from* [illegible] *to green*
Above (Ave + Std dev):	Green zone

In the case of the long term rainfall, the situation is more complex. Since use is made of cumulative rainfall, the bounds on the different zones have to widen as the year progresses, to allow for the cumulative effect.

the front disk of the barometer display containing the different zones does not have to change from one month to the next. In the thermometer display representing the cumulative rainfall, however, the sizes of the different zones, as well as the months they are being applied to, changes every month, and therefore twelve different inserts will have to be supplied to insert into the display depending on the month in question.

4.7 Responsibility for recording and displaying the information

Once the monitoring programme is well established, a structure has to be put into operation to analyse the information locally and display the results in prominent places for the community to be made aware of it. The guidelines proposed in the Discussion Document: "A framework for rural ground water management", prepared by Ricky Murray and Mohammed Dindar of the CSIR (1998), form an excellent starting point for communicating this information. It is proposed that their approach be followed initially and that it be modified with time. The transfer of monitoring information to the next level of authority, should also be according to the recommendations made by Murray and Dindar (1998).

CHAPTER 5. REPORT ON THE PILOT PROJECT AT PHOKWANE, NEBO DISTRICT, NORTHERN PROVINCE

5.1 Introduction

To implement and test the guidelines proposed for rural ground water management, the community at Phokwane near Nebo in the Northern Province was selected (Figure 12). This community is totally dependent on ground water for its water supply. Apart from a large number of privately owned boreholes, the DWA&F is responsible for the operation of a few boreholes which supply water to central storage and distribution points in the vicinity. Three of these boreholes were selected for the pilot study at Phokwane.

Phokwane is a rural community situated approximately 70 km northeast of Groblersdal. It is close to the administrative centre of Nebo and the well-known Jane Furse Hospital. The area is underlain by granite of the Bushveld Complex and has traditionally been known for its low yielding boreholes and associated low ground water potential. Ground water is the only source of water in the area and is abstracted for domestic use by numerous hand-pumps, windpumps and electric submersible pumps. A reticulation system connected to a system of several large storage reservoirs has recently been installed. These reservoirs are supplied from both surface water and ground water sources. No monitoring or management of the ground water resource has been in place prior to the start of the pilot study.

5.2 Selection of monitoring boreholes

Three boreholes were identified and used for the implementing a pilot monitoring study. Relatively large volumes of water are abstracted on a daily basis from these boreholes. These are the boreholes at the Phokwane Community Centre, at Phatametsane Secondary School and the borehole at Nebo supplying water to the Government offices and residences in the vicinity. The position of these boreholes are indicated on **Figure 12**.

The Village Water Committee of Phokwane, which was established during 1998, were informed about the project, its aims and the long term monitoring programme that was envisaged. The role of the Phokwane Village Water Committee, in consultation with the local DWA&F office at Nebo in taking responsibility of monitoring and data collection of the village's ground water resources was explained to Mr Boshelo, a member of the Water Committee. He expressed a keen interest in participating in the monitoring programme and agreed to act as contact person for the monitoring project in the Phokwane Village Water Committee.

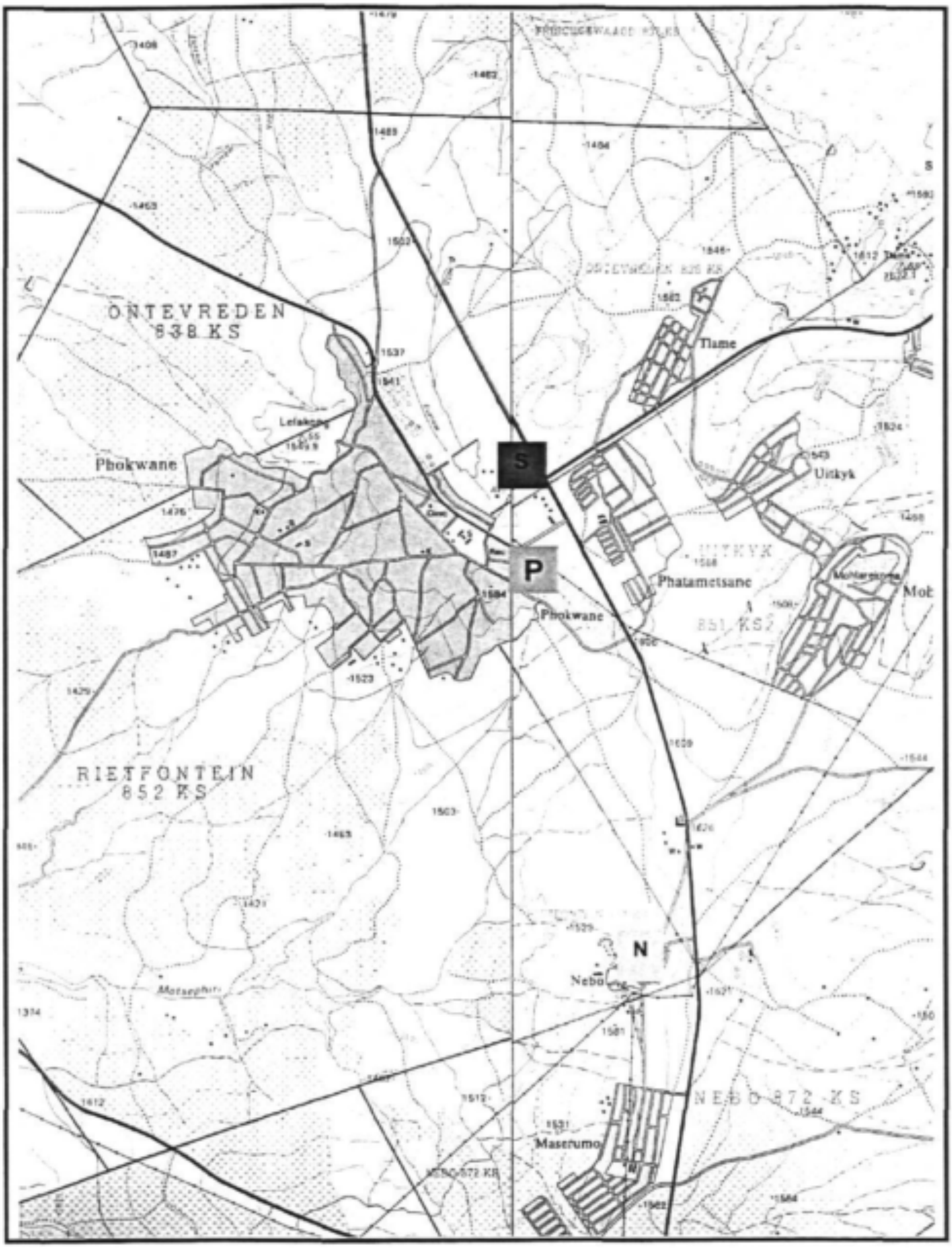


Figure 12: Locality map of the area around Phokwane and Nebo, Northern Province showing the position of the monitoring boreholes used during the pilot study (From 1:50 000 scale Topographic maps 2429DC and 2429DD; **P** :Phokwane; **S**: School; **N**: Nebo)

The DWA&F official responsible for ground water in the Phokwane area, is Mr Thomas Phahlamohlaka, and is stationed at the DWA&F offices in Nebo. He agreed to cooperate with the project team and act as a link between the pump operators, who are under his control, and the project team.

