THE DEVELOPMENT OF A STRATEGY TO MONITOR GROUNDWATER QUALITY ON A NATIONAL SCALE

Report prepared for

Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

Even though knowledge concerning spatial groundwater quality variation on a national scale is still limited, some progress has been made in this regard during the last five years. The present regional groundwater characterization initiatives will further enhance groundwater quality characterization and knowledge. However, almost no information is available concerning temporal changes in groundwater quality. This lack of information makes it difficult to effectively manage the country's groundwater resources. A need therefore exists for the establishment of a national groundwater quality monitoring programme.

The Water Research Commission was approached for funding for a one year literature study in order to provide impetus to the establishment of a national groundwater quality monitoring network. The objective of the research project, as set out in the approved project proposal, was to ***develop a practical strategy for monitoring groundwater quality on a national scale.*** *The following were identified as important considerations*

- *a. the purpose of a national monitoring programme*
- *b. the cost and manpower available for the monitoring programme*
- *c. the most important areas to be covered (major pollution sources, sole source aquifers)*
- *d. the variable nature of groundwater over short distances (representativeness)*
- *e. methods of sampling and frequency, analysis, data storage and information reporting*
- *f. possible linkage to national surface water quality monitoring networks*

At the outset it was recognised that practical strategies would be required if a national groundwater quality monitoring network is ever to be established in South Africa. Such strategies will be aimed at conquering the many challenges and problems which need to be overcome. These include the large areas involved, the high degree of spatial variability and the resources required to establish the network. Further, it was noted that a national effort will never be perfect. An integrative, building approach and the adoption of some positive philosophies are seen as ways of ensuring that a national monitoring network could become a reality.

APPROACH

From the literature it was found that monitoring networks have rapidly evolved over the last 10 years. Networks are now designed on a systems approach which is merely a framework that allows for a logical flow of information. The development of an objective statement was acknowledged to be central in the whole network establishment and operation process. It is important to note that objective statements are flexible and dynamic so that the statement can be modified or evolve as circumstances and knowledge change. The following objective statement is proposed for the national network

> ***The objective of a national groundwater quality monitoring network is to provide ambient groundwater quality information on a national scale over the long term so that national water managers and planners have available to them general information pertaining to quality trends and status in both space and time for resource planning and management purposes.***

Prior to addressing possible strategies, some special constraints and considerations were appraised. It was found that the responsibility for establishing and funding a national groundwater quality monitoring *network rested with the Department of Water Affairs and Forestry. However, it was also found that the state could delegate some of the responsibility for data collection to other organizations such as Regional Services Councils and Municipalities. These major water users could also provide assistance and financial support to the network establishment drive. Current trends in groundwater management in South Africa (DWA&F, 1992) are seen as positive developments which support the need for groundwater quality information. The need to integrate groundwater quality information with surface water quality information was also recognised. The lack of geohydrological knowledge on a national scale was identified as a limiting factor. In some areas, regional and local information are available to facilitate the establishment of a network. In areas with little or no information, strategies will be required to overcome the short-coming.*

STRATEGIES

Strategies used in United States of America and Europe to establish large-scale groundwater monitoring networks and groundwater protection programmes were studied. In some case, literature covering surface water programmes was also evaluated. Strategies and approaches employed in the establishment of the South African surface water quality monitoring networks (Harris et al., 1992) were considered in depth. It was found that numerous different approaches could be used and that a set of strategies, as opposed to a single strategy, was appropriate.

Information

The definition of groundwater quality information was found to be a complex task. The inherent differences between surface and groundwater did not make the task easier. The constituents to be included in the monitoring list were found to be subject to a trade-off between groundwater quality information needs and available financial resources. It is proposed that the following general but short list of chemical constituents be used to define trends and water quality for domestic, agricultural and industrial use

FIELD MEASUREMENT (where possible)	LABORATORY ANALYSIS
Temp	EC
EC	pH
pH	Na
T.Alk	K
	Mg
	Ca
	Cl
	SO_4
	T.Alk
	NH_4
	NO_x
	DOC
	TDS (calc.)

Further, special surveys, in conjunction with national monitoring, can be used to collect information about constituents excluded from the national monitoring list.

Resources

From a practical point of view, it is impossible to put a full national monitoring programme in place *immediately. A strategy of initiating monitoring in priority areas is deemed essential. As resources allow, the areas being monitored can be extended with time and need. A number of information tools were identified which will facilitate the definition of priority areas to be monitored. These include a groundwater users map, the national aquifer vulnerability map, the geohydrological regions and subregions map, the national EC quality map and, as they become available, the regional geohydrological characterization maps. The spatial representativeness of the water quality data collected from the priority areas, however, needs to be addressed. It is beyond the scope of this research project to tackle such a complex and demanding issue. It is proposed that the issue be referred to the Review Committee for consideration at an appropriate time. As a strategy to overcome the problem of defining priority areas, it was argued that towns currently using groundwater should be used to initiate the network. Such an approach offers a number of advantages, particularly financial advantages, and will allow a network consisting of approximately 300 stations to be established relatively quickly and cheaply. The water supply managers can also be used to collect the water samples on behalf of the Department.*

Time

It is proposed that a long term commitment must be made towards implementing a national groundwater quality monitoring program. This is on the understanding that it may be some years before the tangible benefits of the initiative become evident. Even though annual or biennial monitoring appeared to be the most common monitoring frequency for national networks, it is proposed that 6 monthly intervals be used for approximately 5 years. This strategy is aimed at removing network teething problems relatively quickly and obtaining usable data sooner than if a less frequent sampling interval is used.

Funding

Funding and logistical support was found to be critical. Most of the strategies which were examined were geared to making full use of available resources and keeping costs to a minimum. During the study, the financial requirements for the establishment of the South African national groundwater quality monitoring network were not determined. However, DWA&F must make adequate financial and logistical provision for this effort. Further, additional financial and logistical support from other sectors and lower levels of government, which could either make use of the information or are groundwater users, need to be secured. In line with this strategy, it is strongly argued that all hydrological monitoring networks need to be integrated. It is thus proposed that the structures within DWA&F be re-evaluated to promote efficient and effective network establishment, operation and integration. The Directorate of Geohydrology's role and participation also needs to be addressed. Nonetheless, an experienced geohydrologist must be used in the groundwater network development and management process.

Reveiw Committee

As a means of overcoming the size of the task and ensuring momentum in the initiative, it is proposed that a responsible person and a Review Committee be appointed. The responsible person will be dedicated to the task and will manage the design, implementation and on-going operation of the network. A masterplan would have to be compiled to guide the process. The responsible persons will be accountable to the Review Committee. Such a committee could consist of the Groundwater Quality Task Group convened by DWA&F (Braune et al., 1991). The group will have a number of functions to fulfil, including final decision making, checking that the masterplan and target dates are being adhered to and to lobby various quarters for additional financial support.

Pilot Study

Based primarily on experiences in the United States of America, it is proposed that a pilot scale study area be used in the first implementation of the groundwater quality monitoring network. Such a strategy will allow logistical problems to be addressed and teething problems to be solved before embarking on the national establishment.

Technical

It was beyond the scope of this literature study to address all technical aspects which need to be considered in the design of a monitoring network. Four components were found to play an important role in defining network resource requirements. Between 400 and 1 000 monitoring stations will be appropriate for the South African groundwater quality monitoring network. Existing boreholes should initially be used, but specially constructed, dedicated boreholes will, however, be ultimately required. A sampling protocol document will be required to define sampling procedures. This document should be based on Weaver (1992). The selection of laboratories to do the chemical analyses as well as network quality assurance and quality control mechanisms are also considered to be necessary. It is put forward that, where possible, existing structures should be used.

Network

Two global strategies are continually promoted throughout the study. An empirical approach and a hierarchial approach are seen as a means of initiating the installation of a national groundwater quality monitoring network. The network should start at a low level and work towards the ideal. Improvement and modifications can then be knowledged-based. The acceptance of these two approaches has many benefits, particularly during the early stages of network design and implementation. These include easy station selection, simple sampling protocol definition and integration into other networks. The establishment of a national groundwater quality monitoring network will not transpire overnight. It is a major undertaking which will require hard work, continual learning and dedication. The desire to achieve and the commitment to succeed by the organizations and people responsible for the network establishment are vital. Support for the team members will be required from all quarters. The proposed Review Committee will have a major responsibility in this regard. Starting the national monitoring with simple building strategies while working towards feasible and attainable goals is considered essential.

CONCLUSIONS

In conclusion, the key factors to the successful establishment of a national groundwater quality monitoring network are obtaining adequate financial resources, appointing a Review Committee to guide the process and appointing a network manager to administer the process. Initiating the national network using a pilot program is considered fundamental to the attainment of a national groundwater quality monitoring network.

RECOMMENDATIONS

The authors recommend that the network design and implementation be activated immediately. The strategies presented in this report should be incorporated in all further national water monitoring network deliberations.

COMPLETION OF STUDY

The literature study has successfully achieved the stated objective by describing a set of practical strategies that could be used in designing, implementing and operating a national groundwater quality monitoring network. The identified important considerations were all found to be applicable. During the study other topics such as the definition of quality information and the concepts of space and time were also identified as requiring consideration.

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The development of a strategy to monitor groundwater quality on a national scale

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

Mr AG Reynders	Water Research Commission (Chairman)
Mr E Braune	Department of Water Affairs and Forestry
Mr HM du Plessis	Water Research Commission
Prof FDI Hodgson	University of Orange Free State
Dr M Levin	Atomic Energy Corporation
Dr G Tredoux	CSIR
Mr M van Veelen	Department of Water Affairs and Forestry
Mr J Veenstra	Department of Agriculture
Mr PW Weideman	Water Research Commission (Secretary)

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ABBREVIATIONS

AEC	Atomic Energy Corporation
DWA&F	Department of Water Affairs and Forestry
EPA	Environmental Protection Agency (USA)
HRI	Hydrological Research Institute, Department of Water Affairs and Forestry
NAWQA	National Water Quality Assessment Programme (USA)
NGWDB	National Groundwater Database
NHDB	National Hydrochemical Database
NRWQMS	National River Water Quality Monitoring System
pers.comm.	Personal communications
QA	Quality Assurance
QC	Quality Control
RWQO	Receiving Water Quality Objectives
USGS	United States Geological Survey
WRC	Water Research Commission

Standard chemical abbreviations are used throughout

1. INTRODUCTION

1.1. Preamble

The evaluation of groundwater quality in terms of spatial differences and quality associated with different geological units presented by Bond (1946) is still used today as the major reference with respect to groundwater quality on a national scale. The Directorate of Geohydrology, Department of Water Affairs and Forestry (DWA&F) set out to evaluate groundwater quality on a national scale in 1986. A number of different approaches to the problem were identified (Reynders, 1987; Parsons, 1988). The hydrochemical data stored in the National Hydrochemical Database (NHDB) was also evaluated and a set of approaches identified that could be followed to achieve the goals of the project (Parsons, 1989). These included:

a. a generalized national study based on the presently stored data such that the work of Bond (1946) could be updated
b. a Groundwater Quality Information section be developed with the responsibility of collecting and disseminating information
c. The Department undertake detailed hydrochemical investigations in priority areas.

Levin et al. (1989) produced a set of hydrochemical maps using the NHDB to partially satisfy (a). The formalization of the Subdirectorate: Groundwater Information Systems within the Directorate of Geohydrology was the first step in achieving (b) while (c) is on-going by means of the current characterization process and studies similar to those carried out by Simonis (1988), Fleisher (1990), Levin et al. (1991) and others. The collection of hydrochemical data such that a representative distribution of data points is obtained is one of the major tasks of the overall project. Even though knowledge concerning groundwater quality is still limited, it is evident that some progress has been made in this direction during the last five years. The present regional groundwater characterization initiatives will further enhance groundwater quality characterization and knowledge.

However, almost no information is available concerning temporal changes in groundwater quality. Inferences have been made that quality is deteriorating (DWA&F, 1991) but these are either based on site specific case studies or postulations which in turn are based on indirect evidence and / or international experiences. A need therefore exists for a national groundwater quality monitoring programme so that the actual situation can be established and that the requirements for groundwater protection policies and strategies can be determined.

1.2. The Purpose of the Investigation

The design, implementation and maintenance of a national groundwater quality monitoring network is a monumental task by any standards. This research project was initiated in order to provide impetus to the monitoring initiative by means of identifying practical strategies to be employed during the design and implementation of a national groundwater quality monitoring network. This project is considered to be a first step in the process.

The objective of the research project, as set out in the approved project proposal, was to **develop a practical strategy for monitoring groundwater quality on a national scale**. The following were identified as important considerations:

a. the purpose of a national monitoring programme
b. the cost and manpower available for the monitoring programme
c. the most important areas to be covered (major pollution sources, sole source aquifers)
d. the variable nature of groundwater over short distances (representativeness)
e. methods of sampling and frequency, analysis, data storage and information reporting
f. possible linkage to national surface water quality monitoring network

It is important to note that this project was **not** concerned with the technical aspects of a national groundwater quality monitoring network. Technical aspects such as those in (e) above were only discussed if they impacted on the suitability of a particular strategy.

1.3. The Research Method

The project was essentially literature based. Following a world-wide literature search, national and regional groundwater quality monitoring programmes as well as other national and regional groundwater initiatives elsewhere in the world were studied in order to assess successful implementation strategies. Effort in this regard was concentrated on reviews and critical appraisals of strategies successfully used and not on the details of the networks themselves. The strategies used in the implementation of national or regional surface water quality monitoring programs, including the South African surface water quality monitoring programme (Harris et al., 1992), were also studied.

Discussions were held with various parties within DWA&F responsible for the management of water resources in South Africa in order to define groundwater quality monitoring information needs. Resources available for the design, implementation and maintenance of the programme were also investigated. An evaluation of the current knowledge of groundwater quality in South Africa as well as the monitoring thereof was also assessed.

