Southern African Development Community (SADC)
Water Sector Coordination Unit (WSCU)

Funded by the Government of France

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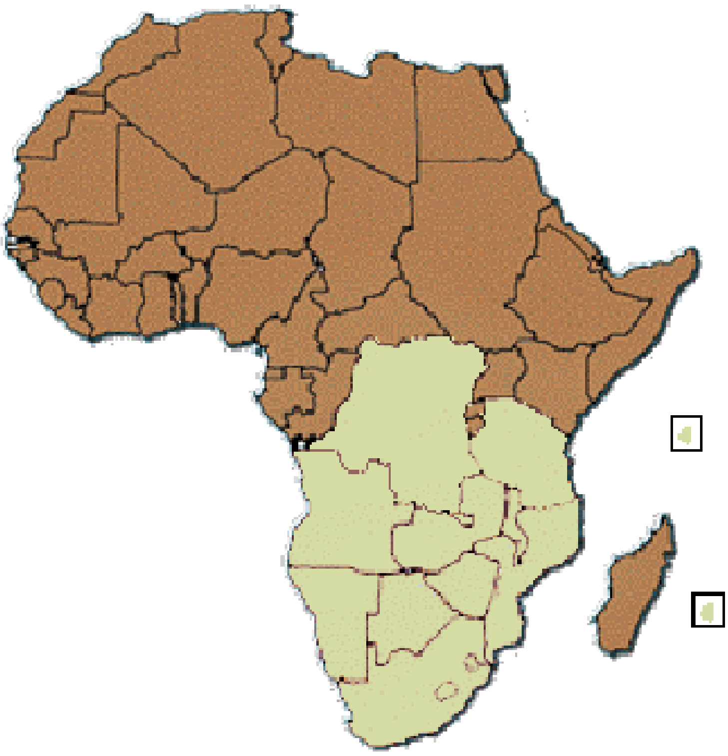
Development of a Code of Good Practice for Groundwater Development in the SADC Region

REPORT No.2 (Final)

GUIDELINES FOR THE GROUNDWATER DEVELOPMENT IN THE SADC REGION



November 2001

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Southern African Development Community
(SADC)
Water Sector Coordination Unit
(WSCU)

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PROJECT

Development of a Code of Good Practice for Groundwater Development in the SADC Region

REPORT No.2 (Final)

TITLE

GUIDELINES FOR THE GROUNDWATER DEVELOPMENT IN THE SADC REGION

November 2001

FOREWORD

On behalf of the Southern African Development Community (SADC) Water Sector, I have the honour of presenting this document entitled "**A Code of Good Practice and Guidelines for Groundwater Development in the SADC Region**".

The member States of SADC have agreed to cooperate on strategic sectors that will contribute to and foster regional economical development and integration on the basis of balance, equity and mutual benefit for all member States. As a result the Water Sector was identified as one of such strategic sectors and thus was established in 1996, and coordination responsibility was given to the Kingdom of Lesotho. The overall objective of the Water Sector is to promote cooperation in all water matters in the region for sustainable and equitable utilisation, development and management of water resources that contribute towards the upliftment of the quality of life of the people of the SADC region.

There are a number of challenges faced by the Water Sector in order to meet its objective that require concerted efforts by all member States to avert the effects of those challenges. The major challenges that need to be addressed include the provision of water of adequate quantity and quality and safe sanitation services mainly to the people living in rural areas of the region, the majority of which still lack access to these basic services.

A number of documented studies have shown that more than 60% of communities in the region depend on groundwater, of which the majority (about 70%) live in rural areas. Studies have also shown that two or more countries share a number of aquifers from which water is abstracted for various purposes and services in member States. The SADC Water Sector therefore acknowledges that groundwater resources are finite and valuable and are recognised as playing a pivotal role in activities aimed at alleviating or combating poverty in the region. The SADC Water Sector also acknowledges that all member States are at different levels in terms of management and development systems used in managing and developing groundwater resources as shown by documented studies. Therefore proper development and management systems need to be in place in order to jointly manage and harness this resource in an economically, environmentally and socially sustainable manner. This is also in pursuance of the Protocol on Shared Watercourses in the SADC Region underlying joint water resources management principle.

The SADC Water Sector Coordinating Unit with the Water Sector Stakeholders in an effort to address some of the concerns raised above, have attempted to put in place preliminary management and development tools and mechanisms to be used by a variety of agencies involved in the groundwater management and development ranging from government departments, consultants and drilling companies. The process leading to the development of this document has been very consultative and has also involved a number of stakeholders in all SADC member States, including other SADC Sectors such as the Trade and Industry Sector. Processes are underway for the Trade and Industry Sector having the mandate of developing "Standards" for the region to adopt this document.

The SADC Water Sector views this document as an on-going evolutionary process with evolving technology, and therefore will continue consultations with a wider range of stakeholders in an effort to improve this document through regular reviews.

We, therefore, appeal to and encourage all agencies involved in water resources development and management to take cognisance of this document when developing and managing groundwater resources. We also hope that the implementation and the application of this Code of Good Practice and Guidelines will prove an effective management and development approach for this resource.

The SADC Water Sector acknowledges the commitment and contribution of the member States in this document. The SADC Water Sector is also most grateful to the French Government for financial and technical support that made it possible to produce this document.

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Chief Engineer – Sector Coordinator

SADC Water Sector.

PREFACE

The project goal was to develop minimum common standards for groundwater development in the Southern African Development Community (SADC) Member States, which would serve as regional standards and guidelines to maintain uniform, good quality development in a cost-effective manner. Implementation of the project is by the SADC Water Sector Coordination Unit (SADC-WSCU) through the financial assistance of the French Government. Groundwater Consultants (Pty) Ltd were commissioned to carry out the project on behalf of SADC-WSCU.

SADC adopted a Regional Groundwater Management Programme (RGMP) consisting of 10 Projects within the overall framework of regional co-operation and development. The present project was identified as the priority project for implementation.

To accomplish the project objectives the project was divided into two interdependent stages. Stage 1 was basically the fact finding, data collection and situation analysis stage, while Stage 2 focussed on the drafting of standards and guidelines based on the feedback received during Stage 1.

The Stage 1 Report (Report No.1) was submitted and discussed in a workshop (Workshop No.1) with the Hydrogeology Subcommittee on 25th and 26th September' 2000. It was agreed in the meeting that the Report No.1 contains useful information for reference and therefore should be produced in final form as a reference report to Report No.2.

The Draft Final Report of stage 2 (Report No.2) was submitted in February 2001. The report was presented to the Hydrogeology Subcommittee on 27th and 28th March 2001 in a workshop in Mauritius (Workshop No.2). Apart from the subcommittee members, the workshop was also attended by the SADC STAN (SADC Cooperation in Standardization) experts as observers. The present Final Report No.2 incorporates the comments and suggestions raised during the workshop on the Draft Final Report.

During the Workshop No.1, there was a significant discussion on the use of the term 'Minimum Standard' versus 'guidelines'. The primary difference between the terms being that 'standard', although effecting only voluntary compliance, has a more strict connotation to most than the term 'guideline', which implies more flexibility in implementation. At the time, no specific consensus was reached on the preferred use of either term.

Similar to Workshop No.1, there was some discussion on the title of the report, following the SADC STAN presentation that apprised the committee of the definition of the words, 'Standards', Guidelines' and 'Code of Practice' during the Workshop No. 2. 'Standards' refer to a technical document that prescribes the quality characteristics of a product for it to meet its intended use, while 'Code of Practice' refers to a document that recommends practices or procedures for the design, manufacture, installation, maintenance or utilisation of equipment, structures or products. Therefore, a consensus was reached on the term 'Code of Practice' instead of 'Standards'.

Following the presentation on the regional process of harmonisation of standards within the SADC Region by the SADC STAN experts, it was realised that the present work on groundwater standards needs to be incorporated within the framework of SADC STAN. It was agreed that the present report should become a basis for the adoption of these groundwater standards and guidelines as the formal 'Code of Practice' by the SADC STAN through its protocol. Therefore the document should be titled "Guidelines for the Groundwater

Development in the SADC Region" under the project title of "Development of a Code of Good Practice for Groundwater Development in the SADC Region".

This 'Code of Good Practice' document is very focused on technical aspects and recommends the correct practices and/or procedures in relation to groundwater development. By and large, the document follows sequentially the logical steps in a typical groundwater development programme, starting from project implementation and planning until the borehole equipping and reporting. In general, the rationale behind the recommendations and current practices in the region is not discussed in this document. For this the reader is referred to Report No.1 and other technical references provided with this document.

In the present document a word 'desirable' has also been used frequently in relation to the standards and guidelines. The standards and guidelines in this document refer to the <u>minimum</u> level that should be implemented during groundwater development. In certain cases it may be possible to easily improve the quality of works or data collected, and/or gain additional confidence in results by implementing extra measures, that in some cases have additional cost implications. In this report, these activities or procedures are defined as 'desirable'.

Implementing these codes of practice can have profound implications for advancement of the hydrogeological science through improved integration of data collection and development practices across national boundaries. Not only will it facilitate the institution of a proper code of practice that will serve the end user much better, but it will also result in enhanced exchange of resources across the region, be it technical, manpower, data, or equipment and instruments.

In the opinion of the authors, this comprehensive document is a valuable guide in groundwater project implementation in addition to setting a minimum level for groundwater development practices. The intention of this document is not to rigidly enforce, but to facilitate and improve the quality of, groundwater development as per the current state of the science. This document further has the advantage of using terminology and reflecting conditions that are common in (and sometimes specific to) the SADC region.

The need for this document is also appreciated in view of the considerable variation in the level of groundwater development activities in the region, from poor or inappropriate to extremely effective and sophisticated methodologies. In essence, it is desirable to have certain Minimum Common Standards and Guidelines for optimal and sustainable development and management of groundwater resources with the ultimate purpose of providing services to the majority of the population in the region and providing maximum benefit to future generations.

It is important that this document be seen <u>not as a static object but as an on-going, evolutionary process</u>. As such, regular review and up-dating of the document is imperative if this first comprehensive document is to continue to serve the overall objective of effectively implementing Regional Groundwater Management Programme for the SADC Region.

ACKNOWLEDGEMENTS

This document is a part of the Regional Groundwater Management Programme for the SADC Region. The document is drafted by Groundwater Consultants, Bee Pee (Pty) Ltd. of Maseru, Lesotho under a project of the SADC Water Sector. The project was managed by the SADC Water Sector Coordination Unit (SADC-WSCU) of Maseru Lesotho, with technical back-up from the SADC Sub-Committee for Hydrogeology, acting as Steering Committee for the Project.