5.3 Ground water education

It is important that communities depending largely on ground water have a basic understanding of ground water in order to understand why management of this resource is required. The implementation of a basic ground water education programme should be done in communities where ground water management is performed. In the case of Phokwane, the education programme has been limited to educating the pump operators. Training included explaining the hydrological cycle, it's various components and how they relate to ground water, and training on how to use water level meters, with emphasis being placed on the accurate measurement of depth to ground water. The recording of the monitoring information, and the proper storing and archiving of it, was also emphasized. The main aim of this brief education programme was to

- to highlight the importance of ground water for domestic water supply purposes in this area and the consequences to the society should these boreholes run dry due to bad management;
- to inform the pump attendants about the role of ground water in the hydrological cycle, and the link between rainfall and ground water; and
- to emphasis the importance of monitoring water levels, rainfall and water consumption or volume pumped on a regular basis in order to implement ground water management programmes.

Water level measurement exercises were designed to test their measurement and recording skills at the completion of the training period. Following this, each pump attendant measured and recorded water level data from their respective boreholes. The data was checked for accuracy by the training instructor. All three pump operators showed the necessary skill to manage the monitoring process and were instructed to monitor water levels, rainfall and pumping volumes/times regularly on data recording sheets. An example of a data sheet provided to each pump attendant is shown in Tables 3(a) and 3(b).

A rainfall gauge was installed at the DWA&F Maintenance Team offices at Nebo and the pump attendant at the Community Centre borehole was trained in how to measure and record rainfall data.

Mr Alfred Sihiangu, the DWA&F Regional head at Nebo was also briefed about the project and it's aims. He agreed to collaborate with the project team and establish a ground water management system for collecting and storing ground water data from the pump attendants on a monthly basis. It was agreed that the pump attendants should submit their borehole log sheets to Mr Sihianqu at their monthly meetings.

5.4 Geohydrological conditions at Phokwane

Geologically the area is underlain by the Nebo Granite of the Bushveld Complex, which is generally regarded as an area with low ground water potential. Vegter (1995) has allocated a 20% probability to drilling a borehole with a yield of >2 l/s in the area and a probability of drilling a successful borehole with this yield being <40%. A current WRC project managed by Prof Willem Botha of the Geology Department at the University of Pretoria in which different sets of geophysical data and other remotely sensed data are analysed and integrated with geological information, has resulted in good successes in the siting of high yielding boreholes in these areas (Combrinck, 1999). High yields were obtained in the newly drilled boreholes sited on the geophysical results in an area some 30 km north of Nebo. Currently similar techniques are employed to site new exploration boreholes in a second study area to the northwest of Nebo, including the area around Phokwane. Provisional interpretation of the aeromagnetic data collected for the area revealed some major geological structures which appear to be associated with dolerite intrusions. These structures will be targeted during the exploration drilling programme.

Vegter (1995) reports that the safe abstraction rate for the area is 4 mm/a (or 4000 $m^3/km^2/a$), whereas Haupt (verbal comm.) is of the opinion that the safe abstraction rate is almost double at about 7 mm/a (or 7000 $m^3/km^2/a$). Due to the apparently low ground water potential, the area is believed to be very vulnerable to the (temporary) depletion of aquifers and subsequent drying up of boreholes. This aspect, coupled to the almost total dependence on ground water for domestic supplies in large parts of this granitic terrain, has led to the selection of Phokwane for the pilot study.

A search on the National Groundwater Database indicated the highest recorded borehole yield to be 5 l/s, although in general yields are below 1 l/s. The pumping rate of the three monitoring boreholes are between 0.29 and 1 l/s. The average annual rainfall in the area is approximately 500 mm/a. According to Vegter (1995) ground water recharge in the area underlain by Nebo granite varies between 10 mm/a and 25 mm/a. This translates into a recharge figure of between 10 000 and 25 000 $m^3/km^2/a$.

Chemical analyses of samples collected during the pilot study as well as those reported in the NGDB indicate that in general the ground water is of very good quality (**Table 8**).

The average Electrical Conductivity of 39 samples from the area is 23 mS/m with the range between 8.2 and 74 mS/m. What is, however, alarming is the high concentrations of NO_3 in selected boreholes. The average for the area is 10.2 mg/l with a range of between 1 and 57 mg/l. There is also a good correlation between high NO_3 and high Potassium (K) which indicates pollution. The high nitrate concentrations prompted the use of nitrogen isotopes to identify the source of the nitrate. Four samples with high nitrate concentration were selected for ^{15}N isotope analyses. These analyses indicated that nitrate concentrations in excess of approximately 8 mg/l can be attributed to faecal contamination, whereas those with a lower nitrate concentration can largely be attributed to mainly natural causes (**Figures 13 and 14**). The high NO_3 concentrations listed in Table 8 are most probably the result of contamination caused by the local sanitation systems. Eight samples were also submitted for microbiological analyses. No faecal coliform bacteria were found in any of these samples, but several samples had heterotrophic plate counts above 100/ml.

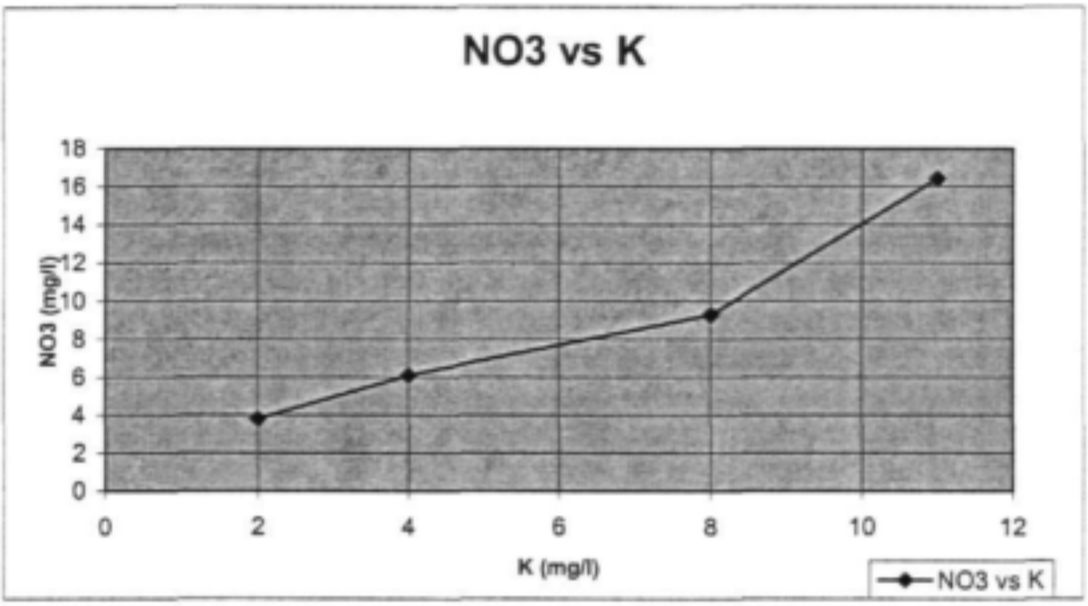


Figure 13: ^{15}N isotope value plotted against $1/NO_3$ concentration for selected water samples from Phokwane.