A special Task Group (Braune et al., 1991) was established by DWA&F and the Water Research Commission (WRC) to investigate groundwater quality management policies and research needs for South Africa. The task group evaluated past and present practices in this regard and presented recommendations concerning the direction that future policy and research should take. This work was followed by DWA&F (1992) which, from a central authority perspective, formalised the work of the Task Group. These two documents, together with the surface water equivalent (DWA&F, 1991), were important to this study in that they defined the local environment and some of the constraints which would influence the implementation of a national groundwater quality monitoring network.

1.4. Report structure

A short overview of the current knowledge of the spatial and temporal variations of groundwater quality in South Africa is presented in Chapter 2. Chapter 3 evaluates current trends and terminology used in the field of groundwater quality monitoring. Chapter 4 presents special considerations and constraints which required attention prior to the development of appropriate strategies to be employed in the design, implementation and operation of a national groundwater quality monitoring network as described in Chapter 5. Owing to the vast amount of literature on similar networks elsewhere, no attempt could be made to critically evaluate all of the identified networks. Use was rather made of specific examples where required. Chapter 6 presents a summary and discussion of the identified strategies while conclusions and recommendations concerning further work to be undertaken are presented in Chapter 7.

2. KNOWLEDGE OF GROUNDWATER QUALITY IN SOUTH AFRICA

2.1. Spatial Distribution

Historically, many groundwater investigations have been carried in the country, most of which have made some reference to groundwater quality. More recently studies focusing on groundwater quality in particular areas have been initiated (Simonis, 1988; Parsons, 1989; Fleisher, 1990; Levin et al., 1991; Cogho et al., 1992 and others). Much data and information pertaining to groundwater quality therefore exists but is hidden in a multitude of files and reports. Only three serious attempts have been made to collate the data and present a holistic picture of groundwater quality and its distribution in South Africa.

The first attempt to define groundwater quality on a national scale was carried out by Bond (1946). Based on approximately 600 samples, he related groundwater quality to lithology. A single map showing the distribution of 5 water types, based on the dominant major ion present in the water, was produced. This work is still used today as a reference for basic groundwater chemistry information.

Van Noort and Macvicar (1958) used 1850 samples collected during the period 1938 to 1957 to carry out a similar study to produce a series of maps depicting chemical distribution. pH, TDS, Na, Ca+Mg, Cl, SO_4, F and Na/(Ca+Mg) distribution maps, using very coarse classes, were presented. They, however, concluded that their work could not be considered as an improvement on the work of Bond (1946). It is probably for this reason that this work was not widely published.

DWA&F initiated a project in 1986 aimed at initially defining ambient groundwater quality but the overall goal was to develop a national groundwater quality monitoring network (Reynders, 1987). The Atomic Energy Corporation (AEC) was commissioned to evaluate data stored in the NHDB in order to define the spatial distribution of groundwater quality in South Africa (Levin et al., 1989). Most of the data stored in the NHDB were collected by state officials, particularly DWA&F. After an initial screening of the original 33 000 stored data points, only 14 000 remained. This, however, constituted a massive increase in available data from that of Bond (1946) and van Noort and Macvicar (1958). With the aid of computing technology, a series of maps depicting EC, Nitrate, F, Cl and SO_4 were produced. Following this effort, it is now relatively easy to produce a variety of such maps. The accuracy of the data used to compile the maps can, however, be questioned. The fact that 19 000 data points had to be excluded from the data set puts some doubt on the reliability on the remaining data (Bredenkamp et al., 1991). Further, little or no information is known about sampling method, sampling depth and analytical accuracy and precision. The data were also unevenly distributed with little data existing in the more humid eastern part of the country.

The current regional groundwater characterization initiatives of DWA&F also evaluate groundwater quality. Hydrochemical data stored on the NHDB again forms the source of data. A simplistic classification, based on electrical conductivity (EC) drinking water standards, is used (Baron, pers.comm., 1992). These maps will provide planners with information pertaining to the acceptability of groundwater for domestic consumption.

It is questionable whether the above considerations and problems with respect to data accuracy should receive close scrutiny at this stage. In the United States of America (USA) for example, regional assessments of groundwater quality are well documented and freely available. The work of Pettyjohn et al. (1979) and Moody et al. (1988) are examples of this. Yet when looking at water quality on such a coarse scale, inaccuracies of some kind will always exist. The American Federal and State water supply managers and planners can still use the maps to rapidly and easily gain impressions about groundwater quality that could be expected in an area before looking at specific cases in more detail. Unfortunately the same cannot be said for the South African situation as the latest maps have not been widely distributed amongst the water community. The water community has to locate pertinent reports for the area in which they are interested in order to build up a global perspective. Together with periodic updates of national scale groundwater quality maps, a concerted effort should be made to widely publicise and distribute the chemical maps amongst all interested parties.

2.2. Temporal Distribution

No national groundwater quality monitoring programme is in place in South Africa today. "Because of a lack of systematic monitoring there is very little knowledge on the status of groundwater quality in the country" (Braune et al., 1991, pg 1). Further only hydrochemical data from about 35 regularly sampled boreholes are stored on the NHDB (Coetzer, pers.comm., 1992). What hydrochemical monitoring does take place is either associated with the operation of groundwater supply schemes, pollution monitoring or research.

Approximately 280 towns and settlements are largely dependant on groundwater (DWA&F, 1992). These supply schemes range from single boreholes for rural village supply to large-scale abstraction schemes for town supply. Examples of the latter include Alldays, Atlantis, Beaufort West, De Aar, Graaff-Reinet, Kuruman, Uitenhage and Verwoerdburg. As part of the supply schemes management programme, water samples are collected and analysed in order to determine fitness-for-use and treatment requirements. The commitment to such actions in itself varies. At Atlantis a total of 40 boreholes are accurately sampled either fortnightly, monthly, quarterly, bi-annually or annually. Bulk EC measurements are taken at De Aar in order to define water treatment needs (Woodford, pers.comm., 1992). At small rural schemes, hydrochemical data is not collected regularly. In the cases where data are collected, the information is kept by the responsible local authority or their consultants and hence is not readily available to national water supply planners and managers.

Pollution-related groundwater quality monitoring takes place at specific sites as a result of legislative and permit requirements. These sites include mine waste dumps, waste disposal facilities and infiltration ponds. The system and process for having data collected by the parties responsible for a particular waste site and then having this data captured by the Directorate of Water Quality Management on a central database is very much in its infancy. Thus little data are available (Abbott, pers.comm., 1992). As the issuing of permits gains momentum, this database will become an important source of information. This data gathering process will provide limited information concerning ambient groundwater quality and therefore cannot be considered as part of the national programme. It can, however, be used to identify existing and potential problem areas.

2.3. Inadequacies in Current Knowledge

Progress has been made in characterising groundwater quality and defining the spatial distribution of groundwater quality in South Africa (Section 2.1). Further, it is now relatively easy to produce a variety of hydrochemical maps. The spatial distribution of data, however, needs urgent attention. The geohydrological characterisation initiatives can be used to address this problem. Efforts need to be geared towards obtaining hydrochemical data collected outside of DWA&F, for example from local authorities, groundwater supply managers and groundwater consultants.

A lack of monitoring has resulted in a gap in our knowledge concerning temporal changes in groundwater quality in South Africa. Known cases of groundwater contamination, particularly those related to non-point sources, are therefore limited (DWA&F, 1991). The lack of both spatial and temporal information concerning groundwater quality on a national scale makes it difficult to manage the country's groundwater resources. At present, decisions have to be made based on either postulations, indirect evidence or international experiences.

3. GROUNDWATER QUALITY MONITORING NETWORKS

3.1. Approaches to Monitoring

The concept of groundwater quality monitoring and monitoring networks has evolved rapidly over the last 10 years. Previously, emphasis was placed on technical considerations such as:

a. where do I sample?
b. how do I sample?
c. how often do I sample?

By ignoring or minimizing the importance of the reasons and the objectives of sampling, a "data-rich but information-poor" syndrome developed (Ward, 1988). The increasing costs of monitoring also forced network designers to reconsider their approach. It is now recognised that a systems approach is required in the field of water quality data collection such that information needs and objectives can be successfully met and that they can be met in a cost effective manner. The systems approach is merely a framework that allows for a logical flow of information.

A number of systems and approaches are proposed in the literature with regard to water quality monitoring network design and implementation procedures (Youngman, 1981; Cheremisinoff et al., 1984; Gilbert et al., 1986; Canter et al., 1987; Everett, 1987; Sanders et al., 1987; Kozlovsky, 1988; Ward, 1988; Aller et al., 1990; Sara, 1991; Harris et al., 1992 and others). In general terms, the systems tend to be similar in broad approach but the approach used depended on the objectives and scale of monitoring. The following main components were common:

a. objective statement
b. conceptualization
c. network design and implementation
d. information reporting and network evaluation.

3.2. Types of Monitoring

The type of monitoring generally refers to a specific purpose or objective of monitoring and / or the scale of monitoring. Everett (1987) and Sanders et al. (1987), for example, identify four types of monitoring networks, namely:

a. ambient trend
b. source monitoring
c. case preparation
d. research monitoring

Rajagopal (1989) presents a more detailed list including eight different categories while Canter et al. (1987) propose a more simplistic categorization in their attempt to avoid the development of excessive terminology. Their system was related more to the cause of water quality change with Basinwide Ambient Trend monitoring being related to natural quality changes and Source Assessment monitoring being associated with some source of contamination. According to Sanders et al. (1987), it is not uncommon to have a combination of purposes for monitoring within one network. Prioritisation is, however, required to define the most important consideration such that account of this can be taken during the network design, network installation and application of the data.

The scale of monitoring usually relates to the purposes. Ambient trend monitoring, for example, is often carried out over a relatively large area while contamination related monitoring is more site specific. Harris et al. (1992) note that the larger scale networks often relate to "what" quality exists while smaller scale networks address the question of "why" or what factors impact on the quality. Nonetheless, the Americans refer to local, district, state and national networks (Gilbert, 1986). Directly equating these scales to the South African situation results in the following scales being identified:

a. local scale
b. regional or provincial scale
c. national scale
d. international scale

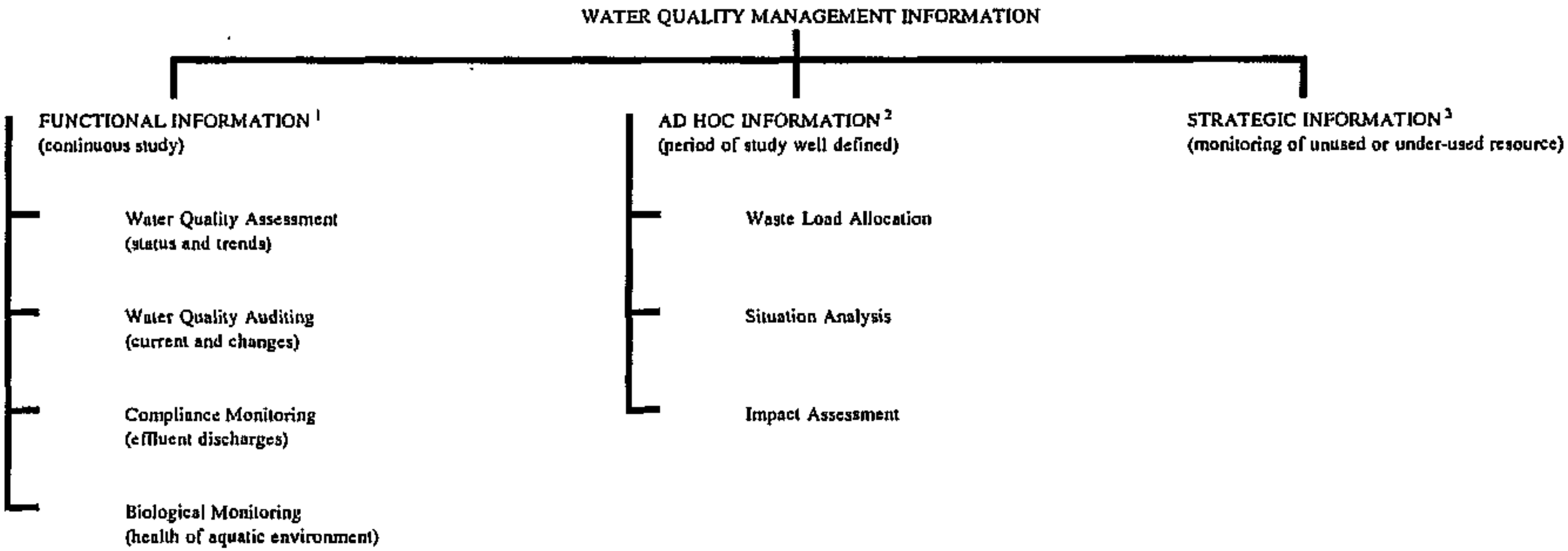
Based on the title of the research project, the scale of monitoring was well defined. From the literature study, however, it was readily apparent that the objectives of a national groundwater quality monitoring would have to be clearly designated before any attention could be given to strategies to be used in implementing such a network. In excess of 40 different monitoring objectives or information uses were identified in the literature. A condensed list of these objectives is presented in Appendix A. The objectives could be classified into 5 main groupings:

a. resource characterisation and quantification
b. resource planning
c. policy development and refinement
d. resource protection
e. other

It was interesting to note that in only one case in the literature was the detection of pollution an objective of a national scale network. A national monitoring program is not geared towards observation of the effects of point sources of pollution. This is usually the objective of regional, local or site specific monitoring programs. In Czechoslovakia, for example, regional monitoring considers localised problems, such as non-point source pollution caused by agricultural activities (Vrba and Pekny, 1991).

An important feature of monitoring networks discussed by Harris et al. (1992) is the strong relationship between water quality management and water quality monitoring. They stressed that monitoring must be geared towards satisfying management information needs. For example, the adoption of the Receiving Water Quality Objectives (RWQO) approach by DWA&F can only be successful if appropriate, sufficient and timely data are available. Similar sentiments were expressed by DWA&F (1992) where dynamic information systems are required to support groundwater quality management and protection efforts. They stated that "groundwater quality monitoring is essential to the quality management process" (DWA&F, 1992, pp 25).