The French Government (Ministry of Foreign Affairs, Cooperation and Francophony), under a Grant agreement with SADC, provided the source of funding for the project to SADC-WSCU.

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The following members were observers and provided significant contribution and guidance on the process:

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MAIN REPORT

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ACRONYMS

BS	British Standards
CBM	Community Based Management
CMAs	Catchment Management Authority
CRT	Constant Rate Test
CSIR	Council for Scientific and Industrial Research
DWAF	Department of Water Affairs and Forestry
DWAs	Departments of Water Affairs
EA	Executing Agency
EIA	Environmental Impact Assessment
ESAs	External Support Agencies
EU	European Union
FIDIC	International Federation of Consulting Engineers
GDs	Geohydrology Divisions
HLEM	Horizontal Loop Elecetro-magnetic
HTN	Handpump Technology Network
IA	Implementing Agency
IGS	Institute for Groundwater Studies
IP	Induced Polarisation
ISO	International Standards Organisation
NGOs	Non Governmental Organisations
NGRB	National Groundwater Regulating Body
SABS	South African Bureau of Standards
SADC	Southern African Development Community
SADC-WSCU	SADC Water Sector Coordination Unit
SDT	Step-drawdown Test
SKAT	Swiss Centre for Development Cooperation in Technology and Management
SP	Self Potential
TEM	Time Domain Electro-magnetic
UNICEF	United Nations Children Fund
UNDP	United Nations Development Project
VES	Vertical Electrical Sounding
WHO	World Health Organisation
WRC	Water Research Commission

REFERENCED STANDARDS

SABS 719 (1971)
SABS 966 (1998)

DEFINITIONS OF TERMS

Alluvium. A general term used for clay, silt, sand and gravel deposited in geologically recent time by a river system.

Annular Space. The space between the wall of the borehole or the outer casing and the inner casing or the drill stem.

Aquifer. A geological formation, or a part of a formation, or a group of formations below the surface that is capable of yielding sufficient amount of water when tapped through boreholes, dug wells or springs.

Aquitard. A geologic formation, or part of a formation, through which practically no water moves

Artesian Well. A borehole in which the water level (or the head) is above the ground level and as a result water flows out of the borehole without any mechanical means. In some instances the term is also used for a well in which the water level stands above the top of the aquifer but not necessarily above the ground surface.

Available Drawdown. The maximum allowable drawdown in a pumping borehole and is the difference between the dry season rest water level and the upper level of first screen or the water strike or the pump intake, whichever is shallower.

Backfill. A term used for filling a drilled borehole, usually a dry or unused borehole, with drill cuttings or other appropriate material.

Bentonite. A colloidal clay used as a drilling fluid.

Blow-out Yield. Yield of borehole measured during the drilling using compressed air.

Casing. A pipe of steel, uPVC or any other suitable material inserted into a borehole to support the screens and/or borehole against collapse.

Casing Shoe. A circular, short length of high tensile hardened steel fitting welded to the bottom end of steel casing for protection against damage during installation into the borehole.

Centralisers. A piece of folded steel (or uPVC) welded (or attached) to the casing/screen to keep the casing and screens in the center of the borehole.

Cone of Depression. A depression in the groundwater level, or the head that develops, around a pumping borehole with the pumping borehole being its axis.

Confined Aquifer. An aquifer that is confined from top and bottom by impervious layers and the piezometric surface is above the top confining layer.

Contamination. The degradation of natural water quality as a result of man’s activity.

Drawdown. The difference between the static water level and lowered water level in any borehole within the cone of depression including the pumping borehole.

Drilling Fluid. A water or air based fluid used in the drilling of a borehole to remove cuttings from the borehole, to clean and cool the bit, to avoid collapse of borehole, to reduce friction between the borehole wall and the drill stem and to seal the borehole.

Electrical Conductivity. A measure of the ease with which a conducting current flows through the fluid. It is used to assess the salinity of the fluid.

Filter Pack. Same as Gravel Pack.

Formation Stabilizer. Same as the Gravel pack but is normally used to stabilize fractured semi-consolidated or consolidated formation. The material may be of sub-rounded nature.

Gravel Pack. Sand or gravel that is smooth, uniform, clean, well-rounded and siliceous. It is placed in the annular space between the borehole wall and the well screen to prevent the entry of formation material into the screen and borehole.

Grout. A fluid mixture of cement and water that is placed at a required depth within the annular space to provide a firm support and impervious layer for protection against contamination.

Head. Energy measured in the dimension of length (usually in meters) of a fluid produced by elevation, velocity and pressure.

Heterogeneous. Non-uniform in structure and composition.

Homogeneous. Uniform in structure and composition.

Injection Borehole. A borehole through which water is poured back to the aquifer.

Interference. A condition occurring when the cone of depression of two nearby borehole pumping from the same aquifer come in contact with each other or overlap.

Leakage Coefficient. It is a measure of spatial distribution of leakage through an aquitard into a leaky aquifer. It has the dimension of Length.

Monitoring Borehole. A borehole used for monitoring of water level and/or water quality.

Porosity. It defines the pore spaces in an aquifer. It is expressed as a fraction and is the ratio of void space to total volume for a unit volume of aquifer.

Production Borehole. A pumping borehole that is used for producing water for consumption.

Pumping Test. A test carried out to assess the aquifer or borehole characteristics.

Regolith. A general term used for soil, unconsolidated material or weathered material overlying the country rock/bed rock.

Residual Drawdown. The difference between the static water level and the water level measured in a borehole during the recovery following pumping.

Rest Water Level. A water level in a borehole that is not affected by the pumping. Also referred to as Static Water Level (SWL) at times.

Rising Main. The pipe from the pump intake (or the pump) to the surface through which water is pumped to surface.

Sanitary Seal. The seal, composed of a cement grout, with which the annular space between the borehole wall and the surface casing is filled in order to prevent contamination of the borehole.

Screen. A filtering device used to restrict the sediments from the formation entering the borehole. (commonly made by perforation of steel or uPVC pipes with apertures of various types and shapes)

Specific Capacity. It is the volume of water that is pumped from a borehole for a unit drawdown of water level for a particular duration of pumping.

Static Water Level. refer *Rest Water Level*.

Storativity. It is the volume of water released from storage per unit surface area of the aquifer per unit decline in the hydraulic head. It is dimensionless coefficient.

Sump. A term used to express the lowermost part of a borehole that is left for sediment accumulation or any other debris falling into the borehole.

Surface Casing. The casing that is used to protect the top regolith/soil falling into the borehole to facilitate drilling of rest of the borehole. It is also used to protect contaminant entering into the borehole annulus through the regolith.

TDS (Total Dissolved Solid). The quantity of dissolved material in water expressed as mg/liter.

Transmissivity. The rate of flow of water across the unit width of the entire saturated thickness of the aquifer under a unit hydraulic gradient. It is expressed in terms of m^2/day or equivalent (dimensions L^2/T).

Tremie Pipe. A pipe that is used to carry/install material (such as cement grout or gravel) at a specified point or depth in a borehole.

Unconfined Aquifer. An aquifer in which the water is in direct contact with the atmosphere through open spaces. It has a free water table and the true thickness of the aquifer is more than or equal to the saturated thickness.

Unconsolidated Formations. Loose (or loosely cemented), soft rock material of any type of rock that includes sand, gravel, breccia or weathered material.

Water Table. The upper surface of the zone of saturation in an unconfined formation, at which the hydraulic pressure is equal to atmospheric pressure.

Note

More definitions related to groundwater can also be found in the UNESCO International Glossary of Hydrology, 1992.

Section 1: GUIDELINES ON GROUNDWATER PROJECT IMPLEMENTATION

1.1 GENERAL

1.1.1 Scope and Purpose

Effective groundwater development is contingent on structured, sufficiently funded and coordinated programmes that are efficiently regulated through an appropriate policy and institutional framework, and are implemented by technically competent personnel.

The present section outlines a generalised guideline on the key role players and the implementation mechanism. These are only guidelines and should be viewed in the context of the national institutional framework. It may be appropriate to accommodate these guidelines in on-going sectoral and institutional reforms that are presently underway in many of the SADC Member States.

1.2 ROLE PLAYERS

A variety of role players are involved in groundwater development projects. These can be broadly categorised as regulator and facilitator, implementer, executor and user. A general hierarchical structure is presented in Figure 1-1.

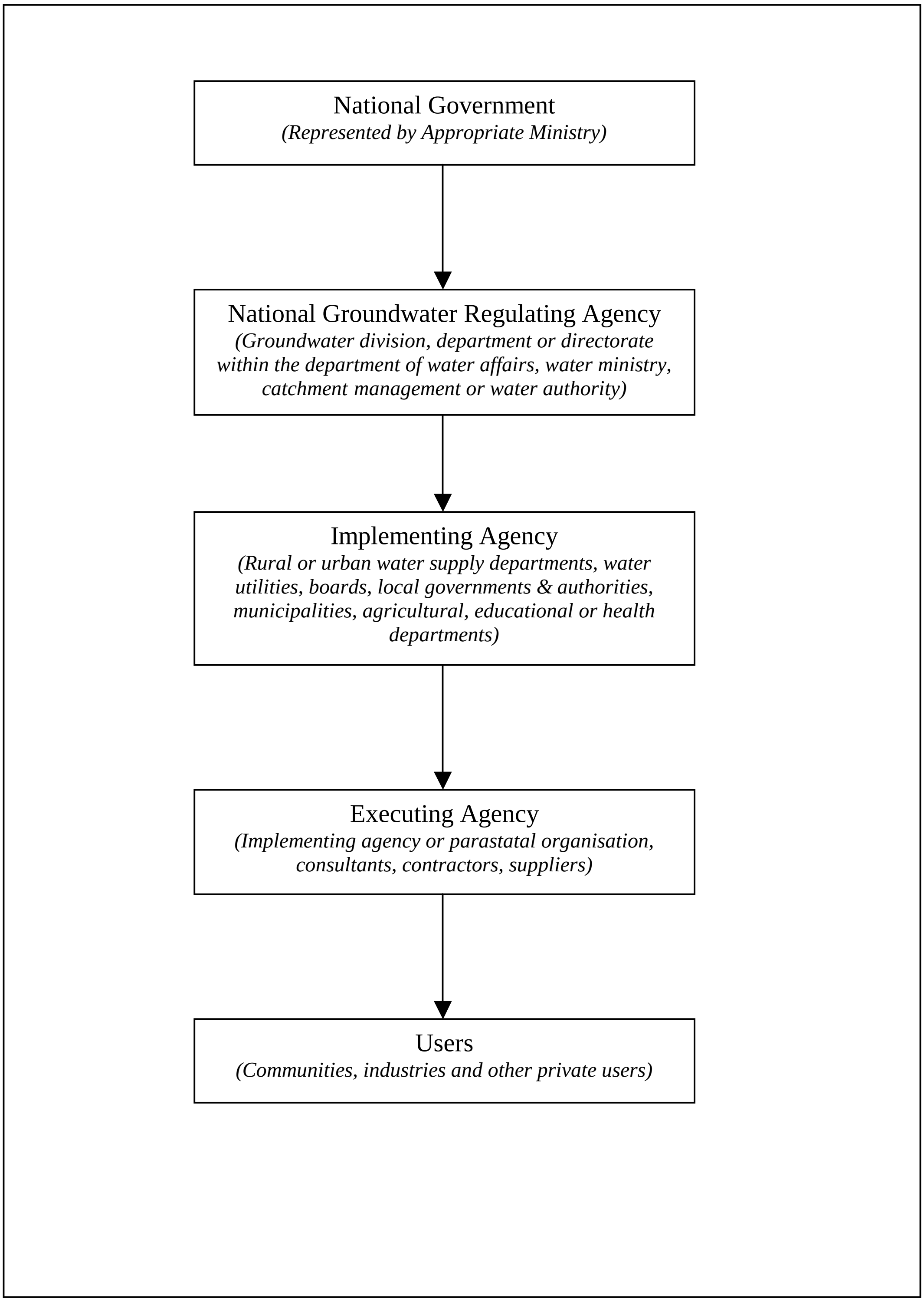
1.2.1 National Groundwater Regulatory Body (NGRB)