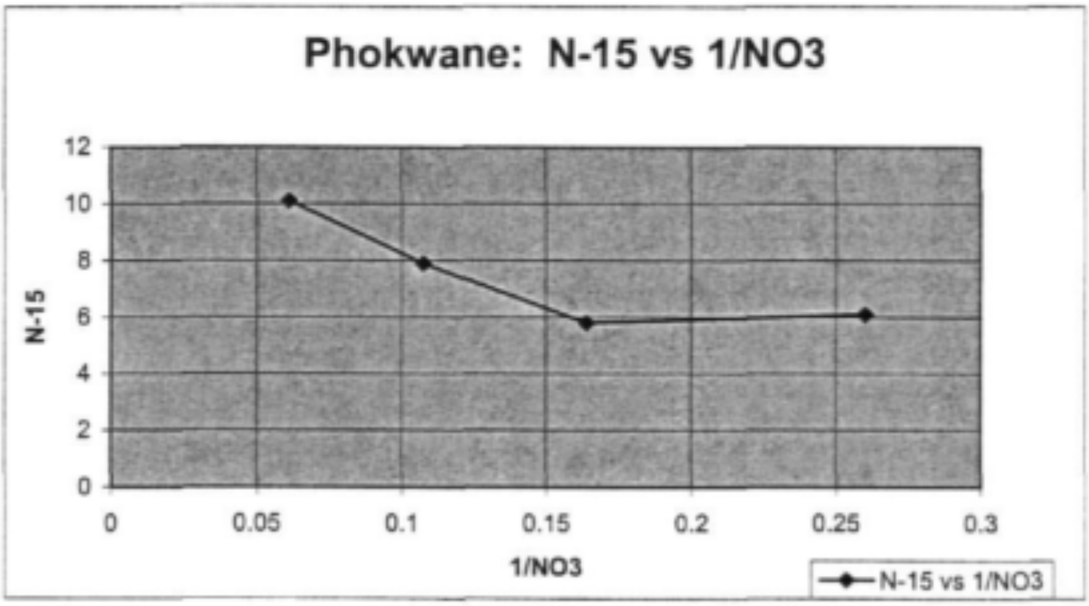


Figure 14: NO_3 concentration plotted against potassium (K) concentration for selected water samples from Phokwane.

Table 8: Results of chemical and isotope analyses of water samples form the area around Phokwane. The majority of the analyses were taken from the National Ground Water Quality Database.