The vast amount of work performed and literature available on the field of water quality monitoring has resulted in a large and varied subject terminology. In order to ensure consistency in this report and avoid confusion, the terminology employed by Harris et al. (1992), which is summarised in Figure 1, was followed. Figure 1 was based on various identified water quality information needs. Based on the objectives of monitoring (Section 4.2.) and this diagram, the national groundwater quality monitoring network could be defined as **water quality assessment monitoring at a national scale**. By implication "general variables" would be used to define water quality (van Veelen, pers.comm., 1992). Further, monitoring activities are performed to yield information relating to water quality trends and fitness-for-use (status).



NOTES

1 At national or regional scale, generally relates to the "what" question
2 At regional or local scale, generally relates to the "why" question
3 At any scale

(After van Veelen, pers.comm., 1992)

Figure 1: Water quality information needs

4. SPECIAL CONSIDERATIONS AND CONSTRAINTS

4.1. Need for Strategies

A strategy is basically an overall plan. It does not propose specific actions but rather the broad approach to be used in solving a problem or to attain a goal. From the strategy, a tactical plan can be developed which specifies specific tasks which need to be carried out. "The challenge of organizing an effort to acquire and interpret data, and to assess the Nation's water quality is formidable" (Hirsch et al., 1988, pg. 9). Difficulties result from:

a. the large areas involved
b. the high degree of spatial (and temporal) variability of water quality
c. the number of water quality constituents of interest
d. the diverse nature of groups interested in such information and active in collecting similar data to one degree or another
e. the costs involved

Because of these and other problems, issues and constraints in the process of designing, implementing and operating a national monitoring program tend to get bogged down and even influence the effectiveness of the effort.

The strategies identified and recommended here are aimed directly at overcoming the long list of obstacles that could prevent such an effort from succeeding. It must be recognized that any national effort will never be perfect. Rather a balance has to be obtained between information needs, resources available and an acceptable degree of accuracy. By an iterative process of evaluating information obtained, the value of that information and the efficiency of the network in terms of providing the desired information, a national network will improve with time.

In addition to the strategies presented in this report, the adopting of a few philosophies will go a long way in ensuring that a national groundwater quality monitoring network can become a reality:

a. the installation of a national groundwater quality monitoring network is not a project on it's own but largely a coordination of effort
b. a poor plan implemented is far better than a brilliant plan never executed - at least if a network is in place it can be criticised and refined based on actuality
c. national water supply managers and planners have the imagination to see the value of the information to be provided and it's wide use within the national community

Prior to the presentation of suitable strategies, it was required that the objectives of a national network be discussed and that the *status quo* with regard to groundwater resources in South Africa be reviewed. This provided a framework from which suitable strategies could be evaluated. The special considerations presented in this chapter deal with the current status and trends in groundwater policy and management and not considerations associated with monitoring networks.

4.2. National Groundwater Quality Monitoring Objectives

The formalization of an objective statement is the first, and probably the most critical, step in the design for any monitoring network (Sanders et al., 1987). Canter et al. (1987) noted that an objective statement should address why the information is needed, what information is to be provided, the technologies that are to be used and how the information is to be used. Based on Brown (1991), a fifth component could be added which defines when the objectives of monitoring have been met and thus when monitoring should cease. It is considered unlikely that this fifth component is significant when dealing with a national or "what" monitoring. By implication, this scale of monitoring is on-going.

The objective statement is a detailed statement which defines the nature of the desired network. The design of the network is therefore matched to this statement. Braune et al. (1991) stated that objectives for the South African national groundwater quality monitoring program are urgently required.

Harris et al. (1992) present a detailed objective statement for the National River Water Quality Monitoring System (NRWQMS). This statement is presented in Appendix B. The purpose of such statements are three-fold. Firstly, to ensure that the person responsible for the network and / or funding the network knows that his needs will be met and what he will be paying for. Secondly, the network designer has a clear understanding as to why monitoring is required and what the information expectations are. Finally, by documenting the objectives of monitoring well, information users will be aware of the need to compromise when multiple objectives exist. It is therefore strongly advisable to have all parties (network manager, designers and users) involved in the development of the national groundwater quality monitoring network objective statement.

As a means of overcoming the complexities associated with a national monitoring effort, the objectives of monitoring were developed from an idealized point of view. No consideration was given during the early stages to any practical aspects. Practical aspects only received attention during the strategy development.

It was recognised that, if at all possible, the implementation of a *good* or *ideal* network would take a number of years to achieve. It is, however, important to define the ideal so that final goal can be well understood. The following vision for a national groundwater monitoring network is thus presented:

VISION FOR A NATIONAL GROUNDWATER MONITORING NETWORK

A national groundwater quality monitoring network is to be developed in order

> *to provide relevant ambient groundwater quality information to national water supply managers. The network is to consist of approximately 1 000 specially constructed and dedicated sampling stations capable of providing both spatially and temporally representative groundwater samples. Samples are to be collected at six monthly intervals by well trained and equipped teams whom follow station-defined groundwater sampling protocols. Sample analysis is to be performed by accredited laboratories strategically located throughout the country. Data capture, storage and analysis is facilitated with computing software and hardware capable of providing information in a format which may be prescribed by managers from time to time. The groundwater quality monitoring network is to be an effective and critical part of a greater national hydrological monitoring network system.*

Based on international and local literature and discussions held with water managers it was clear that the overall objective of a national groundwater quality monitoring network is primarily to provide quality **information**, particularly for management of a resources. Geldenhuys et al. (1991) state that water quality data and information are necessary for the efficient management of the country's water resources and that the information is also required by water users. Similar sentiments were expressed by Youngman (1981), Gilbert et al. (1986), Canter et al. (1987), Hirsch et al. (1988), Moody et al. (1988) and Harris et al. (1992). If it is considered that:

a. almost no temporal groundwater quality information exists in South Africa (Section 2.2)
b. the maintenance of the fitness-for-use of South Africa's water resources on a sustained basis is DWA&F's major overall water quality management goal (DWA&F, 1991) and
c. monitoring networks are designed based on knowledge of conditions, then,

the following objective statement is, **at this stage**, reasonable:

> ***The objective of a national groundwater quality monitoring network is to provide ambient groundwater quality information on a national scale over the long term so that national water managers and planners have available to them general information pertaining to quality trends and status in both space and time for resource planning and management purposes.***

Following this statement, the terms *groundwater quality information* (including *general information* and *trends and status), priority areas, long term* and *space and time* required clarification. This was done during the strategy development (Chapter 5). It is important to note that objective statements are both flexible and dynamic so that the statement can be modified or evolve as circumstances and knowledge change.

Further to the objective statement and Figure 1, attention was only paid to national scale, functional monitoring. Ad hoc, local scale or specialized monitoring was specifically excluded from further consideration.

4.3. Responsibility

Subsequent to the publication of the two DWA&F water quality management policy documents (DWA&F 1991; DWA&F, 1992), it was clear that overall resource management (of which monitoring is a part) rests with the Department. "In terms of the Water Act, 1956 the Department of Water Affairs is responsible for water management, including groundwater, at central government level" (DWA&F, 1992, pp 6). DWA&F (1992) noted that it is desirable that a single department act as a custodian of all water resources and that this should include groundwater quality management, of which the establishment of a national groundwater quality is part. Further, Braune et al. (1991) stated that the Directorate of Geohydrology of DWA&F is responsible for the provision of geohydrological information on a national basis.

The fact that responsibility for national monitoring rests with central government compares well with other countries. For example, in the USA similar Federal functions are vested in the Environmental Protection Agency (EPA) and the United States Geological Survey (USGS) (Youngman, 1981; Gilbert et al., 1986). Regional scale networks are the responsibility of individual States while local monitoring is performed by county and local authorities as well as water suppliers.

Even though responsibility rests with the state, the day to day operation need not be performed at this level. Harris et al. (1992) noted that DWA&F's role is to manage quality and that the responsibility for data collection could be delegated to other organizations such as regional services councils, local authorities etc.

4.4 Funding

Funding of a national groundwater quality monitoring programme is a critical consideration. The funding required is substantial but difficult to plan for. Short term cost benefits, however, can rarely be demonstrated (Kozlovsky, 1988).

Since 1990, South Africa has been undergoing major change in the political and social spheres. The expected economic upswing has, as yet, also not occurred. As a result, available financial resources are under pressure. However, potable water supply is considered to be a limiting factor in the development of our semi-arid country as water demand is expected to exceed water supply in many areas of South Africa early in the next century (DWA&F, 1986). The development of new supplies, which is regarded by most political parties as a high priority, will become increasingly expensive thus placing further stress on available financial resources.

The responsibility of funding a national monitoring network goes hand in hand with the responsibility of ensuring that the desired information is provided. Vrba and Pekny (1991) state that site specific monitoring activities associated with pollution in Czechoslovakia are funded by potential polluters while the government finances regional and national monitoring networks. Braune et al. (1991, pg. 93) recommends that financial support be sought from the government budget for establishing and operating groundwater quality protection programmes.

Major users of the provided information should contribute most to the financing of a national programme. Harris et al. (1992) stated that, with respect to national surface water quality information, information users are principally within the Department. It would seem that essentially the same applies to the groundwater quality information.

DWA&F (1986) recognised that water in South Africa is regarded as quasi-public goods. This implies that the costs of developing and maintaining water supplies is to be financed by both the state and the markets. "...waterworks must be financed and operated on commercial principles aimed at full recovery of the costs of services" (DWA&F, 1986). It also means that all parties involved in water supply must contribute to funding a monitoring network. Ultimately, these costs will have to be recouped from the consumer.

The costs involved in developing the national surface water monitoring networks can be used as a rough indicator of the financial investment required. Youngman (1981) noted however that groundwater quality monitoring is more expensive than surface water quality monitoring because:

a. more monitoring sites are required owing to a high degree of quality variability over short distances, and
b. the cost of establishing groundwater monitoring stations is higher.

He stated that in California, the two hydrological specialities tend to compete for the same financial resources. Because groundwater resources are 'hidden from view' they tend to receive less priority and less financial support.

At this stage it was not possible to determine how much money will be available for the development of a national groundwater quality monitoring network (Braune, pers.comm., 1992). Many of the strategies proposed in this report will have a major bearing on the financial requirements for manpower, running and capital costs. Sampling frequency is a good example of this. Cooperation between various parties can result in the spreading of the financial load. In selecting the final strategies to be employed, due consideration must be given to the financial implications thereof. DWA&F, as custodians of national water resources, will however have to provide financial support for the national groundwater quality monitoring initiative and liaise with other parties to provide assistance.

4.5. Legislative Considerations

Under the Water Act of 1956, groundwater is regarded as private water while surface water is classified as public water. Integrated management of hydraulically connected water resources (both surface and groundwater) is thus complicated. It is not expected, however, that the implementation or operation of a national groundwater quality monitoring network will be hindered by legislation to the same degree as would, say, a local network which would monitor point source contamination. National network managers will have to obtain permission from land owners to perform monitoring and keep the landowners informed of all activities and results.

4.6. Current Trends in Groundwater Management In South Africa

A number of positive developments in groundwater management have occurred over the last few years. Previously, surface and groundwater were usually considered separately. It is now recognised that integrated water resource management is required and, as defined by the hydrological cycle, surface and groundwater form part of a single system.

Historically, attention was focused on quantity issues while quality was afforded scant consideration. The recent publication of "Groundwater quality management policies and strategies for South Africa" by DWA&F (1992) marked a change in approach. It is now recognised that groundwater quality can be managed. A number of policies and approaches are proposed in the document which could result in far reaching changes. These include, amongst others:

a. because of our lack of knowledge of our groundwater resources, we should adopt conservative pollution prevention measures.
b. not all groundwater resources need to be protected to the same degree and a policy of differential protect is proposed.
c. a precautionary approach, as opposed to a reactionary one, is preferred.
d. the polluter pays principle is to be adopted.

Even though much work is still required in this regard, it was clear that groundwater quality information is required for these policies to be effectively implemented. The need for a national groundwater quality monitoring network has been highlighted by these developments.

Recent changes to surface water policy have also promoted the need for a national groundwater quality monitoring network. The adoption of the RWQO approach by DWA&F, which is information intensive, is a good example of this. Groundwater contributes significantly to base flow and, as such, impacts heavily on river quality.

4.7 Existing Information

The design of a national groundwater quality monitoring network needs to be based on existing geohydrological information. Vrba and Pekny (1991) stated that a hydrogeological system can only be monitored if its geometry, physical properties, groundwater flow, and the initial and boundary conditions are known. Hirsch et al. (1988) noted that much of the existing geohydrological information has been collated to form the various hydrogeological maps available in USA. These initiatives have been carried out at Federal, State and local level.

The knowledge of groundwater occurrence and groundwater quality on a national scale is limited (Chapter 2) but knowledge for specific areas is available from reports. The current regional geohydrological characterization drive in South Africa will yield much of the data required to design a national network. The Cape Town hydrogeological map, for example, is nearing completion (Baron, pers.comm., 1992) and would greatly assist the selection of monitoring stations in the area. Unfortunately only a small portion of the country is presently covered by geohydrological maps and the mammoth mapping task will take a number of years to complete. Strategies will have to be developed and used to overcome the current limited national geohydrological knowledge.

5. STRATEGIES

Gilbert et al. (1986) evaluated a number of groundwater protection programmes and their implementation strategies. They noted that numerous different approaches were employed and that no one case could be used as a model. Rather a collection of strategies should be considered with those being most applicable to a particular case being applied.

Strategies are discussed and presented below in two groups, namely Sections 5.1. to 5.4. and Sections 5.5. to 5.11. The first group specifically clarifies the terms used in the objective statement (Section 4.2.) while the remaining strategies cover more general topics. The topics are not debated in any order of priority or importance. The proposed strategies are more formally grouped during the evaluation of the identified strategies (Chapter 6).

For the sake of clarity, proposed strategies are recorded below each section in italics. Only specific tasks identified during the discussions below are presented. A detailed list of tasks to be performed will have to be compiled when investigating and initiating the network implemetation phase.

5.1. Groundwater Quality Information

Defining groundwater quality is a complex task which has many ramifications, particularly with regard to costs. Both the chemical constituents and the methods of presenting information are of concern. If the proposed national groundwater quality monitoring objective statement is considered (Section 4.2.), then general information pertaining to quality trends and status is required. As status refers to "fitness for use", domestic water supply, industrial water supply and agricultural water supply criteria and requirements could be used to define water quality. The criteria and guidelines presented by SABS (1984), Kempster and Smith (1985), Aucamp and Vivier (1987) and Pieterse (1989) could be used as a basis.

