Department of Water Affairs and Forestry

Chief Directorate: Community Water Supply and Sanitation
and
Directorate: Geohydrology

MINIMUM STANDARDS AND GUIDELINES FOR GROUNDWATER RESOURCE DEVELOPMENT FOR THE COMMUNITY WATER SUPPLY AND SANITATION PROGRAMME

FIRST EDITION
APRIL 1997

Acknowledgments

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The Department of Water & Forestry wishes to thank all those organisations which provided constructive comment on the Final Draft of this document dated July 1996.

The document is published by and obtainable from:

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Preface

Groundwater's role and importance has risen dramatically in the last two years. While there has already been a general trend towards greater utilisation of local groundwater resources, the new priority for meeting basic needs of communities has swung the water supply pendulum strongly towards groundwater. This was clearly demonstrated in the recent past in the Drought Relief and Critical Intervention Programme.

The Government White Paper on Community Water Supply and Sanitation (1994) has, as one of its main objectives, the provision for every household of a clean, safe water supply of 25 litres per person per day within 200 m walking distance. Groundwater, because of its widespread occurrence, albeit in relatively low yields, is ideally suited for this water supply situation particularly in the less densely populated areas.

However, the recent history of Africa, also demonstrated in South Africa during the recent drought, has been one of large scale pollution and over-pumping of groundwater and of thousands of abandoned boreholes due to poor construction and maintenance. With the overall objective of sustainable development in terms of the Reconstruction and Development Programme, it has become essential to improve the general standards of groundwater development practice in South Africa.

This document presents criteria for groundwater development for the Community Water Supply and Sanitation Programme and, as such, a framework within which all roleplayers should operate. The criteria must be seen to define the minimum requirements expected by the Department of Water Affairs and Forestry in this regard. Adherence thereto will hopefully bring greater uniformity to the execution of groundwater-based community water supply projects and with it the desired sustainability of projects to the long term benefit of all parties involved.

A document of this nature can never be final. It should now become a living document through the experience of you, the groundwater practitioner and the client. Your ongoing comments will be most welcome.

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Director: Geohydrology
Department of Water Affairs and Forestry

April 1997

Outline of Document Structure and Contents

This document is divided into three Parts. This subdivision facilitates the presentation of material on the basis of distinctly separate yet mutually supportive components of a groundwater resource development project.

Part 1 commences with a brief introduction (Section 1) in which the background to and objectives of the document are presented. This is followed in Section 2 by a description of the broad framework within which the various role players, project activities and personnel requirements are integrated into a groundwater resource development project. Section 3 addresses considerations, mainly of an administrative nature, related to the inception of such a project whilst its execution is discussed in detail in Section 4. The technical detail presented in Section 4 represents the core of the document. Part 1 concludes with Section 5, in which ancillary aspects and considerations relevant to such projects are addressed.

Part 2 of the document contains drawings and data capture and recording sheets relevant to and useful for the standardised execution of a groundwater resource development project.

Part 3 comprises a collection of administrative and contractual documentation presented as three separate Documents. Each of these is aimed at facilitating the procurement of services required for the execution of a groundwater resource development project. Document 1 addresses the professional component represented by hydrogeological consulting services. The technical services of drilling and test pumping are secured in Documents 2 and 3 respectively.

Applications of this Document

At its most basic level of application, this document provides any party with an interest in the development of groundwater resources for community water supply purposes with an indication of the administrative structures, scope of work and methodology required to successfully implement and execute such projects. As such, it introduces the layperson to a wide variety of relevant technical and administrative concepts and considerations.

At a more sophisticated level of application, the document provides role players with a set of criteria defining the minimum requirements expected by the Department of Water Affairs and Forestry (DWAF) regarding the proper and effective development of groundwater resources for community water supply purposes. As such it hopefully ensures, through the inclusion of *pro forma* technical, administrative and contractual documentation, that the development and utilisation of groundwater resources for community water supply purposes is approached in a scientific, structured, orderly and controlled manner.

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PART ONE

REPRESENTATION OF

MINIMUM STANDARDS AND GUIDELINES

FOR THE EXECUTION

OF HYDROGEOLOGICAL INVESTIGATIONS

DIRECTED AT THE DEVELOPMENT OF

GROUNDWATER RESOURCES AS PART OF A

COMMUNITY WATER SUPPLY AND SANITATION

PROGRAMME

Introduction

1-1. BACKGROUND

The implementation of the Reconstruction and Development Programme (RDP) in respect of the provision of potable water to communities relies substantially on the successful development of groundwater resources. This is especially true for the more rural areas of South Africa where greater deficiencies in this sector are more commonplace than elsewhere. It is considered that more than 12 million South Africans do not have access to an adequate supply of potable water (White Paper, 1994).

Since groundwater is increasingly being recognised as a national asset, it is imperative that its development and utilisation for whatever purpose be approached in a scientific, structured, orderly and controlled manner. The need for such an approach is intensified by: (1) the multidisciplinary nature of groundwater development programmes and (2) the ever increasing number of organisations becoming involved in these programmes. The development of groundwater resources for water supply can under no circumstances be viewed as a "quickfix" solution. It is a water supply option which, once identified as appropriate and feasible, must be approached with careful and diligent planning and execution. In the context of community water supply, its development must recognise and address numerous considerations and aspects any of which, if ignored, might lead to failure of the project or programme.

1-2. OBJECTIVE

The aim of this document is to provide the basic framework within which groundwater development programmes for community water supply purposes should be undertaken. In doing so, it recognises the individual components associated with such projects and establishes criteria and a protocol for their method and form of execution. The activities addressed in this document terminate at the stage where a successful borehole has been established and is ready for equipping. The criteria should not be viewed as being exhaustive of the topics addressed. This is especially true of aspects such as: (1) capacity building and training in respect of which specific initiatives have been launched, (2) groundwater protection, which topic is addressed in greater detail in Xu and Braune (1995) and (3) sanitation, which is adrressed in the second draft of a White Paper (1996) on this topic. Although this document must be seen to define the minimum requirements expected by the Department of Water Affairs and Forestry (DWAF) regarding the proper and effective development of groundwater resources for community water supply purposes, its applicability to the development of groundwater resources in general, ie. for purposes other than community water supply, should not be ignored.

SECTION 2

Hierarchical Project Structure

2-1. INSTITUTIONAL FRAMEWORK

The White Paper (1994) makes it clear that local communities are "......*the point at which implementation, operation and maintenance of services will take place.*" It is intended that this function be fullfilled at Local Government level through the offices of a Transitional Local Council (TLC) or a District Council representing a third tier agency. Each community within a district will have representation on these councils through the offices of, amongst others, a Local Water Committee. Second tier agencies/institutions will include Water Boards and Provincial Governments, whilst Central Government, represented by its Department of Water Affairs and Forestry (DWAF), will form the first tier institution. Within this institutional framework, other agencies such as non-governmental organisations (NGOs) and the private sector will occupy a niche supportive of and facilitating the activities associated with each of the three tiers of governance. In regard to the Community Water Supply and Sanitation Programme, this framework can be reconstituted to involve: (1) an activating agency, (2) an implementing authority and (3) an executive agency.

2-1-1. The Activating Agency

The Activating Agency is recognised as the community which the groundwater resource development programme will serve. This community will be represented by a Local Water Committee comprising of community representatives appointed by the local populace.

2-1-2. The Implementing Authority

The Implementing Authority is represented by the institution which carries responsibility for the provision of potable water within a defined area of jurisdiction. In the absence of a water supply authority or Local Government structure, this role falls either to Provincial or Central Government.

2-1-3. The Executive Agency

This comprises the organisation(s) responsible for the actual execution of the project for and on behalf of the Implementing Authority. It might also be termed the Implementing Agency. The Executive Agency is appointed by the Implementing Authority. It could either comprise: (1) a number of specialist firms/organisations acting under separate appointment or (2) a single organisation capable of undertaking all project activities under a single appointment. Whatever form the Executive Agency takes, it is crucial that all project activities be welded together into a single coherent function. This implies that one party within a multiparty Executive Agency assumes responsibility for overall project planning, management and execution.

2-2. ACTIVITY FRAMEWORK

The sequence and structure of project activities follow a logical progression from the initial recognition of water supply needs through to the eventual delivery of water to meet these needs. These activities can be grouped into three components defined as: (1) project inception, (2) groundwater resource development and (3) groundwater resource management.

2-2-1. Project Inception

This component lays the foundation for the groundwater resource development project. As such, it must include: (1) the registration of needs, (2) the prioritisation of registered needs and (3) the sourcing of services and the appointment of service providers to address these.

(a) The Registration of Needs

Water supply needs identified by a community (Activating Agency) are communicated through its Local Water Committee to the District Council or relevant Implementing Authority. The registration of these needs by the latter acknowledges their existence and begins the process according to which they will be addressed.

(b) The Prioritisation of Needs

Once registered with the Implementing Authority, an analysis of the available and most suitable options for addressing each water supply need is required. Instances where the development of groundwater resources presents itself as a viable and cost-effective option (whether short, medium or long term) are then prioritised.

(c) The Sourcing of Services

This requires the Implementing Authority to source the services of companies or organisations able to fullfil the role of executive agency. Such sourcing must recognise certain protocols in regard to: (1) the form of enquiry, (2) the evaluation of enquiry responses and (3) the appointment of service providers. This process is discussed in greater detail in subsection 3-2.

2-2-2. Groundwater Resource Development

The development of groundwater resources for community water supply purposes must be viewed holistically. This includes aspects such as: (1) the current source(s), type and reliability of water supply, (2) the extent of water reticulation, (3) the nature, type and level of sanitation facilities, (4) demographic information in respect of the community, (5) the existence of institutional Implementing Authorities and (6) operation, maintenance and payment-for-services considerations.

It must also be recognised that many communities have had historical access to natural sources of groundwater supply such as seepages, springs, fountains, rain water collection systems and shallow hand-dug wells. The development of groundwater resources for water supply purposes is therefore not limited only to the establishment of boreholes. It must also include, where possible, the development and protection of springs and the integration of these and other of the abovementioned sources into the overall water supply system.

Since the development and protection of natural sources of groundwater involves a lower level of technology than that required for boreholes, greater detail is afforded in this document to the latter as a means of tapping groundwater resources. Under no circumstances must this be seen to be disparaging of natural sources of groundwater (such as springs) in the context of community water supply programmes. It is envisaged that the development and protection of natural sources of groundwater will enjoy full discussion either in a future revision of this document or in a similar but separate document.

(a) The Verification of Needs

This activity is aimed at confirming the water supply need. Since it is a field activity, it also offers the Implementing Authority the opportunity to obtain any additional information that may be required for confirmation and more detailed analysis of the need and which will facilitate the later field investigations.

The needs of the community have to be verified, where practicable, by Local Government authorities.

(b) Communication and Liaison with the Community

Since the community for which a water supply is to be established must be regarded as the single most important participant in such a project, it is imperative that communication and liaison with the community be established at an early stage. This is facilitated in instances where a Local Water Committee already exists. It is much more difficult to identify community representatives where such committees do not yet exist, in which instances initial contact with the community leader(s) is indicated. This must take the form of two-way dialogue initially aimed at: (1) informing the community of project activities, (2) gauging the level of understanding and awareness of what is intended with the project and (3) receiving and acknowledging opinions put forward by the community in regard to its water supply situation.

The actual implementation of the community's requirements can be delegated or passed down to the Implementing Authority where this is appropriate to do so.

(c) Borehole Siting

This activity entails the scientific search for and location of a drilling target which is assessed to have the greatest chance for success. The responsibility for this task must fall to a team of qualified and experienced personnel in the service of the Executive Agency. This team must be capable of successfully integrating the earth sciences of geophysics, geology and hydrogeology.

(d) Borehole Drilling

This activity entails the drilling of a water supply borehole and its proper construction and development. It must be accomplished by a suitably experienced drilling contractor functioning under the direct supervision of the Executive Agency team responsible for the siting of the borehole.

(e) Borehole Testing

This activity provides data for an evaluation of the yield potential of the borehole and the groundwater resource from which it draws its water. The testing must be accomplished by a suitably experienced testing contractor again functioning under the direct supervision of the Executive Agency team responsible for the siting of the borehole and the supervision of its drilling and construction.

(f) Borehole Utilisation Recommendations

This must be based primarily, but not exclusively, on an analysis and evaluation of the borehole testing data and a quality assessment of the groundwater. The responsibility for this activity must fall to the same Executive Agency team involved with the borehole siting, drilling and testing activities.

(g) Reporting

All aspects pertaining to the development of groundwater resources for community water supply purposes must be documented in a technical report. The compilation of this report must be the responsibility of the Executive Agency.

2-2-3. Groundwater Resource Management

(a) Data and Information Management

Project data and information must not only be documented in a technical report (subsection 2-2-2.g). As much relevant data/information as is possible must be entered into an approved electronic data base. The latter must be fully compatible with the National Groundwater Data Base (NGDB) operated and maintained by the Directorate Geohydrology of the DWAF.

The data belongs to the client, ie. the person/body/organisation which has paid for the data to be collected or produced. There is a contractual obligation on the part of the provider/collector of the data (normally the geohydrological consultant) to deliver the data to the Directorate Geohydrology. The data thus provided should either be in hard copy paper format or, preferably, in electronic format which is compatible with HydroCom or its successor and the NGDB or its upgraded version.

Where geophysical surveys have been carried out, those data have also to be supplied to the Directorate Geohydrology.

(b) Capacity Building and Training

This component of the project must seek to develop at least: (1) an awareness of the importance of local groundwater resources to the community and (2) a sense of responsibility for the operation, maintenance and protection of the local groundwater supply source. This might require the presentation locally of informal education sessions and the attendance by designated responsible community members of technical training courses.

(c) Groundwater Protection

The protection of groundwater resources from over-exploitation and pollution threats is vital to the sustainable utilisation of these sources of potable water. This consideration must be recognised from the outset and steps taken to ensure that it is not forgotten in the medium to long term.

2-3 PERSONNEL FRAMEWORK

2-3-1. The Activating Agency

Since this agency is in essence the community itself, its personnel are embodied in the members of a Local Water Committee elected by the populace. There should exist consensus and agreement within this committee regarding the water supply need(s) of the community. Each member of this committee should, therefore, expound the consensus opinion of the committee when acting as its spokesperson.

In the absence of a Local Water Committee, it is important that two or three permanent residents within a community be identified to serve as contact persons with whom communication regarding local water supply issues can be facilitated. These "appointments" should be made by the community or, at least, with the knowledge and consent of the community.

2-3-2. The Implementing Authority

The Implementing Authority must assign a member (or group of members) of its staff to the function of community water supply and sanitation. This individual or group should ideally have a thorough understanding of the technical, administrative and financial aspects related to this function.

2-3-3. The Executive Agency

The complement of professional personnel associated with this agency should encompass the disciplines of: (1) earth science, (2) civil engineering and (3) social science. Within the context of this document, however, emphasis is placed on the earth sciences. The professional earth science personnel must include at least: (1) a hydrogeologist and (2) a geophysicist. Each of these professions may be represented by a scientist from another of these (or other) earth science discipline provided that such individual has proven experience and competence in the disciplines they represent. These scientists together provide the crux of the hydrogeological consulting service offered by the Executive Agency. Their cardinal importance to the project makes them key personnel ranking on a par with the highest management tier within the overall personnel structure of the Executive Agency. They will generally be supported by geotechnical field staff.

SECTION 3
Project Inception

3-1. SCOPING

3-1-1. The Registration of Needs

In order for any water supply need to be addressed, it is required that this first be registered with an Implementing Authority as a request for assistance, thereby raising awareness of the need with this authority. In order for the latter to properly evaluate the request, the activating agent must provide pertinent information in support of its request. This must at least include details in regard to: (1) the source(s) of the current community water supply, (2) the quantity of water available, (3) the number of people served, (4) the existence of administrative structures responsible for community water supply matters and (5) an indication of the capacity and willingness of the community to contribute financially toward the water supply project in the long term. If the Implementing Authority is unable to find or collect the above information, it will be expected to approach its Local Authority who has the responsibility and power to appoint a consultant to gather the relevant, necessary information.

3-1-2. The Assessment and Prioritisation of Needs

The Implementing Authority is required to evaluate the most suitable options for addressing each registered water supply need. This evaluation must necessarily consider: (1) the probable availability of groundwater resources in terms of their accessibility and exploitability, (2) any restrictions on the utilisation of groundwater and (3) its economic viability over the development of alternative sources. Such an assessment must preferably be based on existing reliable geological, hydrogeological and hydrogeochemical information. The value of such information is considerably enhanced through the application of a Geographic Information System (GIS) to compile various types of interpretative hydrogeological maps. Initiatives in this regard have already been implemented by the DWAF. Once the development of groundwater resources is identified as a viable and cost-effective option in meeting a registered need, then its actioning must be prioritised by the Implementing Authority along with other similar requests.

3-2. THE FORM OF ENQUIRY DOCUMENTS

The purpose of an enquiry document includes: (1) defining the framework within which the groundwater development project is to be undertaken, (2) establishing the aim and objectives of such a project, (3) ascertaining the technical capacity and ability of prospective service providers to successfully perform the work required and (4) deriving cost estimates for the various components associated with such a project.

This document addresses those services which are directly related to groundwater resource development, viz. hydrogeological consulting and contracted borehole drilling and test pumping services. The flow diagram presented overleaf outlines this process. Similar detailed documentation in regard to social development and civil engineering services is not addressed.

3-2-1. Hydrogeological Consulting Services

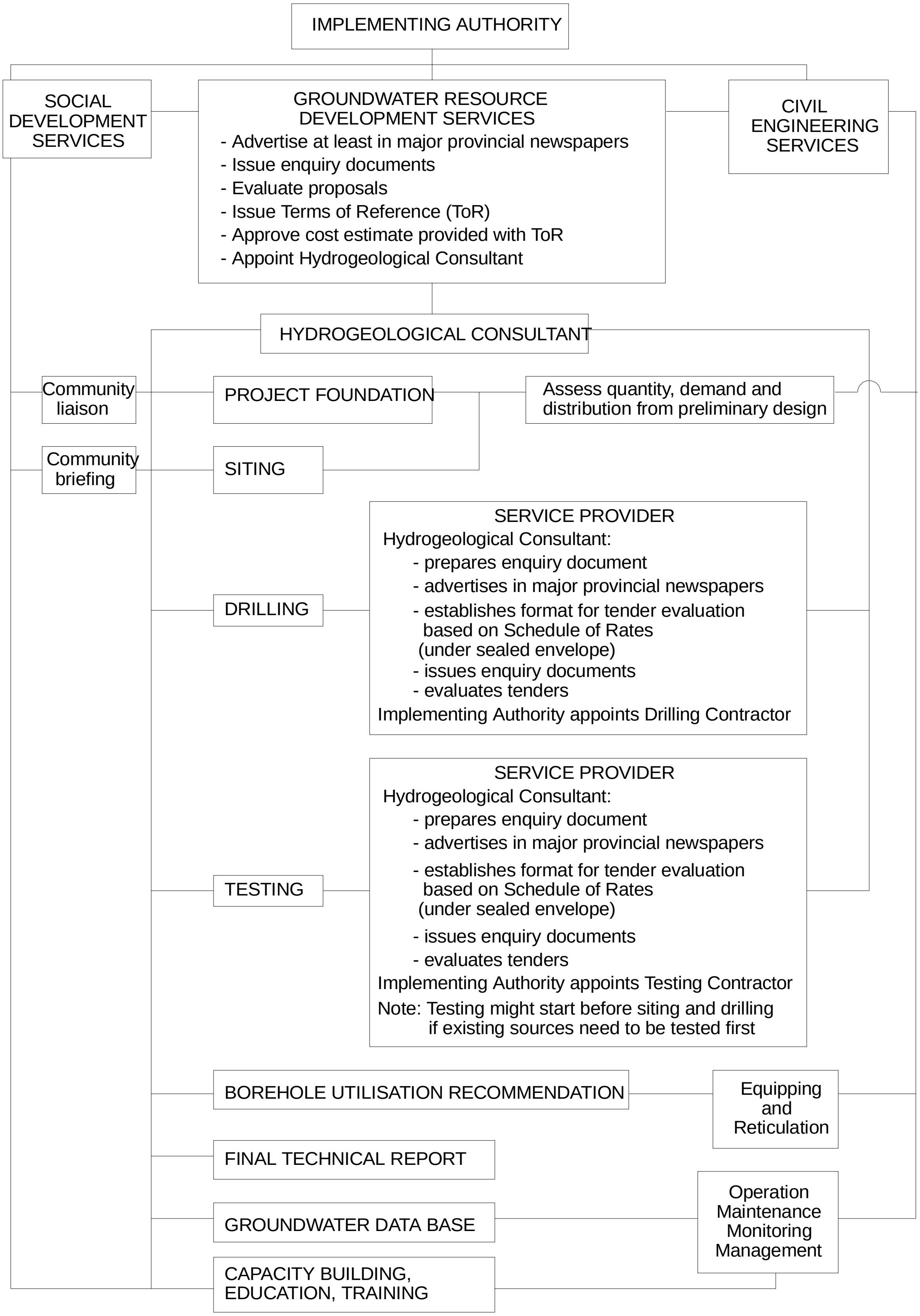
The enquiry document for hydrogeological services must invite the submission of proposals for the provision of a professional hydrogeological consulting service. Submissions must be invited from consultancies or organisations recognised for their proficiency in this regard. The DWAF maintains a list of private firms/companies registered with this organisation as accredited Hydrogeological Consultants.