A national regulatory body, with the sole responsibility for groundwater sector planning and management (in coordination with other related sectors), is essential to oversee the groundwater development activities on behalf of the government. These national agencies could be a groundwater division, department or directorate within the department of water affairs, water ministry or water authority. In other cases, where water resource management at catchment level is gaining momentum, it could be a catchment management authority. NGRB could be represented at regional or provincial level for logistical reasons.

Although at present some of these national agencies in the SADC Region are directly involved in implementation of groundwater development, it is desirable for these agencies to limit their involvement in direct implementation and rather play the role of a facilitator and regulator. The key roles they could play particularly in relation to groundwater development are:

- develop national policies, in close coordination with other relevant sectors, on groundwater exploration, development and management;
- provide a larger framework of policies and technical assistance to various implementing agencies on groundwater development (for example implementation of the guidelines and standards outlined in this document) and associated macro planning;
- provide a framework for registration of professionals, drillers and suppliers engaged in groundwater development activities;
- plan, coordinate and execute if necessary, groundwater assessment and research at national level to facilitate the macro-planning of groundwater development;
- monitor and regulate groundwater development activities to ensure sustainable development, quality data collection and good workmanship;
- ensure the protection of aquifers against the contamination and pollution; and
- develop and maintain a groundwater database to provide easy access to data for groundwater development activities.

Figure 1-1 : A General Organisational Set-up for Groundwater Development Project Implementation



1.2.2 The Implementing Agency (IA)

These are the agencies that are directly responsible for the implementation of water supply projects. In smaller member states this could be the department of rural water supplies or water utilities departments while in larger member states these could be provincial and local government authorities and municipalities. In addition there are other stakeholders such as departments of education and health, agricultural departments, geological surveys, major mining and industrial establishments, external support agencies (ESA's) and non-governmental organisation (NGO's).

It is desirable to have clarity on the role and mandate of implementing agencies. For example in the case of a rural water supply department/division being responsible for rural water supplies, all the rural water supply implementation should either be channelled (particularly for government bodies such as education and health department and ESA's) or coordinated through (for NGO's involved in rural water supply implementation) this agency. It may be necessary to have a regulatory framework to make the coordination effective amongst these agencies.

1.2.3 The Executing Agency

The executing agency should comprise a competent group of people with appropriate resources to undertake the execution of groundwater development projects. It is desirable that the national regulatory bodies put in place an acceptable mechanism and criteria for the recognition and registration of the executing agencies, as necessary, to engage in groundwater development activities.

The Executing agency may be the implementing agency itself, a parastatal organisation or private consulting and contracting companies that are appointed by the implementing agency.

1.3 IMPLEMENTATION STRATEGY

1.3.1 Community Participation and Need Assessment

Community participation and their need assessment is the starting point of any water supply system implementation. It includes:

- assessment of the community's need in regard to water requirement (water demand);
- the type of systems that are preferred by the community i.e handpumps, motorised pumping systems etc.;
- aspects related to ease of running and maintenance of the water supply system with reference to the community's skill level, availability of spares etc;
- the community's ability and willingness to pay for the water supply systems and take the ownership;
- existing community organisation structure (such as water committees); and
- assessment of the impact of planned abstraction and other negative impact on other water users in the area.

It is not the objective of the present document to cover the community aspects in detail. However, it is important to note the significance of these aspects and maintain a continuous interaction with the community during the entire decision making process, as it is essential for the sustainability of the project. The level of interaction and involvement may depend on the community's ability and willingness to take ownership of the system (also refer 9.4).

1.3.2 Feasibility Study

Regardless of the size and the purpose of the scheme (i.e. rural, urban, domestic, non-domestic etc.), a feasibility study must be carried by the implementing agency for any groundwater development programme implementation. The elements of the study will involve:

- All the basic elements of community participation, ability and need assessment, preferred system etc. as outlined in 1.3.1.
- Population estimates from the existing demographic data (a direct head count can also be made for smaller rural communities), including details on schools, clinics and any other institution that may impact the water demand.
- Domestic water demand estimate, based on national standards on per capita consumption.
- Non-domestic water demand, such as industrial, recreational or agricultural demand, as applicable.
- An assessment of the water quality of exiting and potential water supply sources as well as an assessment of water quality requirements.
- A review of existing water supply systems, if present.
- A review of available water supply sources in the area.
- A review of alternate designs that might be required for a specific problem or hydrogeological environment, e.g. in coastal areas alternate designs might be necessary to optimise the exploitation of fresh water zones/aquifers.
- A review of macro-plans for water supply development for the area, if available.

Based on the above information and assessment, an analysis is carried with regard to the most cost effective but sustainable scheme that could meet the requirement for the chosen design period (i.e. 10 or 20 years). Policy and guidelines are generally available at national level as well as at implementation agency level on details of the feasibility analysis.

Only after this stage of feasibility analysis should a decision be made on the extent and details of planned groundwater development. In some cases, decisions on the source of water supply are made without a proper feasibility study, leading to ineffective development. Similarly, premature and general decisions are also made on the type of schemes. For example, often either only handpump systems are chosen for all rural water supply systems or only pumping systems are chosen within the urban areas. However, in many cases a combined system type is often the optimal and most cost effective solution. These generalised practices should be discontinued and these choices should be made specific to schemes. It is desirable to involve a competent groundwater specialist at the feasibility stage.

With specific reference to groundwater development, the feasibility analysis should be able to provide:

- the total water demand to be met by groundwater development;
- type of groundwater development that is found to be feasible (such as springs, open dug well, handpumps, mechanised pumping boreholes etc.);
- total number of required boreholes (or other source) and expected yields; and
- estimated cost of development.

Although, from the above guidelines, a feasibility study may appear to be exhaustive and time consuming, for smaller rural communities it may often take only a day or two to complete the study, provided the base line data are available. On the other hand, the feasibility study for a larger urban type water supply may take years depending upon the complexities involved.

An Environmental Impact Assessment (EIA) should also be carried out independently as an integral component of the feasibility study. The EIA should follow the national guidelines as set by the respective national environmental authority/s. To clearly assess the impact of development, these possible impacts should be clearly defined in terms of:

- direct or indirect;
- significant or insignificant;
- reversible or irreversible; and
- positive or negative.

With particular reference to groundwater development, the various possible components that should be assessed for the environmental impact are (but not limited to):

- Impacts on flora and fauna, particularly on any endangered plant and animal specie, caused during geophysical survey, drilling and testing operations, subsequent construction of water supply system as well as production pumping.
- Impact of planned abstraction on the other users in the area that are already abstracting water.
- Discharge or release of toxic chemicals, fuel, oil etc. during drilling, testing and construction.
- Contamination or pollution of fresh water aquifers from another aquifer of poor quality (e.g. in the coastal aquifers and in the areas of groundwater salinity) water during the drilling and pump-testing.
- Possible movement of saline water interface in coastal areas due to planned abstraction
- Loss or damage or change to a scenic area/landscape over a long period.
- Negative impacts on human health during drilling and construction operations.
- Loss of any cultural, historical, archaeological site.
- Loss of any employment due to development activities.

The nature and scope of EIA should depend upon:

1. the scale of the groundwater development project; and
2. the sensitivity of the area.

In cases where the scale of the groundwater development project is smaller (such as drilling of scattered boreholes for rural water supply), a detailed EIA may not be required. An initial screening of the project should be done to assess the need and scope for the EIA. Similarly, the sensitivity of the area should also be considered during the screening and scoping process. It is recommended that the NGRB (in coordination with the national environmental authority) should delineate sensitive areas where, irrespective of the scale of operation, a proper EIA must be done.

It should be made mandatory that the completed feasibility study, together with the EIA report, is forwarded to NGRB for final review and approval to ensure that it complies with national policies and standards on groundwater development.

1.3.3 Proposal and Financing

Following the feasibility study, IA should prepare a proposal to meet the water demand. The proposal should incorporate all the components of water supply in an integrated manner, starting from water source development to commissioning of the water supply system. It may be necessary to provide a breakdown of groundwater development activities.

IA should incorporate the project proposal into their financing plans or seek funding from an appropriate agency within the framework of their mandate.

1.3.4 Project Plan and Preparation of Tender Documents

Based on the approved feasibility study, the implementing agency should combine schemes of similar nature and/or similar logistical set-up to form a single project. A time frame and resource input schedule should be prepared for the implementation.