In evaluating international trends, South Africa appears to be more closely aligned to European protocol than USA practice. Kozlovsky (1988) noted that at a national level "general" constituents should be considered. These would include major anions and cations presently analysed for by the Hydrological Research Institute (HRI). DWA&F (1992), however, called for an expansion of this list to include organic constituents. Weaver (1992, pg 4-1) advocated that "it is better to obtain more chemical data than the immediate needs require." He proposed that a full major cation and anion analysis with DOC was the minimum requirement. The Dutch network used similar parameters in their monitoring but also included As, Ni and Zn (van Duijvenbooden, 1987). USA regional and national monitoring networks tend to have exhaustive chemical monitoring which include field measurements, major constituents and dissolved solids, nutrients, major metals and trace elements, organics and, at times, radionuclides (Gilbert, 1986; Sabel, 1987; Hirsch et al., 1988; Engelbrecht et al., 1990). Gilbert (1986) noted that the EPA had identified 129 priority pollutants which had to be monitored.

Rajagopal (1989) argued for the careful selection of constituents to be monitored. He stated that among the 35 pesticides monitored in 845 public wells in Iowa, only 4 were detected in more than 1 % of the supplies and 28 were never detected in any supplies. He also found that in about 99 % of cases, when 15 - 20 specific organics were absent in water samples, another 120 to 130 organics were also always absent.

Harris et al. (1992) surveyed a large number of water quality professionals in order to identify variables to be included in the NRWQMS. The survey related to surface water and their final list is therefore not entirely suited to groundwater monitoring. Turbidity, *E.coli* and Chlorophyll *a* are not generally applicable to the geohydrological environment. They do, however, recommend that TDS be determined by means of summation of the concentration of the individual ions as opposed to EC measurement and calculation using a standard constant. This approach allows for more detailed data to be collected at relatively little extra cost.

The ultimate decision regarding constituents to be included on the monitoring list will be a trade-off between groundwater quality information needs and available financial resources. The laboratory analyses listed in Table 1 will cost approximately R 200.00 per sample to preform (Louw, pers.comm., 1992). The addition of, say, Al, As, Cd, COD, F, Fe, Mn, Ni, Pb and Zn to the list would result in an additional cost of R 220.00 per sample. Equating these two sets of analyses to a national network comprising of 400 monitoring stations sampled twice a year, the difference in analytical costs would be R 176 000 per annum.

Table 1: Proposed chemical constituents to be included in the national groundwater quality monitoring network.

FIELD MEASUREMENT (where possible)	LABORATORY ANALYSIS
Temp EC pH T.Alk	EC pH Na K Mg Ca Cl SO_4 T.Alk NH_4 NO_x DOC TDS (calc.)

Consideration also needs to be given to field measurements (Weaver, 1992). pH and Total Alkalinity (T.Alk.), for example, are particularly vulnerable to alteration during sample transportation and storage prior to analysis. In an ideal monitoring network, field measurement of these constituents would form part of the protocol. However, this requires both equipment and training which would, at this stage, add significantly to the network implementation financial demands. It is thus proposed that field measurements only be performed were capabilities already exist. Once the national groundwater quality monitoring network is operational, attention can be given to improving this aspect.

Based on the above considerations and the objectives of the national groundwater quality monitoring network, it is proposed that the general parameters presented in Table 1 be used as the initial national network monitoring list. Further, a nationally consistent list is considered appropriate. As knowledge is gained and unique issues become apparent, the list can be modified.

Periodic analyses for other constituents outside of the standard list could be used as a strategy to collect other chemical information. For example, one year pesticide levels could be investigated and during the next year Fe concentrations in groundwater could be studied. In this way, particular issues can be investigated on a national scale at relatively low cost. Such a strategy was successfully employed in the USA (Perry et al., 1984) and in Holland (van Duijvenbooden, 1987). In the latter example, 40 of the national groundwater monitoring boreholes were sampled for organics in 1986. However, when employing such a strategy, due consideration must be given to the particular sampling procedure and requirements for the chemical of interest. It is however not considered appropriate to initiate special surveys at this stage. Special surveys should only be introduced once the network has been implemented and teething problems sorted out.

One area that does require attention on a national scale is that of microbiological counts in groundwater. This data is rarely collected during groundwater studies. As a result no information is available. A special survey dealing with microbial concentrations should be initiated once the network is operational.

Reporting formats for the NRWQMS have already been considered by Geldenhuys et al. (1991) and Harris et al. (1992). Numerical indices, rating curves, summary statistics, box-and-whisker plots and time-series trend analysis graphs are all used. Reporting is done for the country as a whole, drainage regions and individual stations. It would seem logical to follow a similar format. Consideration must however be given to the less frequent groundwater sampling program and the use of trilinear diagrams such as Piper and Durov diagrams. It might be possible to develop a numeric index based on these diagrams. The work of Tredoux (1981) could be of value in this regard.

STRATEGY

A general but short list of chemical constituents should be used to define trends and water quality for domestic, agricultural and industrial use.

Special surveys, in conjunction with the national monitoring, can be used to *obtain information on chemical constituents excluded from the national monitoring list.*

TASKS

A decision needs to be taken on the final composition of the national groundwater quality monitoring constituent list.

Consideration must be given to the need for a program of special surveys and which constituents are to be investigated.

Groundwater quality monitoring reporting formats must be selected to satisfy management information needs.

5.2. Priority Areas

From a practical point of view, it is impossible to put a full national monitoring programme in place immediately. In fact, a strategy of initiating monitoring in priority areas is essential if a national groundwater quality monitoring network is ever to become a reality. A priority area strategy was successfully applied by the Californian State Water Resources Control Board (Youngman, 1981; Canter et al., 1987). Three priority classifications were developed based on population, average use rate, water quality problems, estimated usable capacity and the availability of alternative supplies. The study was started by investigating 4 of the 24 Priority I basins. As resources allowed, the remaining basins will also be investigated and, ultimately, all basins will be covered.

A number of tools have or will become available in South Africa which can be used to implement such a strategy by defining priority areas. These include:

a. the groundwater users map (Figure 2)
b. the national aquifer vulnerability map (Figure 3)
c. the geohydrological regions and subregions map (Figure 4)
d. the national EC map (Figure 5)
e. the regional geohydrological characterization maps, as they become available (DWA&F)

To some extent, the present water level monitoring network could also be used. The aquifer classification scheme currently being developed for South Africa would also be of value to this aspect. A host of other tools could be prepared, should they be required. The tools can either be used singularly or in conjunction with each other.

In accordance with the hierarchial approach, towns presently using groundwater for supply purposes could be defined as top priority areas in order to initiate network implementation. As time and resources permit, the network priority areas could be more precisely defined using a combination of the groundwater users map, the regions and subregions map and the vulnerability map. It must be noted that a national groundwater quality monitoring network is concerned with ambient conditions and not pollution related situations. Ultimately, and ideally, the geohydrological characterisation maps will form the basis of defining geohydrological priority areas. It was nevertheless important to note that DWA&F (1992) state that priority for groundwater quality management lies in the vulnerable areas. A policy decision must be taken to define the principles by which priority areas will be selected and included into the national groundwater quality monitoring network. The groundwater aquifer classification scheme would provide some assistance in this regard.

An issue that was not well addressed in the literature reviewed was the question of representativeness. Representativeness refers to both:

a. the *temporal representativeness* of a water sample collected from a borehole i.e. does the sample accurately reflect conditions in the aquifer at that time
b. the *spatial representativeness* of groundwater quality monitored throughout South Africa

The temporal representativeness is considered during compilation of the sampling protocol document and can be managed by proper sample collection procedures (Section 5.10.2.). Spatial representativeness is a far more complex problem, particularly when considering fractured rock aquifers at a national scale. It is postulated that the problem is not addressed in the literature as most consider primary aquifer systems in which representativeness is not a major concern.

It is well recognised that groundwater quality varies considerably over short distances in many of South Africa's fractured aquifers. This suggests that the question of spatial representativeness exists at all scales of monitoring. Knowledge about spatial variability of groundwater quality on a national scale is, however, limited (Section 2.1.). Further it was noted that, when operating at such coarse scales, inaccuracies of some kind will always exist. These considerations imply that the information representativeness of the national situation will always remain an issue. With time and information, however, this aspect can be partially addressed and improved. The national mapping initiatives, for example, will yield information about the extent of various aquifer types and their water quality. By using this and other information to carefully select monitoring stations, the issue of information representativeness can be accommodated. This matter can however only be addressed in a proper manner when hydrochemical characterisation of individual aquifers is performed. Spatial representativeness needs consideration when the principles of selecting and defining priority areas are addressed. The matter could thus not be pursued further during this investigation. The proposed Review Committee should address the problem of spatial representativeness in more detail at the appropriate time.

During the early stages of network design and implementation, the issue of spatial representativeness should not be allowed to hinder progress. The philosophy of building from a less-than-perfect network to an ideal situation is well entrenched in the proposed strategies. It must be accepted that a degree of bias will be introduced into the network if those towns using groundwater for supply purposes are used to initiate national monitoring. Further, the geohydrologist charged with selecting the borehole to be included into the national network must be made aware of the need to consider representativeness. He or she should select the borehole which, in their opinion, is the most representative of the prevailing geohydrological and groundwater quality conditions. Eventually, the spatial relationship of this borehole with the aquifer as a whole can be determined by full hydrochemical characterisation. The monitoring results should, nevertheless, give the temporal trends of the aquifer.

STRATEGY

The concept of priority areas should be used to initiate the national groundwater quality monitoring network with those areas regarded as having the highest priority being included into the network first.

Because the definition of priority areas may take some time, it is recommended that all towns currently using groundwater for domestic supply be regarded as top priority and be immediately incorporated into the national groundwater quality monitoring network.

TASKS

A policy decision needs to be taken as to how to define priority areas for the implementation of the national groundwater quality monitoring network.

Once the priority areas have been defined, those priority areas to be included into the network must be identified.

5.3. Long Term

Many authors noted that a national monitoring effort is a long term project with few short term benefits. Unfortunately none of them clearly defined long-term. It can be considered that at least 5 or 6 data sets are required before a trend can be distinguished. If an annual monitoring frequency is used, 5 years monitoring is required before any real information is produced. Van Veelen (pers.comm., 1992) stated that in the case of the surface water monitoring initiative, about 10 years worth of data was required. Van Duijvenbooden (1987) stated that the Dutch groundwater monitoring network took 6 years or 14 man years to fully implement.

By definition, a national monitoring program is on-going (Figure 1). In Czechoslovakia, for example, monitoring has taken place since 1930 (Vrba and Pekny) while in Pennsylvania, USA, groundwater quality monitoring was initiated in 1925 (Canter et al., 1987). Almost all counties in this state have been included into the statewide network. California only started monitoring in 1974 and by the mid-1980's had only four priority 1 area networks fully operational. The Dutch network was started in the late-1970's and was fully implemented by 1985 (van Duijvenbooden). However, by 1987, sufficiently detailed information were available to show that groundwater quality was in fact worse than was previously thought.

These examples merely show the commitment and varying durations required to install a national network. The benefits of having measured data and information available on which to base management and planning decisions are well documented. The Dutch example has already been given. Brown (1984) gave an example in the USA where a lack of groundwater quality information cost both the state and public "tens of millions of dollars". He argued that very little can be done to protect the environment and resources without knowledge. It must be recognised that the collection and provision of such information requires both time and money. A long term commitment is thus required.

It was interesting to note a plea made by Ackerman (1987), in connection with the NAWQA Program, not to alter the program for at least 5 years after implementation. He proposed that such a strategy would allow for the development of stability in the network. Once attained, reviews can be initiated and the network modified based on gained knowledge and experience.

STRATEGY

A long term commitment must be made towards implementing a national groundwater quality monitoring program on the understanding that it may be some years before the tangible benefits of such an initiative become evident.

5.4. Space and Time

Both terms have already been investigated to some degree. Further both have far reaching practical and financial implications. With regard to space, all areas within the boundaries of the Republic of South Africa must eventually be included. A decision needs to be taken whether to include, during the early stages of network development, the TBVC states and other independent or self-governing homelands. Their immediate inclusion into the groundwater network is not as critical as in the case of the surface water networks. It is, however, desirable to include all areas in the long term.

The exact location of monitoring stations will be defined by priority areas, geohydrological considerations and available resources.

A call was previously made for a long term commitment to monitoring groundwater quality on a national scale (Section 5.3.).The frequency of monitoring also plays a role in defining time. "The frequency at which a well is to be sampled must strike a balance between the desire for comprehensive data and costs. It is important to note that sampling too often is just as misleading as not sampling often enough. In short, large numbers of samples produce large amounts of data which can have a lot of 'noise' and be difficult to interpret. On the other hand, infrequent sampling may lead to non-detection of an important subsurface water quality stress" (Canter et al., 1987, pp 343).

In general terms, annual or biennial monitoring seems to be the most common monitoring frequency but little conformity exists (Korkman, 1987; Canter et al., 1987; Hirsch et al., 1988). No adequate technique is available to optimally define monitoring frequency (van Duijvenbooden, 1987) but based on the work of Canter et al. (1987), Kozlovsky (1988), Vrba and Pekny (1991) and others, an annual sampling frequency is proposed.

It is often common practise to perform frequent monitoring in the first year after installing a localised monitoring network. Such practises are aimed at obtaining good background information relating to seasonal fluctuations. A similar strategy may be useful to apply to the national network, but for a different reason. It is perceived that an annual time interval between sampling may be too long to get the network operational quickly and efficiently. If monitoring is initially performed every 6 months, the teething problems can be identified and rectified sooner. Also, network refinement can commence earlier as more information, knowledge and experience would have be gained. Following the call by Ackerman (1987), it is prosed that this strategy be followed for approximately the first five years.