The enquiry document must indicate at least: (1) the nature and scope of professional services required, (2) the time frame for the provision of these services and (3) the geographical boundaries of the project area. Further, it must request: (1) a technical proposal, (2) a financial proposal, (3) a brief statement of capability and relevant experience and (4) summarised *curricula vitae* of proposed project personnel. An enquiry document aimed at securing the provision of a professional hydrogeological consulting service is included as Document 1 in Part 3.

3-2-2. Borehole Drilling Services

The enquiry document for borehole drilling services must invite the submission of tenders for the drilling and construction and, if required, the rehabilitation of water supply boreholes. This invitation must be advertised in at least two major provincial newspapers. Although principally the task of the Implementing Authority, this function may be seconded to the Hydrogeological Consultant. By implication, therefore, the Implementing Authority will have sourced and secured the services of a Hydrogeological Consultant prior to sourcing and securing the services of a Drilling Contractor. The main advantages hereof are: (1) the application of the Consultant's knowledge of the project area when compiling the tender enquiry document for drilling services and (2) the utilisation of the Consultant's expertise in adjudicating the tenders.

An enquiry and tender/contract document aimed at securing the provision of a borehole drilling service is included as Document 2 in Part 3. Tenders must be invited from firms/companies recognised for their proficiency in this regard. The Borehole Water Association of Southern Africa (BWA) maintains a list of firms/companies registered with this organisation as accredited/certified drilling contractors. Preference will be given to drilling contractors who are registered with this organisation when evaluating tender enquiry documents and when making appointments.


IMPLEMENTING AUTHORITY
SOCIAL DEVELOPMENT SERVICES
GROUNDWATER RESOURCE DEVELOPMENT SERVICES
- Advertise at least in major provincial newspapers
- Issue enquiry documents
- Evaluate proposals
- Issue Terms of Reference (ToR)
- Approve cost estimate provided with ToR
- Appoint Hydrogeological Consultant
CIVIL ENGINEERING SERVICES
HYDROGEOLOGICAL CONSULTANT
Community liaison
PROJECT FOUNDATION
Assess quantity, demand and distribution from preliminary design
Community briefing
SITING
SERVICE PROVIDER
Hydrogeological Consultant:
- prepares enquiry document
- advertises in major provincial newspapers
- establishes format for tender evaluation based on Schedule of Rates (under sealed envelope)
- issues enquiry documents
- evaluates tenders
Implementing Authority appoints Drilling Contractor
DRILLING
SERVICE PROVIDER
Hydrogeological Consultant:
- prepares enquiry document
- advertises in major provincial newspapers
- establishes format for tender evaluation based on Schedule of Rates (under sealed envelope)
- issues enquiry documents
- evaluates tenders
Implementing Authority appoints Testing Contractor
Note: Testing might start before siting and drilling if existing sources need to be tested first
TESTING
BOREHOLE UTILISATION RECOMMENDATION
Equipping and Reticulation
FINAL TECHNICAL REPORT
GROUNDWATER DATA BASE
Operation Maintenance Monitoring Management
CAPACITY BUILDING, EDUCATION, TRAINING

The form of the tender must indicate: (1) the nature and scope of drilling services required, (2) the terrain conditions and accessibility of drilling sites within the project area, (3) the nature of geological formations that may be encountered, (4) the availability of facilities and (5) the time frame within which the services are to be provided. It must request: (1) a brief statement of capability and relevant experience, (2) a brief statement of supervisory personnel and their experience, (3) a listing of machinery and equipment which will be employed for the work and (4) a schedule of rates.

3-2-3. Test Pumping Services

The enquiry document for test pumping services must invite the submission of tenders for the scientific test pumping of water supply boreholes. This invitation must also be advertised in at least two major provincial newspapers and the task of compiling and issuing the enquiry document either undertaken by the Implementing Authority itself or seconded to the Hydrogeological Consultant in order to capitalise on advantages similar to those listed in subsection 3-2-2.

An enquiry and tender/contract document aimed at securing the provision of a test pumping service is included as Document 3 in Part 3. Tenders must be invited from firms/companies recognised for their proficiency in this regard. The BWA maintains a list of firms/companies registered with this organisation as accredited/certified test pumping contractors. Preference will be given to test pumping contractors who are registered with this organisation when evaluating tender enquiry documents and when making appointments. It is also required that such contractors be fully conversant with accepted scientific methods of test pumping.

The form of the tender must indicate: (1) the nature and scope of test pumping services required, (2) the terrain conditions within the study area and (3) the time frame for the provision of these services. It must request: (1) a brief statement of capability and relevant experience, (2) a brief statement of supervisory personnel and their experience, (3) a listing of machinery and equipment which will be deployed and (4) a schedule of rates.

3-3. THE EVALUATION OF ENQUIRY RESPONSES

3-3-1. Hydrogeological Consulting Services

The evaluation of enquiry responses for these services should be the task of a committee comprising members representing the various institutions responsible for the planning and execution of the project. Each member of the committee is required to independantly evaluate every enquiry response by assigning scores to each of seven categories as defined in Table 3-1.

Table 3-1. Categories and total score values for the evaluation of enquiry responses	
CATEGORY	TOTAL SCORE VALUE
Written presentation (neatness, conciseness)	10
Company profile (personnel and instrument capacity, support capability)	20
Previous experience in Community Water Supply Projects	30
Motivation for Respondent's preferred geographical area of investigation	10
Implementation of affirmative actions and support for Emerging Consultants	15
Management structure	10
Case study	05
TOTAL	100

The totals scored by each enquiry response are averaged over the number of individual member evaluations and then ranked from highest to lowest by the committee. The selection of consultants must be fair and not subjective so that emergent consultants have an equal chance to compete for work.

The technical expertise and effectiveness of the hydrogeological consultant to do a particular job can be evaluated by using the criteria listed in Table 3-1. In the event that the evaluation process does not deliver a clear result, then a shortlist should be compiled comprising the three highest scoring responses. The shortlisted respondents should then be interviewed by the committee in order to arrive at a final decision by majority vote or concensus.

It must be emphasized that the cost structure of the consultant's submission must be treated as a completely separate issue; it is not considered at the same time as the consultant's technical credentials are being evaluated. The costs, based on the 15 percent ruling, are negotiated between the consultant and the client (DWAF) after the consultant has been selected.

It is important for consultants to also indicate what steps have been taken by them, or are due to be taken, to use emergent consultants as participants in future work programmes. Criteria for evaluating emerging contractors/consultants should also follow, where appropriate, the format used in Table 3-1.

All of the information provided to the client (DWAF) is considered confidential and, as such, no correspondence can be entered into or feedback provided to the unsuccessful applicants.

3-3-2. Borehole Drilling Services

The first step in the evaluation of tenders for these services should be the compilation of a shortlist from which a final selection will be made. The criteria for shortlisting must recognise as evaluation factors: (1) the tendered cost of service, (2) competency and experience allied to membership of the BWA and (3) adequacy of equipment. Since the enquiry document requires only the completion of a Schedule of Rates and not a Schedule of Quantities, it is required of the adjudicator to compile a common basis for the evaluation of specifically the financial component of tenders received.

The basis for evaluation on financial grounds must comprise a number (three or four) of hypothetical borehole drilling and construction scenarios incorporating, amongst other factors, set drilling depths and diameters and the use of set lengths of plain and slotted steel casing for each scenario. One of the hypothetical scenarios might address the case of an abandoned and plugged borehole. Cost items such as initial establishment and equipment set-ups must be included as one-off expenses whereas one interhole move of say 15 km distance should also be factored into the evaluation.

The financial evaluation format should be kept under sealed envelope until evaluation takes place. The evaluation process shall also abide strictly by the uniform application of the prescribed format.

The shortlist must comprise a minimum of three separate tenders together representing the three most favourable tendered costs of service. The shortlisted tenders qualify for further detailed evaluation which may include: (1) a hard look at competency and relevant experience and (2) an inspection of the equipment by someone who is familiar with water borehole drilling equipment and who is able to properly and objectively assess the adequacy thereof for the project. It is therefore expected of tenderers to allow the equipment listed in their tender documents to be inspected. The tenderer has the right to request the credentials of the person designated for the equipment inspection task. It will also be the responsibility of this person to communicate any reservations identified in the course of such inspection to the tenderer.

3-3-3. Test Pumping Services

The first step in the evaluation of tenders for these services should be the compilation of a shortlist from which a final selection will be made. The criteria for shortlisting must again recognise as evaluation factors: (1) the tendered cost of service, (2) competency and experience allied to membership of the BWA and (3) adequacy of equipment.

As in the case of borehole drilling services (subsection 3-3-2), the enquiry document requires only the completion of a Schedule of Rates. It is, therefore, again required of the adjudicator to compile a common basis for the evaluation of specifically the financial component of tenders received.

The basis for evaluation must comprise a number (three or four) of hypothetical borehole test pumping scenarios incorporating, amongst other factors, different yield classes, set test pump installation depths and the use of set lengths of discharge piping for each scenario. One of the hypothetical scenarios might address the case of an existing, equipped borehole.

Cost items such as initial establishment and equipment set-ups must be included as one-off expenses whereas one interhole move of say 15 km distance should also be factored into the evaluation. The financial evaluation format should be kept under sealed envelope until evaluation takes place. The evaluation process shall also abide strictly by the uniform application of the prescribed format.

The shortlist must comprise a minimum of three separate tenders together representing the three most favourable tendered costs of service. The shortlisted tenders qualify for further evaluation along much the same lines as has already been described for borehole drilling services in subsection 3-3-2.

3-4. THE FORM OF APPOINTMENTS

3-4-1. Hydrogeological Consulting Services

This is given effect in an Agreement entered into between the Implementing Authority and the appointed service provider, hereafter referred to as the Hydrogeological Consultant. A *pro forma* Agreement between these two parties is included as Section 3 (Record of Agreement) of Document 1 in Part 3. This agreement defines the responsibilities and obligations of each party, addressing such items as: (1) the conditions and general provisions of agreement, (2) the responsibilities of the Hydrogeological Consultant, (3) the liability of the Hydrogeological Consultant, (4) the obligations of the Implementing Authority, (5) payments to the Hydrogeological Consultant and (6) the settlement of disputes.

The appointment of the Hydrogeological Consultant must be separate from that of any other party in the Executive Agency. This is aimed at establishing: (1) the Implementing Authority as the sole judge of the merits of this appointment and (2) the absolute impartiality and objectivity of the Hydrogeological Consultant.

3-4-2. Borehole Drilling Contractors

The appointment of drilling service providers is given effect in the tender enquiry document included as Document 2 in Part 3. Sections 3, 4 and 5 of Document 2 have specific relevance in this regard. The appointment is made by the Implementing Authority.

3-4-3. Test Pumping Contractors

The appointment of providers of these services is given effect in the tender enquiry document included as Document 3 in Part 3. Sections 3, 4 and 5 of Document 3 again have specific relevance in this regard. The appointment is also made by the Implementing Authority.

SECTION 4

Groundwater Resource Development

4-1. PROJECT FOUNDATION

The development of groundwater resources for community water supply purposes must be based on a clear definition of the needs which such development is intended to satisfy. These are provisionally identified through the registration and prioritisation of needs (subsections 3-1-1 and 3-1-2 respectively). It is required, however, that the project be founded on sound and substantive information. This must be obtained at firsthand from field inspections aimed at verifying the needs. Such inspection visits may also include communication and liaison with the community and familiarisation with the project area. For example, in KwaZulu-Natal it is essential that the correct procedures are adhered to in dealing with the community structures, via the Regional and Tribal Authorities, so that the local Chief or Induna is identified and informed about any prospective development of groundwater resources for a community water supply. While it is accepted that the community plays a very important role in the whole exercise, it does not have the right of veto to unilaterally stop a project under the DWAF's jurisdiction.

4-1-1. The Verification of Needs

The verification of water supply needs within a community represents the first step towards the development of groundwater resources for community water supply purposes. This task can either be undertaken by representatives of the Implementing Authority or delegated to the Executive Agency. This activity must define: (1) the names of the communities encompassed by the project, (2) the boundaries representing these communities, (3) the names of local spokespersons regarding community water supply matters, (4) where and how these spokespersons can be contacted and (5) the positions and status of existing water supply sources within community boundaries. The general geographic locations of the communities can be identified according to coordinates obtained by means of a global positioning system (GPS). A *pro forma* information sheet on which this and other relevant data must be neatly recorded in as much detail as possible is provided in Part 2. A copy of these information sheets must be given to the appointed Executive Agency prior to the commencement of any field investigation activities.

4-1-2. Communication and Liaison with the Community

This activity recognises the community for which a water supply is to be established as the single most important participant in the project. The success of all other activities relating to the project depend on the community having a clear understanding and awareness of what is intended with the project. Issues which should be made abundantly clear include: (1) the apolitical nature of the work and (2) the selection of a borehole site on purely scientific grounds.

The latter issue must dispel any notion that the selection of a borehole site favours any individual or group within a community. This task can either be undertaken by representatives of the Implementing Authority or delegated to the Executive Agency. It is essential that this activity also identifies the principal contact person within a community for onsite communication between the community and project personnel during later project activities.

4-1-3 Familiarisation with the Project Area

This activity must take the form of a reconnaissance survey aimed at assessing such aspects as: (1) the nature of the terrain especially in regard to the execution of geophysical surveys and its accessibility for heavy machinery, (2) the spatial distribution of communities in terms of distances to be covered by project personnel, (3) the geology within the project area as it might relate to groundwater occurrence, (4) the status regarding existing water supply facilities and infrastructure and (5) an assessment of the possible influence of sanitation structures on the positioning of water supply boreholes. The reconnaissance survey should be undertaken jointly by a representative of the Implementing Authority and key personnel of the Executive Agency.

4-2. BOREHOLE SITING

4-2-1. Purpose and Scope

The purpose of this activity is to identify one or more drilling targets which offer the best possibility of locating a groundwater resource capable of supporting a successful borehole for the intended purpose of use. It is not sufficient to be satisfied with meeting the minimum yield required for a borehole to be deemed successful. Every effort must be made to identify a target which offers the greatest chance of success also in terms of borehole yield. This task falls squarely on the shoulders of the Hydrogeological Consultant. The scope of activities related to this task extends from a pre-fieldwork assessment of the groundwater resource potential in the project area to fieldbased exploration efforts. The key to successful borehole siting is understanding, amongst others, the geology, structural geology, geohydrology and geomorphology (in particular weathering patterns and profiles) in detail on a specific site. Geophysics is only one of the tools available with which to obtain a better understanding of these aspects.

4-2-2. Approach and Personnel

The siting of a potential water supply borehole must follow a carefully considered and planned approach aimed at maximising the success rate in the most cost effective and productive manner. The siting activity must not to be rushed because of the imminent arrival of a drilling rig on site.

Rushing of the siting activity may lead to rough and slapdash work which does not serve the aims of the project in that it may result in fewer successful boreholes being established. Since lower success rates impact unfavourably on the financial viability of a groundwater development project, the maximisation of exploration efforts within acceptable project fiscal limits should be encouraged.

The siting activity is carried out jointly by an exploration team of the Hydrogeological Consultant comprising of at least: (1) a hydrogeologist, (2) a geophysicist and (3) a geotechnician. Detailed criteria regarding the educational background and experience levels of these and other relevant earth scientists are provided in Section 3 (subsection 3-1-1) of Document 1 in Part 3.

While a fully competent team is expected to be involved with borehole siting, it does not necessarily mean that all three members of the exploration team have to be on site at the same time. Local conditions will determine who is best suited or most needed to define the correct drilling position.

(a) The Hydrogeologist

The function of the hydrogeologist in the siting activity is to provide direction in regard to the scope and nature of field exploration efforts. This is achieved on the basis of a preliminary assessment of the groundwater regime in the project area aimed at gauging the mode of groundwater occurrence and the potential yield of groundwater resources locally. The hydrogeologist's function will later also extend to and cover all other aspects pertaining to the development of groundwater resources as described in this document.

(b) The Geophysicist

It is the task of this individual to evaluate and interpret geophysical exploration data with a view to identifying suitable drilling targets. The geophysicist must therefore fully understand and appreciate the application and limitations of chosen geophysical exploration techniques in a given geological and hydrogeological regime. This appreciation should be based not only on a sound theoretical understanding but also on proven practical experience associated with an understanding of the geology in the area of investigation.

(c) The Geotechnician

The geotechnician is the individual normally entrusted with the execution of field surveys and the collection of groundwater exploration and resource development data. It is required that this work be undertaken and documented in such a manner that no ambiguity arises or uncertainty exists in regard to its scope and manner of execution.

(d) Other Disciplines

It may also be warranted, on occasion, to make use of the services of another discipline such as a Drilling Inspector. This might be especially valuable in instances where such an individual has an informal yet intimate knowledge regarding the geology of and the occurrence of groundwater within an area or region. The conditions under which such an individual will provide input to and support of a project must, however, be subject to the same degree of inspection and scrutiny as that imposed on any member of the professional hydrogeological consulting team.

4-2-3. Techniques

It is not within the scope of this document to provide a detailed exposition of all the possible techniques (especially those involving geophysics) and their application in the exploration for groundwater resources. It is essential, however, that observational techniques be fully used. Field mapping and geological observation often holds the key to any successful water borehole drilling project. For example, are the existing boreholes in an area drilled on visible targets or on airphoto identified lineaments? The location and assessment of "dry" (unsuccessful) borehole positions also can provide invaluable information when siting new holes.

Communication with owners, community leaders and water committees who often have vital information regarding a borehole's history should not be ignored. Field observations should entail at least detailed mapping of outcrop, particularly along drainages where exposed outcrop and potential targets/nontargets may be visible. The production of a map at a scale of 1:50,000 should ideally show airphoto lineaments, fracture zones, dykes, lithological changes and any associated relevant attributes such as dip and strike. Such a map will also serve to plan geophysical surveys more optimally.

It is reiterated that activities in this regard should aim at maximising exploration efforts within the financial framework budgeted for this work. In broad terms, therefore, it will be expected of the Hydrogeological Consultant to employ a sensible combination of observational and geophysical techniques.

(a) <u>Observational Techniques</u>

These include: (1) a study and interpretation of published geological and hydrogeological maps, (2) a study and interpretation of available remotely-sensed information (aerial photographs and satellite images), (3) the interrogation of existing data bases such as the National Groundwater Data Base and (4) geological observation in the field.

(b) Geophysical Techniques

The geohydrologist should identify potential targets with geophysics serving as a backup to identify optimal positions and/or to move drilling positions to more accessible or favourable places. No geophysics should be done until targets are identified. Specific targets should be identified from existing geological maps, airphotos and field mapping as required. Where good outcrop occurs, geophysics should be used as a backup to field mapping which is the primary "tool". Generally, more geophysics is required as the extent of outcrop becomes less.

Geophysical techniques include: (1) magnetic surveys, (2) frequency domain electromagnetic surveys, (3) electrical resistivity surveys, (4) gravimetric surveys and (5) seismic refraction surveys. The most commonly and widely employed of these techniques are the magnetic, electromagnetic and electrical resistivity techniques. It is required that at least two complementary techniques be employed together with one or more of the observational techniques unless stated otherwise in the enquiry document. Techniques considered appropriate for specific geological environments should preferably also be identified in the enquiry document.

In cases where the electrical resistivity and frequency domain electromagnetic survey techniques are employed, the methods of vertical sounding and horizontal profiling must be regarded as two separate techniques. The execution of horizontal profiling using both the electrical resistivity and the electromagnetic technique shall, therefore, not constitute the application of two separate techniques. If only one of the electrical resistivity or electromagnetic techniques is employed, then the methods of vertical sounding and horizontal profiling will be regarded as the application of two techniques.

Further, it is required that where a potential drilling target is identified on the basis of horizontal profiling by the electrical resistivity method, a minimum of seven vertical soundings must be conducted around the target according to the layout shown in Drawing 1 of Part 2. Under no circumstances will a single vertical sounding be viewed as sufficient or acceptable, irrespective of whether it is supported by another geophysical exploration technique. The similar application of the electromagnetic sounding technique should be considered where this is deemed appropriate.