H-No	Date	Latitude	Longitude	Farm No	Name	EC mS/m	TDS	PH	Na	Mg	Ca	F	Cl	No_3+NO_2 as N	SO_4	PO_4	T Alk	S.I	K	NH_4-N	^{18}O	^{15}N
96016395	19960911	-24.85528	29.76694	TKS0838	Ontevrede	15.3	119	7.83	11.6	3.9	10	0.19	3.5	6.4	0	0.008	48.2	28.05	2.9	0.015	nd	nd
96016383	19960911	-24.85639	29.7625	TKS0838	Ontevrede	18.5	130	7.71	14.6	2.4	13.2	0.12	5.4	9.6	0	0.005	39.7	22.85	3.5	0.013	nd	nd
96016644	19960906	-24.86056	29.75972	TKS0851	Uitkyk	19.5	145	8.2	12.6	6.8	12.6	0.54	4.3	6.6	0	0.005	63.3	31.1	2.1	0.03	nd	nd
96016632	19960910	-24.86167	29.75833	TKS0851	Uitkyk	22.4	144	7.2	14.9	3.8	13.2	1.22	5.6	12.4	0	0.005	36.8	26.5	5.1	0.02	nd	nd
960188352	19960918	-24.86194	29.75389	TKS0838	Ontevrede	10.3	70	7.49	8.4	1.5	3.8	0.2	4.2	4.3	0	0.005	22.6	28.5	5.1	0.03	nd	nd
96016607	19960910	-24.86222	29.75917	TKS0851	Uitkyk	20	124	7	12.1	4.1	6.4	0.1	5.8	13.4	0	0.005	22.5	24.7	8.4	0.02	nd	nd
96016670	19960906	-24.8625	29.76306	TKS0851	Uitkyk	36.2	238	6.84	27.3	7.1	21.7	0.17	20.8	29.7	0	0.005	18.6	21.5	6.9	0.04	nd	nd
96016528	19960905	-24.86306	29.77333	TKS0851	Uitkyk	50.2	316	7.01	31.6	9.3	34.7	0.21	35.6	30.8	0	0.005	49.5	21.8	7.9	0.04	nd	nd
96016711	19960910	-24.86444	29.76056	TKS0851	Uitkyk	23	147	6.82	18.2	4.8	7.6	0.12	12.8	16.2	0	0.005	18.9	23.0	9.3	0.32	nd	nd
96016693	19960910	-24.86556	29.76139	TKS0851	Uitkyk	22.4	138	7.33	15.8	4.9	8.3	0.11	12.6	14.9	0	0.005	17.4	21.1	9.7	0.03	nd	nd
96016668	19960910	-24.86583	29.76056	TKS0851	Uitkyk	41.3	267	6.84	24.9	11.5	17.1	0.13	28.9	31.8	0	0.005	21.4	23.4	15.5	0.11	nd	nd
96016681	19960906	-24.86611	29.7625	TKS0851	Uitkyk	18.2	118	7.19	14.1	3	8.5	0.17	7.9	12.6	0	0.005	19	23.6	4.9	0.04	nd	nd
96016553	19960905	-24.86611	29.77861	TKS0851	Uitkyk	20.6	158	7.84	11	6.9	17.9	1.19	3.8	3.3	0	0.005	82.8	25.9	1.2	0.04	nd	nd
96016530	19960905	-24.86722	29.77065	TKS0851	Uitkyk	10.7	79	7.38	8.5	1.8	7.4	0.48	6	3.9	0	0.005	30.8	24.8	2.4	0.03	nd	nd
96016541	19960906	-24.86722	29.77278	TKS0851	Uitkyk	19.4	131	7.2	12.7	2.5	14.8	0.58	83.4	11	0	0.005	35.9	23.5	2.1	0.04	nd	nd
96016700	19960906	-24.8675	29.76222	TKS0851	Uitkyk	74	496	7.47	55.6	25.5	38.8	0.12	7.2	56.6	0	0.005	25.7	21.7	10.3	0.16	nd	nd
96016723	19960911	-24.86889	29.76194	TKS0851	Uitkyk	16.6	109	7.15	13	2.5	6.9	0.14	3.3	9.8	0	0.005	25.1	23.2	4.5	0.02	nd	nd
96016590	19960911	-24.86972	29.75417	TKS0851	Uitkyk	10	72	6.97	10.4	1.6	4.5	0.29	3.4	101	0	0.005	36.2	26.14	2.8	0.03	nd	nd
96016820	19960906	-24.86972	29.755	TKS0851	Uitkyk	13.6	89	7.22	9.7	2.5	6.7	0.81	9.9	2.8	0	0.005	41.2	24.9	3.4	0.02	nd	nd
96016619	19960910	-24.87028	29.76361	TKS0851	Uitkyk	18.9	111	6.71	15.7	2.7	6.9	0.11	3.9	12.3	0	0.005	13.6	19.0	4.7	0.07	nd	nd
96016656	19960904	-24.87389	29.76028	TKS0851	Uitkyk	11.5	87	7.22	8	2.1	4.6	0.25	12.4	3.4	0	0.005	39.4	26.7	5.2	0.03	nd	nd
96016450	19960905	-24.88028	29.77583	TKS0851	Uitkyk	22.8	147	7.56	16.3	2.6	17.5	0.22	4.2	13.5	0	0.005	27	23.1	4.6	0.02	nd	nd
96016401	19960904	-24.88083	29.78194	TKS0851	Uitkyk	12.6	94	7.19	9.7	3.2	6.9	0.28	3.1	4.8	0	0.005	37.1	25.1	2.8	0.01	nd	nd
96016462	19960904	-24.88389	29.77361	TKS0851	Uitkyk	8.9	70	7.54	9.1	0.9	3.3	0.22	4	2.9	0	0.005	29.5	24.9	3.0	0.04	nd	nd
96016747	19960904	-24.88778	29.7725	TKS0851	Uitkyk	14.4	96	7.65	10.3	1.4	5	0.32	3.5	3.1	0	0.005	45	25.4	3.3	0.06	nd	nd
96016413	19960904	-24.88944	29.76917	TKS0851	Uitkyk	8.5	66	7.07	7.9	1.3	2.8	0.21	3.7	2.5	0	0.005	28.2	21.0	4.3	0.02	nd	nd
96016759	19960904	-24.89	29.77028	TKS0851	Uitkyk	8.5	77	7.31	9.1	1.9	4.7	0.26	3.1	0.4	0	0.005	37.9	18.1	2.1	0.03	nd	nd
96016449	19960904	-24.89056	29.76833	TKS0851	Uitkyk	8.2	68	7.36	6.9	1.4	2.3	0.24	4.9	1.1	0	0.005	36	20.1	5.0	0.02	nd	nd
96016589	19960829	-24.91889	29.76139	TKS0872	Nebo	14.8	94	6.93	13.4	2.2	5.5	0.16	4.3	9.1	0	0.005	20.3	22.4	3.4	0.03	nd	nd
96016577	19960829	-24.92389	29.76147	TKS0872	Nebo	12.1	82	7.54	6.2	2.9	6.2	0.17	21.5	2.8	0	0.005	35.9	25.8	6.6	0.03	nd	nd
96016565	19960829	-24.93	29.755	TKS0872	Nebo	32.9	194	7.47	19	8.1	16.9	0.27	5	17.5	0	0.005	34.5	21.0	8.0	0.04	nd	nd
Phokwane-1						10.4		6.4	10	2	6	<0.2	<5	3.8	0	0.005	26	17.6	2	0.2	-3.7	6.1
Phokwane-2						9		6.4	9	1	4	<0.2	<5	3.2	0	0.005	25	23.4	4	0.2	-3.0	nd
Phokwane-3						10.6		6.3	12	1	4	<0.2	6	2.2	0	0.005	35	27.2	4	0.2	-3.6	nd
Phokwane-4						12.1		5.9	10	2	5	0.3	11	6.1	0	0.005	19	20.7	4	0.2	-3.8	5.8
Phokwane-5						17.5		6.1	14	3	9	<0.2	<5	9.3	0	0.005	19	24.1	8	0.2	-3.9	7.9
Phokwane-6						10.6		6.1	11	1	4	<0.2	21	2.3	0	0.005	32	25.5	5	0.2	-3.8	nd
Phokwane-7						26.1		6.1	16	7	14	<0.2	<5	16.4	0	0.005	25	23.8	11	0.2	-3.9	10.1
Phokwane-8						10.8		6.1	11	1	3	<0.2		2.9	0	0.005	20	18.2	5	0.2	-3.6	nd

5.5 Results from monitoring at Phokwane

Monitoring of water levels, pumping periods and volumes, and rainfall started in August 1998 with the recording of water levels at the Phokwane Community Centre borehole. This was followed by the Nebo Community Centre borehole in November 1998 and the Phatametsane Secondary School in December 1998.

Water level history, as recorded on a weekly basis, over these periods from the three boreholes is displayed in **Figures 15 to 17**. It is clear from these graphs that there were problems with the water level measurements during the course of the year. The more serious problems have been gaps in the datasets and incorrect measurements resulting in sudden changes in the water level.

From these graphs it appears that the boreholes have not really been stressed for the last year as there is little variation in the water levels before pumping started and those just before pump switch off. This can either be an indication that the boreholes are pumped at a rate well below their sustainable yield, the presence of an extensive aquifer with large storage, and good annual recharge. No distinctive water level variation patterns are visible on the record of the Phokwane Community Centre borehole data. Statistical analyses of water level and rainfall data of a site with similar geology as the pilot site, indicate that the lag between rainfall and ground water recharge is less than 6 months, i.e. ground water recharge takes place in the same rainfall season.