Once the frequency of monitoring has been set, attention can be focused on the time of the year or season during which monitoring should be performed. From the literature and experience, this aspect is not critical *if* sampling is performed during the same month of each year. It would, however, be advisable not to perform monitoring near the start or end of each season. Monitoring should rather be scheduled during the middle of a season.

STRATEGY

Monitoring should be performed at 6 monthly intervals, for approximately the first 5 years of network operation. Thereafter annual or biennial monitoring will be adequate.

TASKS

A decision needs to be taken whether to include the TBVC states and other independent homelands into the national network. Once made, this decision can be regarded as a strategy.

5.5. Funding and Logistical Support

The availability of sufficient resources required for the implementation and operation of a national groundwater quality monitoring programme is critical. Iterative strategies have to be developed to ensure on-going adequate support. The financial support required for the monitoring initiative and the benefits thereof should be seen in the context of:

a. water being a national growth limiting factor

b. the meeting of future water demands will become an expensive exercise owing to South Africa's limited water resources

Engelbrecht et al. (1990) presented annual budgets for various National and State water quality assessment and monitoring efforts (Table 2). They further estimated that federal agencies spend about $ 5 million a year (1989) on environmental monitoring. A similar amount of money was estimated to be spent by non-federal agencies for a total estimated annual expenditure of $ 1 billion per year. Information concerning the cost of monitoring implementation and annual operating costs from other countries could not be found. It was therefore difficult to compare budgets and difficult to place these costs into a South African context. The cost implications are, however, well recognised. "The costs of groundwater quality monitoring, both in the network implementation stage and during the routine monitoring phase, are substantial and should be planned for" (DWA&F, 1992, pg 25).

Table 2: Annual budgets for USGS and EPA national and state water quality assessment and monitoring efforts.

AGENCY	PROGRAM	ANNUAL BUDGET (million $)
USGS	NAWQA (when fully funded)	60.0
	National Streams Quality Accounting Network	3.6
	Hydrological Benchmark Program	8.0
	National Trends Network	3.0
EPA	National Water Quality Inventories	27.0
	Environmental Monitoring and Assessment Program (proposed)	60.0
	National Status and Trends Program (near coastal waters)	5.0
	National Pesticide Survey (once-off cost)	11.0

(after Engelbrecht et al., 1990)

As previously stated, many of the proposed strategies impact directly on resources required for network implementation and operation. These are discussed under appropriate sections but included:

a. network integration
b. integration with other water users
c. technical considerations in the network design

Based on Section 4.3., central government will largely be responsible for installing and maintaining the national groundwater quality monitoring network. DWA&F (1992, pg 33) however noted the following: "As regards funding at a national level it is important to make a substantial initial input to ensure an efficient management system which is able to secure support from other sectors and lower levels of government." This suggests that water users should also make a significant contribution into the network. It will, however, be necessary to demonstrate to each user the benefit of contribution and participation.

Gilbert (1986) proposed a more formal "monitoring tax" system as a means of obtaining the required funding. Tax is built into the retail cost of the water. It is questionable whether such a strategy would be well received at the present time. The current heavy tax burden, pressing political and social reform policies and the economic recession are all factors to be deliberated.

STRATEGY

DWA&F must make adequate financial and logistical provision for the establishment and maintenance of a national groundwater quality monitoring network.

Secure additional financial and logistical support from other sectors and lower levels of government, which could either make use of the information or are groundwater users, for the establishment and maintenance of a national groundwater quality monitoring network.

5.6. Network Integration

This broad strategy of integration was strongly supported and recommended in almost all the literature dealing with national monitoring networks (Miller, 1978; Brown, 1984; Patchett and Dent, 1985; Ackerman, 1986; Gilbert, 1986; Haffner, 1986; Romijn and Foster, 1987; Vrba, 1987; Kozlovsky, 1988; Hirsch et al., 1988; Vrba and Pekny, 1991; DWA&F, 1992; Harris et al., 1992 and others). It is merely an effort to make efficient and effective use of all available resources and prevent duplication.

Brown (1984, pg 6) argued that the major obstacle to significant progress (in developing a national monitoring program) was institutional. "With environmental responsibilities spread out across a host of Federal, State, regional and local authorities, each with limited resources, it isn't surprising that each agency has focused on its own immediate needs without regard to overall needs of a coordinated data collection and analysis programme." This situation resulted in either a duplication of effort and data or in one where no monitoring takes place at all.

Hirsch et al. (1988, pg 7) claimed that "the NAWQA Program is an evolutionary step in organization concepts, goals and levels of effort rather than the start of a totally new set of activities." As such, communication and coordination was critical. After the pilot studies were completed, the surface and groundwater study units were integrated which resulted in the improved usefulness of the NAWQA Program. Mlay (1981) also found that it was useful to include different disciplines in the planning process of the USGS

Groundwater Protection Strategy. People outside of the discipline tend to present fresh ideas and are not influenced by traditional thinking within a particular field.

Vrba and Pekny (1991) stated that in Czechoslovakia, coordination between various programs resulted in substantial reductions in design and operating costs. Here, the groundwater monitoring program is coordinated with surface water, climate, precipitation and soil monitoring networks. Van Duijvenbooden (1987) stated that a similar situation exists in the Netherlands. Kozlovsky (1988) argued the need for integration of effort from a scientific and holistic perspective. He argued that integration is required because of the inter-relationship between the various components of the hydrological cycle. He warned, however, that the fundamental difference between the components must not be ignored.

The implementation of an integrated strategy appears to be well suited and desirable to the groundwater quality monitoring network. DWA&F have been identified as having the responsibility of water resource management (Section 4.3.).Other Departments could also make use of the data and as such should contribute to the establishment of the network. Further, DWA&F already run a number of national monitoring networks. These include the National River Gauging Network, the National River Water Quality Assessment Program and the National Reservoir Water Quality Monitoring Network. It would be logical to integrate the groundwater network into the present DWA&F structure for data collection, data handling and storage and data interpretation and information reporting. At present the HRI coordinates, manages and operates the national monitoring efforts. Much of the infrastructure are thus already in place e.g. data capture, data storage and retrieval, data analysis procedures and reporting formats (Section 5.10). Data collection on the other hand is performed primarily by the Directorate of Hydrology with the Regional Offices providing staff to participate in the field aspects of monitoring.

It is beyond the scope of this research project to investigate possible means of adopting a network integration strategy within DWA&F. This would be a complex task and impossible to achieve without full knowledge and understanding of Departmental structure and functioning. Aspects which would have to be considered include restructuring, staff re-assignments and appointments, rationalization of tasks and responsibilities and the allocation of funds. However, should the option of making the HRI responsible for all national water monitoring be adopted, an experienced geohydrologist should be seconded to them to provide the required technical expertise. Further, the Directorate of Geohydrology should liaise closely with the network developers such that the "local area geohydrological knowledge" in the Regional Offices be put to full use.

STRATEGY

All national water monitoring and related networks should be integrated.

TASKS

Re-evaluate structures within DWA&F so that the proposed strategy can be *effectively implemented.*

Re-define the Directorate of Geohydrology's role and participation in the establishment of a national groundwater quality monitoring network.

5.7. Integration With Other Water Users

In Papua New Guinea, the need for integration was based neither on economic nor technical considerations. Pachett and Dent (1985) found that the level of staffing was inadequate and this impacted on the ability to implement a national water quality monitoring network. They found that the only way to establish such a network was to get the water users to supply the desired information. The information was collated by the central authority to produce a national monitoring report.

The use of water users as data and sample collectors may be particularly applicable to the groundwater quality monitoring network. Town Engineers, Health Officers and farmers would be targeted to perform these tasks. Groundwater sampling stations will often be in remote areas and / or distant from current surface water monitoring stations. The situation is made more complex in that the sampler only has to service the groundwater quality stations twice a year while the surface stations are visited on a weekly or monthly basis.

This strategy complements those presented in Section 5.2., 5.5. and 5.6. Further, DWA&F (1992, pg 24) noted that "the key to successful groundwater protection is cooperation, coordination and communication at all levels and between the state and private sector." Such a strategy would allow other groups to contribute to the financial and logistical requirements of the network by reducing for example travel costs and manpower needs. The drawbacks of such a strategy include longer standing time between collection and analysis, greater costs associated with the need for extra equipment and reliance on people or groups outside of the network team. The network manager would have to give consideration to training and field equipment requirements, quality assurance, ensuring standardised field and transportation procedures and reminding data collectors to perform the tasks on a specific day.

STRATEGY

Make use of water users to collect field data.

5.8. Responsible Persons and Review Committee

The establishment of a national groundwater quality monitoring network is a major task which will involve a large number of people and organizations. Organization, planning, control and administration will form important components of the effort. To ensure that all these tasks are performed as required and to maintain momentum in the design, implementation and maintenance of the groundwater quality network, it is strongly recommended that a responsible person or network manager be appointed. If the integration strategy proposed above is accepted then it may require that an overall water monitoring manager be appointed with a responsible person or manager for each type of network (Figure 6). These managers would then make effective and efficient use of all resources available to them.

It is essential that the groundwater network manager be appointed with the sole responsibility of the rapid establishment of the network. The information is urgently required for, amongst other needs, the effective management of groundwater quality in South Africa. The establishment of a national groundwater monitoring network was first initiated in 1987 but little progress has been made. It is estimated that it will take approximately 6 to 8 years before any real information is available, ie. the network will only be fully operational by the year 2000. A concerted effort in this regard thus has to be made.

Two further strategies can be used to support the groundwater quality monitoring network manager. Working and adhering to a network design, implementation and operation masterplan could be a useful tool in ensuring the initiative is maintained. Such a masterplan would present in detail specific tasks which need to be performed, completion dates for each task and who will be executing each task. It will however remain the responsibility of the network manager to ensure that each task progresses as scheduled. A strategy of working to carefully planned target dates can only be successful if it is strictly adhered to. Mechanisms need to be in place to assist in getting the tasks back within schedule should delays occur.

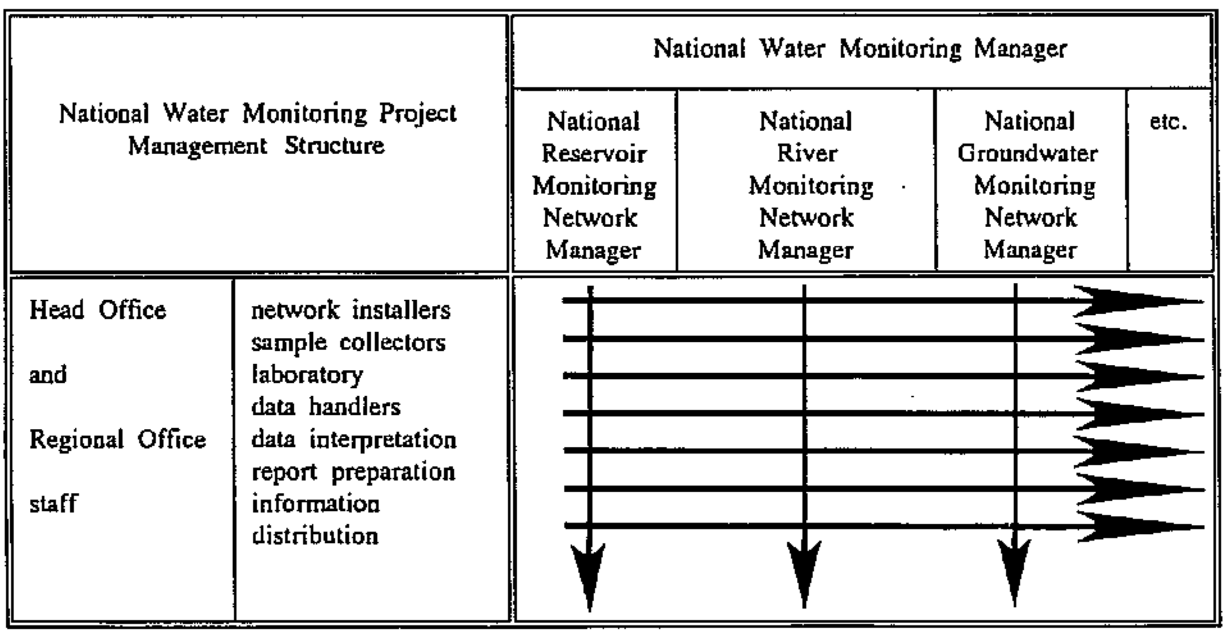


Figure 6. Possible national water monitoring management structure within DWA&F.

The NAWQA Program effectively used review committees to provide guidance and policy during the implementation of the 7 pilot scale projects and to review the findings of the work (Hirsch et al., 1988; Engelbrecht et al., 1990). If all of the discussion presented above is considered, the appointment of a review committee could be the key to the successful establishment of a national monitoring network:

a. the committee would make final decisions regarding technical design considerations e.g. final monitoring chemical constituent list, selection of priority areas.
b. the committee could lobby to various quarters for additional financial and logistical support.
c. the network manager would be held accountable to the committee for project progress.
d. the committee would review the findings of monitoring and ensure that the monitoring remains objective and goal orientated.
e. the committee could provide feedback, by means of a short annual monitoring review, to all the network contributors and participants such that they can monitor the effective use of their investment.

The Groundwater Quality Task Group convened by DWA&F (Braune et al., 1991) would be ideal to fulfil this role. A representative of local authorities could also be incorporated to facilitate support and "buy-in"from this sector. Such a group would however add to the financial requirements of the network.

STRATEGY

Appoint a responsible person or network manager whose sole function is to manage and control the design, implementation and operation of a national groundwater quality monitoring network.

Appoint a National Groundwater Quality Monitoring Review Committee with executive powers whose responsibility is to provide guidance and policy and to ensure that the masterplan is adhered to

TASKS

Compile and adhere to a network design, implementation and operation masterplan which sets out in detail specific tasks, completion target dates and task executors.

5.9. Pilot Study Areas

The strategy of pilot study areas was used successfully in the NAWQA Program (Hirsch et al., 1988; Engelbrecht, 1990) and by the Californian State Water Resources Control

Board (Youngman, 1981). This strategy allows for the monitoring system to be developed in a small area, thereby removing many of the logistical problems associated with a national effort. Focus can be concentrated on many of the technical issues, and once all the teething problems have been sorted out, other staff, institutions and areas can be included.