Subsurface conditions such as deep groundwater resources (say deeper than 80 m) and/or a very conductive near-surface environment may indicate the application of more specialised and costly geophysical exploration techniques. These include: (1) time domain electromagnetic surveys, (2) seismic reflection surveys and (3) magneto-telluric surveys. In such instances, this must either be identified in the enquiry document prior to the appointment of a Hydrogeological Consultant or fully motivated by the appointed Hydrogeological Consultant in the course of fieldwork.

4-2-4. Geophysical Surveying Protocols

Geophysical exploration is generally carried out along measured survey lines (traverses). These survey lines often follow roads or tracks which provide ready pedestrian accessibility within the area of investigation. In some instances geophysical surveys lines may form a rectilinear grid. The geographic position of the survey lines/grids must in all instances be determined as accurately as possible. This can be achieved by using a combination of coordinates obtained from a global positioning system instrument and the identification and plotting of the line(s) or grid on a map of a suitable scale. The smallest acceptable map scale is that provided by the published 1:50 000 scale topocadastral maps. The 1:10 000 scale orthophoto maps, if available, provide a more convenient, accurate and therefore preferred scale for this purpose. The survey lines as plotted on a map must indicate the start and end points as well as the direction of the geophysical surveys carried out along each traverse. The latter information is, for example, critical when it comes to the interpretation of magnetic survey data.

All geophysical survey lines must be clearly marked in the field such that these can be located at any stage within the period it is expected drilling will take place. Survey station intervals along each traverse must be set out accurately using a measuring tape or similar distance-calibrated tool. The pacing out of survey lines must be avoided.

It is further required that the choice of survey station interval be sufficiently short to fully define any natural geophysical anomaly which is identified. Further, that the length of survey lines as far as possible be long enough to properly define the regional or background field signature of geophysical data. If necessary, survey lines might need to be extended or portions of survey lines repeated at a shorter station interval in order to obtain suitable definition of anomalies. Any additional geophysical surveying required along a survey line must be undertaken within the period that the exploration team is active in the vicinity.

It should also be emphasised that the nature of the targeted geological structure must be identified in order to assess the applicability of the particular geophysical exploration techniques and the methodology used in its identification. Examples hereof are: (1) dyke intrusions and their associated contact zones, (2) basins of weathering or decomposition, (3) buried alluvial channels, (4) fault or fracture zones, (5) lithological contacts occurring laterally or in depth and (6) zones of subsurface leaching in karst terrains. In the case of subvertical and linear features, the number of survey lines covering a targeted geological structure must be sufficient to define not only its strike but also its true dip and width. In other instances, some indication of the depth of weathering or decomposition should be provided. Opinions in regard to these aspects must be supported by demonstrable interpretations of the geophysical data.

The collection of geophysical data must be accompanied by field notes regarding the occurrence of natural and unnatural features which are observable along the survey line. Such notes must be recorded opposite the station nearest to these features. Natural features might include: (1) rock outcrop, (2) gullies and surface water drainages, (3) visible changes in soil cover and (4) sudden marked changes in terrain slopes. Unnatural features would include: (1) existing boreholes with an indication of their assessed yield, (2) fences, (3) telephone lines and powerlines, (4) gates and gateposts and (5) building structures and dwellings. The interpretation of the geophysical data must be undertaken as soon as possible after the data have been collected. This activity should seek to identify as many potential drilling targets as might be indicated by the data. The targets should be ranked firstly according to their scientifically adjudged potential for success and secondly according to the convenience of their location in respect of the service area.

4-2-5. Marking of Borehole Site(s)

The actual marking of the prospective borehole site(s) must be undertaken as soon as possible after the survey data have been interpreted. This task is the responsibility of the exploration team. The site and its identification number must be marked clearly in the field. It is preferable that more than one method of marking be used, eg. a whitewashed cairn of rocks packed around or over a tagged one-metre long steel peg hammered at least two-thirds of its length (if possible) into the ground. If the use of a metal peg is not considered suitable, then the planting of a concrete block with dimensions approximately 200 mm x 200 mm x 200 mm (and bearing the assigned number of the borehole) in the ground a distance of five metres to the north of the borehole must be considered. It is important that each such site be pointed out to at least one and preferably more than one of the contact persons responsible for water supply matters within the community. The preservation of the marked prospective borehole site(s) must form part of the collective responsibility of the community.

4-2-6. Documentation of Geophysical Data

Raw geophysical field data must be recorded on appropriate data sheets. On these must be indicated basic information such as: (1) the 1:50 000 scale topocadastral map sheet number, (2) the drainage basin number at tertiary level, (3) the date of the survey, (4) the unique identifying number assigned to the survey line, (5) the direction of the survey line, (6) the coordinates of the start and end points of the survey line, (7) the name of the community within which the survey is carried out, (8) the name of the district within which the community is located and (9) coordinates according to which the geographic position of the community can be identified on a map.

It is further required of the Hydrogeological Consultant to present the geophysical field data in a neatly documented graphical format. The positions and identification numbers of marked borehole sites must: (1) be indicated on these graphs against their true positions along the survey line and (2) be cross-referenced to the locality map(s) (subsection 4-2-4). A brief interpretation of the geophysical data leading to the choice of each marked borehole site must be provided in the final technical report compiled by the Hydrogeological Consultant (subsection 4-6).

4-3. BOREHOLE DRILLING

4-3-1. Purpose and Scope

Simply stated, the purpose of this activity is to establish a means to access and tap groundwater resources. This is most often provided by the drilling of a borehole. It is not sufficient for this facility to represent just another hole in the ground. It is vital that the borehole be constructed and completed to certain minimum standards in order to secure the long term viability and serviceability of the installation. This component of the project is served jointly by the Hydrogeological Consultant and the Drilling Contractor. It is therefore expected of these parties to function as a team within the framework of their individual briefs as set out in their respective contract agreements with the Implementing Authority.

4-3-2. Approach and Responsibility

In general, it is required that the drilling of any borehole be approached with due diligence and care on the part of the appointed drilling contractor(s). Specifically, it is required that the drilling of each borehole be approached on the premise that it will be successful and, as such, will serve the function of a community water supply source. Under normal circumstances, the pre-drilling of a small diameter pilot borehole will not be allowed. Such an approach may only be considered with the approval of the Hydrogeological Consultant who will be required to fully motivate such an approach to the Implementing Authority.

The Drilling Contractor(s) will function under the direct supervision of the Hydrogeological Consultant. This by no means implies that the Drilling Contractor(s) is absolved from any responsibility. All drilling activities will, therefore, be approached through communication and discussion between the Hydrogeological Consultant and the contractor(s) with a view to developing the most suitable and mutually acceptable finished product serving the best interests of the project. The fact that the Drilling Contractor is also appointed for the skills which he can offer the project and is often able to provide, from experience, practical approaches and solutions to specific problems must be recognised and accepted by the Hydrogeological Consultant.

Failure by the contractor(s) to timeously render advice and input where required will be regarded as a dereliction of duty. This responsibility extends to informing the Hydrogeological Consultant of serious reservations regarding any aspect of the work. The contractor(s) will also be required to maintain the aesthetic appearance of the site during drilling operations, including keeping the site neat, tidy and free of litter. More importantly, the contractor must ensure that safety standards are met and that the work site is kept free, as far as is possible, from vehicular and pedestrian traffic and from interested bystanders and onlookers not involved with the project.

In essence, the final responsibility for the finished water supply borehole and all actions and activities leading up thereto must be carried jointly by the Hydrogeological Consultant of the Executive Agency and the appointed Drilling Contractor(s).

4-3-3. Techniques

The most common method employed for the sinking of a water supply borehole is that of rotary air percussion drilling employing a down-the-hole (DTH) hammer. This drilling technique is ideally suited to hardrock formations and therefore finds wide application in most of the geological environments encountered in South Africa. Other techniques which might be applied depending on site specific circumstances include: (1) mud rotary drilling, (2) Odex drilling, (3) dual-tube reverse circulation and (4) cable tool percussion drilling. Methods (1), (2) and (3) represent technically more sophisticated techniques which find specific application in loose and unconsolidated materials such as sand and gravel deposits. Method (4) employs the familiar jumper rig, its most useful application being the cleaning and rehabilitation of existing boreholes.

In light of the above, the preferred drilling technique to be employed on community water supply projects is that of rotary air percussion. Instances where another drilling technique might be considered more appropriate and efficient must be recognised at the time of going to tender and communicated to prospective tenderers in the tender enquiry document.

4-3-4. Equipment and Materials

The equipment made available by the Drilling Contractor must be in good working order. It must also be maintained in good condition for the duration of the project. In order to achieve this, time should be set aside each week for the routine service and preventative maintenance of all equipment (subsection 4-3-5). The drilling equipment must include a full air/foam pumping system. At the start of the project, the gauge diameter of the button drill bits to be employed with the rotary air percussion drilling technique must conform closely to their manufactured gauge and must also possess all of their tungsten carbide buttons.

The Hydrogeological Consultant will discuss with the Drilling Contractor the retirement of a bit due to excessive wear or damage incurred during the course of the project. Further, it is imperative that the equipment be of a suitable size and capacity to deal, on occasion, with: (1) deep boreholes (up to 200 m), (2) larger than average borehole diameters (up to 254 mm), (3) large quantities of groundwater and (4) potentially onerous drilling conditions. Since this capability is provided in large measure by the air compressor, it is considered that a compressor having a capacity of at least 2400 kPa (24 bar) and a volume of at least 750 cfm is appropriate for most water borehole drilling applications and conditions using the rotary air percussion technique. In order to maintain the straightness of a borehole, the Hydrogeological Consultant may insist that the drilling contractor employ at least an overshot sleeve (drill collar) fitted to the pneumatic DTH hammer. Further precautions to ensure this aspect might include the use of a stabiliser rod immediately behind the bit/hammer/overshot combination. All materials to be used on the project should be new and meet project specifications. This applies particularly to steel casing which shall be: (1) of the seam-welded type, (2) round, (3) straight, (4) of uniform wall thickness and (5) have bevelled edges. Secondhand material such as steel casing recovered from an earlier borehole can be used provided that it has been refurbished to an acceptable condition (refer subsection 4-3-5.f). The Hydrogeological Consultant will have the right to reject, with motivation, any material (including casing) which is deemed inappropriate, substandard or otherwise unsuitable for the project.

4-3-5. Workmanship and Performance

The standard of workmanship of the Drilling Contractor will be subject to close scrutiny by the Hydrogeological Consultant. Many aspects hereof are of a subjective nature and not readily quantifiable. Every attempt must, therefore, be made to render this beyond possible criticism. Judgement of the performance of the Drilling Contractor in the execution of assigned work is similarly of a subjective nature. Although it can not be expected of the contractor to complete a specified number of boreholes in a given time period, it is reasonable to expect that "favourable progress" be made under normal circumstances and drilling conditions. An indication of what might be regarded as "favourable progress" is considered to fall in the range of 50 to 100 m of drilling advancement per day taking into consideration interhole moves and setup time. Performance being related to efficiency and efficiency in turn being a function of, amongst other factors, the number of mechanical equipment breakdowns suffered by the contractor, it will be in the best interests of the contractor to set aside time for the routine preventative maintenance of equipment. If the contractor is inclined to work a 6- or 7-day week, it is preferred that maintenance activities be scheduled for the weekends. Such schedule must be communicated to the Hydrogeological Consultant. This party may insist that the Drilling Contractor not start with the drilling of a borehole over a weekend. Although work-in-progress may be completed, the contractor shall under no circumstances vacate a site before the Hydrogeological Consultant has inspected the completed works and sanctioned the move to the next borehole.

4-3-6. Borehole Construction

The extremely diverse nature of subsurface conditions, sometimes over very short distances, renders it virtually impossible to address this aspect in great or specific detail. This factor also rules out standardisation in this regard. It is possible, however, to address certain basic borehole construction practices which will contribute to final acceptance of the successfully finished product.

(a) Drilling Diameter

Drilling of the water supply borehole must commence at a diameter which will allow for the troublefree insertion of casing. Under normal circumstances, this entails drilling a 203 mm (8") or 216 mm (8½") diameter bore through the weathered overburden and any other potentially unstable nearsurface material. The bore must penetrate at least three metres into fresh, more competent material before this horizon can be secured from potential collapse or wash-out by casing it off with nominal 165 mm (6½") or 152 mm (6") diameter steel casing. Thereafter, the bore is continued at 165 mm (or 152 mm) drilling diameter to its completion depth.

The presence of unstable rock formations (which are often also associated with groundwater-bearing horizons) at greater depths in the bore generally account for complications which will impact on the abovementioned approach. The Drilling Contractor must firstly attempt to penetrate through such horizons in order establish their vertical thickness. Such horizons often possess only a temporary instability and become "cleaned out" as drilling advances. In instances where such horizons remain unstable and severely hamper drilling progress, it will become necessary for the contractor to remove the surface casing and ream (widen) the borehole to a diameter of at least 203 mm (or 216 mm) to the depth of such unstable horizon. It will then be required to re-insert 165 mm (or 152 mm) nominal diameter casing to this depth and attempt to advance this casing through the unstable horizon.

In exceptional circumstances it may even be necessary to re-drill or ream the borehole to a diameter of 254 mm through unstable overburden material, insert nominal 203 mm (or 216 mm) diameter casing through this horizon and widen the borehole to 203 mm (or 216 mm) diameter below this depth to the unstable zone. Extremely onerous drilling conditions at depth might even warrant the commencement of drilling at a diameter of 305 mm or greater. This approach is often taken when aiming to maximise the exploitation of groundwater from a productive karst aquifer.

Two conceptual borehole designs incorporating the above and other considerations to be discussed later are presented in Drawings 2 and 3 in Part 2 of this document.

Information regarding the dimensions of the more commonly used button drill bits for rotary air percussion drilling is given in Table 4-1 together with casing diameters generally associated with each bit gauge.

Table 4-1. Dimensions of commonly used button drillbit gauge diameters for use with the rotary air percussion drilling method

BIT GAUGE DIAMETER	CASING INSIDE DIAMETER FOR DRILL-THROUGH PURPOSES
127 mm (5 in.)	143 to 146 mm
152 mm (6 in.)	156 to 159 mm
165 mm (6½ in.)	168 to 171 mm
203 mm (8 in.)	207 to 212 mm
216 mm (8½ in.)	
254 mm (10 in.)	257 to 264 mm
305 mm (12 in.)	

NOTE:
1. The bit gauge diameter is also given in the Imperial unit of inches (in.) since this unit is still in common use when referring to this parameter.
2. Casing inside diameter varies according to wall thickness (refer Table 4-2).

The information provided in Table 4-1 shows that each bit gauge passes comfortably through casing with a similar nominal diameter. For example, a 203 mm gauge bit can be used to extend the depth of a borehole already equipped with 207 to 212 mm inside diameter casing without having to reduce to the next smallest drilling diameter. Note also that a borehole drilled to a given diameter is able to accept casing having the next smallest diameter. For example, a 203 mm diameter borehole can be fitted with either 152 mm nominal inside diameter or preferably 165 mm nominal inside diameter steel casing.

In view of the foregoing, it is clear that the minimum final cased diameter of a successful community water supply borehole shall seldom be less than 152 mm nominal.

The contractor will be remunerated for drilling per linear metre of depth at the rate tendered for each relevant drilling diameter employed as set out in the Schedule of Rates included as Section 4 of Document 2 in Part 3.

(b) Steel Casing

Steel casing may either be used in a temporary manner or form a permanent part of the borehole infrastructure. Its temporary use is indicated in instances where, for example, the borehole is unsuccessful or the need for it to remain in place becomes redundant. Under these circumstances it is also referred to as a pre-collar, surface casing, starter casing, outer casing or soil casing generally to be removed (recovered) on completion of drilling. It will be left in place where the Hydrogeological Consultant is of the opinion that the unsuccessful borehole should be secured to serve a long term groundwater monitoring purpose. In such instances, additional provision must be made to protect the borehole against actions which may compromise this function.

More commonly, however, this casing constitutes the final casing with which a successful borehole is equipped. Its proper installation, therefore, is mandatory. It is installed from surface through unstable, unconsolidated or fractured materials usually occurring in the nearsurface. Under these circumstances, the function of steel casing includes one or more of: (1) supporting unstable materials against collapse into the borehole during drilling, (2) facilitating the installation or removal of other casing, (3) minimising the erosion and widening of the unstable upper portions of the borehole sidewall caused by the return flow established during drilling and/or the passage of drilling equipment/tools and (4) facilitating the placement of a sanitary seal and/or gravel pack or formation stabiliser. The casing must conform to the specifications set out in subsection 4-3-4.

In order to ensure as far as is possible that the annular space between this casing and the borehole sidewall remains open for the later emplacement of a sanitary seal, the circumferential entrance to this space must be temporarily plugged. Hessian sacking packed around and lightly tamped into the surface entrance to this annular space can be used for this purpose. In instances where steel casing needs to be driven through unstable horizons (generally at greater depths in a borehole), it will be also be required that such casing be fitted with a casing shoe to protect the "mouth" of the casing from damage (subsection 4-3-6.c). Irrespective of the casing used to facilitate the drilling of the borehole, the final cased diameter of the finished product must be sufficient for the borehole to easily accept a borehole pump. Since the outside diameter of the latter are generally in the order of 100 mm, it is required that the final cased diameter of the borehole not be less than 152 mm (6 in.) nominal where steel casing is used. Information on the dimensions of the more commonly used steel casing available locally is given in Table 4-2.

The Drilling Contractor will be remunerated for steel casing per linear metre thereof supplied, delivered and installed at the rate tendered for each relevant casing diameter as set out in the Schedule of Rates included as Section 4 of Document 2 in Part 3.

Table 4-2. Dimensions of commonly used and locally available steel borehole casing

OUTSIDE DIAMETER	WALL THICKNESS	INSIDE DIAMETER
165 mm (6 in. nominal)	3.0 mm 4.0 mm 4.5 mm	159 mm 157 mm 156 mm
177 mm (6½ in. nominal)	3.0 mm 4.0 mm 4.5 mm	171 mm 169 mm 168 mm
219 mm (8 in. nominal)	3.5 mm 4.5 mm 6.0 mm	212 mm 210 mm 207 mm
273 mm (10 in. nominal)	4.5 mm 6.0 mm 8.0 mm	264 mm 261 mm 257 mm

NOTES: 1. The casing outside diameter dimensions are also given in the Imperial unit of inches (in.) since this unit is still in common use when referring to this parameter.
2. Use of the term "nominal" when referring to casing diameter provides a direct association with the gauge of the bit (Table 4-1) which most closely passes through it.

(c) Casing Shoe

This item is fitted (welded) to the bottom end (foot) of a casing string in order to protect the "mouth" of the casing from damage due to forcing the casing through unstable horizons. Its use is therefore only warranted (indeed mandatory) in instances where such conditions reveal themselves to require securement through the emplacement of casing.

The Drilling Contractor will be remunerated for each casing shoe supplied and used at the rate tendered for each relevant shoe diameter as set out in the Schedule of Rates included as Section 4 of Document 2 in Part 3.

(d) uPVC Casing

Also referred to as thermoplastic casing, the material generally comprises PVC (polyvinyl chloride) which, when treated to withstand ultraviolet radiation, is known as uPVC casing. Its application in the construction of community water supply boreholes is rather specific, being used mainly in instances where security against the collapse of a borehole sidewall is required and where steel casing does not already offer such security. In such instances, the casing is inserted the entire length of the borehole and will certainly be perforated for some portion of its length.

The diameter of this casing will also necessarily be smaller than that of the steel casing used which, in most instances, will have a nominal diameter of 165 mm. In order not to compromise too severely on the minimum nominal diameter requirement of 152 mm for successfully completed community water supply boreholes (subsection 4-3-6.b), the inside diameter of the uPVC casing shall not be less than 128 mm with a wall thickness of 6 mm. It is also common practice to leave the steel casing in place in order to provide protection for the uPVC casing. The decision to use uPVC casing in the final construction of a borehole shall be made by the Hydrogeological Consultant.

The Drilling Contractor will be remunerated for uPVC casing per linear metre thereof supplied and installed at the rate tendered for each relevant casing diameter as set out in the Schedule of Rates included as Section 4 of Document 2 in Part 3.

(e) Perforated Casing

Also referred to as slotted casing, this is used in instances where a casing string inserted into a borehole will extend across a waterbearing horizon. The perforations or slots will allow the groundwater to enter the borehole. Perforations can be made in a number of ways ranging from prefabricated machine- or plasma-cut slots to hacksaw, anglegrinder or oxyacetalene torch-cut slots made in the field. The latter type of slots are seldom satisfactory since it is difficult to produce perforations which are: (1) of uniform size, (2) clean, open and free of restrictions and (3) small enough to control the ingress of finer material into the borehole. It is therefore preferred that perforated casing used in the construction of community water supply boreholes be of a prefabricated type. As a general guideline, slots should be: (1) 300 mm in length, (2) 3 to 4 mm wide, (3) positioned in bands around the circumference of the casing, (4) spaced equally in each band, (5) each circumferential band of slots separated by 100 mm of plain pipe, (6) every second band of slots aligned with one another and (7) a 300 mm section of plain pipe left at both ends of the casing. This slot pattern is illustrated in Drawing 4 (Part 2). Bearing in mind that the number of slots forming each circumferential band depend not only on the casing diameter but also impact on the strength of the casing, it is suggested that the guidelines presented in Table 4-3 be adhered to in this regard.