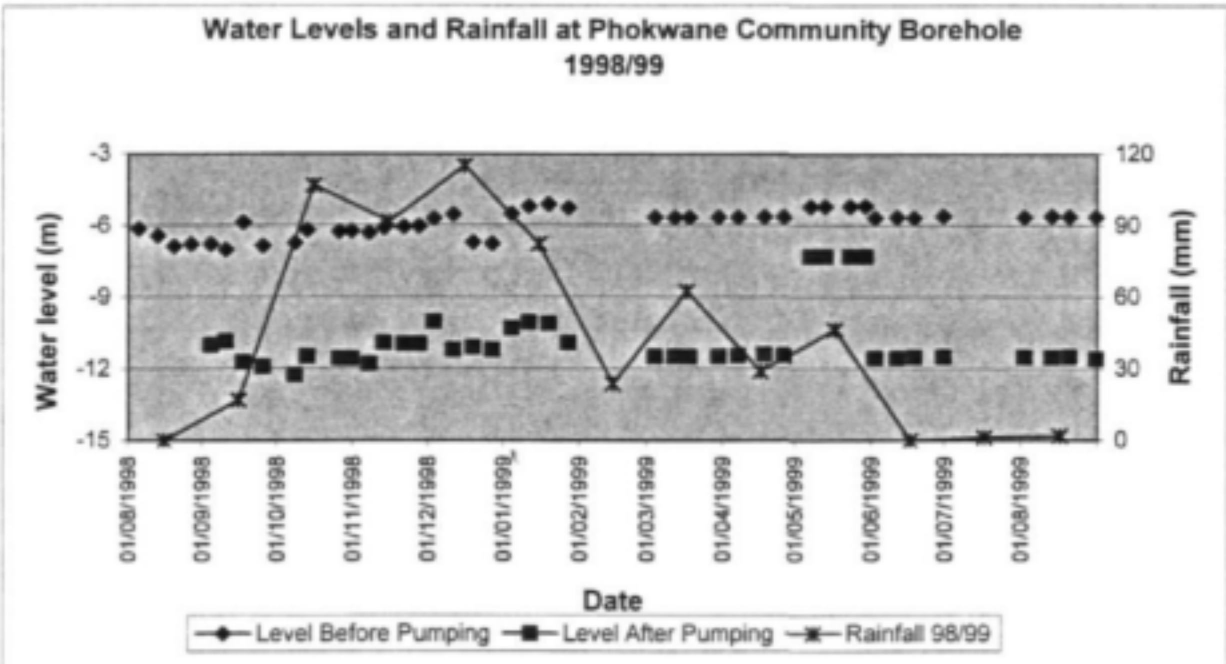


Figure 15: Water level and rainfall record at the Phokwane Community Centre borehole for 1998/199

However, at two of the boreholes, the Nebo and the school boreholes, interesting trends are noted (**Figures 16 and 17**). In the case of the Nebo borehole, there is a clear long term decline in the water level as measured just before pump switch off. Although the magnitude of the decline is less than one metre, the downward trend is still important to note. This declining trend is not visible in the static water level measured at pump switch on, but correlates well with the decline in rainfall. This trend is interpreted as being due to a reduction in storage. In the case of the Phatametsane Secondary School borehole a slight long-term decline in water level before pump switch off can be seen.

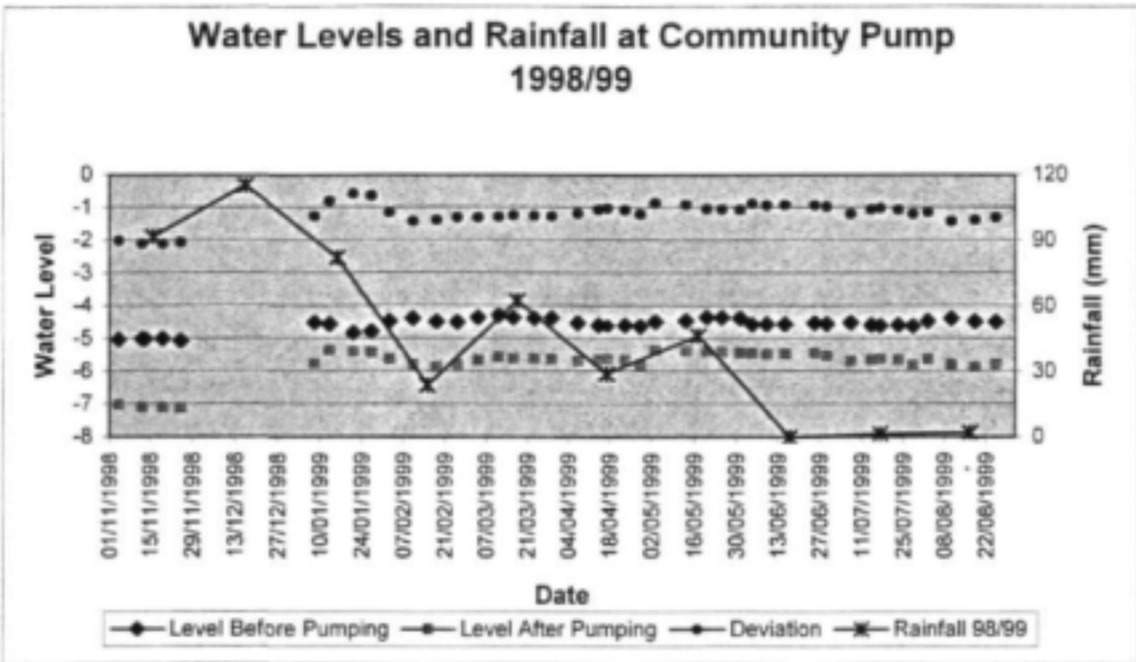


Figure 16: Water level and rainfall record at the Nebo Community borehole for 1998/199

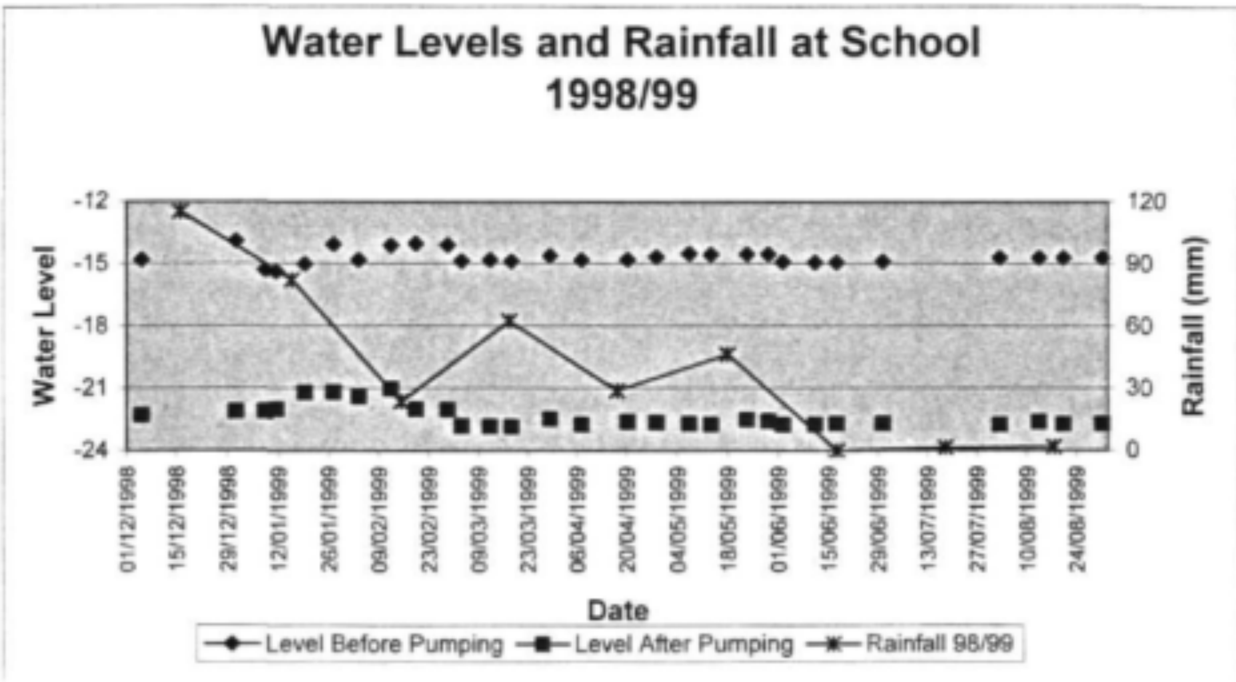


Figure 17: Water level and rainfall record at the Phatametsane Secondary School borehole for 1998/1999.