In cases where the implementing agency does not have the resources to execute the project itself, and has a mandate to outsource the execution, the implementing agency should prepare appropriate tender documents. Two separate tenders should be prepared: one for the consulting services including services such as desk study, borehole siting, borehole drilling and pumping test supervision, production pumping recommendations, supervision of hand pump installation and final reporting; and the other one for the works: to include drilling, pumping test and equipping of handpumps or motorised pumps (as applicable). In order to ensure quality of the product it is firmly recommended that the two functions should not be mixed in any case.

Sometimes groundwater development becomes an integral part of a larger engineering/water supply project. In such cases it is desirable that consulting and contracting issues for groundwater development activities are identified clearly, and preferably should be separated as parallel sub-contracts.

Although both tenders for services and works could be prepared by IA, it is desirable that tender document for works should be prepared by the consultant (or by the IA where it carries out the services itself and outsources the works only) during the execution. This provides an extra opportunity to make the tender more specific to particular requirements as it is based on additional knowledge gained during the feasibility study.

A typical tender for groundwater development should include:
- Terms of Reference (ToR) and specifications;
- Indicative manpower resources (for services only) and time schedule;
- Bill of quantities (BoQ);
- Draft contract document including the General and Special conditions of contract; and
- Form of agreement and other applicable forms for tender boards.

Terms of reference and specifications should clearly provide the details of the intended groundwater development activities. They should either cross-refer to the relevant national and regional (e.g. the present document) standards and guidelines on groundwater development or be customised.

An indicative manpower resources and time schedule for the implementation should be provided with the services tender, as it is often based on financial constraints and/or implementation strategy of the implementing agencies.

The tender should be accompanied by a detailed bill of quantities based on the ToR and specifications. A general BoQ for a groundwater development programme is provided as guideline in Appendix B. Explanations and elaborations on items should be provided wherever applicable. In general the BoQ's should be structured according to rated items and measured quantities and not on based on Lump Sums. Broad items such as complete drilling and installation per meter should be avoided and instead specific aspects (i.e. drilling, casing installation, etc.) should be itemised for better control.

The Contract should broadly be according to the procedures and guidelines set by the relevant national authorities or funding agencies. Standard FIDIC contract documents can also be used as a basis.

If services and the works are carried out by the IA itself then an overall project execution plan, including the resource input, implementation schedule and project monitoring mechanism, should be prepared and approved by the regulatory body.

1.3.5 Tendering and Appointment of Executing Agencies

Once the tender documents are prepared these must be approved by the NGRB as well as any other relevant authority at national level, if required (such as Tender Board).

Tender evaluation should be carried out by the implementing agency within the framework of its own procedures. It is essential that the tender for services should be evaluated for its technical merit first before opening the financial bid. It is also essential to involve at least one groundwater professional (hydrogeologist, geophysicist, engineer) from the implementing agency in the evaluation committee. Wherever this is not possible, assistance from the NGRB should be requested.

Tendering and appointment of an executing agency will not be applicable in cases where IA is directly involved in execution.

1.3.6 Manpower Resource Input and Management Structure

Manpower resource input and management structure varies primarily according to the magnitude and complexity of groundwater development project implementation and available financial resources.

Typical manpower resources are categorised to provide a general guideline on their input, level of expertise and qualifications for typical personnel involved in groundwater development. These are categorised and presented in Table 1-1 below. The table only includes key manpower on typical technical aspects of groundwater development. Additional manpower such as sociologist, environmentalist, sanitation expert, etc. may be required on specific projects.

Table 1-1: Categorisitaion of Personnel Involved in a Typical Groundwater Development Project/Programme

Category	*Qualification and Experience*
Hydrogeologist Level A	A competent hydrogeologist with a master's degree in an appropriate discipline or higher and minimum 10 years of relevant experience *Or* A competent hydrogeologist with a bachelor's degree in an appropriate discipline and minimum 13 years of relevant experience
Hydrogeologist Level B	A competent hydrogeologist with a master's degree in an appropriate discipline or higher and minimum 5 years of relevant experience *Or* A competent hydrogeologist with a bachelor's degree in an appropriate discipline and minimum 8 years of relevant experience
Hydrogeologist Level C	A competent hydrogeologist with a master's degree in an appropriate discipline *Or* A competent hydrogeologist with a bachelor's degree in an appropriate discipline and minimum 3 years of relevant experience
Hydrogeologist Level D	A competent hydrogeologist with a minimum of a bachelor's degree in an appropriate discipline
Geophysicist Level A	A competent geophysicist with a master's degree in an appropriate discipline or higher and minimum 10 years of relevant experience *Or*

	A competent geophysicist with a bachelor's degree in an appropriate discipline and minimum 13 years of relevant experience
Geophysicist Level B	A competent geophysicist with a master's degree in an appropriate discipline or higher and minimum 5 years of relevant experience *Or* A competent geophysicist with a bachelor's degree in an appropriate discipline and minimum 8 years of relevant experience
Geophysicist Level C	A competent geophysicist with a master's degree in an appropriate discipline *Or* A competent geophysicist with a bachelor's degree in an appropriate discipline and minimum 3 years of relevant experience
Geophysicist Level D	A competent geophysicist with a minimum bachelor's degree in an appropriate discipline
Technician Level A	A competent technician with a diploma in an appropriate discipline and minimum relevant experience of 10 years
Technician Level B	A competent technician with a diploma in an appropriate discipline and minimum experience of 5 years *Or* A competent technician with Standard 10 or higher level and minimum relevant experience of 8 years
Technician Level C	A competent technician with a diploma in an appropriate discipline *Or* A competent technician with Standard 10 or higher level and minimum relevant experience of 3 years
Groundwater Specialist	A person of suitable qualification and experience and recognised in a specific field pertaining to groundwater such as modelling expert, geochemist, drilling expert etc. These may not be hydrogeologist or geophysicist but personnel required for specific aspects on a more complex and larger scale groundwater development projects.

Handpump Programme

Project Management

Overall project management, quality control and technical support should be by a Project Manager/Team Leader (PM) who is a hydrogeologist of level B or higher. In case the project is an integrated project with other components of water supply/health also involved, the PM could be a non-hydrogeologist but in that case the Team Leader should be a hydrogeologist of level B or higher for groundwater development component. His involvement should be continuous on the project. PM/TL should be supported by a hydrogeologist of category C (may not be full time) wherever the scale of operations and logistics require such support.

Target Delineation and Borehole Siting

A Hydrogeologist (HS) of category C should carry out target delineation for detailed siting and geophysical survey (if required) with support from the PM and a Geophysicists (GP) of level C or higher (if geophysical survey is to be carried out) for 10% of the time involvement of the HS. For projects of smaller magnitude, these duties could be fulfilled by the PM. HS/PM should be supported by a Technicians (TS) of level B or higher during geophysical survey. The number of technicians should depend on the scale of geophysical survey.

Borehole Drilling Supervision

Borehole drilling should be supervised (at a minimum) in the field by a Technician (TD) of level B or higher. There should be one TD per drilling rig on a full time basis during the drilling operations. The TD should be supported by a Hydrogeologist (HD) of level C or higher on all aspects as needed. HD's time input should be at least 25% of the TD's time input. Provided there is no overlap of activities, HD could be same as the HS. For small projects duties of HD could be fulfilled by the PM.

Borehole Testing Supervision

Borehole testing should be supervised (at a minimum) in the field by a Technician (TT) of Level C or higher. There should be one TT per testing rig on a full time basis during the testing operations. The TT should be supported by a Hydrogeologist (HT) of category D or higher on technical matters. HT's time input should be at least 20% of the TT's time input. Provided there is no overlap of activities and input, HT could be same as the HS/HD. For small projects, duties of HT could be fulfilled by the PM.

Handpump Installation Supervision

Handpump installation should be supervised (at a minimum) in the field by a Technician (TI) of Level B or higher. There should be one TI per installation crew on a full time basis. The TI should be supported by a Hydrogeologist (HI) of category D or higher on technical matters. HI's time input should be at least 20% of the TI's input. Provided there is no overlap of activities and input, HI could be same as the HS/HD/HT. For small projects duties of HI could be fulfilled by the PM.

Final Reporting

Final reporting should be carried out by the PM with support from the hydrogeologists involved on the project. At the completion of any project, it is crucial to also transfer all data to an existing national database (if present) or fully update the project database if no national database exists.

<u>Motorised Pumping Borehole Programme</u>

Project Management

Overall project management, quality control and technical support should be by a Project Manager/Team Leader (PM) who is a hydrogeologist of level B or higher. In case the project is an integrated project with other components of water supply/health also involved, the PM could be a non-hydrogeologist but in that case the Team Leader should be a hydrogeologist of level B or higher for groundwater development component. For smaller scale projects the role of PM may be fulfilled by the siting or drilling hydrogeologist, while a hydrogeologist of category A may be required in specific cases where the magnitude and complexities of the project so requires. PM should be supported by a hydrogeologist of category C (may not be full time) wherever the scale of operations and logistics require such support.

Target Delineation and Borehole Siting

A Hydrogeologist (HS) of level B or higher should carry out target delineation for geophysical survey (if required) with support from a Geophysicist (GP) of level B or higher. GP's time input should be for a minimum of 25% of the time input of the HS. For projects of smaller magnitude, these duties could be fulfilled by the PM. HS/PM should be supported by a Siting Technicians (TS) of Level C or higher during geophysical survey. The number of technicians should depend on the scale of geophysical survey.

Borehole Drilling Supervision

Borehole drilling should be supervised (at a minimum) on a full time basis per drilling rig in the field by a Hydrogeologist (HD) of level D or higher. The HD should be supported by the PM. Provided there is no overlap of activities, HD could be same as the HS. For small projects duties of HD could be fulfilled by the PM.

Borehole Testing Supervision

Borehole testing should be supervised (at a minimum) in the field by a Technician (TT) of Level B or higher supported by a Testing Hydrogeologist (HT) of level C (on the basis of 20% of the time input of technician) or higher through proper communication means. In cases where the sites are remote and communication is not possible at all times, field supervision should be by hydrogeologist of level D or higher on a full time basis.

Water Quality Sampling and Analysis

Water sampling plans for chemical and microbiological analysis should be prepared by the PM. Sampling should be done by the drilling supervisor (hydrogeologist) or the pump-testing technician, as appropriate. Specialised technician may be required for sampling for microbiological analysis.

Analysis of Data and Production Pumping Recommendations

Analysis of pumping test data and associated recommendations on production pumping should be carried by a hydrogeologist of category C or higher.

Borehole Equipping

It is desirable to involve a hydrogeologist of level C or higher (preferably the same who has given the recommendations on production pumping) in working out final design details and equipment for the installation. His role would be that of a reviewer to ensure that hydrogeological aspects are duly considered in the design. Hydrogeologist's involvement should for 15% of time input of design engineer.