Table 4-3. Recommended number of slots per circumferential band for various steel casing diameters and associated percentage open area provided

NOMINAL CASING DIAMETER	NUMBER OF SLOTS PER CIRCUMFERENTIAL BAND	PERCENTAGE OPEN AREA
152 mm	6	3.0%
165 mm	8	3.7%
203 mm	10	3.7%

Also presented in this table is the approximate open area provided by the above slot pattern applied to each of the given casing diameters. In certain instances, however, it may be required to use more sophisticated and expensive slotted casing. Also known as screens, these include: (1) continuously wound wedgewire screens, (2) louvred screens or bridge-slotted screens and (3) screens pre-coated with gravel. The decision to use such screens shall again be made by the Hydrogeological Consultant after providing motivation to and gaining acceptance from the Implementing Authority.

The Drilling Contractor will be remunerated for perforated casing per linear metre thereof supplied and installed at the rate tendered for each relevant casing diameter as set out in the Schedule of Rates included as Section 4 of Document 2 in Part 3.

(f) Recovery of Steel Casing

The contractor shall make every effort to recover, only on instruction from the Hydrogeological Consultant, steel casing from unsuccesful or abandoned boreholes. This casing can also be refurbished to an acceptable condition for re-use.

The Drilling Contractor will be remunerated for the recovery of steel casing per linear metre thereof salvaged from a borehole as per the rate tendered in the Schedule of Rates included as Section 4 of Document 2 in Part 3. Payment for the proper refurbishment of such casing shall be made on a time basis against tendered standing time rates subject to verification and certification of the amount/duration of this work by the Hydrogeological Consultant.

(g) Borehole Straightness

The straightness (alignment) of a borehole is defined by the degree to which it deviates along its length from an imaginary centreline drawn through the borehole. This is readily determined by passing a "dummy" or "dolly" through the borehole. The equipment comprises a rigid hollow steel pipe having an outside diameter which is smaller by not more than 20 mm than the inside diameter of the final casing. Caution should be exercised when conducting a straightness test in an uncased or partially cased borehole since irregularities in the borehole sidewall may cause the "dummy" to become jammed. Since the casing string is normally constructed from six-metre lengths, it is required that the "dummy" itself have a length of at least six metres in order to adequately "straddle" casing joints. This equipment must form part of the standard equipment supplied by the Drilling Contractor. It must also be readily available since the Hydrogeological Consultant may request a straightness test at any stage during drilling. The "dummy", suspended from a flexible steel rope (normally the hoist line with which most drilling rigs are equipped), is slowly lowered down the borehole.

The borehole will be considered straight if the "dummy" passes down the entire length of the borehole and can be withdrawn without it binding or becoming stuck in the borehole. The straightness test must be performed by the Drilling Contractor in the presence of the Hydrogeological Consultant and its success (or failure) recorded by this party.

A borehole which fails a straightness test will be deemed lost (subsection 4-3-6.l) and it will be required of the Drilling Contractor to drill a replacement borehole at own expense. In the event that a straightness test is made before completion of the borehole, then the contractor will be required to cease operations and facilitate access to the borehole for the duration of such activity. The contractor will recover the cost of production loss (incurred for the duration that drilling activities are interrupted) against the rate tendered for standing time in the Schedule of Rates (Section 4 of Document 2, Part 3). It will be the responsibility of the Hydrogeological Consultant to verify and certify any claim by the Drilling Contractor in this regard.

(h) Borehole Verticality

This represents the plumbness of the borehole as measured by the deviation of the centre of the borehole from the vertical at any depth within the bore. The deviation must not exceed two-thirds of the borehole diameter (casing inside daimeter) per 30 m of depth. Although the SABS 045-1974 standard code of practice for testing water boreholes (including for verticality) has been withdrawn, the nature and form of the apparatus to be used for this purpose remains valid. Drawing 5 in Part 2 of this document illustrates the equipment.

The equipment comprises of a tripod (shear legs), a plumb-bob and a flexible wire line. The plumb-bob must be fitted with a centre-mounted spindle at one end and a centralising device on its circumference. The tripod is erected over the borehole such that its apex is above the centre of the borehole. The wire line is passed through a small pulley mounted at the apex. The plumb-bob, suspended from the wire line, must hang vertically from the pulley such that the wire line passes exactly through the centre of the borehole when the plumb-bob is centrally positioned within the mouth of the casing (tolerance 3 mm). The vertical distance from the pulley to the top of the casing must be measured accurately (tolerance 0.01 m). This distance must not be less than 2.4 m. The plumb-bob is then lowered in equal increments (generally 3 m) down the borehole. The deviation of the wire line measured in millimetres from the centre of the casing must be determined at each depth increment and the measurements recorded on a data sheet. An example of such a sheet is provided in Part 2. This procedure must be continued for the entire length of the borehole. The measured deviation of the wire line from the centre of the mouth of the casing at each depth increment indicates the drift (f) of the plumb-bob. The measured deviation is used together with a deflection factor (D_f) to calculate the actual deflection (D_a) of the borehole from the vertical at each depth increment according to the equation:

$D_a = f(d + h)/h$

where f = the measured drift (in millimeters) of the wire line at a given plumb-bob depth,
d = depth of plumb-bob below casing collar (in metres) for each drift (f) measurement,
h = vertical distance between the casing collar and the pulley (at the tripod apex) over which the wire line passes (in metres), and
(d + h)/h represents the deflection factor (D_f).

The wire line deviation measurement is most accurately performed if a revolving template with a graduated radial slot is mounted directly over the collar of the casing. The slot is graduated in millimetres outwards from the centre of the template. The template is revolved until that the wire line passing through the slot hangs free and straight in the slot and its deviation from the centre read off on the graduated slot.

The verticality test must be performed by the Hydrogeological Consultant in the presence of the Drilling Contractor. The consultant will therefore be required to provide the necessary equipment for conducting a verticality test. A borehole which fails a verticality test will be deemed lost (subsection 4-3-6.l) and it will be required of the contractor to drill a replacement borehole at own expense. In the event that a verticality test is made before completion of the borehole, then the Drilling Contractor will be required to cease operations and facilitate access to the borehole for the duration of such activity. The contractor will recover the cost of production loss (incurred for the duration that drilling activities are interrupted) against the rate tendered for standing time in the Schedule of Rates (Section 4 of Document 2, Part 3). It will be the responsibility of the Hydrogeological Consultant to verify and certify any claim by the Drilling Contractor in this regard.

(i) Backfilling

This entails filling the annular space between the borehole sidewall and the outside of the casing with suitable material. The purpose of annular backfilling includes: (1) the provision of a base on which to found a sanitary seal and (2) the provision of support for the sidewalls of the borehole and the casing. In instances where casing has been seated at a comparatively shallow depth in fresh material below a weathered near-surface horizon, all of the drill cuttings removed from the borehole whilst drilling represents suitable material for this purpose. Annular backfilling with this material is not advisable in instances where this is not the case, such as for example where the casing extends to a substantial depth and comprises slotted/perforated sections or where the waterbearing horizon is shallow and open to the borehole via slotted/perforated casing. In these instances, it will be required to insert a formation stabiliser into the annulus. The backfilling must extend to within approximately 5 m of the ground surface.

The Drilling Contractor will be remunerated for backfilling against the standing time rate (which shall include the supply and insertion of material required therefore) tendered for in the Schedule of Rates included as Section 4 of Document 2 in Part 3.

(j) Formation Stabiliser

This comprises material which is placed in the annulus between the borehole sidewall and perforated/slotted sections of casing to stabilise the formation against collapse and ingress into the borehole. The drill cuttings and spoils removed from the borehole is not suitable material for this purpose. The stabiliser must comprise material which is: (1) well sorted, (2) well rounded, (3) low in calcareous content and (4) graded such that the smallest grain size is larger than the casing perforations/slots. The stabiliser material can either be placed by hand or through a tremie pipe. Excessive bridging of stabiliser material in the annulus can be prevented: (1) through the use of centralisers on the casing or (2) by washing it in with clean water. The formation stabiliser should extend some 10 m above the top of the uppermost perforated/slotted section of casing before the borehole is developed.

The Drilling Contractor will be remunerated for formation stabiliser per kilogram supplied and installed at the rate tendered for in the Schedule of Rates included as Section 4 of Document 2 in Part 3.

(k) Concrete Collar

The Drilling Contractor will construct a shallow circular concrete collar around each successfully completed borehole. This collar shall have the dimensions set out in Drawing 6 (Part 2) yielding a volume approaching 0.08 m^3. The concrete mixture shall consist of water, portland cement, stone aggregate (10 mm) and river sand. Quantities of these materials sufficient to make 0.1 m^3 of concrete with the required strength of some 30 MPa after 28 days are: (1) 20 l of water, (2) 42 kg (0.8 bag) of portland cement, (3) 0.07 m^3 of stone aggregate and (4) 0.07 m^3 of river sand. A similar collar may need to be constructed, on request of the Hydrogeological Consultant, over unsuccessful or abandoned boreholes as per Drawing 7, Part 2.

The contractor will be remunerated for a concrete collar per unit constructed at the rate provided in the Schedule of Rates (Section 4 of Document 2, Part 3), which rate shall include for the transport, supply, mixing and placement of all the materials required.

(l) Unsuccessful and Abandoned Boreholes

A borehole will be declared unsuccessful at the discretion of the Hydrogeological Consultant. The latter may also, at any time during the course of the work, order the abandonment of a borehole in progress.

In such instances, the Hydrogeological Consultant must instruct the Drilling Contractor on further actions to be taken. These may include either: (1) the salvage of any casing from the borehole and (2) the plugging of the borehole or (3) the securement of the borehole for long term monitoring purposes, in which it case it will be provided with a sanitary seal (subsection 4-3-6.n), concrete collar (4-3-6.k), protection (4-3-6.q) and marking (4-3-6.r).

Plugging (or finishing) of an unsuccessful or abandoned borehole is aimed at removing any danger or hazard such boreholes may present to the environment, eg. as a conduit for the inflow of surface water into the groundwater regime or as a danger to traffic (whether human, stock or vehicular) in the immediate vicinity thereof. This is achieved by shovelling the drill cuttings and other suitable natural material back into the unsuccessful borehole. In order to prevent this material from "hanging" in the borehole, it might be required to periodically wash it in with clean water during the infilling process. Once the infill material extends to the ground surface, it must be compacted by tamping it down manually and any subsidence topped up with fresh backfill material. The compacting and topping up activities should be repeated until assurance can be had that all reasonable precaution has been taken to prevent future subsidence. It will also be required to cast a concrete collar over the infilled borehole (subsection 4-3-6.m). This process is illustrated in Drawing 7 of Part 2.

The Drilling Contractor will be remunerated for an unsuccessful or abandoned borehole on the basis of tendered rates in the Schedule of Rates (Section 4 of Document 3, Part 3) for such of the following items as are relevant: (1) drilling per linear metre of depth for each relevant drilling diameter employed, (2) steel casing per linear metre thereof recovered, (3) backfilling, (4) a sanitary seal, (5) borehole protection and (6) borehole marking. Payment for any casing left behind in an unsuccessful or abandoned borehole will only be made, on the same basis as described in (2) above, on written certification by the Hydrogeological Consultant that the contractor has made every reasonable attempt in this regard.

(m) Lost Boreholes

A borehole will be declared lost by the Hydrogeological Consultant in the event that it can not be completed satisfactorily due to factors such as: (1) the irrecoverable loss of drilling equipment, materials or tools therein, (2) accident to plant or heavy machinery, (3) failure to pass a straightness test and (4) failure to pass a verticality test. A decision in this regard must be made after consultation with the Drilling Contractor, who will have the considered option to either attempt remediation of the situation to the satisfaction of the Hydrogeological Consultant or, alternatively, declare the situation irretrievable. No payment shall be made for any work done, materials used or time spent by the Drilling Contractor on a lost borehole. The cost of any materials recovered in a damaged state from a lost borehole will be borne by the contractor.

A borehole which is declared lost shall be replaced with a new borehole to be constructed by the Drilling Contractor in the vicinity of the lost borehole and at a position indicated by the Hydrogeological Consultant. Payment for a new borehole constructed under these circumstances shall be made on the same basis as for any other successfully completed borehole. Materials recovered in good condition may, however, be re-used by the contractor.

(n) Sanitary Seal

The purpose of a sanitary seal is to prevent the ingress of potentially contaminated surface water into the borehole via the annular space between the borehole sidewall and the outside of the casing. It is required, therefore, that every successful community water supply borehole be provided with a sanitary seal. The seal must consist of portland cement mixed to a slurry with bentonite and water which is free of oil and other organic matter. The bentonite and water should be thoroughly mixed in the ratio of 2 kg bentonite to 25 l water prior to adding and mixing in 50 kg (one bag) cement. The final grout seal must extend to a depth of at least 5 m below ground surface, ie. founded on the backfilling. In such shallow applications, the slurry can be gravity-fed into the annulus through a small diameter tube (tremie pipe) extending to the depth of emplacement. The tremie pipe should be withdrawn slowly as the slurry fills up the annulus. Care should be taken not to leave voids in the sanitary seal. These may result from: (1) chanelling caused by casing which is not centred in the borehole, (2) an improperly mixed slurry which contains lumps and (3) an annular space which is too small to assure a uniform thickness of seal.

The Drilling Contractor will be remunerated for a sanitary seal per linear metre thereof against the rate tendered in the Schedule of Rates included as Section 4 of Document 2, Part 3. This rate will include for the supply, delivery, mixing and installation of all material.

(o) Borehole Development

This activity entails flushing all loose material from the borehole upon the completion of drilling. This material might comprise one or more of: (1) drill cuttings resting on the bottom, (2) loose material forming insecure portions of the borehole sidewall, (3) clayey material "plastered" to the borehole sidewall during the drilling process and (4) fine material which has collected behind screened portions of the borehole. The removal of this potentially "clogging" material often leads to an improvement in the yield of the borehole. The most common borehole development technique used simply entails repeatedly running the drillbit up and down in sequential passes across portions of the borehole with the compressed air turned open. The length of each pass will be dictated by the length of the drill rods used by the contractor. The process is normally performed from the bottom up, one drill rod being removed from the drill string upon development of the preceding (lower) section.

The borehole will be deemed sufficiently developed when very little or no material is brought to the surface in the return flow from the borehole as evidenced by collecting a portion of this flow in a bucket placed at the borehead during development. Other methods which may be employed for borehole development include: (1) surge plunging using a surge block and (2) jetting using a purpose-built jetting tool. This activity must be concluded with the collection of a one-litre representative water sample obtained from the return flow during development.

The Drilling Contractor will be remunerated for borehole development on a time basis against the worktime rate tendered in the Schedule of Rates included as Section 4 of Document 2 in Part 3. It will be the responsibility of the Hydrogeological Consultant to verify and certify any claim by the contractor in this regard.

(p) Borehole Disinfection

Also known as sterilisation, the purpose hereof is to disinfect the borehole and its contents of any bacteria, and particularly coliform bacteria, introduced into the borehole during drilling operations. Sterilisation is most readily accomplished by introducing chlorine (or chlorine-yielding compounds) into the borehole. Commercially available chlorine-yielding products include: (1) calcium hypochlorite ($CaClO_2$) in granular or tablet form, (2) sodium hypochlorite (NaClO) in aqueous form and (3) chlorinated lime. Preference is given to the use of sodium hypochlorite since it does not contain calcium which may react with the natural concentration of calcium in the groundwater to form a precipitate of calcium hydroxide causing a reduction in the natural permeability of waterbearing formation materials. It is generally required to establish a chlorine concentration of some 1000 mg/l in the borehole. This must necessarily take into account: (1) the volume of water in the borehole and (2) the concentration of available chlorine, also referred to as free-chlorine, in the sterilant. A formula by which the amount (either by volume or by weight) of sterilant required can be estimated is given as:

Volume (or weight) of sterilant required = $(V_w)(C_d/C_s)$

where V_w = volume of water in the borehole (in litres),

C_d = desired concentration of available chlorine (in mg/l) and

C_s = concentration of available chlorine in the sterilant (in mg/l).

Since the concentration of available chlorine in the sterilant is often given as a percentage, it is required that this be converted to mg/l units. This is achieved simply by multiplying the trade percentage by 10,000, viz. 70 percent available chlorine is equivalent to a chlorine concentration of 700,000 mg/l. Guideline volumes/weights of common compounds to be used for disinfection purposes under most normal circumstances can be derived from the information provided in Table 4-4.

Table 4-4. Guideline volumes/weights of common sterilants to be used per unit volume of water for various borehole diameters

NOMINAL INSIDE DIAMETER OF BOREHOLE	VOLUME OF WATER PER METRE OF BOREHOLE	VOLUME/WEIGHT OF STERILANT TO BE USED FOR DISINFECTION PER UNIT VOLUME OF WATER BELOW GROUNDWATER REST LEVEL		
		Sodium hypochlorite	Calcium hypochlorite	Chlorinated lime
152 mm	18 l	500 ml (2 cups)	26 g (¼ cup)	90 g (1 cup)
165 mm	21 l	600 ml (2½ cups)	30 g (_ cup)	105 g (1 cup)
203 mm	33 l	940 ml (4 cups)	47 g (½ cup)	165 g (1½ cups)
254 mm	51 l	1500 ml (6 cups)	73 g (¾ cup)	255 g (2½ cups)

NOTES: 1. No distinction is drawn between open and cased portions of a borehole since these differences are considered to have a negligible impact on calculated unit volumes.

2. The trade percentage of chlorine in the listed sterilants is taken to be:
 3.5 percent by volume (35 ml/l) for sodium hypochlorite,
 70 percent by weight (700 g/kg) for calcium hypochlorite, and
 20 percent by weight (200 g/kg) for chlorinated lime.

EXAMPLE: A 100-metre deep borehole with a nominal diameter of 165 mm and with a rest water level standing at a depth of 25 m below surface will require 75 x 30 g = 2,250 g (2.25 kg), alternatively 75 x _ cup = 25 cups, of <u>calcium hypochlorite</u> to achieve adequate disinfection. The same situation would require 75 x 600 ml = 45,000 ml (45 l) of <u>sodium hypochlorite</u> to achieve adequate disinfection.

Since any disinfectant agent destroys only the bacteria it contacts, simply pouring the solution into the borehole does not promote complete disinfection. This can be achieved by agitating the water in the borehole to effect thorough mixing with the disinfectant. Alternatively, the required amount of granular, dry compound (calcium hypochlorite) can be placed in a short perforated tube capped at both ends, suspended from a cable or rope and then raised and lowered through the column of water in the borehole until all of the compound is dissolved.

Use of calcium hypochlorite: The required quantity of this compound can either be dissolved in clean, clear water or introduced in dry form as described above. If introduced as a solution, the required quantity should be dissolved using ten litres of water per kilogram of compound. For the example provided in Table 4-4, this means dissolving 2.25 kg of calcium hypochlorite in 2.25 x 10 l = 22.5 l of water. The calcium hypochlorite solution must then be poured into the borehole. Granular HTH chlorine is an example of such a compound.

Use of sodium hypochlorite: The required volume of this solution may be poured directly into the borehole without further treatment (such as premixing/blending with clean, clear water). Concentrated household bleach (eg. JIK®) is an example of such a solution.

Use of chlorinated lime: The same procedure as described for calcium hypochlorite should be followed.

The Drilling Contractor will be remunerated for borehole disinfection per single application at the cost (which shall include for all materials supplied and used and the time spent) tendered for one such application as set out in the Schedule of Rates included as Section 4 of Document 2 in Part 3.

(q) Borehole Protection

This entails sealing the borehole from the introduction of foreign material directly through the casing. It is often achieved by means of a lockable cap fitted to the borehole collar. Experience suggests, however, that a 3 to 4 mm thick steel plate (lid) welded onto the borehole collar ensures better security. Of course, it will later be required of the Testing Contractor to remove this plate in order to gain access to the borehole for testing purposes. In order to provide the Hydrogeological Consultant with ready access to the borehole for water level measuring purposes, it is required that a small hole be drilled in the lid. This hole must be furnished with a tamper-proof plug such as a "dead-end" threaded into a water pipe connector welded on the hole. The final diameter of the hole providing access to the borehole must be sufficient to allow a "normal" dipmeter probe to pass through it. It is considered that a diameter of at least 10 mm and not more than 20 mm is suitable for this purpose. The Drilling Contractor will be remunerated for borehole protection per single installation at the cost (which shall include for all materials supplied and used and the time spent) tendered for one such installation as set out in the Schedule of Rates (Section 4 of Document 2 in Part 3).