The first pilot study area needs to be identified. It would appear that the Western Cape could be suitable. The completion of the 1 : 500 000 hydrogeological map will be of great assistance to the establishment of the network and the geohydrological staff in the Regional Office can be used to select the most suitable monitoring stations. Further, groundwater is well used in the area, particularly in the smaller towns and villages. The only real drawback with using the Western Cape is the distance from DWA&F Head Office, whose staff must be intimately involved with the network development. In making this decision, a hierarchial approach can be adopted. The area needing a network most urgently (based on the outcome of Section 5.2.) could be used as the first study area. Subsequent expansions could then include lower priority areas.

STRATEGY

Adopt a strategy of using pilot scale study areas in the implementation of a national groundwater quality monitoring network.

TASKS

Select an appropriate area for use as the first pilot scale investigation.

5.10. Technical Considerations in the Network Design

The design of a monitoring network includes all aspects of monitoring. Activities which need to be considered are presented in Appendix C. It is beyond the scope of this research project to address all of these aspects but it is recognised that all impact on the resources required to establish a national network. Strategies can be used to address some of these concerns. Through the design and implementation of the surface water quality monitoring networks, many systems and structures are already in place within DWA&F e.g. sample transportation, data handling system, data interpretation. Where possible, use should be made of existing facilities. The current short-comings identified by Harris et al. (1992) however require attention.

Based on a review of the literature, four components were identified which required further review. All four play an important role in defining network resource requirements. The components are:

a. station selection
b. sampling protocol

c. laboratory analysis
d. quality control

5.10.1. Station Selection

Station selection probably has the greatest impact on the development of a national monitoring network. A few decisions taken during the design process can have a major bearing on the whole network. Such decisions include:

a. the total number of boreholes to be included into the national network.
b. whether existing boreholes or specially drilled boreholes are to be used as monitoring stations.
c. whether depth is to be considered during network design.

No generally valid standards for the number of monitoring stations per unit area exist (Vrba and Pekny, 1991). In general, the density of monitoring stations increase with the degree of the aquifers importance and vulnerability and with the extent of potential human impacts on the hydrogeological system. Kozlovsky (1988) presented a classification which could be used as a rule of thumb (Table 3).

Table 3: Station density as a function of network scale.

SCALE OF NETWORK	SAMPLING STATION DENSITY (km^2 / sampling point)
Global Environmental Monitoring System	10 000 to 100 000
National or State	100 to 10 000
Regional or Provincial	10 to 100
Local or Site-specific	< 10

(After Kozlovsky, 1988)

Some actual monitoring station densities gleaned from the literature are presented in Table 4. Comparative figures from the USA are difficult to determine because of the number of different networks and organizations operating them. Canter et al. (1987) stated that average densities range from 3 to 7 stations per county but that some of the more developed networks may contain 20 to 50 boreholes per county.

It was difficult to present an optimal number of monitoring stations to be included into the national network. Management objectives, priority areas and resources will all play a role in defining the total number of stations to be used. It would seem however that between 400 and 1 000 stations would be appropriate. If the suggestion to immediately include one borehole from all towns presently using groundwater for domestic supply into the network is implemented (Section 5.2.), the first national groundwater quality monitoring network will consist of about 300 stations.

Table 4: Typical European National Groundwater Quality Monitoring Network sampling station densities.

NATIONAL GROUNDWATER MONITORING NETWORK	STATION DENSITY (km^2 / borehole)	TOTAL STATIONS
Netherlands	110	370
Czechoslovakia	250	322
Denmark	290	150

(After Kozlovsky, 1988)

The decision to use existing boreholes for monitoring or to drill new boreholes will also impact on the resources required for network establishment. Both schools of thought are presented in the literature. For example, in California, use was made of existing boreholes (Youngman, 1981) while in the Netherlands and Denmark, special monitoring boreholes were drilled (Van Duijvenbooden, 1987; Korkman, 1987). Given the present emergency drought relief drilling program and the cost of drilling between 400 and 1 000 boreholes, it would be more appropriate to make use of existing boreholes where possible. The judgement and knowledge of the area of the geohydrologist responsible for selecting monitoring stations will have to be relied on. Ultimately, properly sited and constructed, dedicated monitoring boreholes should be used. In this way consistency and standardization will be achieved.

In a similar fashion, depth of monitoring has to be considered. Both the Dutch and Danish national monitoring networks made use of specific depth monitoring. For example, two boreholes were installed at each Dutch monitoring station, one to a depth of 10 m and one to a depth of 25 m. It is questionable whether such a standard approach is applicable in fractured rock environments. Further, the adoption of such a policy would require the drilling of dedicated monitoring boreholes which has not been recommended at this stage. A national network provides general information (Section 5.1). It is thus proposed that only viable aquifers be monitored and where two aquifers exist in close proximity, the aquifer yielding the better quality water be monitored.

5.10.2. Sampling Protocol

The aim of a sampling protocol and the documentation thereof is to attain procedural consistency in the network and to ensure the representativeness of the collected samples. The network protocol document thus serves as a consistent reference for correct procedures and promotes quality assurance (QA) and quality control (QC). With respect to a national network and the large number of field and office staff involved, a sampling protocol document is essential. Vrba and Pekny (1991) noted that data acquisition methods, field and laboratory analyses, field monitoring records and laboratory record forms must be standardised. A standardised study approach was also adopted by the NAWQA Program (Hirsch et al. 1988).

A sampling protocol document would typically cover the following activities with detailed step-by-step descriptions being given for each aspect:

a. office preparation and equipment requirements
b. field sampling procedure
c. sample transportation and handover

Following the publication of Weaver (1992), appropriate groundwater sampling procedures and standards applicable to local conditions are well documented. It is proposed that this work be used to compile a sampling protocol document dedicated to the national groundwater quality monitoring network. This document can be used to train all the samplers in the required sampling procedure.

5.10.3. Laboratory Analysis

Even if all the correct procedures are applied, the final accuracy of monitoring depends on the accuracy and precision of the analytical laboratory. At present the HRI water laboratory is run at full capacity (van Veelen, pers.comm., 1992). It is therefore uncertain whether this laboratory could cope with additional groundwater samples. It may be required that other laboratories be used to perform the analytical work. The network could be divided, say, into five geographical regions with a designated laboratory in each region serving that particular network sub-area e.g. Pretoria, Cape Town, Port Elizabeth, Durban and Bloemfontein. The selection of suitable laboratories requires careful consideration but could be based on the results of the Inter-laboratory study, turn-around time and cost. Such an approach will nevertheless impact on the financial requirements of the network.

5.10.4. Quality Assurance and Quality Control

With the large amount of money that will be required to establish and maintain a national groundwater quality monitoring network, QA and QC are vital. The value and effectiveness of QA and QC initiatives will ultimately be defined by the accuracy of the data. The fact that 19 000 or 57 % of the groundwater quality data stored on the NHD were found unsuitable for use by Levin et al. (1990) suggests that this is an area which requires urgent attention. Based on current costs and considering analytical costs only, this equates to about R 2 300 000 worth of data that was lost.

QA relates to efforts to assure that all procedures of the monitoring system are followed correctly while QC refers to efforts to assure that specific results of the laboratory analysis procedures are repeatable (Harris et al., 1992). QA and QC have to be exercised in all monitoring activities and at all levels. One of the important on-going tasks of the national groundwater quality monitoring network manager will be to implement an effective QA and QC program.

STRATEGY

Make use of existing systems, facilities and structures presently being used by the surface water quality monitoring networks.

Make use of geohydrologistsfamiliar with specific regions to select monitoring stations and / or provide specialised input.

Where possible, make use of existing boreholes for monitoring purposes.

TASKS

Make strategicand policy decisions regardingvarious aspects of network design which can be complied with on a national basis.

Compile a sampling protocol document for the national groundwater quality monitoring network.

Investigate and decide on which laboratories are to used for hydrochemical analyses.

Formulate and implement an effective QA and QC program

5.11. Generalized Strategies and Approaches

Throughout the above discussion on strategies to be used in the design, development and operation of a national groundwater quality monitoring network, two global strategies have been continually promoted. These are:

a. an empirical approach
b. a hierarchial approach

Both support the approach of starting a national monitoring network at a low level and working towards an ideal. Probably the best example of this is using the boreholes which supply 280 towns and settlements with water as sampling stations and working towards between 400 and 1 000 properly sited, dedicated national groundwater quality monitoring network boreholes. The old adage of *a mediocre plan implemented is always better than a brilliant plan never executed* holds true. By getting the network operational, refinements and improvements can be made from a knowledge base. Experience gained during the early stages of network implementation will also be an asset in working towards the ideal.

An approach of standardisation is appropriate during the early stage of network development. It must be accepted that major geohydrological differences exist throughout South Africa. In an ideal network, these differences would be carefully considered. The acceptance of this approach has, however, many benefits at this stage, including relatively easy station selection, simple sampling protocol definition and integration into other networks. Temporary measures such as these are, however, vulnerable to change. It is for this reason that limited modifications should be made to the network during the first 5 years. Only once the network is fully operational and some data are available on which to base decisions, should network refinement be instigated.

The establishment of a national groundwater quality monitoring network will not transpire overnight. It is a major undertaking which will require hard work, continual learning and dedication. The desire to achieve and the commitment to succeed by the organizations and people responsible for the network establishment are vital. Support for the team members will be required from all quarters. The proposed Review Committee would have a major responsibility in this regard. Starting the national monitoring with simple building strategies while working towards feasible and attainable goals is considered essential.

STRATEGY

An empirical and hierarchial approach must be adopted at the start of the national groundwater quality monitoring initiative.

6. DISCUSSION

When a task has to be performed, the availability of four components have a bearing on the capability of performing and completing the task. These interdependent components are:

a. resources (financial, manpower, infrastructure)
b. skills and technology
c. procedure and method
d. time

The resource component could be further broken down into financial, manpower and infrastructure sub-components. The identified strategies were grouped under these essential elements. These groupings are presented in Tables 5 to 8. Many of the strategies could fit into two or more of the components but they were grouped into the component in which they were considered to fit best. Twelve of the strategies related to resources, 3 to time and one each to skills and technology and procedure and method. Considering the resource sub-components, 9 strategies related to financial aspects, 2 to manpower and 1 to infrastructure. This simple analysis was used to identify those components or factors which could be regarded as limiting, and hence require special attention, and identify those aspects which do not appear to be major obstacles.

The bulk of the strategies considered in this study focused on resources required to establish a national groundwater quality monitoring network (Table 5). Of the three sub-components, financial considerations are the most important. It could be argued that with sufficient financial resources, limitations related to manpower and infrastructure can be overcome. As financial resources are limited, strategies have to be used to keep the level of funding required to an absolute minimum.

Obtaining adequate financial support for the implementation and operation of a national network was judged to be the most critical aspect which needs to be considered. It was also regarded as the most significant limiting factor in the successful establishment of the desired national groundwater quality monitoring network. The majority of strategies considered, therefore, related to achieving low network establishment expenditure and reducing operational costs. This aspect was regarded as a key to successful network development. With other pressing political and social needs and the present poor state of the economy, competition for state funds is extremely intense. There is no doubt that additional funding is required but this can be limited by:

a. making efficient and effective use of existing resources, and by
b. matching the national network to available resources.

Additional funding could possibly be obtained from within DWA&F, from other public sector sources and from the private sector. A drive to secure adequate funding will have to be initiated.

If existing DWA&F resources are considered, manpower and infrastructure requirements

Table 5. Strategies applicable to Resources

Financial Resources
* An empirical and hierarchial approach must be adopted at the start of the national groundwater quality monitoring initiative. * All national water monitoring and related networks should be integrated. * DWA&Fmust make adequate financial and logistical provision for the establishment and maintenance of a national groundwater quality monitoring network. * Secure additional financial and logistical support from other sectors and lower levels of government, which could either make use of the information or are groundwater users, for the establishment and maintenance of a national groundwater quality monitoring network. * The concept of priority areas should be used to initiate the national groundwater quality monitoring network with those areas regarded as having the highest priority being included into the network first. * Make use of water users to collect field data. * A general but short list of chemical constituents should be used to define trends and water quality for domestic, agricultural and industrial use. * Special surveys, in conjunction with the national monitoring, can be used to obtain information on chemical constituents excluded from the national monitoring list. * Where possible, make use of existing boreholes for monitoring purposes.
Manpower Resources
* Appoint a responsible person or network manager whose sole function is to manage and control the design, implementation and operation of a national groundwater quality monitoring network. * Make use of geohydrologists familiar with specific regions to select monitoring stations and / or provide specialised input.
Infrastructural Resources
* Make use of existing systems, facilities and structures presently being used by the surface water quality monitoring networks.

for a national monitoring network do not appear to be major limitations. By employing water users and staff from other monitoring networks to collect groundwater samples, manpower requirements can be drastically reduced (Sections 5.6 and 5.7.). If such an approach is adopted, management of manpower resources will be critical.

Network responsibility and accountability were seen as important considerations in maintaining momentum in the network establishment process. The appointment of a national groundwater quality monitoring manager and a Review Committee were proposed as mechanisms of ensuring progress (Section 5.8). It must be stressed that the appointed manager needs to be solely dedicated to the task of implementing a national network.

With regard to the national network infrastructure requirements, DWA&F already have well developed infrastructures for operating national water quality monitoring networks. Through the installation and operation of surface water monitoring networks, the existing infrastructures have been refined and are thus probably quite mature. The manager of the groundwater quality monitoring network must thoroughly exploit this advantageous situation by linking into the existing networks.

From the analysis of the strategies, it would appear that the skills and technology required to install a national groundwater quality monitoring network are readily available and are not limiting factors in the network design, installation and operation. The literature reviewed during this investigation support this (e.g. Sanders et al., 1987; Aller et al., 1990; Sara, 1991; Weaver, 1992).