The monitoring of rainfall was not satisfactory during the period of the pilot study. The cumulative rainfall as recorded by the pump attendants is also much lower than that recorded at the Lobethal rainfall station some 15 km north of Nebo. This indicates incomplete recording of rainfall and is not representative of the total rainfall the are received over this period. For the purpose of this report rainfall information from the Weather Bureau was used in the different graphs. Three rainfall monitoring stations with a reliable recording record of more than 10 years have been selected and used in the interim. Of these the rainfall station Lobethal is the closest to Phokwane.

The average cumulative monthly rainfall for the three stations, together with the cumulative average for 1998/99 shown in **Figure 18**. These graphs clearly reflect that the bulk of the rainfall is experienced during the period October to January (~100 mm/month average), with a slightly reduced rate between February and May (~40mm/month average), and almost no contribution during the months of June to September (~5 mm/month average). Historical data show that the average annual rainfall in the pilot area is approximately 510 mm, with a standard deviation of 18.4%. This is displayed on Figure 18. Combining this information with the information on the monthly deviations from average rainfall, we can calculate the different zones for our cumulative rainfall graph. The cumulative graph with its safety zones (calculated at a 18.4% standard deviation) is shown in Figure 18. From this it is seen that the 1998/99 rainfall season was abnormally high by 18% standard deviation above the annual rainfall, and plots almost exactly on the highest rainfall year on record.

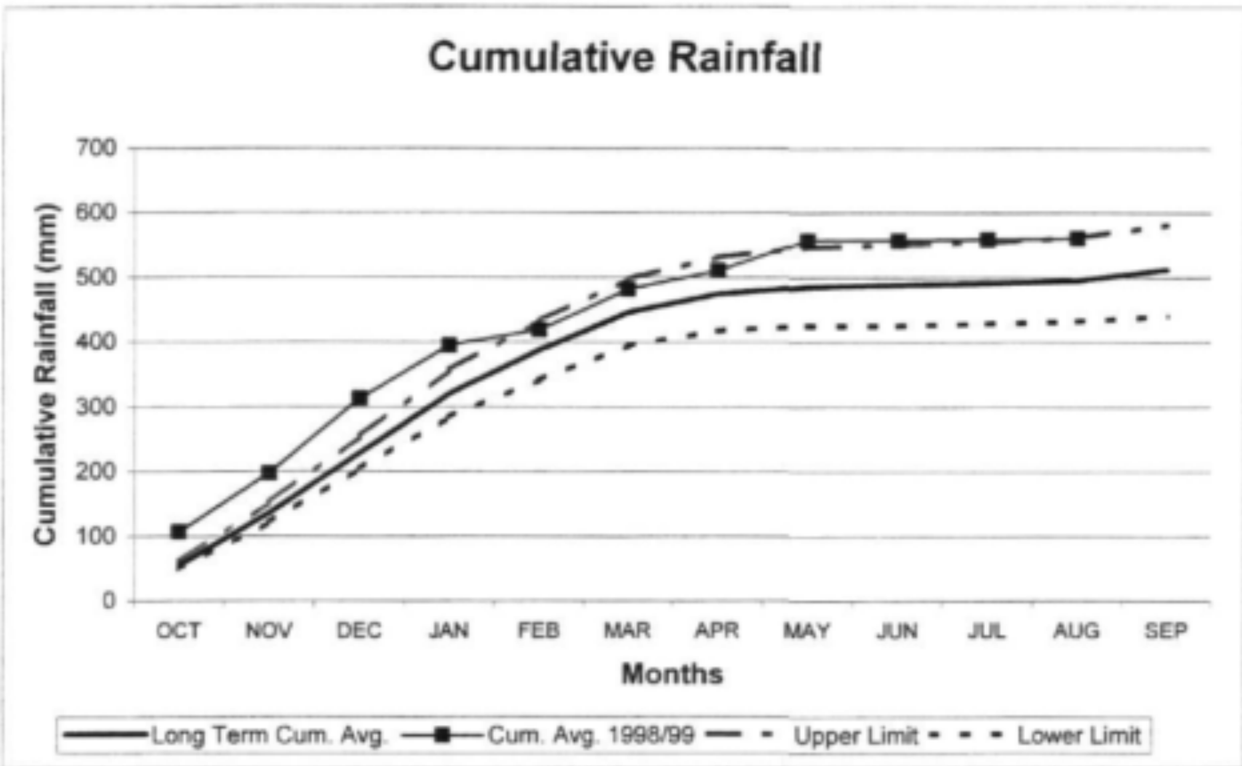


Figure 18: Cumulative average monthly rainfall for the Nebo District.

Comparing the water level fluctuations, and in particular the water level Adeviation@ (difference between water level before pump switch on and just before pump switch off) with the rainfall pattern (**Figure 19**), it appears that the aquifer response is different at the different boreholes:

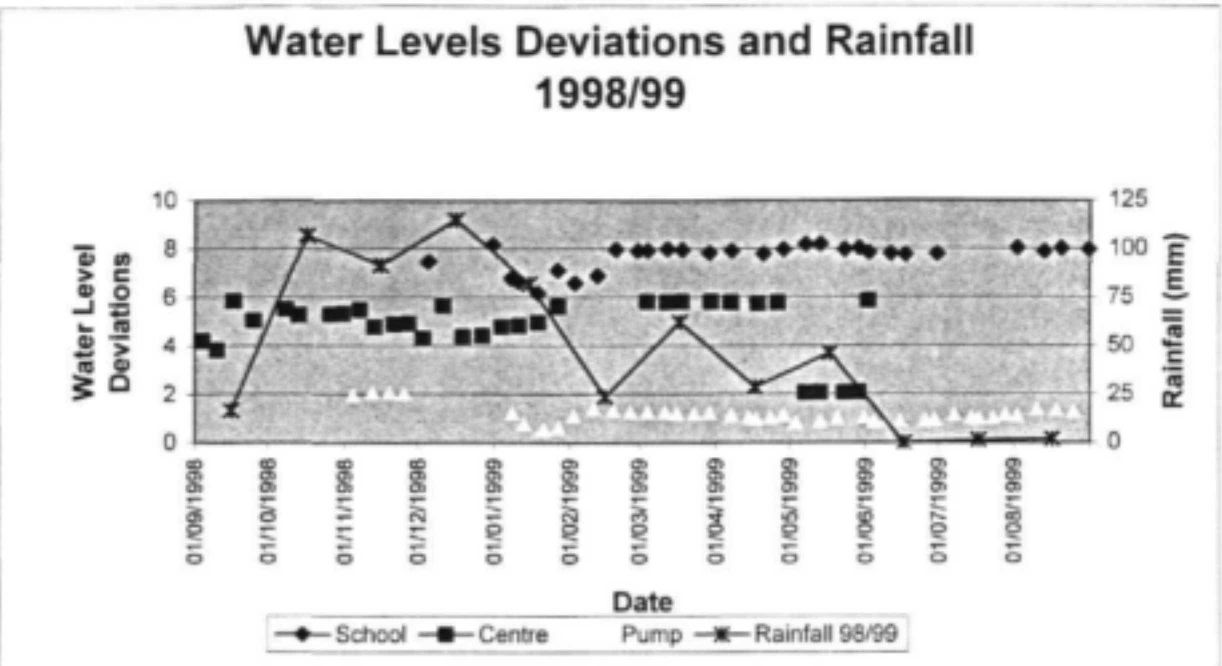


Figure 19: Weekly water level deviations and monthly rainfall record for the three monitoring boreholes.

- In the case of the Phokwane Community Centre borehole the decrease in water level correlates well with the period of high rainfall. It would, however, appear that during the first few months of the rainfall season (October 1998 to January 1999), recharge did have an effect on the borehole as the difference between "before" and "after" pumping water levels is less than over the period when no rainfall has been recorded (**Figure 19**). Also in the period before the rainfall season started, static water levels were somewhat deeper (August to September 1998). It would therefore appear that there is very little delay between the larger rainfall events and the response of the water level. However, towards the end of the rainfall season, the recharge contribution is not visible in terms of rising water levels.

- Because the 1998/99 rainfall season appeared to be an high rainfall year (Figure 20), more recharge can be expected and therefore ground water levels in the monitoring boreholes, will react less than in dry years. The cumulative rainfall for 1998/99 is almost identical to the upper limit of the 'safe yield= zone of boreholes in this area.

- In the case of the Phatametsane School borehole there is a lag of about 1-2 months before water levels start reacting to rainfall. As is the case with the Phokwane borehole, once the main part of the rainy season is over (end February), no further deviations in water level can be observed.

- In the case of the Nebo Community borehole there is a general decrease in the "deviation" over a period of about 7 months (November 1998 to May 1999). Comparing this to the cumulative rainfall pattern, there is a lag of about 2 months.

The situation here differs from that at the Phokwane borehole in that the decline in the deviation occurs apparently over the entire rainfall season, where as in the case of Phokwane, the recharge contribution is only manifested during the high rainfall months.

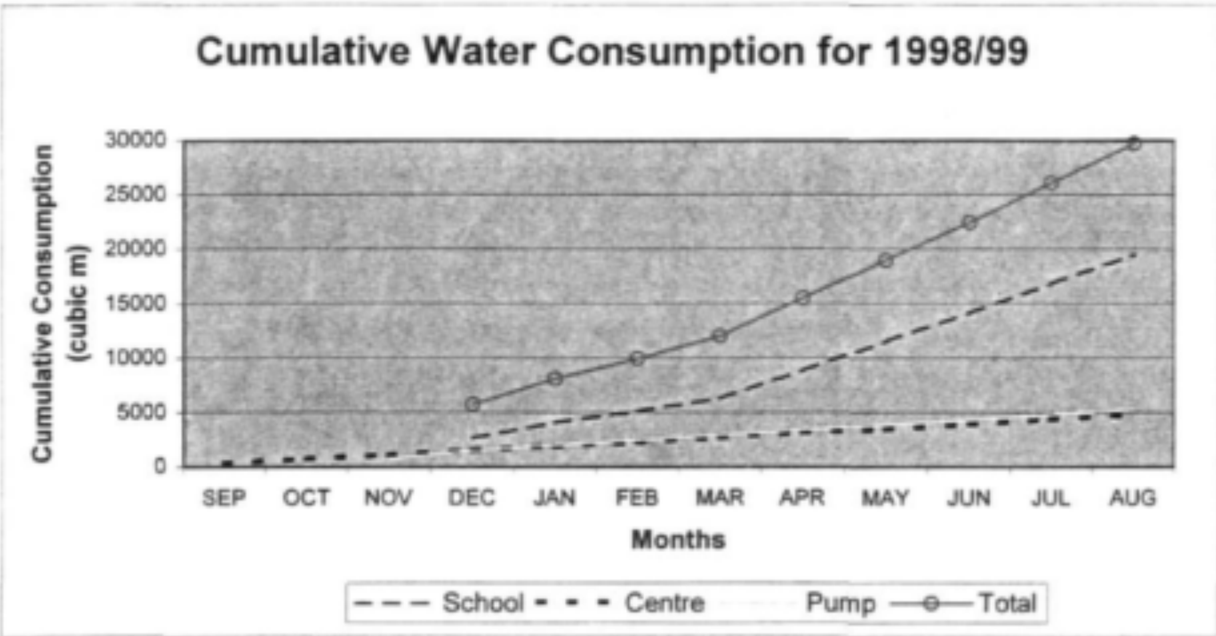


Figure 20: Cumulative water consumption at the three monitoring boreholes.

It must be remembered that all the conclusions described above a only based on a one year record, and that in some cases the data set is rather incomplete due to measurement errors and other reasons described earlier. The longer the data set becomes, the more reliable will any predictions be that are made from these results. Once longer datasets are available, Cumulative Rainfall Departure (CRD) theory described by Bredenkamp *et al* (1995) can be applied to the data.

The cumulative water consumption (1998/99) graph displayed in **Figure 20** is not a true representation of the volume of water used, but rather displays the cumulative monthly volume of water pumped from the three boreholes individually and the total cumulative volume pumped. The reason for this is that the pumping schedule is not demand driven, but operates according to a fixed pumping schedule (i.e. switch on and switch off times are predetermined). One way to change this pattern, would be to implement an automatic switch on and switch off system that is activated by the water level in the reservoirs. This would also necessitate a flow meter in the distribution line.