(r) Borehole Marking (in the field)

The identifying number of a borehole to be drilled will be provided by the Directorate Geohydrology or its appropriate Regional Office in the province in which the drilling is to take place. Neither the Hydrogeological Consultant or the Drilling Contractor is to use an own numbering system. The consultant will be responsible for securing a batch of numbers from the Directorate Geohydrology (or one of its regional offices) and pass these on to the Contractor as is deemed fit and appropriate. The numbering system will cater for all provinces.

The activity itself represents marking the borehole by: (1) script-welding its assigned and unique identifying number onto the lid of the borehole and (2) planting a concrete block with dimensions of 200 mm x 200 mm x 200 mm (also bearing the number of the borehole) in the ground a distance of five metres to the north of the borehole.

For all Community Water Supply and Sanitation projects, the borehole identifying number will be provided by the Directorate Geohydrology of the DWAF, or else by the Implementing Authority. It is the responsibility of the Hydrogeological Consultant to ensure that the correct number is provided to the contractor for this purpose. The Drilling Contractor will be remunerated for borehole marking per single application at the cost (which shall include for all materials supplied and used and the time spent) tendered for one such application as set out in the Schedule of Rates (Section 4 of Document 2 in Part 3). The hardware left down the borehole becomes the responsibility of the Local Authority who is tasked with all aspects of Operation and Maintenance (O&M).

(s) Site Finishing

The activities associated with this task must include the repair of construction scars on the work site resulting from drilling activities as well as the general cleanup of the site of waste materials, debris and oil spills. The latter must be shovelled over and worked into the ground wherever possible. The Drilling Contractor will be remunerated for site finishing per single application at the cost (which shall include for the time spent) tendered for one such application as set out in the Schedule of Rates (Section 4 of Document 2 in Part 3).

4-3-7. Data Recording and Reporting

It is imperative that a detailed and accurate record of all information arising from the borehole drilling activity be recorded with care and diligence. Much of this information can be collected by the Drilling Contractor. It must be recorded on a driller's log such as is provided in Part 2. This must be kept current and available for inspection on request by the Hydrogeological Consultant. The contractor will include the cost of these activities as a single sum per borehole in the Schedule of Rates (Section 4 of Document 2, Part 3). It will be the responsibility of the Hydrogeological Consultant to verify receipt of this information prior to certifying a claim by the Drilling Contractor in this regard. The following items of information represent the minimum number of parameters which must be monitored and recorded by the contractor.

(a) Penetration Rate

This represents the time taken, as measured with a stopwatch, to advance the borehole a specific depth (generally one metre). In broad terms, the harder the rock formation the slower the penetration rate and vice versa. Since the hardness (or softness) of a rock formation is a characteristic which can be associated with specific rock types, an accurate record of penetration rates serves as an additional means of identifying changes in rock type with depth. Although a slow penetration rate may be of hydrogeological significance, it can also be caused by worn equipment or difficult drilling conditions such as are presented by loose, unstable material. The measured penetration rate must, therefore, not include time spent overcoming technical problems or remedying mechanical breakdowns encountered during drilling.

(b) Formation Sampling and Description

This entails a brief description of the visual appearance of the rock formation being drilled. It is performed by inspection of the rock chips (also known as drill cuttings) brought to the surface during drilling. A spadeful of chips should be collected at the mouth of the borehole for each metre drilled. The "samples" should be placed as sequential piles in ordered rows at a cleared and visible location away from the immediate area of activity and traffic around the borehole being drilled. The samples should be described by a suitably qualified geotechnician/earth scientist according to the guidelines set out by the South African Institute for Engineering Geologists (SAIEG, 199?). The driller's description must include, as a minimum, a note on the colour of the formation, the relative size of the drill cuttings and, if possible, an identification of the possible rock type.

(c) Water Strike Depth

This information relates to the depth at which any water, including seepage, is encountered in a borehole during drilling. It is possible for water to be encountered at more than one depth as drilling advances. The depth(s) at which water is encountered must be determined to an accuracy of one metre and recorded. It is also necessary to record the nature of the formation associated with the water strike(s). This may, for example, be represented by a single fracture or fissure, a system of such features or a noticeably softer or more weathered horizon.

(d) Blow Yield

Water which is encountered in a borehole being drilled by the rotary air percussion method is blown out of the borehole during drilling. The amount of water being blown from the borehole provides an indication of the possible yield of the borehole. The blow yield must not be guestimated, even though a fair visual estimate based on experience can often be provided by the Drilling Contractor. Also, since water may be encountered at more than depth, it is necessary to measure and record the blow yield immediately following each water strike. These measurements should be repeated as drilling continues until constancy is revealed by at least four consecutive measurements each representing a further metre of drilling.

The accurate measurement of the blow yield does not require the use of sophisticated equipment. The most acceptable and preferred means of measurement is provided by the use of a 90° V-notch weir, details of which are provided in Drawing 8, Part 2. The use of a 90° V-notch weir entails channelling all of the water being blown from the borehole through such a weir which has been placed level in the channel (or ditch) leading the return water flow away from the borehole being drilled. The height of water flowing over the notch is translated into a flow rate or yield as indicated in Table 4-5. It is imperative that the height of water flowing over the weir is not measured within the notch itself but at and from a position in the weir upstream and to the side of the notch and which corresponds exactly in height to the inverted apex of the notch.

Table 4-5. Tabulation of height vs. flow rate data for a 90° V-notch weir						
HEIGHT (mm)	FLOW RATE (l/s)	FLOW RATE (l/s) FOR				
		HEIGHT +2 mm	HEIGHT +4 mm	HEIGHT +5 mm	HEIGHT +6 mm	HEIGHT +8 mm
10	0.01			0.04		
20	0.08			0.15		
30	0.23			0.34		
40	0.47	0.53	0.60		0.67	0.74
50	0.80	0.88	0.97		1.06	1.16
60	1.26	1.36	1.47		1.59	1.71
70	1.84	1.97	2.11		2.25	2.40
80	2.55	2.71	2.88		3.05	3.23
90	3.41	3.60	3.80		4.00	4.21
100	4.42	4.64	4.87		5.10	5.34
110	5.59	5.85	6.11		6.38	6.65
120	6.94	7.22	7.52		7.83	8.14
130	8.46	8.79	9.12		9.46	9.81
140	10.17	10.53	10.90		11.28	11.67
150	12.07	12.47	12.88		13.30	13.73
160	14.17	14.61	15.07		15.53	16.00
170	16.48	16.96	17.46		17.96	18.48
180	19.00	19.53	20.07		20.62	21.18
190	21.75	22.32	22.91		23.50	24.11
200	24.72	25.34	25.97		26.61	27.26
210	27.92	28.59	29.26		29.95	30.65
220	31.36	32.08	32.80		33.54	34.28
230	35.04	35.81	36.58		37.37	38.17
240	38.97	39.79	40.62		41.45	42.30

Another common but less preferred method in use is the "drum-and-stopwatch" technique. This requires only that all of the water blown from the borehole be channelled to a point where the concentrated flow can be collected in an open-ended drum of known volume (generally 20 litres) and the time taken to fill the container measured with a stopwatch for accuracy. Dividing the full volume of the drum (in litres) by the time taken (in seconds) to fill the drum gives the blow yield in litres per second (l/s). It is cautioned, however, that this method is only effective and reliable for yields of less than approximately 2 l/s.

(e) Groundwater Rest Level

This parameter represents the depth, as measured from surface, to the level of standing water in the borehole. This measurement can be made with the use of any liquid level indicating device, the most common of which is an electrical contact meter (dipmeter). The groundwater level measurement must be accurate to the nearest 0.01 metres (one centimetre). The measurement reference point, which may either be the ground level or the collar of the borehole, should be identified against the measured depth value. The latter reference point will generally be represented by the top of the casing with which the borehole has been equipped. In these instances, it will also be necessary to measure the height by which the casing extends above ground level. If the borehole is drilled and completed on the same day, then a groundwater level measurement must be taken immediately before leaving the site.

If drilling and borehole construction extends over two or more days, then such measurements must also be taken before daily drilling activities commence provided that water, including seepage water, has been encountered in the borehole. A groundwater level measurement must be referenced to the date on which it is made and, if more than one such measurement is made per day, then also the time of each such measurement must be recorded.

4-3-8. Down-the-hole Loss of Equipment

Drilling equipment, materials or tools may be lost down a borehole during drilling operations. Since this can often result in the irretrievable loss of a borehole, substantial efforts are generally employed by the Drilling Contractor to recover such material. This activity is also referred to as fishing. The Hydrogeological Consultant will afford the contractor every opportunity and reasonable time to fish for lost equipment. The Drilling Contractor must, in turn, keep the Hydrogeological Consultant informed of progress and the likelihood of success in this regard. The contractor will have no claim against any other party for any losses incurred in this regard. Further, the fate of a borehole which can not be continued or completed due to the presence of lost equipment, materials or tools therein will finally be decided by the Hydrogeological Consultant. It may either be declared successful or lost.

(a) Borehole declared Successful

Circumstances under which a borehole may be declared successful include: (1) the borehole has encountered significant water, (2) pumping equipment can be installed to an acceptable depth in the borehole and (3) the lost equipment does not pose a threat to the present and future quality of the groundwater. In the event that a borehole is declared successful despite the irrecoverable loss of drilling equipment, materials or tools therein, then the exact nature and position of the equipment lost in the borehole must be recorded and appear in relevant project documentation. The Drilling Contractor will be remunerated for a borehole declared successful under these circumstances on the same basis as for any other successfully completed borehole.

(b) Borehole declared Lost

Although the circumstances under which a borehole will be declared lost are varied and diverse, the criteria which should apply include: (1) the borehole has not yet encountered water irrespective of the depth reached, (2) the borehole has not yet encountered water even though the geological and hydrogeological indications are positive, (3) the borehole has encountered water but in too small a quantity to warrant the installation of pumping equipment yet the geological and hydrogeological indications are positive that more water can be obtained and (4) the borehole has encountered a significant quantity of water but the lost equipment prevents the installation of pumping equipment to an acceptable depth. In the event that a borehole is declared lost under these circumstances, then the criteria set out in subsection 4-3-6.l for further actions, payment, etc. shall apply.

4-3-9. Down-the-hole Borehole Measurements

This activity is more commonly referred to as borehole logging. The measurements are carried out by manually or mechanically lowering tools or instruments of various technical sophistication down a borehole. Borehole logging is useful in instances where: (1) surface geophysical data need to be calibrated against subsurface information, (2) geological information for a borehole is absent or suspect, (3) borehole construction information is absent or suspect and (4) information is required for the proper and effective stimulation by various means of borehole yields. Although down-the-hole borehole measurements may be made at any time during the construction of a borehole, they are generally performed on completion thereof. In the event that such measurements need to be made before completion of the borehole, then the Drilling Contractor will be required to cease operations and facilitate access to the borehole for the duration of such activity. The contractor will be able to recover the cost of production loss (incurred for the duration that drilling activities are interrupted) against the rate specified for standing time in the Schedule of Rates (Section 4 of Document 2, Part 3), any claim in this regard to be verified and certified by the Hydrogeological Consultant.

The nature of the information to be gathered dictates the technique(s) to be used and the time required to complete these measurements. Basic information such as the depth of the borehole and the amount of steel casing installed therein is readily and cheaply determined by means of straightforward and uncomplicated intruments. Geophysical and geological information, on the other hand, requires the more costly application of specialised borehole logging instrumentation including the use video cameras. It is required that the more sophisticated of these investigations: (1) be motivated to and authorised by the Implementing Authority prior to their execution and (2) be applied judiciously at the discretion of the Hydrogeological Consultant.

(a) <u>Borehole Construction Information</u>

This includes information such as: (1) the depth and diameter(s) of the borehole, (2) the depth and diameter(s) of casing installed in the borehole and (3) the integrity of the casing. This information can be used to verify/check the documented construction details of a borehole. The depth of a borehole can be determined simply by plumbing with a weighted line. A caliper tool can be used to determine borehole and casing diameters and the length and integrity of the casing string. The length of steel casing can also be determined more simply with a sensor operating on electromagnetic principles.

(b) <u>Geological Information</u>

This covers aspects such as identifying: (1) the nature of different rock formations occurring at various depths within a borehole on the basis of their geophysical (geo-electrical) properties and (2) the presence and size of fractures and/or fissures intersected by a borehole. This information can be used to: (1) calibrate surface geophysical data obtained from similar geological environments, (2) determine the optimum depth at which a borehole pump should be installed in a borehole and (3) direct the application of borehole yield stimulation activities such as hydrofracturing.

(c) <u>Hydrogeological Information</u>

This includes information such as: (1) the porosity of rock formations and (2) the rate of groundwater movement. These measurements generally require the use of more sophisticated and costly instrumentation.

(d) <u>Hydrochemical Information</u>

This covers aspects such as the variation of groundwater quality with depth in a borehole. These measurements again require the use of generally more sophisticated instrumentation. Not quite in the same vein as these measurements yet of probably greater importance is the representative water sample obtained from a borehole during its development (subsection 4-3-6.o).

The water sample must be submitted to a laboratory soon as is reasonably possible for chemical analysis of: (1) the electrical conductivity, (2) the nitrate concentration and (3) the fluoride concentration. These results will provide an early indication of whether the groundwater quality is acceptable or not and, if not, whether test pumping is warranted.

4-3-10. Rehabilitation of Existing Boreholes

This service might or might not be included the scope of work for a Community Water Supply and Sanitation Project. If this service is required, it should be brought to the attention of prospective tenderers in the enquiry document (Section 2 of Document 2, Part 3). The scope of this work may vary from the basic cleaning out and re-development of an existing borehole to the recovery of casing, the reaming and subsequent re-installation of casing. As far as it is possible, the nature of the rehabilitation required in each individual instance should be identified prior to undertaking this activity since this will indicate which equipment will most suitably complete the task. This is illustrated in the following examples. The straight-forward cleaning out and redevelopment of an existing borehole can readily be accomplished using a rotary air percussion drilling rig. On the other hand, the recovery of casing and the removal of unnatural material from a borehole is more readily accomplished using a cable tool (jumper) drilling rig.

It is particularly helpful to both the Hydrogeological Consultant and the Drilling Contractor undertaking the rehabilitation to know as much about the original construction (eg. depth, diameter, length and type of casing, geology, etc.) of the borehole as possible. This is impossible in instances where original records are either lost, deficient, vague or poorly documented/archived. It will be required in such cases to obtain as much information as can reasonably be gleaned from an *in situ* inspection the borehole. This might include such basic measurements as plumbing the current depth of the borehole and establishing, by means of a casing detector, the length of casing (steel) installed, to carrying out various of the more sophisticated down-the-hole borehole measurements and observations (subsection 4-3-9).

The rehabilitation of an existing borehole should preferably be carried out under the supervision of the Hydrogeological Consultant. In any event, the execution of such work will be subject to the same degree of data collection and record keeping as is required of a new borehole.

The Drilling Contractor will be remunerated for this service on the basis of the rates tendered in the Schedule of Rates (Section 4 of Document 2, Part 3). It will be expected of the contractor to have assessed the potential technical risks involved with such work and, as a consequence, the contractor shall have no claim against any other party for the loss of equipment, materials or tools incurred in the course of such work.

4-3-11. Final Acceptance

The Hydrogeological Consultant shall accept a successfully finished community water supply borehole by certifying the Drilling Contractor's invoice for such borehole as true and correct for payment by the Implementing Authority. At this stage, the Hydrogeological Consultant will have established that all aspects pertaining to the work and the final product meet, at least, those of the various criteria and requirements set out above which have been imposed.

4-4. BOREHOLE TESTING

4-4-1. Purpose and Scope

The efficient operation and utilisation of a borehole requires insight into and an awareness of its productivity and that of the groundwater resource from which it draws water. Such insight and awareness is provided by borehole testing. This activity, which is also known as test pumping, provides a means of identifying potential constraints on the performance of a borehole and on the exploitation of the groundwater resource. The recognition and understanding of these constraints promotes the proper, judicious and optimum exploitation of the groundwater resource. Ignorance and disregard of these constraints can lead, at best, to the uneconomical operation of the borehole and, at worst, to over-exploitation of the resource.

The Test Pumping Contractor (Testing Contractor) may be required to test either: (1) newly drilled boreholes which have not yet been equipped, (2) existing "older" boreholes which may or may not already be equipped with pumping installations or (3) a mixture of the aforementioned. The requirements of the project in this regard must be identified in the enquiry document in which tenders for test pumping services are requested and clearly communicated therein to prospective tenderers (Section 2 of Document 3, Part 3).

Test pumping serves two primary objectives. The first of these is an assessment of the productive capacity (yield potential) of the borehole. The second objective addresses the productivity of the groundwater resource. These objectives are met by various types of borehole tests performed separately and often sequentially. These are identified as: (1) the slug test, (2) the calibration test, (3) the stepped discharge test, (4) the constant discharge test and (5) the recovery test. Factors determining which of these tests must be performed include: (1) the potential yield of the borehole and (2) the amount of water which it will be required to supply.

(a) The Slug Test

The slug test provides a rapid means of assessing the potential yield of especially low yielding (less than 1 l/s) boreholes (Vivier *et. al.*, 1995). The results may indicate whether it is feasible and warranted to perform other tests on the borehole. As with any of the other tests, a slug test can be executed in any borehole and not necessarily only newly drilled boreholes.

The test involves measuring the water level response in a borehole to the rapid displacement of water therein. This displacement might cause either: (1) a rise in water level as would result from the introduction of a slug below the rest water level or (2) a drop in water level as would be caused by the removal of a quantity of water from the borehole.

In instances where a slug is introduced, the water level will recede to its original level. The sudden removal of a quantity of water from the borehole will cause the water level to rise to its original level. The rate of recession or rise provides an indication of the yield of the borehole. In qualitative terms the more rapid this is, the higher the potential yield of the borehole.

(b) The Calibration Test

A calibration test requires that water be pumped from the borehole at three or more different rates over short (15 minutes), sequential periods of time. The response of the water level to each known pumping rate is measured and recorded. The calibration test provides a means of assessing the yield potential of borehole according to the magnitude of the water level decline associated with each pumping rate. This information is used to select appropriate pumping rates at which to perform a stepped discharge test or a pumping rate at which to perform a constant discharge test.

(c) The Stepped Discharge Test

Also known as a step drawdown test, it is performed to assess the productivity of a borehole. It also serves to more clearly define the optimum yield at which the borehole can be subjected to constant discharge testing if required. The test involves pumping the borehole at three or more sequentially higher pumping rates each maintained for an equal length of time, generally not less than 60 minutes and seldom longer than 120 minutes. A step length of 100 minutes is recommended. The magnitude of the water level drawdown in the borehole in response to each of these pumping rates must be measured and recorded in accordance with a prescribed time schedule. The actual pumping rate maintained during each "step" must also be measured and recorded. As a rule, the rate of water level recovery for a period of time immediately following the period of pumping should also be monitored according to the same time schedule as during pumping.

(d) The Constant Discharge Test

A constant discharge test is performed to assess the productivity of the aquifer according to its response to the abstraction of water. This response can be analysed to provide information in regard to the hydraulic properties of the groundwater system and arrive at an optimum yield for the medium to long term utilisation of the borehole. This test entails pumping the borehole at a single pumping rate which is kept constant for an extended period of time. The test duration shall not be less than 12 hours and, in some instances, might last up to 72 hours or more. The duration is generally determined by the importance which is attached to the borehole and groundwater resource not only in terms of its yield potential but also in terms of its intended application (subsection 4-5-1, Part 1).