Table 6. Strategies applicable to Skills and Technology

Skills and Technology
* **Adopt a strategy of using pilot scale study areas in the implementation of a national groundwater quality monitoring network.**

It has been stressed throughout this report that some form of network must be started without delay, even if it is far from perfect. If the strategies presented in this report are adopted, much of the early work will be related to decision making and organisation. For example, the Review Committee would be required to make decisions regarding the chemical constituents to be monitored and reporting formats, defining priority areas and selection of a pilot study area, etc. The appointed network manager would, on the other hand, be involved with the organisational aspects such as computer support, network integration, sample collection, sample analysis, etc. In order to provide a starting point, it was recommended that a pilot program be initiated as a means of launching the national effort (Section 5.9.). The approach allows that the infrastructure, methods and procedures be developed relatively quickly without the restrictions which could be imposed when working over large areas. The Western Cape could, for example, be used for this purpose as it encompasses a variety of aquifer types as well as sole-source situations.

Procedures and methods to be adopted were also found not to be limiting factors (Table 7). Much information is available on these subjects. However, defining appropriate practices to be employed and staff training is required to ensure that the methods and procedures are applied uniformly throughout the national network. Some initial fundamental decisions regarding design and operation by the Review Committee and the application of Weaver (1992) would be constructive in this regard. The selection of the first monitoring stations to be used in the national network is of particular importance.

Table 7. Strategies applicable to Procedure and Method

Procedure and Method
* **Because the definition of priority areas may take some time, it is recommended that all towns currently using groundwater for domestic supply be regarded as top priority and be immediately incorporated into the national groundwater quality monitoring network.**

Table 8. Strategies applicable to Time

Time
* **A long term commitment must be made towards implementing a national groundwater quality monitoring program on the understanding that it may be some years before the tangible benefits of such an initiative become evident.**
* **Monitoring should be performed at 6 monthly intervals, at least for the first 5 years of network operation. Thereafter annual or biennial monitoring will be adequate.**
* **Appoint a National Groundwater Quality Monitoring Review Committee with executive powers whose responsibility is to provide guidance and policy and to ensure that the masterplan is adhered to**

In the analysis of the various task components, time was found to be relatively significant (Table 8). A number of years have already passed since the concept of a national groundwater quality monitoring network was first proposed in 1986. Further, it is estimated that another 5 or 6 years after network installation are required before any information will be generated (Section 5.3.). As the information to be provide from the network is required to manage the groundwater resources of the country, it is essential that network design and installation be instituted immediately. By making use of an empirical and hierarchial strategy, a "low level" or imperfect national network can be installed relatively quickly. With time and knowledge gained from monitoring, the network can be improved and expanded. In this way, the vision of an "ideal" network may be realised.

In summary, the key factors to the successful establishment of a national groundwater quality monitoring network are obtaining adequate financial resources, appointing a Review Committee to guide the process and appointing a network manager to administer the process. Initiating the national network using a pilot program is also considered fundamental to the attainment of a national groundwater quality monitoring network.

7. ACHIEVEMENT OF PROJECT OBJECTIVES

The objective of the research project, as set out in the approved project proposal, was to develop a practical strategy for monitoring groundwater quality on a national scale. The following were identified as important considerations:

a. the purpose of a national monitoring programme
b. the cost and manpower available for the monitoring programme
c. the most important areas to be covered (major pollution sources, sole source aquifers)
d. the variable nature of groundwater over short distances (representativeness)
e. methods of sampling and frequency, analysis, data storage and information reporting
f. possible linkage to national surface water quality monitoring network

This literature study has successfully achieved the stated objective by describing a set of strategies that could be used in designing, implementing and operating a national groundwater quality monitoring network.

The important considerations identified were all found to be applicable. During the study other topics such as the definition of quality information and the concepts of space and time were also identified as requiring consideration.

The purpose of monitoring was discussed in some detail in Section 4.2. A vision for a national network was presented followed by a more practical and attainable objective statement. The objective statement then became central to further strategy developments.

The resources available for the establishment of a national groundwater quality monitoring network was found to be an important factor in defining the nature and extent of the network as well as the approaches that could be adopted in establishing and operating the network (Sections 4.4). Continual reference is made to resource availability throughout Chapter 5. Most of the strategies are thus aimed at making use of available resources so that the network can be attained at affordable costs.

It was found during the literature study that a national network is aimed at establishing ambient groundwater quality (Section 3.2). Contamination studies are performed at regional or local scales. The defining of priority areas received attention in Section 5.2. A policy decision needs to be taken as to exactly how priority areas will be defined. Until such time that the desired policy is provided, it was proposed that all towns using groundwater be designated as top priority. They should be automatically included into the first national groundwater quality monitoring network.

It was found that spatial representativeness was not well discussed in the literature. This is a complex problem, particularly when dealing with fractured rock environments. It was recommended that spatial representativeness be considered more closely by the Review Committee. However, it was argued that this aspect should not be allowed to hindered the installation of the network (Section 5.2).

Technical considerations in the design of the national groundwater quality monitoring network were discussed in Section 5.10. Owing to the vastness of this topic, only those aspects which were found to play an important role in the network resource requirements were addressed.

Network integration and integration with other water users were found during the study to be viable strategies in the establishment of the desired network (Section 5.6 and 5.7.). Both are aimed at making efficient and effective use of all available resources and at preventing duplication. It was further proposed that use be made of water users to collect the groundwater samples.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Conclusions

a. No national groundwater quality monitoring programme is in place. Some information is available concerning spatial groundwater quality distribution but almost no information exists regarding temporal changes.

b. Information pertaining to the status and trends of groundwater quality on a national scale is required to manage the country's resources.

c. A national monitoring program addresses the "what" question while regional and local networks address the "why"question. As such, a national network is not used to monitor contamination but rather ambient groundwater quality conditions.

d. A national groundwater quality monitoring objective statement was defined which formed the basis for the investigation of possible strategies. The provision of groundwater quality information from priority areas was recognised as central in the objective statement.

e. DWA&F are responsible for the establishment and operation of the network but this does not exclude obtaining financial and logistical support from outside organisations.

f. An empirical and hierarchial approach should be adopted. This allows that an imperfect network can be installed relatively quickly and, as knowledge is gained from monitoring and more resources become available, the network can be refined and improved.

g. It will take a number of years before the benefits of a national groundwater quality monitoring effort are evident. A long term commitment to the program is therefore required.

h. Funding was recognised as the major limiting factor in the establishment of a national monitoring network. Strategies dealing with integration with other monitoring networks, integration with groundwater users and specific technical considerations are all effective approaches in reducing the network financial requirements.

i. Consideration has to be given to the fact that most of South Africa's groundwater resources are found in fractured rock introducing a critical need to ensure representative monitoring of such aquifers.

j. The selection of monitoring stations is a major consideration which can be addressed by applying a priority area strategy. A policy is required concerning the definition of these areas.

8.2. Recommendations

a. The strategies proposed in this report must be incorporated in all further national water monitoring network deliberations.

b. Network design and implementation must be activated immediately.

c. Adequate financial resources required for the establishment of the desired network must be procured by DWA&F. A long-term commitment should be ensured.

d. A manager of the national groundwater quality monitoring network should be appointed such that technical and network integration aspects can receive immediate considerations.

e. The Review Committee must be appointed so that the process of establishing a national network can be effectively guided and such that timely decisions can be taken.

f. Integration with other water quality monitoring networks must be investigated. Some restructuring or re-assignment of staff within DWA&F may be required.

g. Towns presently using groundwater for water supply purposes should be used as monitoring stations in the initial national network. The policy to be applied in defining priority areas must be addressed.

h. Where possible, use must be made of existing infrastructure and facilities.

i. A sampling protocol document has to be compiled. The use of non-DWA&F laboratories and a quality assurance and quality control program also require consideration as part of the protocol.

j. Monitoring frequency should initially be set at 6 monthly intervals but after 5 years of network operation it should be reviewed and could be reduced to annually or biennially.

k. The use of a pilot scale study area to begin the national monitoring network is strongly recommended. The Western Cape area is proposed as a suitable area for this in view of the variety of aquifers represented.

REFERENCES

ACKERMAN, W.C., 1987: Objectives of national water quality monitoring and assessment; National Water Quality Monitoring and Assessment; National Academy Press, Washington DC.

ALLER, L., BENNET, T.W., HACKETT, G., PETTY, R.J., LEHR, J.H., SEDORIS, H., NIELSON, D.M. and DENNE, J.E., 1990: Handbook of suggested practises for the design and installation of ground-water monitoring wells; US EPA Report No. EPA/600/4-89/034, pp 1 - 398.

AUCAMP, P.J. and VIVIER, F.S., 1987: A novel approach to water quality criteria in South Africa; IWSA Int. Conf. Proc., Water 2000, Nice.

BOND, C.W., 1946: A geochemical survey of the underground water supply of the Union of South Africa; Memoir 41, Geological Survey, Department of Mines.

BRAUNE, E., BROWN, S.A.P., HODGSON, F.D.I., LEVIN, M., REYNDERS, A.G. and TREDOUX, G., 1991: Groundwater quality management policies and research needs for South Africa; Report in preparation for Department of Water Affairs and Forestry and Water Research Commission.

BREDENKAMP, D.B., LEVIN, M. and van BLERK, J., 1991: Countrywide characterisation of groundwater quality specifically in relation to average annual rainfall distribution; Conf. Proc. Ground Water Quality and Pollution, Midrand, Aug. 1991.

BROWN, A, 1991: Prediction of groundwater inflows and groundwater inflow impact in mines; Conf. Proc. Ground Water Quality and Pollution, Midrand, Aug. 1991.

BROWN, G.E., 1984: A national environmental monitoring system: An essential step towards achieving water quality goals; AWRA Conf. Options for Reaching Water Quality Goals, Washington, pp 5 -7.

CANTER, L.W., KNOX, R.C. and FAIRCHILD, D.M., 1987: Ground water quality protection; Lewis Publ., Michigan, pp 562.

CHANDRA, A., 1985: Water quality monitoring in Fiji Islands; Water Quality Bulletin, Vol 10 No. 4, pp 197 -203, 217.

CHEREMISINOFF, P.N., GIGIELLO, K.A., O'NEILL, T.K., 1984: Groundwater leachate: modelling / monitoring / sampling; Technomic, Pennsylvania.

COGHO, V.E., VAN NIEKERK, L.J., PRETORIOUS, HPJ and HODGSON, F.D.I., 1992: The development of techniques for the evaluation and effective management of surface and groundwater contamination in the Orange Free State Goldfields; Report No. 224/1/92, Water Research Commission.

DEPARTMENT of WATER AFFAIRS and FORESTRY, 1986: Management of the water resources of the Republic of South Africa; Department of Water Affairs and Forestry, Pretoria.

DEPARTMENT of WATER AFFAIRS and FORESTRY, 1991: Water quality management policies and strategies in the RSA; Department of Water Affairs and Forestry, Pretoria.

DEPARTMENT of WATER AFFAIRS and FORESTRY, 1992: Groundwater quality management policies and strategies for South Africa; Department of Water Affairs and Forestry, Pretoria.

ENGELBRECHT, R.S. (Chairman), 1990: A review of the USGS National Water Quality Assessment pilot program; National Academy Press, Washington, D.C.

EVERETT, L.G., 1987: Groundwater monitoring; Genium Publishing Corporation, New York.

KEMPSTER, P.L and SMITH, R., 1985: Proposed aesthetic / physical and inorganic drinking water criteria for the Republic of South Africa; Research Report No. 628, National Institute for Water Research, CSIR.

FLEISHER, J.N.E., 1990: The geochemistry of natural groundwater in the West coast sand aquifer. Part 1: Atlantis; Report No. 6/605/3, Groundwater Programme, Watertek, CSIR.

GELDENHUYS, W., NELL, U. and van VEELEN, M., 1991: Surface water quality of South Africa 1978 - 1988 Volume 5 : drainage region J, K, L, M, N, P, Q, R and S; Technical Report TR 145, Department of Water Affairs and Forestry.

GILBERT, J.B. (Chairman), 1986: Ground water quality protection - state and local strategies; National Academy Press, Washington, D.C.

HAFFNER, G.D., 1986: Water quality branch strategy for assessment of aquatic environmental quality; Scientic Series Report No. 151; Inland Waters Directorate, Canada.

HARRIS, J., van VEELEN, M. and GILFILLIAN, T.C., 1992: Conceptual design report for a national river water quality assessment programme; Report No 204/1/92, Water Research Commission.

HIRSCH, R.M., ALLEY, W.M and WILBER, W.G., 1988: Concepts for a national water-quality assessment program; USGS Circular 1021, United States Government Printing Office.

KORKMAN, T.E., 1987: Strategies for groundwater monitoring in Denmark; in van Duijvenbooden, W. and van Waegeningh, H.G. (eds), 1987: Vulnerability of soils and groundwater to pollutants; Int. Conf. Proceedings and Information No. 38, TNO Committee on Hydrological Research, The Hague.

KOZLOVSKY, E.A.,(Ed) 1988: Geology and the environment. Vol. 1. Water management and the geoenvironment; UNESCO Publ.; Paris.

LEVIN, M., LANGTON, C., BRINK, R., van der MERWE, P and HEARD, R.G., 1989: A report on the results of phase one of the ground water quality study of the Republic of South Africa; Restricted Report AEC\1989\73(B\R); Earth and Environmental Technology Division, Nuclear Technology Department, Atomic Energy Corporation of South Africa.

LEVIN, M., van der MERWE, P and WALTON, D., 1991: A statistical and conventional approach to a ground water study within the dolomites of the H-region; Report GEA-947; Department of Earth and Environmental Technology, Atomic Energy Corporation of South Africa.

MILLER, R.L., 1978: State water quality control program in Arizona; Wat. Res. Bull., Vol. 14 No. 6., pg. 1503 - 1507.

MLAY, M., 1981: Remarks on the proposed groundwater protection strategy; Environmental Professional, Vol. 3 No. 1, pp 15 - 18.

MOODY, D.W., CARR, J., CHASE, E.B. AND PAULSON, R.W., 1988: National water summary 1986 - Hydrologic events and ground-water quality; U.S. Geological Survey, Water Supply Paper 2325, pp 560.

PARSONS, R.P., 1988: Evaluation of the National Hydrochemical Databank: Progress report and further work proposals; unpubl. project proposal, Directorate of Geohydrology, Department of Water Affairs and Forestry.