Final Reporting

Final reporting should be carried out by the PM with input from other project hydrogeologists contributing to the report for their respective components. Again, at the completion of any project, it is crucial to also transfer all data to an existing national database (if present) or fully update the project database if no national database exists.

The scale of project for motorised pumping borehole programmes may vary from a single borehole to a wellfield for domestic and/or non-domestic purposes. Irrespective of the scale of project, certain expertise is essential depending on the activity level as outlined above. On smaller projects a single hydrogeologist of level C may fulfil most of the criteria (including the project management) and carry out the project alone, with support from technicians, provided there is no or very limited overlap of activity. On the other hand for bigger projects more than one hydrogeologist may be required to coordinate each activity (such as modelling, recharge assessment, hydrochemistry). The key is to ensure that each of the activities is carried out by appropriately qualified personnel as outlined above.

In regard to personnel involved in carrying out drilling and pump-testing operations (usually referred to as the 'Operators'), it is difficult to define their qualifications as there are very limited institutions providing formal qualification/training in that area. However, awareness in that regard is developing and some institutions may provide such trainings in future. Till that stage, the decision on assessing the operator's qualification has to be on subjective basis and may relate to registration of contractors (refer to Section 1.6 for more details as well as to Protocol on Quality Assurance for the Contractors). It has to be ensured that the chief operator or foreman has sufficient experience in particular area of operations and hydrogeological environment.

1.3.7 Execution of Groundwater Development Project

Once an appropriate project team is in place, the execution should start. Irrespective of the scheme types, typically a groundwater development programme should start with desk study, a preliminary survey to delineate the target, followed by ground geophysical survey, drilling, testing and finally data analysis and reporting. A general flow diagram of these activities is presented in Figure 1-2. Further details on these activities are provided in sections 2 to 5 of this document.

1.3.8 Monitoring and Evaluation (M&E)

Establishment of a proper monitoring and evaluation mechanism for the groundwater development projects is essential. The IA and NGRB should together develop the indicators and tools, with associated guidelines, for M&E of groundwater development programmes/projects. In most cases, these should not be isolated for groundwater development alone but should rather be integrated with overall programme objectives.

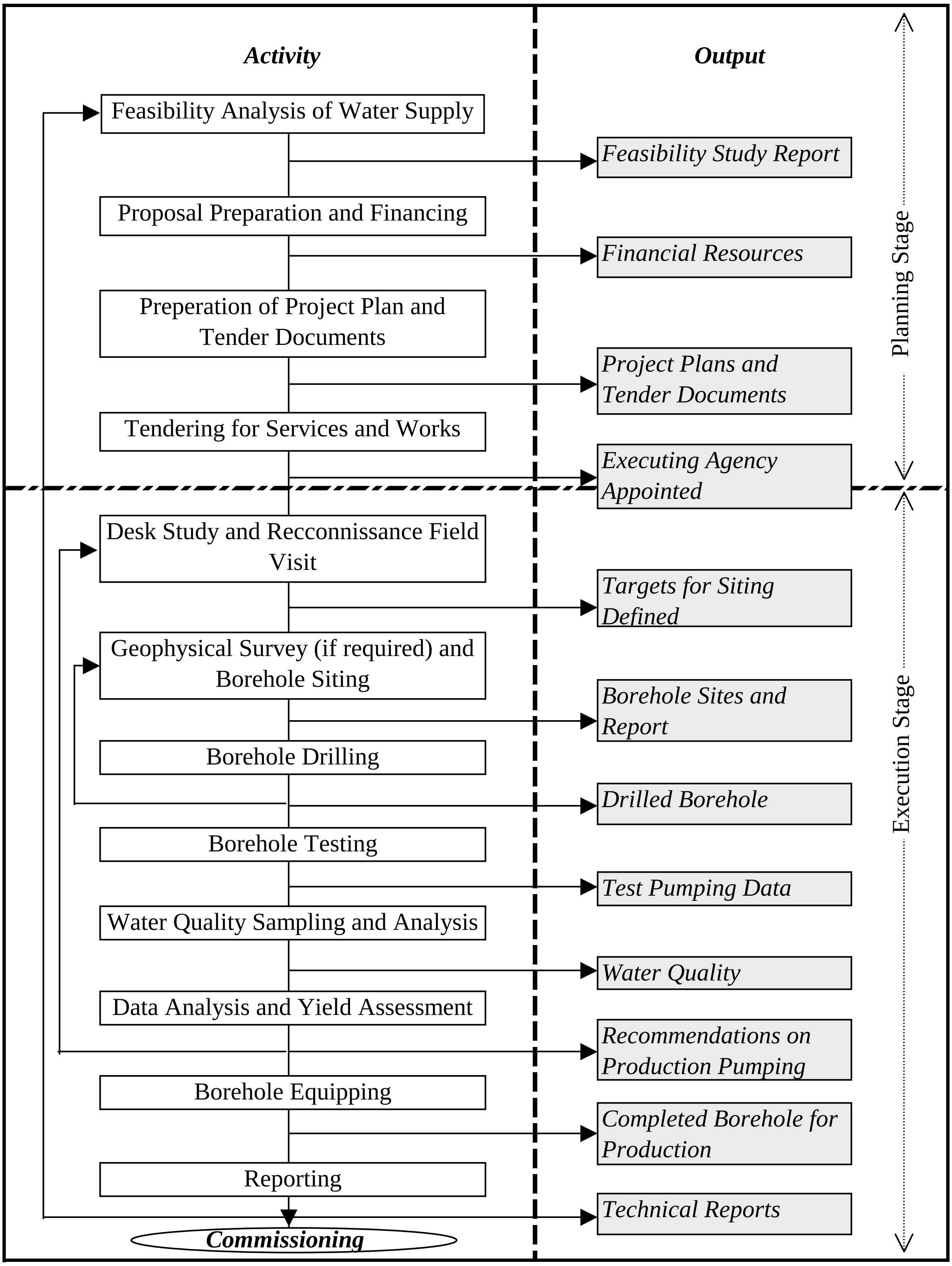
A typical M&E process is required to ensure that:

- the required services are carried out in line with the expected standards and guidelines (such as compliance to this and/or other relevant document/s);
- the services are delivered effectively and timely within the framework of overall programme scheduling and budget (accountability);
- the project/programme feeds in timely and effectively to other dependent programmes in a holistic manner;
- the project/programme meets all the necessary policy and legal requirement;
- the activities are transparent to all parties involved in the implementation, including the community; and
- the required feedback is provided to policy makers and programme managers to dynamically optimise the present and future programmes.

With particular reference to groundwater development, the key components of the M&E process should be:

- standard and guidelines for groundwater development.;
- guidelines and clear definitions of the M&E process and the parties involved;
- necessary indicators;
- forms for relevant data collection; and
- information system that can be updated regularly and can provide the required information.

Figure 1-2 : A Flow Diagram of Activities for the Implementation of a Typical Groundwater Development Project/Programme



1.4 PRIVATE BOREHOLES

A large number of private boreholes are drilled within the SADC Region. By nature, private groundwater development does not generally follow a structured implementation programme. However, at the same time it is extremely important to regulate these activities to ensure the effective management of resources and protect the interests of the private clients. National governments should play an advisory role and provide assistance to groundwater development in the private sector.

It is important to note that the approach to private groundwater development (boreholes, springs, wells) should largely follow the one described in previous sub-sections. It is only the scale of operations that may vary. To illustrate this, Table 1-2 below provides an elaboration and adjustment that may be required for implementation of groundwater development for private domestic and non-domestic uses.

Table 1-2 : Implementation Plan for Private Groundwater Development

Implementation Item	*Elaboration for private development*
Feasibility Study	Although not commonly undertaken, this is the most important component of private groundwater development. It is often found that failed or non-optimised groundwater development is due to lack of, or improper, feasibility analysis.
Proposal and Financing	This is also applicable to private development. In most cases it may simply be part of feasibility analysis.
Project Plan and Preparation of Tender Documents	This may not be applicable for small-scale private development. However, in case of larger scale development (e.g. industrial water supply, irrigation supply) this may still be applicable.
Tendering and Appointment of Executing Agency	For private boreholes this may simply be getting a quote for the services and works. Private users should generally avoid using the drillers for borehole siting and production pumping recommendations. The user should approach only recognised service providers and contractors.
Manpower Resource Input and Management Structure	This is also applicable to private development. It should be noted that for one or two boreholes for a mechanised pumping system a single hydrogeologist could easily fulfill the requirements and carry out the necessary services.
Execution	This remains the same for private development.

It is often an incorrect perception that following the standard procedures and hiring the services of a hydrogeologist for private development is too ‘expensive’. However, in many cases the additional cost of professional assistance is more than made up for in terms of efficient programme implementation and extended life span of the system.

It is important that government agencies and groundwater regulatory bodies also realise the significance of private groundwater development activities. Uncontrolled private development may be a serious groundwater management problem (such as through over-exploitation of aquifers, groundwater contamination, etc.). In addition, valuable data and information is often lost due to lack of coordination between private developers and government agencies.

In view of the above it is desirable that NGRB in most countries should put a tighter framework of regulations (within the framework of national water rights and water abstraction laws) and enforcement mechanisms to ensure that proper development does take place and that information is supplied to the appropriate agency. A practical way of achieving this could be by having a licensing policy for consultants and contractors involved in groundwater development activities. For example it could be made mandatory for drillers that no borehole should be drilled without the prior approval of the regulatory agency and the submittal of required information. If the driller is found to dishonour the regulations, his licence should be forfeited. Unlike enforcing the groundwater regulations at user level, it may be more practical to enforce it at the executing agencies level, as they are much fewer in numbers and in general are in touch with NGRB. In return regulatory agencies should consider providing technical support for groundwater development (for feasibility, supervision and recommendations) to private users wherever the user is unable to afford it.

1.5 DATA CAPTURE AND MANAGEMENT

Valuable and huge amounts of data are generated during a groundwater development project. It is essential to capture this data and build up the national information system as an on-going process. The subject will be dealt with in much detail in another project of the Regional Groundwater Management Programme for the SADC Region. The present sub-section provides general guidelines on data capture and management as it relates to groundwater development activities.

1.5.1 Recording Forms

It is normally the responsibility of the NGRB to develop, populate and maintain the information system on groundwater resources. These agencies should then develop standard recording forms for data collection during groundwater development projects so that data collected is meaningful and compatible with the national information system.