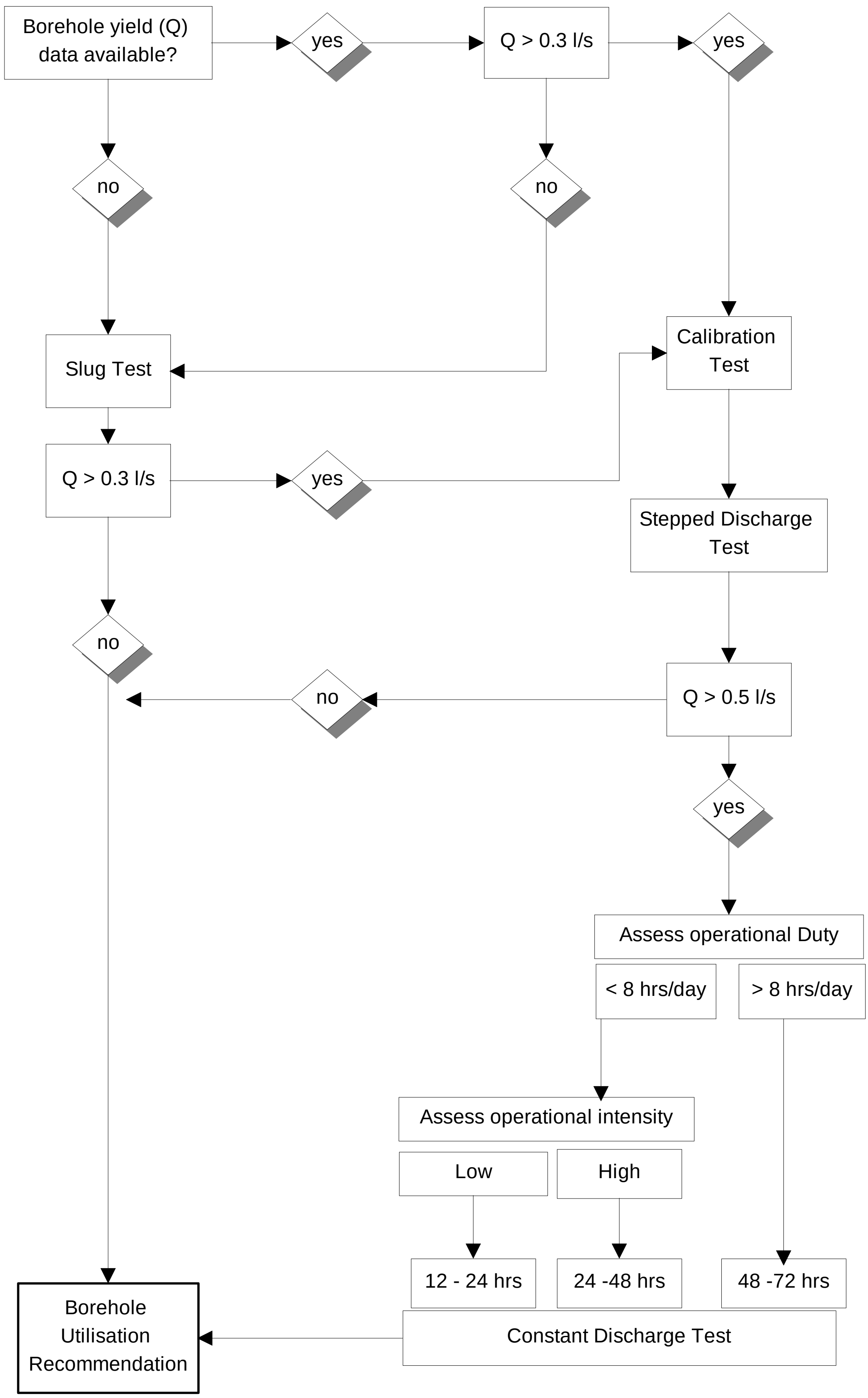
The pumping rate is set at a yield which it is considered the borehole and groundwater system will be able to maintain for the entire planned duration of the test and, in the process, utilising better than 70 percent but not exhausting the available drawdown. It is critical that the pumping rate during the entire duration of the test be kept as constant as possible. The drawdown in water level in the borehole during the course of the test is again measured and recorded according to a prescribed time schedule. In the case of this type of test, it is imperative that water level measurements be made during the recovery period following the end of pumping.

(e) The Recovery Test

This test provides an indication of the ability of a borehole and groundwater system to recover from the stress of abstraction. This ability can again be analysed to provide information in regard to the hydraulic properties of the groundwater system and arrive at an optimum yield for the medium to long term utilisation of the borehole. Although referred to as a test, it rather represents a period of monitoring activity following a period of pumping. The rate at which the water level in the tested borehole (or any other borehole affected by the abstraction) recovers towards its starting level (the groundwater rest level before pumping started) is monitored in this period. The duration of this monitoring is generally equal to that of the preceding period of pumping unless the rate of recovery is sufficiently rapid so that the starting water level is reached in a shorter period of time.

4-4-2. General Approach and Methodology

As mentioned in subsection 4-4-1, various factors determine which type of pumping test (or tests) might need to be performed. It is the responsibility of the Hydrogeological Consultant to formulate a test pumping schedule for each successful borehole. The flow diagram presented overleaf provides an indication of the considerations which determine the scope of test pumping based on a logical decision-making process.


Borehole yield (Q) data available?
yes
Q > 0.3 l/s
yes
no
no
Calibration Test
Slug Test
Q > 0.3 l/s
yes
Stepped Discharge Test
no
no
Q > 0.5 l/s
yes
Assess operational Duty
< 8 hrs/day
> 8 hrs/day
Assess operational intensity
Low
High
12 - 24 hrs
24 -48 hrs
48 -72 hrs
Borehole Utilisation Recommendation
Constant Discharge Test

All project-related test pumping activities will also be carried out under the direct supervision of the Hydrogeological Consultant. The execution of a pumping test in accordance with established scientific protocols must be undertaken by a suitably experienced and equipped Testing Contractor. The South African Bureau of Standards (SABS) is currently (July 1996) finalising a Standard Code of Practice titled "The test-pumping of water boreholes". A draft of this Standard has been considered in the compilation of this document. It will be the task of the Hydrogeological Consultant to evaluate and analyse the data, draw conclusions with regard to the productivity of the borehole and the aquifer, and make recommendations with regard to a suitable operating schedule for the borehole and the optimum exploitation of the groundwater resource. The scope of these recommendations is discussed in greater detail in subsection 4-5 of Part 1.

Both the practical and analytical aspects of test pumping benefit greatly from prior information regarding the borehole and the aquifer which it taps into. This information is gleaned during the drilling and the construction of the borehole. It includes knowledge of: (1) the amount of water blown out of the borehole during drilling operations, (2) the depth(s) at which water was struck in the borehole, (3) the construction of the borehole in terms of the setting of especially perforated (slotted) casing and (4) the nature of the rock formation at the depth(s) where water was struck. This information should be communicated to the Testing Contractor by the Hydrogeological Consultant. If not, the contractor has the right to request and expect to receive this information from the Hydrogeological Consultant prior to the testing of any borehole.

The Testing Contractor must keep a full record of the test pumping which was undertaken and provide this on completion of the test. This record must include the following basic information: (1) the depth to water level before the start of testing, (2) the depth at which the test pump was installed, (3) the type, make and model of the test pump used, (4) the pumping rate as measured at regular intervals during the test and (5) the water level in the borehole as measured according to a prescribed time schedule both during and after pumping. The contractor must be sufficiently well equipped to gather this information with acceptable accuracy.

The rationale behind the flow diagram is explained as follows. A slug test should be performed on a borehole in instances where there is no prior indication of its possible yield. The result of the slug test will indicate whether additional test pumping is warranted. A slug test will also be performed in instances where the possible yield of a borehole from prior information is indicated to be less than 0.3 l/s. The result of the slug test will again indicate whether additional test pumping is warranted. In instances where the possible yield of a borehole from prior information is indicated to be equal to or greater than 0.3 l/s, then a calibration test followed by a stepped discharge test will be performed.

The result of the stepped discharge test will indicate whether further test pumping in the form of a constant discharge test is warranted or whether the borehole is judged to be sufficiently weak (potential production yield less than 0.5 l/s) to make a utilisation recommendation without further testing. Should the result of the stepped discharge test indicate that a constant discharge is warranted, then the Hydrogeological Consultant will need to make an assessment of the possible operational duty to which the borehole might be subjected.

The operational duty describes the number of hours per day for which the borehole must operate in order to meet the water demand locally. By implication, the potential production yield of the borehole must be compared to the water demand. In qualitative terms, a lower yielding borehole would need to operate for a longer period per day to meet a given demand than a higher yielding borehole would need to. Further, the water demand is often too great for even a high yielding borehole pumping continuously to meet. The flow diagram indicates, however, that any borehole which reveals the potential to yield more than 0.5 l/s and which will operate for a period in excess of 8 hours per day must be subjected to a constant discharge test of 48 to 72 hours duration. A borehole which does not fit this category requires an assessment of its possible operational intensity.

The operational intensity describes the yield at which a higher yielding borehole must operate in order to meet a water demand in a pumping period of eight hours or less per day. By implication, a high operational intensity requires the borehole to be pumped at a yield approaching its maximum, whereas a low operational intensity will place less stress on the borehole. These considerations will indicate whether a 24- to 48-hour or a 12- to 24-hour duration constant discharge test respectively will be performed.

The final step in the flow diagram requires the Hydrogeological Consultant to make a borehole utilisation recommendation (subsection 4-5).

4-4-3. Equipment and Materials

This represents the test unit and all ancillary equipment and materials needed to accurately and efficiently perform borehole testing. Details are provided as follows.

(a) Test Unit

The test unit must comprise of a positive displacement (PD) type pump element and a pumphead driven by a motor fitted with an accelerator, gearbox and clutch. The unit must be in good working order and capable of maintaining a minimum of 72 hours of continuous operation.

The unit must be capable of delivering water at a rate in excess of the expected maximum yield of the borehole to be tested. It may be acceptable under certain circumstances to employ a submersible pump for testing purposes. This must, however, be identified in the tender enquiry document. It is imperative that any submersible pump used for testing purposes be equipped with a non-return valve fitted at the bottom of the pump column (rising main).

(b) Discharge Piping

This comprises both the pipe (rising main or pump column) which brings the water to surface and the pipe (discharge hose) used to lead the pumped water away from the borehole being tested. The Testing Contractor must supply sufficient rising main to set the test pump at a depth of at least 100 m below the surface. It may, however, be required under certain circumstances to set the test pump at a greater depth in the borehole. This possibility must be identified prior to the compilation of the enquiry document in which tenders for test pumping services are requested and, if required, must be communicated to prospective tenderers in this document. The pump column must be of uniform diameter throughout. The contractor must also provide discharge piping in the amount of at least 50 m. This must be free of leaks for its entire length (subsection 4-4-3.c). It may again, under certain circumstances, be required to discharge the pumped water at a point further away than 50 m (possibly in excess of 300 m) from the borehole being tested. In such instances, a similar procedure to that discussed above in regard to the rising main must be followed.

(c) Discharge Measuring Equipment/Instrumentation

This must be adequate to accurately measure the pumping rate within the range of yields expected from successful project boreholes. If volumetric methods are used, a stopwatch for measuring time to an accuracy of at least one-tenth of a second is required. The full capacity of each container must be determined accurately. The contractor must also ensure that a container stands level when it is being used for discharge measurements. Guidelines regarding the use of different size containers for volumetric discharge rate measurements in specific yield ranges are given in Table 4-6. Other acceptable methods of discharge measuring are: (1) an orifice weir and (2) a flow meter. Their use is further subject to various application criteria.

Use of orifice weirs: These must be installed in a horizontal position at the end of the discharge pipe. The orifice plate opening must be sharp, clean, bevelled to 45 degrees and have a diameter less than 80 percent of the diameter of the approach tube to which it is fixed. The orifice plate must be vertical and centred on the end of the approach tube. There must be no leakage around the perimeter of the orifice plate mounting. The piezometer tube must not contain entrained air bubbles at the time of pressure head measurement. The latter measurement must be at least three times the diameter of the orifice.

Table 4-6. Yield range vs. container size for volumetric measurements	
YIELD RANGE	CONTAINER SIZE
Less than 2 l/s	20 l
2 l/s to 5 l/s	50 l
5 l/s to 20 l/s	210 l
20 l/s to 30 l/s	500 l
30 l/s to 50 l/s	1000 l
Greater than 50 l/s	Other suitable methods

The orifice weir equipment must be calibrated for various combinations of approach tube and orifice diameters so that pressure head readings can be converted to accurate discharge measurements.

Use of flow meters: These must be calibrated and of similar diameter to that of the discharge pipe. The latter must be straight and of uniform diameter for a distance of four times the diameter of the pipe before the position of the meter. There must be no turbulent flow or entrained air in the discharge pipe before the meter. The discharged water must be free of solid material carried in suspension.

It is recognised that some water leakage will generally occur especially at the borehead during pumping. This is acceptable provided that: (1) such leakage does not interfere with any water level monitoring and (2) the total amount of leakage to the end of the discharge pipeline does not exceed one percent of the pumping rate as measured at the end of this pipeline.

(d) <u>Water Level Measuring Equipment/Instrumentation</u>

The contractor must provide at least three water level measuring devices which are each capable of providing an accuracy of at least 0.01 m (10 mm) and are of sufficient length to match the pump installation depth. If ungraduated electrical contact meters (dipmeters) are used for this purpose, each such instrument must be equipped with a measuring tape of an acceptable length and approved standard and which is graduated to an accuracy of at least 0.01 m (10 mm). These instruments must be in good working order and number at least one spare for each two on site. Circumstances where the project may require the use of more than three such instruments must be identified prior to the circulation of the enquiry document in which tenders for test pumping services are requested and, if required, must be communicated to prospective tenderers in this document.

The contractor must further provide conduit tubing of sufficient length to match the pump installation depth (subsection 4-4-5). The diameter of this tube must be large enough (minimum 15 mm) to allow free movement of the dipmeter probe and cable therein. The tubing must be made of material strong enough to withstand reasonable pressure on its sidewall which might cause a constriction. The tube must be open at its lower end to allow the free entrance of water into the tube. This is facilitated by perforating the bottom section of the conduit tube sidewall. Precautions should also be taken to prevent the dipmeter probe from passing beyond the bottom end of the conduit tube and, as a result of entanglement, not able to be withdrawn.

(e) Other Materials

No pumping test should commence without field data sheets on which to record all data and information relevant to the test pumping activities in an acceptable format. These can either be provided by the contractor or the Hydrogeological Consultant. The examples provided in Part 2 indicate the format and level of detail which is required of these data sheets. The contractor must also provide backup measuring equipment and instrumentation which is immediately available to replace any similar item which may become damaged or broken during the course of the test such that measurements are no longer accurate or reliable.

4-4-4 Arrival-on-site Actions

The contractor must firstly establish whether the borehole is equipped or not. If so, the contractor will be required to: (1) remove the equipment taking care not to damage either it or the installation, (2) inspect the equipment for defects and (3) note down all particulars regarding the equipment and the installation. The latter includes but should not be limited to the manufacture and type of pump (and motor if motorised), the depth to which the pump was installed, the power rating of the motor and the diameter, length and quantity of pump column sections. The contractor must next establish whether there are any other boreholes in the vicinity of that to be tested. If so, then the following information must be gathered and recorded for each: (1) the straight-line distance (in metres) between each such borehole and that to be tested, (2) whether the borehole is equipped, open or sealed and, if equipped (3) whether the installation is operational or not. Depending on the degree of access allowed by such a borehole, the contractor must establish whether there is water in the borehole and if so, measure and record: (1) the depth to the groundwater rest level, (2) the height of the borehole collar above ground level and where possible also (3) the depth of the borehole.

The final activities to be carried out prior to the actual installation of the test pump into the borehole to be tested must involve measuring and recording: (1) the diameter of the borehole, (2) the depth of the borehole as determined by means of a weighted line or plumb bob and (3) the depth to the groundwater rest level in the borehole, again referenced to a date.

An example of a field data sheet for recording the above information is presented in Part 2. Payment for this work shall be incorporated into that for data recording (subsection 4-4-8).

4-4-5. Test Pump Installation

The conduit tube should be attached and secured to the first section of pump column behind the pump element and the test pump installed to the required depth, attaching and securing the conduit tube to the riser main every 2 to 3 m. If the pump installation depth has not been specified by the Hydrogeological Consultant beforehand, then this must be determined on the basis of the guidelines provided in Table 4-7.

The Testing Contractor will be remunerated for the installation of a test pump per linear metre of depth installed at the rate tendered as set out in the Schedule of Rates included as Section 4 of Document 3 in Part 3. The rate tendered for this activity shall also apply to the withdrawal of the test pump from the borehole on completion of all testing activities.

Table 4-7. Guidelines for test pump installation depth if not specified

DEPTH OF WATER IN BOREHOLE	TEST PUMP INSTALLATION DEPTH
Less than 5 m	Do not install the test pump.
Between 5 m and 30 m	±2 m above the bottom of the borehole.
Between 30 m and 60 m	±3 m above the bottom of the borehole.
Between 60 m and 90 m	±4 m above the bottom of the borehole.
More than 90 m	±5 m above the bottom of the borehole.

NOTES: 1. Depth of water in borehole is calculated as the difference between the total depth of the borehole and the depth to the groundwater rest level as measured.
2. ± denotes a variation of not more than 0.5 m either way.

4-4-6. Equipment Set-up and pre-Test Actions

Where possible, the discharge pipe must be laid out in a downhill direction from the borehole to be tested unless this will take it in the direction of or past another borehole located in the vicinity of that to be tested. If such instances, lay the discharge pipe out in a downhill direction which will take its furthest end as far as possible away from any other borehole in the vicinity.

In field situations where the terrain is extremely flat, the length of the discharge pipe must be extended from 50 m to at least 300 m if any possibility exists that the discharged water may infiltrate to the groundwater resource within the radius of influence of the test. A final decision in this regard must be made by the Hydrogeological Consultant and communicated to the contractor before the latter arrives on site. The dipmeter should be inserted into the installed conduit tube and run down this tube to the bottom to make sure that it passes freely along the full length of the tube. If the dipmeter used is not graduated to an accuracy of 0.01 m, mark the position on the dipmeter cable where it indicates the depth to the groundwater rest level and attach the end of the graduated tape at this position on the cable ensuring that the zero mark of the graduated tape corresponds exactly to this mark. Slowly lower the dipmeter and graduated tape down the conduit tube, in the process securing the tape to the dipmeter cable every 2 to 3 m. Ensure that there is no slack between each point where the tape is secured to the dipmeter cable. Also make sure that the dipmeter cable and graduated tape combination passes freely along the full length of the conduit tube.

The Testing Contractor shall be remunerated for this work per set-up at the rate tendered for one such activity as set out in the Schedule of Rates (Section 4 of Document 3, Part 3).

4-4-7. Final pre-Test Measurements

Make sure that all the basic information required on the field data sheet has been collected and recorded as completely as possible. The basic information data entry fields can be used as a checklist for information to be measured/collected and recorded. Do not guess at any information which has not been measured.

Payment for this work shall be incorporated into that for data recording (subsection 4-4-8).

4-4-8. Data Recording

(a) Discharge Measurements

The measurement of discharge (yield or pumping rate) must be consistently accurate and reliable. The method of measurement must be appropriate to meet this requirement (refer subsection 4-4-3.c for information in this regard). Where volumetric calculation methods are applied, time will be measured using a stopwatch and the container volume must be accurately known. The volumetrically measured yields recorded on the field data sheets must be based on the average obtained from a set of three sequential measurements. Guidelines for the number and periodicity of discharge rate measurements for each type of test are given in Table 4-8.

Table 4-8. Number and periodicity of discharge rate measurements		
TYPE OF TEST	DISCHARGE RATE MEASUREMENTS	
	NUMBER	PERIODICITY
Calibration test	2 per step	At ±5 and ±10 minutes into each step.
Stepped discharge test	5 per step	At ±5, ±15, ±30, ±60 and ±90 minutes into each step.
Constant discharge test	See periodicity column	At ±5, ±15, ±30, ±60, ±90 and ±120 minutes into test and every 60 minutes thereafter for the full duration of pumping.

(b) Water Level Measurements

Rigid guidelines for the periodicity of water level measurements for each type of test are given in Table 4-9. This information can be found duplicated on the field data sheets which must be filled in as a record of all data collection activities carried out for a pumping test. The type of water level measurement values required to be recorded on the field data sheet are the actual (or true) drawdown values. These represent measurements which reflect the depth of the water level below the groundwater rest level depth, ie. which already take into account the groundwater rest level depth below the reference measuring point. It should be noted that the more basic type of measurement which reports the depth of the dynamic water level as a distance below the reference measuring point, ie. which combines the depth of the water level below the groundwater rest level depth and the depth of the groundwater rest level below the reference measuring point, gives only an apparent (or false) drawdown value. All water level measurements must be measured to an accuracy of at least 0.01m (10mm). The water level data must be plotted on the semi-logarithmic graph paper provided with each set of field data sheets. The plotting of these data must take place as the test proceeds, ie. each water level measurement must be plotted on the graph as soon as possible after it was measured. The field data sheets and accompanying water level graphs must be shown to any authorised supervisory personnel on request and will be up-to-date at the time of such request.

(c) Other Information

The Testing Contractor must also record any extraordinary observations made during the test. These may include: (1) changes in the colour of the discharged water, (2) changes in the turbidity of the discharged water, (3) the presence of air in the discharged water and (4) rainfall events which occur during a test. Remuneration for all data collection and recording activities by the Testing Contractor in the course of a pumping test shall be incorporated into an hourly rate as set out in the Schedule of Rates (Scetion 5 of Document 3, Part 3).

Table 4-9. Periodicity (in minutes) of water level measurements during pumping tests			
CALIBRATION TEST	STEPPED DISCHARGE TEST	CONSTANT DISCHARGE TEST	RECOVERY TEST
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
7	7	7	7
9	9	9	9
12	12	12	12
15	15	15	15
The above periodicity (measured in minutes after the start of each increased pumping rate) must be followed for each step of the calibration test	20	20	20
	25	25	25
	30	30	30
	40	40	40
	50	50	50
	60	60	60
	70	70	70
	80	80	80
	90	90	90
	100	120	120
	The above periodicity (measured in minutes after the start of each increased pumping rate) must be followed for each step of the stepped discharge test	150	150
		180	180
		210	210
		240	240
		Every 60 minutes toend of pumping.	Every 60 minutesto end of recovery.