PARSONS, R.P., 1989: An assessment of hydrochemical changes of groundwater around De Aar; Unpubl. Tech. Report Gh 3628, Directorate of Geohydrology, Department of Water Affairs and Forestry.

PATCHETT, M.A. and DENT, J.E., 1985: Development of a national policy for water quality monitoring in Papa New Guinea; Water Quality Bulletin, Vol. 10 No. 3, pp 126 - 132.

PERRY, J.A., WARD, R.C. and LOFTIS, J.C., 1984: Survey of state water quality monitoring programs;

Environmental Management, Vol. 8 No. 1, pp. 21 - 26.

PETTYJOHN, W.A., STUDLICK, J.R.J., BAIN, R.C. and LEHR, J.Y., 1979: A groundwater quality atlas of the United States; National Demonstration Water Project.

PIETERSE, M.J., 1989: Drinking-water quality criteria with special reference to the South African Experience; Water SA, Vol. 5 No. 3, pp 169 - 178.

PINTER, J. and SOMLYODY, L., 1987: Optimization of regional water quality monitoring strategies; Wat. Sci. Tech., Vol. 19, pp 721 - 727.

RAJAGOPAL, R., 1989: Empirical methods in the design of ground-water quality monitoring strategies; ASCE Conf. Proc. Hydraulic Engineering, Aug. 1989, New Orleans.

REYNDERS, A.G., 1987: Attendance of AGWSE Conference, Minneapolis, and fact finding tour of institutions actively involved in groundwater quality research, U.S.A.; unpubl. Tech. Report Gh 3566, Directorate of Geohydrology, Department of Water Affairs and Forestry.

REYNDERS, A.G., 1987: National water quality assessment of South Africa; unpubl. project proposal, Directorate of Geohydrology, Department of Water Affairs and Forestry.

REYNDERS, A.G., 1991: A critical evaluation of US ground-water protection strategies and their possible implementation in the South African context; Unpubl. Report AE 695 V on independent study tour, WRC

REYNDERS, A.G. and LYNCH, S.D., 1993: Compilation of a national groundwater vulnerability map of South Africa; Conf. Proc. "Africa Needs Ground Water", Johannesburg, September 1993, Poster Paper No. 75.

ROMIJN, E. and FOSTER, S.S.D., 1987: Monitoring strategies for the quality of soil and groundwater; in van Duijvenbooden, W. and van Waegeningh, H.G. (eds), 1987: Vulnerability of soils and groundwater to pollutants; Int. Conf. Proceedings and Information No. 38, TNO Committee on Hydrological Research, The Hague.

SABEL, G.V., 1987: The role of ambient ground water monitoring in standard setting and groundwater protection strategy development in Minnesota; 1st National Outdoor Action Conf. "Aquifer Restoration, Ground Water Monitoring and Geophysical Methods", Las Vegas, May 1987.

SANDERS, T.G., WARD, R.C., LOFTIS, J.C., STEELE, T.D., ADRIAN, D.D, and YEYJEVICH, V., 1987: Design of networks for monitoring water quality; Water Resources Publications, Colorado.

SARA, M.N., 1991: Ground-water monitoring systems design; in Nielson, D.M. (ed.): Practical handbook of ground-water monitoring; Lewis Publishers, Michigan.

SIMONIS, J.J., 1988: Grondwaterkwaliteit van die Matlabasrivier-omgewing (Noord Transvaal) Fase 1; Unpubl. Tech. Report Gh 3605, Directorate of Geohydrology, Department of Water Affairs and Forestry.

South African Bureau of Standards (SABS), 1984: Specifications for water for domestic supplies; SABS 241-1984, Pretoria.

TREDOUX, G., 1981: 'n Geohidrochemiese ondersoek van die artesiese kom Stampriet, Suidwes-Afrika; Unpubl. Ph.D. Thesis, University of Orange Free State.

YOUNGMAN, J.M., 1981: Ground water quality monitoring; 13th Biennial Conf. on Ground Water, Irvine, Sept. 1981, pp 70 - 78.

van DUIJVENBOODEN, W., 1987: Groundwater quality monitoring networks: design and results; in van Duijvenbooden, W. and van Waegeningh, H.G. (eds), 1987: Vulnerability of soils and groundwater to pollutants; Int. Conf. Proceedings and Information No. 38, TNO Committee on Hydrological Research, The

Hague.

van NOORT, D. and MACVICAR, C.D., 1958: Attempts to type and map South African borehole waters; Unpubl. Report 302/58, Division of Chemical Services.

VEGTER, J.R., 1990: Groundwater regions and subregions of South Africa; Unpubl. Tech. Report Gh 3697, Directorate of Geohydrology, Department of Water Affairs and Forestry.

VRBA, J., 1987: Groundwater quality monitoring - strategy, objectives, programmes and methods; in van Duijvenbooden, W. and van Waegeningh, H.G. (eds), 1987: Vulnerability of soils and groundwater to pollutants; Int. Conf. Proceedings and Information No. 38, TNO Committee on Hydrological Research, The Hague.

VRBA, J. and PEKNY, V., 1991: Groundwater-quality monitoring - effective method of hydrogeological system pollution prevention; Environ. Geol. Water Sci, Vol. 17 No. 1, 9 - 16.

WARD, R.C., 1988: Water quality monitoring as an information system; EPA Nat. Symp. on Water Quality Assessment, 1 - 3 June 1988, Annapolis, Maryland.

WEAVER, J.M.C., 1992: Groundwater sampling manual; Report No TT 54/92, Water Research Commission.

ZOETMAN, B.C.J., 1987: Soil pollution: an appeal for a new awareness of the earths's intoxication; in van Duijvenbooden, W. and van Waegeningh, H.G. (eds), 1987: Vulnerability of soils and groundwater to pollutants; Int. Conf. Proceedings and Information No. 38, TNO Committee on Hydrological Research, The Hague.

APPENDIX A

GROUNDWATER QUALITY INFORMATION USES

GROUNDWATER QUALITY INFORMATION USES

a. RESOURCE CHARACTERIZATION AND QUANTIFICATION

- to provide a basis for the development and refinement of a geohydrological classification system
- for the description and characterization of water quality of aquifers from different geohydrological provinces, in a nationally consistent manner, in terms of status and spatial and seasonal trends
- to develop a nation-wide understanding of baseline groundwater quality conditions and trends and and develop an understanding of the natural physical, chemical and biological factors which influence groundwater quality
- for the development of a long-term historic groundwater quality information data set which can be used to predict future conditions and trends in groundwater quality
- for the identification of areas where little or no data exists and, where needed, the rectification thereof.
- for the identification of priority and / or important groundwater areas
- for the identification of important areas to monitor
- for the identification of emerging national and regional water quality problems
- for the identification of areas where groundwater quality is changing such that potential problems can be addressed by means of more detailed localized investigation

b. RESOURCE PLANNING

- for the identification of areas where groundwater could be used as a viable water source in either the short-, medium- or long-term
- information pertaining to quality is vital to the whole groundwater planning process
- for the identification of areas where water quality management is required
- for planning purposes outside of the field of water eg urban planning

c. POLICY DEVELOPMENT AND REFINEMENT

- for the formulation of guidelines, regulations, principles and policy for developing, conserving and managing groundwater resources
- for the evaluation of the effectiveness of management actions and, where necessary, make improvements

d. RESOURCE PROTECTION

- to define or assist in defining the degree of a geohydrological systems vulnerability to contamination
- to develop and implement groundwater protection strategy, policy and action and evaluate the effectiveness thereof
- for the subsequent enhancement and refinement of anti-pollution strategy, policy and management
- for the identification of existing problem areas and / or contaminated areas such that resource protection monitoring and remedial actions can be initiated
- to detect pollution of principal aquifers in the country and identify the major factors causing it

e. OTHER

- to evaluate chemical quality data collected from other monitoring networks to determine the adequacy of the networks for describing baseline groundwater quality
- for education and public awareness purposes
- to determine the significance of the data in respect of primary health care and safe drinking water
- coordinate groundwater monitoring activities and determine what other agencies are doing in terms of monitoring groundwater quality and special short-term studies
- to assist local water managers in implementing groundwater monitoring such that they have information pertaining to groundwater quality

APPENDIX B

OBJECTIVE STATEMENT OF THE NRWQMS

OBJECTIVE OF THE NATIONAL RIVER WATER QUALITY MONITORING SYSTEM

The following statement was accepted by the User Team as the objective of the National River Water Quality Monitoring System.

The objective is to produce water quality information that will describe the fitness for use of the water resources of Southern Africa and the changes in quality over time and space.

The monitoring system is designed as an information system and will consists of a statement of the information requirements, statistical design criteria, operating plans and procedures, and reporting procedures and formats.

Initially it will be implemented in the Republic of South Africa, but cooperation with neighbouring states will be sought to encourage its implementation throughout the region.

Information on the fitness of water bodies for the purpose for which they are or could ordinately be used will be regularly reported to Government officials and the public. The reports will describe average levels and the changes in those levels over time and space. The water quality variables reported on will be general indicators of the fitness of water for use. The major water uses that will be addressed in the monitoring system are:

> *Domestic water supply*: The provision of raw water to facilities that will treat the water to drinking water standards
>
> *Industrial water supply*: The provision of water for use in any industrial setting, e.g. manufacturing, food processing, mining, and power generation
>
> *Agricultural water supply*: The provision of water for irrigation and stock watering
>
> *Recreation*: The use of water for angling, non-contact recreation such as boating, contact recreation such as swimming or diving, and other forms of land-based recreation that are done near bodies of water, such as hiking or picnicking. In this category it is also recognized that, despite attempts to discourage it, some people drink raw, untreated, water
>
> *Conservation*: The uses of water bodies which require them to function as healthy, viable ecosystems.

It is important to stress that the National Water Quality Monitoring System is not intended to be the **only** monitoring conducted. There are important water quality information needs that cannot be met by any one system. Therefore, separate monitoring systems will be created that operate in parallel with this one, perhaps sampling from the same sites, but at different frequencies and analyzing samples for different variables.

Analysis of data records of electrical conductivity and pH measurements indicated that a monthly frequency will allow the detection of a change equivalent to 2,0 times the standard deviation of the variable at the site after two years of data collection, with a significance level of 0,10 and a power of 0,90. Significance level refers to the probability of incorrectly saying a trend exists when it does not. Power is the probability of correctly saying a trend exists when it does.

Additional analysis will be required to determine the sampling frequency of other variables.

The Analytical Hierarchy Process was used to select the variables for inclusion in the National River Water Quality Monitoring System. They were:

Total dissolved solids ((TDS)
Turbidity
E. coli
Chlorophyll *a*
pH
Dissolved oxygen (DO)

In a separate project, Moore (1990) has investigated the construction of an index to combine information from these six variables into a single number. Individual rating curves were developed for each variable that show the "fitness for use" rating ((on a scale from 1 - 100) as a function of the measured value. Weights were assigned to each variable according to its importance in defining fitness for use.

By combining the two measures, rating curves and weighting factors, the index value will indicate the general fitness for use of the specific combination of the six measurements at each site.

The choice of sampling sites in any water quality monitoring system is influenced by the objectives of the system. The two objectives of the NRWQAPS that determine the distribution of sampling sites are:

(a) To assess river water quality of Southern Africa;
(b) To describe how river water quality changes over space.

A sampling site was chosen near the outflow of each tertiary drainage region with additional sites located on tributaries which drain at least 60 to 70 % of the tertiary drainage region.

In order to describe how water quality changes over distance, each major river or stream will be monitored over its entire length. A major river or stream was defined as one that drains at least a secondary drainage region. The tertiary drainage regions were used to determine the maximum distance between sampling sites. Each major river will be monitored where it passes through a tertiary drainage region, as close as possible to the point where it leaves the drainage region.

In addition, each river will be monitored just upstream of the confluence with any major tributary. the tributary will also be monitored just upstream of the confluence. A major tributary is defined as a stream that drains at least a tertiary drainage region.

All results of analyses will be stored on the water Quality data Base of the Hydrological Information Systems (HIS), developed in a separate project. Provision is made for a standard series of retrieval options for supplying data to general data users. Users with more data-intensive demands can get direct access for data retrieval.

The current water quality status can be determined by examining the statistics for each of the six variables separately and in combination. It is recommended that rank order statistical methods are used to analyze the data. The statistics to be calculated for each variable at each point are the 10th, 25th, 75th and 90th percentiles. The percentiles will be calculated for the year under review and the values for each point reported.

In order to allow easy assessment of the fitness for use, an index will be used to report the water quality in terms of the combined variables. A water quality index is one way of summarizing water quality data to present concise information on the suitability for use of water.

In order to allow the user to put the current water quality into perspective, information on the historical water quality will be provided. Any trends that are detected by making use of the whole record will indicate long term changes taking place in the catchment. A trend detected with the last three years of data will indicate sharp changes over a short period.

Maps showing drainage regions with a positive, negative, or no trend for each variable and the index will be supplied. These will be colour-coded to indicate negative trend, no change, positive trend or insufficient data. The graphical presentations can also be used to provide information on spatial changes.

Annual reports are proposed. The need for more frequent reports will be evaluated, based on requests for information. Procedures for immediate reporting of significant deviations from historical values have been developed.

The programme will be evaluated regularly to determine whether or not the stated objectives are being met.

The Department of Water Affairs and Forestry has, in principle, decided to implement this design.

(from Harris et al., 1992)

APPENDIX C

TECHNICAL DESIGN CONSIDERATIONS

MONITORING SYSTEMS ACTIVITIES

NETWORK DESIGN

Sampling station location
Variable selection
Sampling frequency

SAMPLE COLLECTION

Sampling Technique
Field measurement
Sample preservation
Sampling point
Sample transportation

DATA HANDLING

Data reception
- laboratory
- outside sources

Screening and verification
Storage and retrival
Reporting
Dissemination

DATA ANALYSIS

Basic summary statistics
regression analysis
Water quality indices
Quality control interpretation
Time series analysis
Water quality models

INFORMATION UTILIZATION

Information needs
Reporting formats
Operational procedures
Utilization evaluation.

(After Sanders et al., 1987)