The projected cumulative volume of ground water pumped from the three boreholes is 40 000 m^3/a or about 3 300 m^3/month. The distance between the furthest two boreholes is approximately 5 km. The sustainable yield figures reported by Vegter (1995) and Haupt (1998) for this area are approximately 4 000 m^3/km^2/a and 7 000 m^3/km^2/a respectively. This is equivalent to a recharge of 4mm/a and 7 mm/a respectively. The boreholes at Phokwane and Nebo are about 5 km apart. By using the 4 mm/year safe abstraction rate proposed by Vegter (1995), 100 000 m^3 is theoretically available. The cumulative annual abstraction from the three boreholes is currently about 40% of this volume. Based on these estimates, it appears therefore that the ground water resources of the area are under-utilised. Using the safe abstraction rate proposed by Haupt (1998), only about 25% of the available on a sustained basis is currently used. It must also be realised that many private boreholes exist in this area, but the combined volume of water pumped from these is estimated to be far less than that is pumped from the three main production boreholes. In this assumption, the possible effect linear structures are not taken into consideration. The work by Combrinck (1998) has shown that major linear structures, notably faults and dykes occur within the Nebo granite. The from her work it would appear that the contact zone between the dykes and the Nebo granite is in general not a significant water bearing zone, but it may influence lateral movement of ground water.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

During the first part of the project different techniques were proposed for the display of ground water monitoring information. In order to test these, a monitoring programme was implemented in Phokwane, a village in the Northern Province which is totally dependent on ground water for its water supply. Although monitoring information was only available for a one year period, a number of important lessons were learnt. Several conclusions and recommendations for the implementation of future ground water management programmes in rural communities could be derived. These can be summarized as follows:

- Through the monitoring of only four fundamental geohydrological parameters, water level, rainfall, discharge and water quality, sufficient information can be collected to prepare time series graphs of these parameters which can be used for ground water management at community level.
- A number of different and easily understandable graphical display techniques have been proposed which can be used to visualize the behaviour of the aquifer for different abstraction and rainfall conditions.
- A disadvantage of most ground water management programmes is the lack of historic ground water monitoring information. Management of ground water schemes will continuously improve as longer time series of monitoring data become available.
- It is also important to keep the community responsible for the management of the ground water resource not only interested in the management programme during this period while building a longer term data set, but hey also need to understand why the monitoring is important and in their own interest. Accurate monitoring and buy-in from the community is crucial for the proper management of the ground water resource.
- From the short record of monitoring information collected during the pilot study at Phokwane, it would appear that, despite all three boreholes situated in the same geological environment, each borehole reacts differently to pumping. In some cases there appears to be a lag of a few months between rainfall events and the water levels responding to such events. On the other hand, at one of the three monitoring boreholes no lag could be observed. This illustrates how important it is to obtain baseline information on all boreholes used for abstraction and in larger monitoring programmes. A proper knowledge of the hydraulic characteristics of boreholes, will lead to an improved understanding of the behaviour of the aquifer under conditions of abstraction.
- A monthly cumulative rainfall plot is very informative and can be used to provide a first indication of whether sufficient recharge is occurring and whether the aquifer is over or under exploited. By using the rainfall information of nearby rainfall recording stations, maximum and minimum monthly cumulative rainfall curves can be constructed which can be used as a guideline as to whether ground water recharge would occur in a specific season or not. As soon as a rainfall record for a number of

years is available, this will replace the data from the surrounding stations. In this regard it is recommended that cumulative rainfall measurement instrument be installed at each borehole used in future monitoring programmes.

- It is also clear from the monitoring programme that unless the abstraction rate from a borehole is such that the aquifer is placed under stress from time to time, the monitoring data is of little use. In such cases the monitoring and management of the resource is actually not required, and the danger exists that the community responsible for the management will loose interest in the continuous monitoring.

A number of important lessons were learnt during the one year of monitoring different parameters at the three boreholes at Phokwane.

It is important that reliable geohydrological information of all the boreholes forming part of the monitoring network is available. It is critical to know what the sustainable yield of each borehole is in order to be able to pump the borehole at maximum sustainable yield. This will ensure that available funds for operating the ground water scheme are used optimally. By pumping at the maximum yield but for shorter periods, the aquifer is put under more stress, and managing becomes relevant. By not putting the aquifer under stress, monitoring of aquifer behaviour may become irrelevant and result in a lack of interest to maintain the monitoring programme. For each community where ground water management programmes are to be implemented, a survey of water needs and demands and average expected water consumption is required. The survey should also include a hydrocensus.

It was also clear that especially in setting up the monitoring and management scheme, frequent visits to the pump attendants are required to attend to problems and to ensure reliable data are collected. For each pump operator, a backup operator, trained to perform the monitoring functions, should be available. This will ensure that no gaps occur in the monitoring data sets.

It is recommended that cumulative rainfall monitoring equipment be installed at all ground water monitoring schemes. From a management point of view, it is preferable to have information on consumption rather than abstraction volumes. Apart from all fitting to all production boreholes in line flow meters to measure volumes abstracted, it is further recommended that volumes released from the storage reservoirs is also monitored and recorded. This will provide valuable information on water losses occurring in the scheme.

Due to the high nitrate concentrations observed in selected borehole, it is recommended that when sampling for microbiological analyses are conducted bi-annually, nitrate concentrations should also be analysed for. Any substantial increases in the nitrate concentration should be immediately reported to for example the Service provider for the area. Pump operators should also be issued with a portable EC meter and instructed to measure EC on a weekly basis. They should further also receive training in the measurement of EC and the correct way to collect samples for chemical and microbiological analyses. A simple calibration routine for EC meters should also be implemented to ensure reliable measurement.

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A synthesis of the hydrogeology of the Table Mountain Group - formation of a research strategy

Kevin Pietersen and Roger Parsons

A project was initiated during 2000 to synthesize the current knowledge about the Table Mountain Group (TMG) aquifer systems. This resulted in a document on the "Synthesis of the Hydrogeology of TMG – Formation of a Research Strategy." The document is subdivided into technical papers and appropriate case studies. This exercise resulted in the understanding that to realize the potential, of this groundwater supply, many uncertainties and barriers need to be overcome, including: deficient understanding of the occurrence, attributes and dynamics of TMG aquifer systems; lack of understanding of environmental impacts of exploitation; and uncertainties about how best to manage the resource within a multi-objective environment. Research of a multi-disciplinary nature is thus needed to find appropriate answers to questions concerning the water resource potential and optimal management of TMG aquifers, in the interest of furthering integrated water resource management in the region.

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Grounwater vulnerability to pollution in urban catchments

OTN Sililo, IC Saayman, MV Fey

This report lists a number of methods for vulnerability assessments, which include empirical, deterministic, probabilistic and stochastic methods. A serious omission is risk-based approaches to pollution risk. The report further discusses current techniques used in South Africa and the limitations of these techniques. However, adoption of "classical" vulnerability mapping methods may cause problems, because they do not deal with fractured rock systems. Further attention is given to soils, and its role in vulnerability assessments. Finally a research strategy is formulated which should form the core of a research programme to be developed on "Groundwater Quality Impacts and Protection".

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