4-4-9. Groundwater Sampling

Sampling for Macro-element Analysis

The Institute for Water Quality Studies of the DWAF, in conjunction with the Department of Health, commenced in May 1996 with the compilation of guidelines addressing all aspects of water sample collection aimed at routinely establishing the quality thereof for drinking purposes. Until such time as these guidelines become available, the following recommendations in this regard should be followed.

A water sample should be collected from the end of the discharge pipeline no sooner than 15 minutes before the scheduled end of a pumping test whether this be of a calibration, stepped discharge or constant discharge nature. This will ensure that a water sample is collected in case testing does not proceed to include either one or both of the latter two types of test. The standard amount of sample normally collected is in a clean, sterilised plastic bottle of capacity 240 ml or greater and equipped with a watertight screw-on cap. This is the standard issue sample bottle provided by the DWAF. Depending on the analysing laboratory's requirements, however, a sample of up to two litres in volume may have to be collected. The Hydrogeological Consultant will advise on this matter in instances where the contractor is required to collect samples, in which case the consultant will provide ampoules containing preservative chemicals if required. All other materials such as sample bottles, tie-on labels and sample custody forms are to be provided by the contractor. The mandatory sample custody form DW45 (Form 8 in Section 2 of Part 2 of this document) must be completed for each sample collected. Note that the code MACR01 in Instruction 8 ("analyse for") of form DW45 defines the macro-element analysis. This code is also defined by the underlined "substances" in Table 4-12 (section 4-5-4, p. 4-52).

(a) Sampling Procedure

Wash hands thoroughly and rinse the sample bottle three times with the water to be sampled, ie. that being pumped from the borehole. Fill the bottle so that a space of five to ten millimetres is left at the top. Add the preservative as instructed in (b).

(b) Sample Preservation

Gently tap the bottom of an ampoule of preservative on a firm surface so that all the chemical flows to below the constriction. Hold the ampoule firmly upright with thumbs placed either side of the constriction, flex off the neck, turn the ampoule upside down and place it in the bottle together with the broken-off neckpiece. Firmly screw on the cap of the sample bottle after rinsing it well with water from the borehole. Shake the capped sampled bottle well. Caution should be exercised when handling the preservative since this chemical is poisonous.

(c) Sample Custody

Fill in the information requested on the tie-on label and attach this securely to the neck of the sample bottle. Place the sample bottle in a cooler or ice box and keep it stored under chilled conditions. Complete the sample custody form (DWAF Form DW45, Part 2) as per the example provided in Part 2. The water sample and its custody form will be collected by the Hydrogeological Consultant. It is the responsibility of the Hydrogeological Consultant to ensure that the above procedures are adhered to and complied with.

Sampling for Environmental Isotope Analysis

Use a new, clean, one litre polyethylene bottle with watertight screw-on cap for routine stable (hydrogen and/or oxygen) isotope and tritium analysis. Take the same basic precautions as for macro-element analysis. Ensure that the water is as clean as possible, but do not filter or add anything. Turbidity does not matter. Rinse the bottle three times with the water to be sampled, fill till overflowing and tighten cap well. Turn bottle upside down and squeeze to test for tightness. Clearly label the bottle by waterproof marking pen on the bottle shoulder or tie-on label.

In special cases of confined to semi-confined (older) water, where tritium values <0.5 TU are observed (refer Section 5, subsection 5-5), or where it is specifically requested, samples for radiocarbon analysis may be required. Since this involves special procedures of field extraction of larger quantities of water, the Hydrogeological Consultant should contact experts in this field for the procedures and materials required.

The standards of isotopic measurement for hydrological applications are defined as follows:

(a) Minimum Detectable Values

Tritium:	0.3 TU (tritium units)
Radiocarbon:	2 pMC (percent modern carbon)

(b) Maximum Analytical Error

Tritium:	±0.3 TU (0 - 3 TU); otherwise ±10%
Radiocarbon:	±2 pMC (>40 pMC); ±1 pMC (<40 pMC)
Oxygen-18:	$d^{18}O$; ±0.15‰
Deuterium:	$d^{2}H$; ±1.5‰

4-4-10. Aborted Tests and Breakdowns

The Hydrogeological Consultant may at any stage during the execution of a pumping test request the Testing Contractor to abort a test if, in the opinion of the consultant, continuation of the test is not in the interests of the project. Factors which might contribute to a such decision by the Hydrogeological Consultant are: (1) sufficient data having been collected for an adequate scientific evaluation thereof, (2) the execution of the test not meeting project criteria and requirements (such as for constancy of yield, accuracy of yield measurements or accuracy of water level measaurents, sufficiency of discharge line length, etc.) or (3) a mechanical breakdown occurring during pumping which causes a test to be interrupted or aborted.

(a) <u>Tests aborted due to sufficiency of data</u>

The Hydrogeological Consultant will be required to fully motivate its decision to abort the test in a written statement to the Implementing Authority. In such instances, the Testing Contractor will be remunerated for the actual duration of testing (including recovery testing) at the hourly rates set out in the Schedule of Rates (Section 4 of Document 3, Part 3).

(b) <u>Tests aborted due to incorrect execution</u>

The Testing Contractor will be required to remedy the cause(s) for an abort decision by the Hydrogeological Consultant. The test shall be restarted, as if it were the first attempt, after the water level has recovered to within five percent of the pre-test rest water level or the contractor is instructed thereto by the Hydrogeological Consultant. The consultant will be required to fully motivate its decision to abort the test in a written statement to the Implementing Authority. The Testing Contractor shall not be entitled to remuneration for any test which is aborted under these circumstances irrespective of the time elapsed up to receipt of the instruction to abort.

(c) <u>Tests aborted due to breakdowns</u>

The following procedures are recommended when a mechanical breakdown occurs during pumping which causes a test to be interrupted or aborted.

Calibration test: Start immediately with the measurement and recording of the water level recovery rate according to the periodicity given in Table 4-9. Irrespective of how long after the start of pumping the breakdown occurs or how rapidly the breakdown can be fixed, continue with water level recovery measurements until the water level is within five percent of the pre-test rest water level or, at the discretion of the Hydrogeological Consultant, may be discontinued. Restart the calibration test as if it is the first attempt. The Testing Contractor shall not be entitled to remuneration for a calibration test which is aborted under such circumstances.

Stepped discharge test: Record the time of the breakdown and start immediately with the measurement and recording of the water level recovery according to the periodicity given in Table 4-9. If the breakdown occurs during the first or second steps of the test, continue with water level recovery measurements until the water level is within five percent of the start rest water level and then restart the stepped discharge test as if it is the first attempt. If the breakdown occurs during the third step of the test, can be fixed and the pump restarted to produce the same yield (as before the breakdown) within five minutes of the breakdown occurring, continue with the test at this yield after measuring and recording the water level immediately before restarting the pump. Only one such breakdown event is allowed.

If a second breakdown occurs, proceed as described for a first step breakdown. If the breakdown occurs during the fourth or later step of the test, can be fixed and the pump restarted to produce the same yield (as before the breakdown) within five minutes of the breakdown occurring, continue with the test and complete it at this yield after measuring and recording the water level immediately before restarting the pump. If a breakdown at this stage can not be fixed within five minutes, continue with water level recovery measurements as if the test has been fully completed. The Testing Contractor shall not be entitled to remuneration for a stepped discharge test which is aborted: (1) within the first or second step or (2) within the third step and can not be restarted within the time allowed for repair.

Constant discharge test: Note the time of the breakdown and start immediately with the measurement and recording of the water level recovery according to the periodicity given in Table 4-9. If the breakdown occurs within the first two hours after the start of pumping, continue with water level recovery measurements until the water level is within five percent of the pre-test (start) rest water level and then restart the test. If the breakdown occurs later than two hours into the test, can be fixed and the pump restarted to produce the same yield as before the breakdown within the time periods (after the breakdown occurring) given in Table 4-10, continue with the test at this yield after measuring and recording the water level immediately before restarting the pump.

If the breakdown can not be fixed and the pump started within one hour of the breakdown occurring, continue with water level recovery measurements until the water level is within five percent of the pre-test rest water level and then restart the constant discharge test as if it is the first attempt unless the following condition has been met. If the breakdown occurs after approximately 80 percent of the planned duration of the constant discharge test has been successfully completed, continue with water level recovery measurements as if the test has been fully completed. The allowable elapsed time (in hours) in regard to selected constant discharge test total durations in order for this specification to be acceptable is given in Table 4-11.

Table 4-10. Period allowed for breakdown repair and continuation of testing	
TIME OF BREAKDOWN AFTER START OF TEST	PERIOD ALLOWED FOR REPAIR
2 hrs to 4 hrs	6 minutes
4 hrs to 6 hrs	12 minutes
6 hrs to 8 hrs	18 minutes
8 hrs to 10 hrs	24 minutes
10 hrs to 12 hrs	30 minutes
12 hrs to 14 hrs	36 minutes
14 hrs to 16 hrs	42 minutes
16 hrs to 18 hrs	48 minutes
18 hrs to 20 hrs	54 minutes
Longer than 20 hrs	60 minutes

Table 4-11. Period after which a constant discharge test may be considered completed in the event of a breakdown	
CONSTANT DISCHARGE TEST DURATION	ALLOWABLE TIME ELAPSED TO BREAKDOWN
24 hours	20 hours (equivalent to 80% of total time)
36 hours	30 hours (equivalent to 83% of total time)
48 hours	38 hours (equivalent to 79% of total time)
72 hours	60 hours (equivalent to 77% of total time)

The Testing Contractor shall not be entitled to remuneration for a constant discharge test which is aborted under circumstances which preclude its restart within the time allowable for repair and continuation. The contractor will, however, be entitled to remuneration for a constant discharge test which is aborted after approximately 80 percent of the planned duration of the constant discharge test (refer Table 4-11) has been successfully completed, payment being made for the actual duration of the test (including the recovery test) at the hourly rates set out in the Schedule of Rates (Section 4 of Document 3, Part 3).

4-5. BOREHOLE UTILISATION RECOMMENDATIONS

4-5-1. Use Application

Within the framework of this document this will invariably be for community water supply purposes for which the criteria is a minimum of 25 litres per capita day. In order for the borehole to deliver any water, however, it must first be furnished with pumping equipment.

The most basic level of technical sophistication in this regard is generally associated with hand operated borehole pump installations delivering water at source. A greater level of technical sophistication becomes feasible as the yield which a borehole is capable of supporting increases. This implies: (1) the use of motorised (diesel engine driven or electrically powered) pumps with greater delivery capacities, size and energy requirements and (2) the installation of reticulation networks incorporating water storage tanks or reservoirs, pipelines and standpipes. Community water supply from groundwater need therefore not only be associated with hand pump installations. This may, however, represent a short term and temporary measure in instances where motorised borehole installations are not immediately feasible.

It is also possible that circumstances may exist where a borehole earmarked for the provision of drinking water is not suitable for this purpose because of an unacceptable groundwater quality due to excessive nitrate, fluoride or other hydrochemical parameter. In such instance(s) the groundwater may still be suitable for stock watering or irrigation purposes, which possibility should be identified by the Hydrogeological Consultant. Instances where possible limitations which may be restrictive on the particular use of a borehole exist must be identified and clearly and unambiguously defined. In instances where such limitations pose a serious health hazard, provision must be made that the source can not be accessed and used for drinking water purposes.

4-5-2. Equipment Installation Details

The Hydrogeological Consultant must furnish recommendations in respect of: (1) the type of pumping equipment suitable for exploitation of a successful borehole and (2) the depth to which pumping equipment must be installed. The type of pumping equipment will be dictated by the borehole yield as determined from test pumping data or other reliable yield information. The two basic types of equipment are: (1) hand operated pumps and (2) motorised pumps. A general guideline is to regard only an assessed production yield of more than 0.5 l/s as suitable for a motorised pump installation. It is not in the interests of the project for the Hydrogeological Consultant to be overly conservative when making assessments and recommendations in regard to the utilisation of a borehole.

Finally, it is required that every community water supply borehole be fitted with a conduit tube to facilitate the future measurement of groundwater rest levels following the installation of the production pump.

4-5-3. Borehole Operation Details

The primary consideration in this regard must be the requirement to provide as many members of the community as possible with a minimum of 25 litres of water each per day. A general rule-of-thumb based on this consideration indicates that a borehole yielding 0.5 l/s is sufficient to provide every 72 individuals with 25 litres of water each for every hour of operation. Since it is difficult to establish a regimen for the operation of boreholes fitted with hand pumps, an assessment in this regard applies particularly in instances where motorised installations are recommended. In such cases the borehole operation details provided by the Hydrogeological Consultant must include information on: (1) the recommended pumping capacity for some duty cycle less than 24 hours per day, (2) the recommended pumping capacity for continuous operation, viz. 24 hours per day, (3) the theoretical long term pumping (dynamic) water level and (4) the maximum (safe) allowable drawdown in the borehole whilst pumping. Other considerations which need to be referred to in this regard are presented in subsection 5-1 (Source Management).

4-5-4. Groundwater Quality

This must be established on the basis of the proposed guidelines for the health related assessment of water quality for domestic use recently published jointly by the Departments of Water Affairs and Forestry and of Health (Kempster *et. al.*, 1996). These guidelines recognise four classes of water quality identified as Classes 0, I, II and III. In qualitative terms, Class 0 represents an ideal quality of water, Class I a good quality of water, Class II water which is safe for short term use only and Class III an unacceptable quality of water. These classes apply to untreated water which represents the quality of water obtained directly from a borehole.

For the purposes of this document, information on the use of water for drinking by humans has been drawn from the referenced publication. This by no means ignores the other possible domestic uses of water such as for bathing and personal hygiene, laundry and watering of edible crops. Information in regard to the suitability criteria for these uses must be sought in the referenced publication. The water quality substances which are recognised as being of concern to domestic users are identified in Table 4-12 together with the concentration limits of each per water class defined above. It is therefore required that samples of groundwater which are collected for quality assessment purposes must be analysed for these substances.

Table 4-12. Water quality substances and criteria of concern for drinking purposes.

SUBSTANCE	UNIT OF MEASURE	UNIT OF MEASURE RANGE PER CLASS OF WATER			
		CLASS 0	CLASS I	CLASS II	CLASS III
Faecal coliforms	counts/100 ml	0	0 to 1	1 to 10	> 10
Total dissolved solids	mg/l	0 to 450	450 to 1000	1000 to 2450	> 2450
Electrical conductivity	mS/m	0 to 70	70 to 150	150 to 370	> 370
pH	pH units	6.0 to 9.0	5.0 to 6.0 9.0 to 9.5	4.0 to 5.0 9.5 to 10.0	< 4.0 > 10.0
Turbidity	NTU	0 to 1	1 to 5	5 to 10	> 10
Arsenic	mg/l As	0 to 0.010	0.010 to 0.05	0.05 to 0.2	> 0.2
Cadmium	mg/l Cd	0 to 0.005	0.005 to 0.010	0.010 to 0.020	> 0.020
Calcium	mg/l $CaCO_3$	0 to 32	32	32 to 80	> 80
Chloride	mg/l Cl	0 to 100	100 to 200	200 to 600	> 600
Fluoride	mg/l F	0 to 1.0	1.0 to 1,5	1.5 to 3.5	> 3.5
Iron	mg/l Fe	0 to 0.1	0.1 to 0.2	0.2 to 2.0	> 2.0
Magnesium	mg/l Mg	0 to 30	30 to 70	70 to 100	> 100
Manganese	mg/l Mn	0 to 0.05	0.05 to 0.1	0.1 to 1.0	> 1.0
Nitrate	mg/l N	0 to 6	6 to 10	10 to 20	> 20
Potassium	mg/l K	0 to 50	50 to 100	100 to 400	> 400
Sodium	mg/l Na	0 to 100	100 to 200	200 to 400	> 400
Sulphate	mg/l SO_4	0 to 200	200 to 400	400 to 600	> 600
Total Alkalinity	mg/l $CaCO_3$	not reported	not reported	not reported	not reported
Zinc	mg/l Zn	0 to 3	3 to 5	5 to 10	>10

NOTES: Underlined "substances" denote macro-element determinands.
Class 0 denotes water of an ideal quality, Class I a good quality water, Class II a water which is safe for short term use only and Class III an unacceptable quality of water.

The Hydrogeological Consultant will collect water samples for microbiological or bacteriological analysis in instances where this aspect of groundwater quality is considered to represent a real concern. The collection and custody of water samples obtained for microbiological or bacteriological analysis is subject to specific protocols which, if not adhered to, can compromise the validity of analytical results. The protocols must be followed with due diligence. These will at least include: (1) the proper disinfection of sampling equipment and containers, (2) storing the water sample under cooled conditions at 5° Celsius and (3) delivering the water sample to the analysing laboratory within eight hours of being taken.

4-6. REPORTING

This component of a groundwater development project encompasses the compilation and submission by the Hydrogeological Consultant of: (1) routine progress reports on a weekly basis and (2) a final technical report following completion of the project.

4-6-1. Progress Reporting

It is required of the Hydrogeological Consultant to provide the Implementing Authority with a weekly progress report. This report should be faxed through on the Monday following the week for which progress is being reported on. It should address the following aspects of the work: (1) activities (referenced to localities) completed in the reporting week, (2) the dates on which the completed actions were undertaken, (3) a summary of estimated expenditure associated with each of the completed actions, (4) activities (referenced to localities) to be undertaken in the forthcoming week and (5) a summary of estimated expenditure associated with each of the forthcoming actions to be undertaken.

The format of a weekly progress report must subscribe to the accuracy, brevity and clarity of data and information reporting.

4-6-2. Technical Report

This report must bring together in a single coherent document all relevant project activities and results due to the efforts of the Hydrogeological Consultant. The technical report must contain **all** the information on which the Hydrogeological Consultant's interpretation(s) and final decision(s), conclusion(s) and recommendation(s) are based. This document will serve as the primary source of project information for purposes of future reference. It should be completed and three copies thereof submitted to the Implementing Authority within 45 days of completion of the project. The format of the technical report must again subscribe to the key issues of accuracy, brevity and clarity.

A conceptual structure and content for such reports is provided hereunder.

(a) An **Introduction** containing a brief discussion of: (1) the locality of the study area, (2) the terms of reference and (3) the scope of work performed.

(b) A section on **Desk Study** activities mentioning: (1) sources of information and (2) the volume, type and nature of information sourced and material consulted.

(c) A section on **Borehole Siting** activities providing a brief description of: (1) the methods employed, (2) the efficacy of the individual methods in relation to drilling results (success or failure rate achieved) as well as (3) a summary of the scope of this work, as relevant, in terms of the total number and length (line-kilometres) of traverses, the range of station interval between measurements and the total number of resistivity soundings undertaken.

(d) A section on **Borehole Drilling** activities providing a tabulated summary of salient data and information.

(e) A section on **Test Pumping** activities providing a tabulated summary of salient data and information.

(f) A section on the **Geology** and **Hydrogeology** of the study area in which previously known and available information is collated with "new" project data.

(g) A section on **Groundwater Quality** providing a tabulated summary of hydrochemical data and addressing any specific concerns in this regard.

(h) A section on **Borehole Utilisation** providing a tabulated summary of recommendations in this regard.

(i) An **Appendix** comprising, for each borehole, a set of: (1) graphed geophysical data presented as profiles, (2) a borehole construction and hydrogeological log, (3) a set of test pumping data sheets, (4) a set of test pumping graphs and (5) a borehole utilisation recommendation report.

In addition to the above, the technical report must contain one or more locality maps showing the positions of all boreholes drilled during the project. The scale of these maps must not be smaller than 1:50 000 (refer also to subsection 4-2-4, Part 1).

SECTION 5

Additional Information

5-1. SOURCE MANAGEMENT

The Hydrogeological Consultant responsible for the siting and evaluation of the water source should assess the sustainable yield of the groundwater resource which has been developed for the community. This assessment should incorporate consideration of the variability of recharge from rainfall in determining the annual volume of groundwater available to the community in the long term.

Further, it is considered that subjecting a production borehole to continuous pumping (24 hours per day) provides the most effective manner in which to exploit a groundwater resource. This is more readily achieved in instances where the borehole can be fitted with an electrically powered motorised installation rather than a diesel-engine driven installation. Nevertheless, combining this consideration with the annual volume of groundwater available in the long term indicates the daily production rate, expressed as m^3/day, at which the borehole can safely be operated. Conversion of this unit to the standard borehole yield unit of litres per second (l/s) facilitates the selection of pumping equipment. The principal advantages of continuous borehole operation are: (1) a smaller pump design and energy input requirements leading to capital savings, (2) the elimination of fluctuating groundwater levels, thereby minimising the potentially detrimental effect on borehole yield due to incrustation from iron or manganese hydroxides as a result of the growth of iron bacteria enhanced through excessive aeration of the aquifer and (3) curbing the urge to increase the production yield and/or extend the pumping schedule to which a borehole is subjected.