In many of the member states, however, in practice a proper information system either does not exist or is still under developmental stage. Therefore, in most cases standard forms for data collection are either non-existent, inappropriate or not uniformly used (refer Situation Analysis Report, Section 4.8 for details).

Standard recording forms for collecting data during groundwater development are suggested in this document for various components such as drilling, testing, equipping, etc and are presented as Appendix B. These forms are based on the minimum level of data that should be collected during a particular activity and are generally independent of local variations. It is therefore desirable to use these forms across the various types of implementing agencies wherever national forms are not available or do not contain this minimum information. If required, national agencies could add their additional requirements to these forms to suit the specific needs.

1.5.2 Coordination

Lack of coordination has been identified as the major cause of poor data collection and management in most member states, and therefore it is important to improve upon the coordination of groundwater development activities. Coordination is closely related to the policy and regulatory framework of the particular member state as well as to the implementation strategy. Based on the analysis of the present situation in the member states, some of the suggestions and general principles for effective coordination are listed below:

1. The National agency for groundwater development and management should focus solely on regulating groundwater development and avoid direct implementation of groundwater development programmes.
2. Proper legislation and enforcement mechanisms should be provided to NGRB at national and regional level to maintain the coordination.
3. There should be clarity on water rights and abstraction permits in relation to groundwater development. For example it could be made mandatory to seek permission/permit prior to

borehole drilling, and not after it, (because if the abstraction permit is refused for any reason significant resources may already have been squandered) and later on to water abstraction. This should apply across the user type and implementing agencies (i.e. public or private).

4. Registration and licensing of executing agencies (consultants, contractors and suppliers) should be made mandatory to operate on any groundwater development activities at national level. NGRB should be empowered to keep the registration authority to itself or should be directly involved on an equal basis if the registration is required with other relevant bodies (such as department of works etc.).
5. Enforcement of regulations (borehole registration) should be aimed at targeting the executing agencies to coordinate and provide information. For example, if any executing agency is found to be involved in groundwater development (including drilling of boreholes) without approval of the regulating agency, then its licence should be forfeited. Unlike enforcing the groundwater regulations at user level, it may be more practical to enforce it at the executing agencies level, as they are much fewer in numbers and are normally in touch with the regulating agencies.
6. In cases where supporting regulations are lacking, the regulating agency should consider appointing an independent consultant with the sole responsibility of coordinating and capturing the information on their behalf.
7. The regulating agency should conduct regular meetings on coordination and capturing of information on groundwater development, involving cross-sectoral stakeholders and implementing agencies.

1.5.3 Borehole Numbering System

A national and legally binding system of borehole numbering is crucial to controlling and managing groundwater development. The borehole numbering system applied has an important bearing on data management. Lack of proper numbering that can be applied in the field results in many problems (refer Section 4.8 of the Situation Analysis Report).

There are two types of borehole numbering systems common in the SADC region. One utilises a sequential numbering system, the other a geographically based numbering system (i.e. a number based on map sheet, quadrant, etc.). At the national level a sequential borehole numbering system is recommended, wherein the number of a borehole is issued by the regulating body prior to drilling. It could be attached as a condition to drilling companies that they must receive the number from the regulating body prior to drilling and subsequently submit the information. This way it is easier to ensure that the borehole is registered and is given a proper number irrespective of the implementing agency and user.

1. A limit on the depth beyond which a borehole could be made necessary for registration and/or data forms to be filled should be defined. A general limit of 10 m is suggested and all boreholes beyond this depth should be registered and forms completed.
2. A simple register could be maintained on the issuance of numbers. A drilling company would then be issued prior to drilling with a series of numbers based on the anticipated number of boreholes to be drilled. Once the drilling is completed the company should submit the forms (and necessary information for registration) for completed boreholes, together with unused numbers for cancellation or for re-issue to another user.
3. There should also be provision to receive the borehole numbers through communication media such as radio or telephone. There should be no temporary borehole numbering.
4. Borehole numbers must be engraved on the borehole cap as well as on the cement slab for easier field identification.
5. For member states with larger areas and logistical problems, the system could be adopted separately for regions or provinces with an appropriate prefix (preferably alphabetic) attached to it. In this case the regional or provincial offices would issue numbers.

6. Borehole location should be fixed with GPS and coordinates should be provided in lat/long as well as in local UTM grid.

Some member states have existing geographic borehole numbering system that are based on location and/or catchment. These systems offer the advantage of providing specific location information as part of the number itself. However, the problem with this system is that it is difficult to issue numbers prior to drilling, as one cannot be sure of the final location of drilling sites in advance. As a result, temporary numbers are often used in the field, which are subsequently rarely changed to the final official number. This can lead to confusion when trying to gather information about previously completed project boreholes.

To overcome this shortfall, however, the geographic system could be continued in addition to the use of a sequential numbering system, thus gaining the advantages of both systems. At the onset of a project a series of official sequential numbers can be given to the driller and marked permanently on boreholes in the field. The geographic numbers can then be assigned afterwards at the office and maintained as an additional column or filed in the database, while the sequential number remains for direct reference and field identification.

Irrespective of the numbering system that is used, a reinforced concrete identification pillar should be built next to the borehole with the borehole number clearly inscribed in it. The height of the pillar should not be less than 0.5 m and the width should not be less than 0.2 m. On one side of the pillar the number should be clearly engraved while on the other side a steel plate should be firmly fitted with the same number inscribed in it. In addition, immediately after the drilling, the number should be welded or engraved on top of the borehole cap as well as on the concrete slab that is built around it.

1.5.4 Record Keeping and Data Management

Record keeping and data management is a broad and complex topic and is planned to be the subject of a follow up project by the SADC WASCU on the development of a digital information system. Regardless of the information system used, data should always be kept in its original form within properly catalogued files for easy retrieval. One file each could be dedicated to individual boreholes containing location, map, survey data, drilling and testing data as well as cross references to other information that could not be kept in the files (such as reports on other boreholes).

1.6 REGISTRATION OF CONSULTANTS AND CONTRACTORS

Registration of professionals, technicians, consultants and contractors involved in groundwater development is a very useful tool to maintain the standards of groundwater development. There has recently been some discussion in this regard but a general consensus has not yet been reached on the exact nature and form of the registration process.

The registration could be perceived at two different levels, at individual level and at organisation level.

Registration at individual level could be for the professionals, technicians and drillers that are competent and have required qualifications to carry out the designated services. The services should be categorised in terms of broad development activities such as basic data analysis, drilling supervision, pump-test supervision etc. Under each category there could be different levels of expertise in line with the manpower categorisation as outlined in section 1.3.6. The expertise and categorisation should be judged from the qualifications, courses, publications and proven experience record. Therefore, there may be a case that a particular person, because of his certain experience, may qualify under a particular category but may not qualify as a general practicing hydrogeologist.

At organisation level the registration could be for the consultants, contractors and other organisations that are to be engaged in groundwater development. The organisation could also be categorised in a similar manner as for the individuals. However, the organisation could essentially be judged by its past experience and facilities.

The two basic questions on registration are the legal status of registration and the authority that should be responsible for registration. To a certain extent these two relate to each other. Ultimately, the registration could be made compulsory with the NGRB, and enforced through an appropriate regulatory framework, for all the professionals, technicians, consultants and contractors involved in groundwater development.

There are also some professional and drilling contractors' associations that have their own criteria for registration. The registration is on a voluntarily basis and relies on self regulatory mechanism.

While a compulsory registration process is developed and put in place, a voluntarily registration should be encouraged by the NGRB in cooperation with the relevant national associations. The NGRB and IA should encourage and support the organisation to form associations (where they are non-existent) and put in place the self-regulatory registration mechanism. In addition NGRB should also establish a mechanism for registration of individuals and organisation with itself on a voluntarily basis in the beginning. A 'Draft Charter of Quality Assurance by the Drilling and Pump-testing Contractor' is also prepared with the current document and is provided as a separate brochure.

Section 2: DESK STUDY AND RECONNAISSANCE SURVEY

2.1 GENERAL

2.1.1 Scope and Purpose

The standards and guidelines covered under this section are those for the desk study and reconnaissance survey prior to borehole siting. The purpose of the Desk Study and Reconnaissance Survey is to delineate the target areas of highest expected potential for groundwater sources. These apply to all water supply boreholes (for motorised pump as well as handpump installation) constructed by manual or mechanical means, aside from those that meet the definition of “hand dug wells”. In cases where geophysical survey is not required, the desk study and reconnaissance survey may conclude with identification of potential sites for drilling.

2.2 BACKGROUND INFORMATION

Prior to definition of the siting programme, information about the project location should be gathered, to provide a basic understanding of the possible constraints associated with the planned development areas. This may be undertaken by the executing agency, in collaboration with the implementing agency, in the initial phase of project implementation, if not already completed at the feasibility stage. The following primary issues should be addressed at this stage.

2.2.1 Legal Aspects

The legal and regulatory framework applicable to the given area should be researched and any implications for groundwater development noted. This may also include the definition and issuance of water rights if applicable.

2.2.2 Environmental Aspects

The environmental aspects applicable to the given area should be reviewed and considered. An EIA shall be done at the project planning stage (refer 1.3.2) and recommendations made during the study shall be reviewed and taken into account during the desk study and siting process.

2.2.3 Physical

The accessibility of the project area (especially for heavy equipment associated with borehole drilling if applicable) may limit the locations where boreholes can feasibly be drilled, irrespective of groundwater potential or community needs. The definition of the planned areas of exploration should take these factors into account.

2.3 DESK STUDY

The first component of a siting programme for boreholes shall consist of a desk study. The desk study is based on existing information and data available for the project area and is a critical foundation for preliminary groundwater resource assessment and target delineation for borehole siting. Since the desk study relies on existing available information, it is inexpensive to undertake (reflecting only the manpower costs for data collection and review), but provides relatively extensive information on the hydrogeological conditions in the project area. A hydrogeologist of appropriate level, as outlined in 1.3.6, should carry out the desk study.