It is therefore required of the Hydrogeological Consultant responsible for groundwater development to provide a 24-hour abstraction rate for each production borehole capable of supporting a motorised installation. Such instances will necessarily require the establishment of additional storage capacity from which to meet peak demands not able to be met by a lower yield.

5-2. DATA AND INFORMATION MANAGEMENT

The Department of Water Affairs and Forestry operates and maintains, through its Directorate Geohydrology, a National Groundwater Data Base (NGDB). Further, the DWAF has commenced standardising on a Geographical Information System (GIS) geohydrological data base content and output requirements with specific reference to the Community Water Supply and Sanitation Programme. The purpose of the latter exercise is to establish a common GIS which will be decentralised to the DWAF's regional offices with the primary objective of providing a tool for integrated planning and having as secondary objective the provision of a customer-oriented service.

In light of the above, it is required that all hydrogeological and geological information collected in the course of Community Water Supply and Sanitation projects eventually be taken up in these data bases. In order to ensure that this is accomplished in a uniform and structured manner, relevant project data and information must be returned to the DWAF. This can be done by: (1) the completion of the prescribed data capture and recording forms provided in Part 2 and/or (2) the entry of the data into an electronically compatible data base.

5-2-1. Data Requirements

The minimum requirements for the registration of a groundwater point source in the NGDB include: (1) the identifying number assigned to each source, (2) the name of the topocadastral farm and its administrative district and farm number on which the groundwater point source(s) is/are located, (3) the latitude and longitude coordinates of each groundwater point source, (4) the 1:50,000 scale topocadastral map reference number, (5) the surface elevation of each groundwater source, (6) the depth and the date drilled if the groundwater source is a borehole, (7) the yield of the source and (8) the depth and measurement date of the groundwater rest level.

Each registered groundwater point source must further carry the following minimum geological and hydrogeological information: (1) the groundwater strike depth(s), (2) the yield associated with each groundwater strike, (3) the type of aquifer in which groundwater was encountered, (4) the lithology of the rock formations penetrated with depth, (5) borehole yield testing information and (6) groundwater quality data as obtained from chemical analyses. The Hydrogeological Consultant is, however, generally capable of providing more than this basic information and should therefore not limit its contribution to these items only. Additional information which may be provided, if available, are: (1) the type of equipment with which a groundwater source is equipped and (2) the name of the community (or communities) served by the source.

5-2-2. Data Capture and Recording Forms

These comprise the suite of forms presented in Part 2 of this document. The proper completion of these forms will ensure that the minimum requirements for the registration of a groundwater point source as set out in subsection 5-2-1 are met. The completed data recording forms must be posted to the DWAF at the following address:

Directorate Geohydrology
Private Bag X313
PRETORIA
0001

The DWAF is aware of the criticism which has been expressed toward these forms in general.

Since no alternative official forms for this purpose currently exist, however, their use and application must unfortunately be made mandatory for projects carried out for and on behalf of the DWAF.

5-2-3. Electronic Data Capture

The Hydrogeological Consultant has the option to return project hydrogeological and hydrochemical data to the DWAF in electronic format provided that this format is fully compatible with that of the NGDB. The NGDB has historically been most directly supported by the HydroCom software developed by the Institute for Groundwater Studies (IGS) at the University of the Free State. Electronic data capture using the HydroCom software is therefore preferred. This software can be bought from the IGS at the following address:

Institute for Ground-Water Studies
University of the Free State
P O Box 339
BLOEMFONTEIN
9300

5-3. CAPACITY BUILDING, EDUCATION AND TRAINING

In regard to borehole-based community water supply projects, this activity addresses such wide-ranging issues as: (1) establishing an awareness within the community for the importance of water supply and sanitation, (2) providing a core of community support personnel with basic appropriate administrative and technical skills through training and (3) ensuring that Local Authorities (eg. District Councils) and Local Water Committees are equipped to responsibly administer and perform their function as implementing, operation and maintenance agents.

In May 1996 a Unit tasked with developing a Groundwater Training / Awareness Building / Extension Programme was established within the Directorate Geohydrology of the DWAF to address these issues. According to the White Paper (1994), this task will eventually be fulfilled by the National Community Water and Sanitation Training Institute. In the interim, however, this task will fall to the integrated efforts of the aforementioned Unit and the Social Development Consultant(s) appointed to each groundwater development project. In essence, this aspect must seek to secure the full involvement and participation of the community in a groundwater resource development project through the establishment of a capacity within the community to: (1) understand, (2) operate, (3) maintain, (4) monitor and (5) manage the source(s) of its water supply.

In instances where the water supply is based on the utilisation of groundwater resources, the operation and maintenance capacities will apply to the equipment fitted to the borehole and the reticulation system whereby the water is distributed. The monitoring and management capacities will apply to the groundwater resource itself. Before these issues can be addressed, however, it will be necessary to consider the level of technical sophistication of the water supply system.

5-3-1. Capacity Building

The target groups in this regard are provisionally identified as: (1) Water Boards, Local Water Committees or Local Authorities and (2) relevant non-scientific personnel responsible for the operation, maintenance and management of groundwater supply schemes.

5-3-2. Education

This encompasses: (1) community education as part of any water supply project implementation, (2) sectoral education such as of farmers and Local Authorities and (3) awareness building amongst the general public, schoolchildren and specific sectors of the socio-economic community. The vast scope of this activity renders a discussion thereof beyond the extent of this document.

5-3-3. Training

The principal components of this activity in regard to groundwater supply schemes are identified as: (1) the operation of pumping equipment, (2) the maintenance of pumping equipment, (3) the monitoring of the source and (4) the management of the natural resource. It is accepted that each of these components incorporates a level of technical sophistication which ranges from very advanced to basic. It is the latter level of sophistication which is considered relevant in the context of this document since higher levels of technical sophistication will generally be provided by specialist service providers. The Executive Agency responsible for the development of groundwater resources for community water supply purposes can be requested to undertake a one-year custodianship period of operation and maintenance (including a training component) of all successful borehole installations. If so, this should be indicated in the enquiry document and budgeted for in the financial proposal submitted by respondents.

(a) <u>Operation</u>

The objective hereof must be to ensure that borehole-based water supply installations are operated within the yield, duty schedule and other parameters recommended by the Hydrogeological Consultant.

(b) <u>Maintenance</u>

The community member(s) assigned to this activity should be familiarised with basic borehole pump maintenance procedures. These might include: (1) the removal of pumping equipment from a borehole, (2) the inspection of this equipment for visible signs of damage, (3) the re-installation of the equipment and (4) the inspection of water supply pipelines and storage tanks for leaks and the repair of such.

(c) Monitoring

The tasks associated with this activity should comprise the routine measurement, collection and/or recording of: (1) groundwater rest levels, (2) borehole pump operating schedules, (3) groundwater abstraction quantities and (4) groundwater samples. The community member(s) assigned to this activity should be familiarised with the execution of these tasks which would be facilitated by the provision of uncomplicated and as yet unavailable data capture/recording forms.

(d) Management

The management of groundwater resources should aim to secure the long term, sustainable utilisation of boreholes for community water supply purposes taking into consideration the factors discussed in subsections 5-1 and 5-2.

5-4. GROUNDWATER PROTECTION

This subject is addressed in detail in the publication by Xu and Braune (1995a). It is therefore not considered warranted to discuss this aspect at great length in this document but only to present the basic framework and more relevant and practical applications.

5-4-1. Strategy

Xu and Braune (1995a) recognise a strategy comprising three tiers of implementation.

(a) First Tier

This comprises the implementation of measures aimed at immediately securing a basic and minimum degree of protection of groundwater resources from point sources of contamination. These include: (1) the protection of springs, (2) the placement of water supply boreholes with due regard to existing sanitation facilities, (3) the placement and construction of sanitation and waste disposal facilities with due regard to the nature and occurrence of groundwater resources, (4) the proper construction of water supply boreholes and (5) cultivating the community awareness in the importance of sanitation. The implementation of this level of protection devolves to all parties associated with the development of groundwater resources for community water supply purposes. As such, it is the level of implementation which has the greatest relevance to this document.

(b) Second Tier

The strategy associated with this tier of implementation: (1) addresses appropriate measures aimed at the wider protection of groundwater resources in the medium term and (2) requires the involvement of and contribution from other parties toward pro-active differentiated protection on a regional scale.

Responsibility for its implementation therefore must include first and second tier agencies/institutions representing Central and Provincial Government.

(c) Third Tier

This entails the implementation of advanced measures aimed at securing groundwater protection in the long term. The method by which this is achieved involves the establishment of groundwater protection zones within which controls and restrictions can be imposed on any activity identified as posing a threat to groundwater resources. Its level of implementation will therefore include Local Government as a third tier institution.

5-4-2. Implementation

The implementation of first tier groundwater protection measures recognises a set of Best Management Practices (Xu and Braune, 1995a) "*......to be implemented through the communities within a health and environment protection education and awareness framework.*" These must include: (1) adherence to point supply construction standards, (2) implementing minimum distances between point supply sources and existing or potential sources of contamination, (3) establishing monitoring and management protocols and (4) meeting minimum sanitation and waste disposal requirements.

(a) Construction Standards

These are addressed in detail in subsection 4-3-6 (Borehole Construction) of this document. Of particular relevance in this regard are the aspects of backfilling, sanitary seals, disinfection and protection. Adherence to the directives in regard to these aspects of borehole construction are obligatory.

(b) Minimum Distances

Xu and Braune (1995a) put forward proposed minimum distances between point sources of groundwater supply and pit latrines. Although in essence the minimum distance ranges from 25 to 50 m depending on the geological regime, the depth to the water table and the nature of surface material, these authors have admitted that the guideline distances put forward in their publication (1995a) are conservative and should, therefore, be applied with the greatest of circumspection.

(c) Monitoring and Management

Protocols in this regard are addressed only in very broad terms in subsections 5-3-3.c (Monitoring) and 5-3-3.d (Management). Adherence to these rudimentary directives will assist in countering the general historical disregard for these aspects and pay dividends in the medium to long term.

(d) Minimum Sanitation Requirements

A discussion of this topic can again be found in Xu and Braune (1995a), where latrines (wet and dry), waste disposal sites, cattle kraals, drinking troughs and cemeteries are identified as facilities which need to be considered in this regard. These authors put forward basic criteria for the location of such facilities in terms of groundwater vulnerability and protection considerations. The information provided in Table 5-1 summarises these criteria and requirements.

Table 5-1. Simplified requirements for sanitation facilities (Xu and Braune, 1995a)

FACILITY	POLLUTANT FLOWPATH	REQUIREMENT CONSIDERATIONS	HIGH-RISK SITUATIONS
Cattle kraals, drinking troughs, cemeteries	* Downward leaching	* Meet minimum distance	* Point sources of water supply located downgradient
Dry latrines	* Daylighting due to stormwater flooding * Downward leaching with rain water	* Meet minimum distance * Locate downgradient from point source of water supply	* Located in a depression * Serves concentrated sources (schools, clinics)
Wet latrines	* Downward leaching as soakaway * Daylighting due to stormwater flooding	* Meet minimum distance * Locate downgradient from point source of water supply * Ensure suitable soil permeability	* Located on dolomite outcrop * Presence of fault, fracture or fissure zone in soakaway area
Off-site sewerage	* Daylighting due to maintenance breakdown * Downward leaching due to leaks	* Carry out an environmental impact assessment * Ensure proper operation and maintenance	* Technical support not readily available

5-5. ENVIRONMENTAL ISOTOPES

Environmental isotopes, along with hydrochemistry and in addition to the use of the latter in terms of potability considerations, are indispensible tools in the scientific evaluation of a groundwater resource. Apart from general information obtained during initial development stages, factors such as the determination of recharge, resource evaluation and assessment of groundwater vulnerability to pollution can often be determined by standard geohydrological methodology only after long periods of observation. This could be inadequate where decisions on further steps in resource development have to be taken within weeks or months rather than years.

Along with the scientific methods of geohydrology and geophysics, environmental isotope techniques coupled to hydrochemistry are now state-of-the-art. They can rapidly (an isotope "snapshot") and economically allow for the estimation of recharge, delineation and characterization of groundwater bodies and assessment of groundwater vulnerability.

Isotopic data should be available as part of the basic information obtained in any groundwater development and resource assessment, and should be an integral part of a comprehensive South African groundwater data base. The isotopic component of an investigation is efficient in the information it provides as compared with the cost, and usually constitutes a small fraction of the overall development expenditure. South Africa has internationally recognized expertise and facilities in the field of isotope hydrology with considerable experience of local conditions.

The application of environmental isotope measurements in a groundwater development project should conform to the following steps:

(a) At the outset of a groundwater develompent project, any existing boreholes and wells in the area should be sampled (refer Section 4, subsection 4-4-9) for the basic measurements of tritium and at least one of the stable isotopes of hydrogen and oxygen along with macro-element (major ion) chemistry. The results should be scrutinised in terms of an initial assessment of groundwater mobility, system coherence and vulnerability, and is needed as feedback information before further borehole development is to be undertaken. Where tritium values are low (<0.5 TU), radiocarbon measurements may be required.

(b) A routine isotope sample (refer subsection4-4-9) should be taken along with the hydrochemistry sample during test pumping. If initial indications (see (a) above) are of water with longer residence time, a sample for radiocarbon may be required. The isotope and hydrochemical data obtained from the pumping tests, along with the test pumping data, should be scrutinized by competent Consultants before decisions on the further development and equipping of the borehole are made. Such scrutiny will revolve around assessment of groundwater vulnerability, recharge and the projected sustainability of the supply in the light of the inferred system parameters and projected demand.

(c) Follow-up monitoring of groundwater supply installations is essential in order to ensure sustained quality and yield. Quality assessment (hydrochemistry) has to be conducted relatively frequently. An isotopic re-assessment of the supply should be conducted after 2 to 3 years of operation.

Significant changes in isotopic and hydrochemical parameters would act as an early warming of, for example, the imminent onset of quality problems or significant changes in yield. Isotopic re-sampling should be undertaken whenever significant changes in quality and/or yield are observed during production.

(d) The principle should be that routine samples for isotopic analysis be taken at every appropriate opportunity. It should be kept in mind that such opportunities arise during active field investigations, drilling operations, pumping tests, etc. The need to sample at other times could involve considerable costs. Situations can arise where the budget is inadequate to cover the cost of analysing all of the available samples or the volume of samples can not be handled by the analytical facility at a given time. Only a selection of such samples may then be measured immediately. Provided that samples are taken according to the guidelines set out in subsection 4-4-9, they can safely be stored for several years before analysis. Such a sample "library" may prove to be an important asset in terms of further studies or enhancement of the National Groundwater Data Base or Information System.

References and Bibliography

Anon., 1981. Ground Water Manual; a guide for the investigation, development, and management of ground-water resources. U.S. Dept. of the Interior. Rev. reprint.

BWA et. al., (undated). Groundwater : Guidelines for Boreholes. (Available from either the Directorate Geohydrology of the Dept. of Water Affairs & Forestry or the Borehole Water Assoc. of Southern Africa).

Driscoll, F.G. (ed.), 1986. Groundwater and Wells. Johnson Division. St. Paul. Minnesota. 2nd ed. ISBN 0-9616456-0-1.

DWAF, 1994. Water Supply and Sanitation Policy White Paper. Cape Town. R.S.A.

Vegter, J.R., 1995. An Explanation of a Set of National Groundwater Maps. Publ. TT74/95. Water Res. Comm.

Vivier, J.J.P., Van Tonder, G.J. and Botha, J.F., 1995. The use of slug tests to predict borehole yields: correlation between the recession time of slug tests and borehole yields. In Conf. Papers. "Ground Water Recharge and Rural Water Supply", Groundwater '95 Conference. Sept. '95. Midrand. S. Afr.

Weaver, J.M.C., 1992. Groundwater Sampling: An abbreviated field guide for sampling methods. Publ. TT56/92. Water Res. Comm.

Xu, Y. and Braune, E., 1995a. A Guideline for Groundwater Protection for the Community Water Supply and Sanitation Programme. Dept. Wat. Aff. & For. 1st ed. ISBN 0-621-16787-8.

Xu, Y. and Braune, E., 1995b. Minimum distance as an important concept for borehole source protection in South Africa. In Conf. Papers. "Ground Water Recharge and Rural Water Supply", Groundwater '95 Conference. Sept. '95. Midrand. S. Afr.

Glossary of Terms

Annulus. The space between the casing outer sidewall and the wall of the borehole.

Aquifer. A formation, group of formations or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to boreholes or springs.

Aquifer testing. The process whereby an aquifer is subjected to pumping from a borehole under controlled test conditions in order to determine the hydraulic parameters of the groundwater system through its response to the stress of abstraction.

Available drawdown. The height of water above the depth at which a pump is set in a borehole at the time of water level measurement. The unit of measure is metres (m).

Blow yield. The volume of water per unit of time blown from a borehole during drilling. The unit of measure is litres per second (l/s).

Borehead. The surface infrastructure erected on a borehole and which supports the pumping installation.

Borehole testing. The process whereby a borehole is subjected to pumping under controlled test conditions in order to determine the performance characteristics of a borehole.

Casing. The pipe, either of steel or PVC, which is inserted into a borehole primarily to secure the borehole against collapse.

Casing shoe. A circular, short length of high-tensile hardened steel fitting flush with and welded to the bottom end of steel casing for protection against damage.

Casing string. The length of casing formed by joining individual sections of casing together as these are introduced into the borehole.

Conduit tube. A tube, usually made of PVC and having a diameter of 15 to 25 mm, which is inserted into a borehole together with the pump, is strapped to the rising main and protrudes from the borehead so that easy access to the borehole can be gained for water level measurements.

Dipmeter. The instrument which is used to measure the depth to the water level in a borehole.

Discharge rate. The volume of water per unit of time abstracted from a borehole. The unit of measure is litres per second (l/s).

Drawdown. The distance between the groundwater rest level and the depressed water level in a borehole located within the radius of influence of a borehole being subjected to pumping, including that in the pumped borehole itself. The unit of measure is metres (m).

Drill bit. The cutting tool attached to the bottom of the drill string.

Drill collar. A length of extremely heavy steel tube placed in the drill string immediately above (behind) the drill bit to minimise bending caused by the weight of the drill pipe.

Drill cuttings. The rock chips resulting from the cutting action of the drill bit and which return to the surface in the air- or water-stream blown from the borehole during drilling.

Drill rod. The pipe in the form of hollow steel rods used to transmit the rotation from the rotary drive head to the drill bit and which conveys the air and/or drilling fluid which removes drill cuttings and water from the borehole being drilled.

Drill string. The combination of drill pipe, drill collar, drill bit and, in the case of the rotary air percussion drilling, the down-the-hole pneumatic hammer, whereby drilling is effected.

Drilling fluid. A water- or air-based fluid used to improve the removal of drill cuttings from the borehole, to lubricate, clean and cool the drill bit and, in certain instances, to stabilise the sidewall of the borehole against collapse during drilling.

Fishing. The activities associated with attempting to recover drilling equipment, materials or tools lost down a borehole during drilling.

Formation stabiliser. The material, generally gravel, which is placed in the annulus between the casing and the borehole sidewall in order to provide, amongst others, additional security against collapse of the borehole sidewall.

Geohydrologist. Someone with a sound theoretical and practical background in Geohydrology.

Geohydrology. That branch of the Earth Sciences associated with the study of groundwater resources.

Geophysicist. Someone with a sound theoretical and practical background in Geophysics.

Geophysics. That branch of the Earth Sciences associated with the application of geophysical techniques in the study of natural resources.

Geotechnician. Someone with a sound technical and practical background in the study of natural resources.

Groundwater. The water which occurs in the zone of saturation below the surface of the earth.

Groundwater rest level. The natural level at which water stands in a borehole. The unit of measure is metres (m) expressed as depth below surface.

Hydrogeologist. See Geohydrologist.

Nominal. The term used to describe standard sizes for pipe specified on the basis of the inside diameter which, depending on the wall thickness, may be less than or greater than the value indicated.

Pumping test. A test that is conducted to determine borehole or aquifer characteristics.

Rising main. The pipe through which the water pumped from a borehole is delivered to surface.

Sanitary seal. The seal comprising of a cement grout with which the annulus between the borehole sidewall and the casing is filled in order to prevent the ingress of foreign material into the borehole via this space.

Test pump. The pump with which test pumping is executed.

Test pumping. The process whereby a borehole and/or an aquifer is subjected to pumping under controlled test conditions.

Yield. The volume of water per unit of time that can be obtained from a borehole. It measures the performance of a borehole. The unit of measure is litres per second (l/s).

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