2.3.1 Existing Borehole Information

If there is any national or regional/local repository of borehole information available (often the NGRB), borehole records for the project area should be reviewed. In general, it is desirable to review borehole and other groundwater resource records for an area encompassing approximately ten (10) kilometres radius surrounding the community or project area. Because boreholes with motorised pumps can be some distance from the required users, a larger area could be considered (i.e. 20 km radius or more) when collecting data to assist in target area delineation. Generally the following types of information should be compiled from the existing borehole records, if available:

- Geology and lithologies of subsurface formations;
- Water quality and its variation (spatial and according to depth) in the area;
- Average and maximum borehole yields;
- Groundwater levels;
- Information to assess probable success rates;
- Commonly used or required drilling methods;
- Information on drilling difficulties;
- Information on types of aquifers encountered;
- Depth to water strikes and aquifer horizons;
- Data from pumping tests; and
- Existing land use planning

2.3.2 Maps

Maps of the project area, if available, can provide useful information to guide siting activities. At a minimum, the appropriate topographic and geologic map(s) should be consulted to assess the distribution of geologic units in the area, their disposition and geologic structures that may be important to groundwater occurrence. If a hydrogeologic map(s) is available that covers the project area, it should also be consulted. Other maps that may be consulted include:

- Orthophoto maps;
- Geophysical maps (i.e. aeromagnetic surveys, gravity surveys, etc.);
- Saline water interface maps in coastal areas;
- Special purpose maps (i.e. groundwater vulnerability, recharge potential, etc.); and
- Land use and development planning maps.

2.3.3 Water Quality Analyses

Historical water quality analysis data are often available for existing boreholes in the area with the appropriate government institution (i.e. Ministry of Health, Geologic Survey, etc.). The critical parameters that must be examined (but not limited to) are:

- Salinity (total dissolved solids mg/l or electroconductivity µS/cm)
- Fluoride (F^-)
- Nitrate (NO_3^-) and Nitrite (NO_2^-)
- Total coliforms
- Faecal coliforms
- Sodium (Na^+) and Potassium (K^+)
- Chloride (Cl^-)
- Magnesium (Mg^{+2})
- Sulphate (SO_4^{-2})
- Hardness (if required)
- Carbonate (CO_3^{-2}) and Bicarbonate (HCO_3^-)
- pH, Eh and turbidity

If the purpose is for drinking water, the data should be compared with the existing national drinking water standards, or the WHO standards for drinking water if no national standard is available. The WHO drinking water standards are presented in Appendix C for reference. For other purpose (i.e. irrigation or industrial), the parameters should be compared to relevant or specific standards.

In areas of variable or poor groundwater quality, hydrochemistry data should be plotted on Piper diagrams (or others, i.e. Durov, etc.) to assess the various types of groundwater possibly associated with specific areas, as well as trends in groundwater evolution. Other pertinent information, such as regional groundwater flow patterns and areas of recharge or discharge, may be inferred from plotted groundwater chemistry data.

2.3.4 Existing Reports

Available technical reports covering the project area should be collected. These may include reports (water supply, exploration/assessment, environmental) from government projects, private consultants or NGO's. The information obtained will largely be similar to that from existing boreholes (2.3.1) but may include interpretation and analysis, detailed maps and cross sections.

2.3.5 Aerial Photograph Review

Aerial photographs can be examined both singly and under stereoscope for three-dimensional viewing. Extensive information and features pertinent to borehole siting can be obtained from aerial photographs such as:

- Land morphology and topography;
- Geologic contacts;
- Geologic structures (faults, fracture zones, folds);
- Surface water features (river/stream courses, wetlands, lakes);
- Vegetation patterns and anomalies;
- Land use patterns.

Pertinent analysis from the aerial photo (such as structural lineaments) should be transferred onto the base map, if possible, to facilitate the target delineation.

2.3.6 Pumping-test Data

If available, pumping test data for existing boreholes in the study area should be collected and analysed. Analysed data may be available from existing reports, but the analysis should be reviewed in terms of the quality of the interpretation, data quality, applicability of the methods utilised and the potential for use of additional or alternative methods.

Interpretations from pumping test data are particularly important to motorised borehole siting programmes due to the need to locate areas of highest yields and transmissivities, where available drawdown is maximised, where potential negative boundaries are less likely, and where possible recharge sources (positive boundaries) or leakage may improve sustainable yield potential.

2.3.7 Tentative Borehole Design

From the available information on the area hydrogeological environment, a tentative borehole design should be conceptualised with associated costs. This is particularly important in specific areas where an alternate system for groundwater abstraction may be required. For example in coastal areas where thin fresh water zones/aquifer exist, a conventional borehole may not be appropriate and instead infiltration gallery or other similar systems may be more appropriate to minimise or eliminate saline water intrusion during pumping.

2.3.8 Additional Activities

If project budget and timeframes allow, the following additional activities, although not essential, are also desirable as part of the desk study. These may be particularly important in areas of complex or limited groundwater occurrence.

Satellite Imagery Analysis

In some cases, existing satellite images for a given project area may be available from various government institutions (i.e. agriculture, meteorology, planning departments). Older (i.e. 1980's) Landsat images can also often be purchased at reduced prices and are generally as useful as recent images (aside from looking at recent land use or vegetation patterns). Also when a handpump borehole project covers a large area or many communities, a single satellite image may be more cost effective than many aerial photographs, provided the resolution is good. Satellite images provide similar information to aerial photographs, but also offer important advantages such as:

- A synoptic coverage which can allow definition of large and/or faint structures;
- A wide range of processing methods and techniques which can highlight or emphasise various features;
- Images that contain a much broader band of energy (unlike photographs which record only visible light) and can therefore show features which may not be visible in aerial photographs.

The processing and quantitative interpretation of satellite images generally requires advanced computing equipment and a specifically qualified professional. However, a simple print of a satellite image may still be useful to an experienced professional person in the absence of additional facilities.

2.4 RECONNAISSANCE FIELD SURVEY

A reconnaissance survey of the area proposed for borehole installation should be completed by an appropriately qualified hydrogeologist (refer 1.3.6) as part of the siting process. At this time input from local authorities and community members can be solicited, if applicable, which may impose limitations on the possible areas for siting of the boreholes. Furthermore the reconnaissance allows first hand examination of the project area and field checking of features or boreholes of interest identified during the desk study.

An assessment of contaminant sources and pollution potential of possible siting areas should be carried out, particularly in fractured and shallow unconsolidated aquifer areas and anywhere aquifers are developed at shallow, near surface depths. A reconnaissance survey should include, but not be limited to, the following activities:

- Observation of the geomorphology of the project area. Special focus should be directed toward topography, surface water features (streams, wetlands, standing water), and springs;
- A detailed inventory of existing groundwater sources, such as boreholes, springs, dug wells (including their location by GPS), and verification of information and data on these sources (boreholes, springs, dug wells) that are compiled from existing reports, databases etc.
- Assessment of the presence and distribution of vegetation that may be associated with groundwater;
- Examination of local geology and structure, including lithology, degree of weathering, evidence of folding or faulting and orientation of fractures, cleavage, bedding planes, etc.;
- Verification of features identified with, and/or interpreted from, the aerial photographs/ satellite imagery (ground truth checks);

- Measuring of water levels in existing boreholes and wells. Measurement of field parameters (EC, pH) and/or collection of water samples for laboratory analysis;
- Discussion with community members in terms of existing water sources (boreholes, springs, wells, streams), their reliability and any perceived quality problems;
- Assessment on the accessibility to site during drilling and logistical information for follow up geophysical survey (if required); and
- Location and examination of boreholes and wells not identified in the desk study.

2.5 ADDITIONAL ACTIVITIES

In some cases of complex groundwater occurrence, and where project resources allow (normally for projects of bigger magnitude), additional activities can be carried out during the reconnaissance phase to improve understanding of the area prior to geophysical surveys.

2.5.1 Limited Hydrogeologic Mapping / Data Collection

In addition to general reconnaissance, some level of limited hydrogeologic field mapping and data collection can be included. In areas where existing geologic maps are at a small scale (i.e. 1:250 000), or control data and detail are significantly limited, some hydrogeologic mapping may be valuable in high capacity motorised borehole siting programmes. This is often true in areas where targeted aquifers are fractured and outcrop exposure is present. Mapping of specific geologic units, contacts and structures in the field can add greatly to the understanding of the area and focus geophysical surveys on areas of highest potential. In areas underlain by unconsolidated sediments (i.e. river alluvium) limited hand augering surveys can be implemented to gain valuable information on depth to groundwater, depth to bedrock, water quality of shallow aquifers and shallow lithologies.

2.5.2 Water Point Inventory

If sources of existing borehole and well data are limited, non-existent, or considerably out of date, a detailed inventory of water points in the study area may be desirable. The survey would generally include collection of GPS coordinates for each water point, recording of any number or marking, measurement of water levels (boreholes, wells) or discharges (springs), description of water point type and condition, measurement of field parameters and collection of water samples for analysis.

2.6 TARGET AREA DELINEATION

After completion of the desk study and reconnaissance, all of the data and information should be thoroughly reviewed and analysed by a suitably qualified hydrogeologist. To assist in the spatial interpretation of the data, a basemap should be developed for the project area. This may be in a computerised (digital) format or drafted onto an existing topographic or geologic map. The following information should appear in the basemap:

- Borehole, well and spring locations (specific data associated with features can be entered as appropriate i.e. borehole yield, water quality, static water level, water strike depth).
- Geologic contacts and structures (previously mapped as well as those identified during reconnaissance), inferred geological structures and lineaments derived from air photos and/or satellite images;
- Groundwater flow direction (if possible); and
- Any other pertinent information (i.e. wetland/marsh areas, possible pollution sources, delineation of water quality zones). Contoured data can also be included (i.e. water level, TDS, transmissivity, yield).

Thorough analysis of all the available, collected and synthesised data in the project area, areas/zones of potential groundwater occurrence should be delineated for follow up borehole siting and geophysical survey (if required). These target areas should be prioritised and clearly marked on the base map. Choice of the appropriate geophysical methods for the type of groundwater occurrence and hydrogeological environment also be made at this time if required.

Although not strictly limiting the subsequent geophysical surveys, the target areas form a focus for the surveys in order to ensure efficient collection of data. Based on the geophysical method(s) planned for the survey, a tentative plan can be developed based on the target areas. Preliminary locations, lengths and alignments of planned profile lines can be defined to intersect identified structures and features, and locations for soundings (including calibration soundings) can be chosen. This would form the initial plan for the geophysical survey and will allow estimation of the cost and required timeframe for the survey.

Section 3: BOREHOLE SITING

3.1 GENERAL

3.1.1 Scope and Purpose

The standards and guidelines covered under this section are for the siting of boreholes. These apply to all water supply boreholes (for motorised pump as well as handpump installation) constructed by manual or mechanical means, aside from those that meet the definition of "hand dug wells". The standards and guidelines presented in this section should be treated as a follow-up of the previous section on desk study and reconnaissance survey for target area delineation.

The purpose of borehole siting is the location of areas and specific sites that are most likely to provide the quantity and quality of groundwater required on a sustainable basis.

3.1.2 Principle

Borehole siting is the process of locating potential site/s for the drilling of boreholes where there is the highest probability of drilling a borehole of a particular yield. In no case does the process guarantee success. However, with proper use of applicable methods, understanding and experience, the probability of success can be maximised. In addition, siting also takes into account factors such as physical, legal, social and environmental aspects, which may influence where boreholes can be sited.

3.2 CONTROLLING FACTORS

Although, siting is primarily defined as locating a borehole site for drilling based on the probability of obtaining a required yield, there are other factors that are equally important to the siting process. Although some of these factors are considered at the desk study stage, at the siting stage the actual location of the planned developments (i.e. boreholes, access tracks for drilling rigs) becomes more specific and defined.

3.2.1 Legal Aspects

Legal aspects reflecting the right of drilling a borehole on the proposed site and abstracting the water need to be addressed. A legal binding (Wayleave) may be required between the implementing agency and the owner of the land to cater for access to the site and compensation for any damages. It is also important to establish the ownership of the borehole. Clearance for access to private land should always adhere to applicable local and national laws and regulations.

3.2.2 Social Aspects

Social aspects are particularly important in rural water supply programmes. The community's wishes should be considered with regard to the location of the site; such as the distance from the users (handpump) or the possibility of the site being on private land (i.e. in someone's field). There are also possible issues to be addressed if a site falls within another community area. These issues should be resolved through the appropriate community structure/committees. Involving and informing the community during the siting process also develops a sense of responsibility and ownership among them for the project and facilitates the operation and maintenance at a later stage (refer 9.4).

3.2.3 Accessibility

Accessibility should be viewed with regard to the accessibility for the drilling rig and equipment as well as accessibility for the community to fetch water (for handpump programmes) and to operate and maintain the boreholes. There is no point in having a high yielding borehole that is not easily accessible to the community or the operators. In most cases there are national guidelines in regard to the maximum distance within which handpumps (or any other type of water points) should be available to the community. In case these guidelines are not available, a distance of 250 m should be used as a guideline for handpumps.

3.2.4 Environmental Aspects

Selected sites for drilling should be assessed in terms of the potential for pollution, contamination and environmental threats. The following criteria should be followed:

1. National guidelines on environmental impact assessment should be considered in terms of the potential development areas if regulations so require (refer 1.3.2 for more details). If available, findings of existing EIA study for the proposed development or area should be referred to.
2. The site should be placed a sufficient distance away from any pit latrine, graveyard or similar pollution source on the upstream or downstream side. The distance should be based on local geological and hydrogeological conditions.
3. The site should be assessed for any possible contamination between aquifers of different quality. For example, if the developed aquifer is adjacent to, or in hydraulic contact with, another aquifer of poor quality (e.g. saline), the potential of degradation of the good quality aquifer by the poor quality aquifer, as a result either of drilling or later by on-going abstraction, must be considered.
4. The planed abstraction should not cause saline water to move inward into the fresh water aquifers in coastal areas.
5. There should be no activity that may create pollutants (i.e. industrial facility) within 75 m of the site. This distance may vary based on the local site specific conditions.
6. The site should be assessed for pollution potential from any nearby mining/ agricultural/ industrial activity, waste dumping site, fuel/oil storage facilities etc.
7. The site should be assessed in relation to storm water/ floodwater pounding in the vicinity.

3.2.5 Yield Requirement

This is an important aspect of borehole siting. The expected yield that is to be achieved by drilling the selected sites should be clearly defined to the best degree allowed by the findings of the Desk Study and Reconnaissance Survey. Priority should always be given to achieve the target yield from the minimum number of sites, taking the above factors into consideration. Wherever applicable, possible interference from the nearby existing boreholes should also be considered.

3.3 SITING TECHNIQUES AND METHODS

An appropriate siting component is crucial in all environments to optimise success rates and ensure long term sustainability of borehole yield. The actual format and methods employed as part of the siting component vary considerably based on hydrogeological conditions and required yields, as well as available budget, equipment and expertise.

The two basic techniques that should be followed for siting are:
1. The geological and hydrogeological technique
2. The geophysical technique.

The first technique may be used alone while the second follows the first when required.

3.3.1 Geological and Hydrogeological Technique

This is the most basic siting technique. Under this method, siting is based on the findings of the Desk Study and Reconnaissance Survey (refer Section 2:). The sites are qualitatively selected by appropriately qualified personnel (refer 1.3.6) based on the favourable geomorphological, geological and hydrogeological factors as well as field observations and previous experience in the area. This siting technique alone is generally best suited under the following conditions:

- The aquifer is of relatively extensive and homogenous nature (e.g. coastal / alluvial aquifers, extensive porous sandstone aquifers etc.).
- In fractured aquifers, where extensive outcrop is present and significant structures are easily located in the field and on air photographs.
- The aquifer(s) is well explored and established from previous groundwater development/exploration programmes.
- The cost of geophysical survey to gain higher success rate is more than the cost of drilling (due to limited depth of boreholes, simple design etc.) additional boreholes (without geophysical surveys).

In such cases where geophysical survey is not required, the desk study and reconnaissance survey may conclude with identification of potential sites for drilling.

3.3.2 Geophysical Techniques

These techniques are used in conjunction with the geological and hydrogeological appraisal and should be viewed as a follow-up to the desk study and reconnaissance survey (when required), as outlined in the previous section.

The geophysical techniques most widely applicable for groundwater exploration are the electrical, electromagnetic and magnetic methods. These are the most direct methods, whilst other methods indirectly provide information on subsurface geology and structure.

Depending upon the objectives of the project and geological and hydrogeological environment, a combination of methods can be used for exploration. For example in coastal areas it may be of particular importance to locate the freshwater/saline water interface and, therefore, resistively sounding and profiling followed by specific analysis may be required.

In the SADC region the most commonly used methods are resistivity and magnetic, while increasing application of electromagnetic is being noticed in some member states.

The geophysical methods involve measurement of physical properties of rocks such as resistivity, conductivity, magnetic susceptibility, density and acoustic properties. Some physical properties of rocks show significantly different behaviour when they are saturated with water and can be identified by appropriate geophysical method(s). Therefore selection of appropriate geophysical method(s) is extremely important. Some of the factors that should be considered while planning geophysical survey are as follows:

- Propose an initial geophysical hypothesis based on geological understanding of the project area and expected aquifer's physical properties.
- Consider the nature of stratification of the geological formations (wherever applicable).
- Consider the depth of saline water interface in coastal areas.
- Consider the orientation and geometry of expected water bearing features (such as fractures).
- Assess the type and thickness of regolith and weathered zone.
- Take into account the depth of aquifers from surface and the nature of the overlying formations.
- Determine the degree of confidence required for achieving a successful borehole.
- And finally, consider the resources available - financial, types of equipment and expertise.

Based on an assessment of these and any other pertinent factors, one can then choose a method or a combination of methods.

Electrical Methods

Electrical methods are commonly classified as resistivity, induced polarisation (IP) and self-potential (SP) methods. The resistivity method is the most widely used method in siting boreholes in the SADC region. The advantage of the method is that it involves lower instrumentation cost. In addition, it is applicable in most of the geological conditions except in areas covered by thick, highly resistive material (basement complex or calcrete). Resistivity surveys are conducted in sounding (known as Vertical Electrical Sounding or VES) and profiling (known as resistivity profiling) mode. They provides information on subsurface resistivity distribution that is interpreted to infer depth and thickness of aquifers, faults, saline water interface and lithological contacts, which are important features in groundwater exploration. IP and SP methods are less applicable methods and only used in special cases (i.e. to differentiate between clay/sand content in an unconsolidated aquifer).

Electromagnetic Methods

Electromagnetic methods are also used in groundwater exploration, though not extensively in the SADC region. This is largely due to high instrumentation costs as well as need of qualified geophysicists to interpret the data. Electromagnetic methods for groundwater exploration are Horizontal Loop Electro-Magnetic (HLEM) profiling and Transient Electro-Magnetic (TEM) soundings. These methods provide information on subsurface conductivity variations. The HLEM profiling method is fast and effective in areas where groundwater is confined to vertical and sub-vertical fracture zones. The TEM method is extremely effective in identification of fresh and saline water in unconsolidated sediments and has better resolution than VES method. The advantage of these methods is that they are applicable in areas covered by thick resistive material where resistivity methods are ineffective

Magnetic Method

The magnetic method is a fast and cost effective method. It involves lower instrumentation cost. The method is based on measuring the Earth's magnetic field intensity and its variation, which is interpreted in terms of subsurface geology. It is widely used as a reconnaissance tool in groundwater exploration. The advantage of this method is that it is applicable in most of the common geological conditions. This method provides useful information in delineating subsurface geology, faults, lithological contacts and intrusive rocks. Numerical modelling of magnetic data, in conjunction with geology, gives an estimation of depth and disposition of magnetic sources.

Gravity Method

The gravity method is a slow and less commonly used method in groundwater exploration. The time involved in data collection is high as compared to all other geophysical methods. The instrumentation cost however is not very high. This method measures the Earth's gravitation force and its variation, which is interpreted in terms of subsurface geology, faults, lithological contacts and basement structure.

Seismic Methods

The seismic methods are also less commonly used for groundwater exploration. These methods involve high instrumentation cost. Seismic methods are classified as seismic refraction and seismic reflection methods. Both methods provide information on acoustic properties that are used to infer subsurface geology and basement structure.

3.4 MISCELLANEOUS

3.4.1 Number of Sites

Sufficient sites should be chosen, given the required yield and an assessment of the expected success rate. The number of sites selected for each successful borehole is estimated as part of the Desk Study. At a minimum, 2 sites for each successful borehole should be selected. This may be increased to 4 or more per successful borehole in complex environments.

3.4.2 Prioritisation of Sites

The sites should be prioritised and a logical sequence of selection of sites from the priority list should be provided. As drilling results become available, re-prioritisation of sites and re-interpretation of data should be on-going to maximise success rates. In some cases additional siting activities may be warranted during drilling or after an initial phase of drilling.

3.4.3 Marking of Sites

The sites should be properly numbered and clearly marked in the field so that the driller can locate the site even if delays occur prior to mobilisation. A document detailing the sites and including location information (including a sketch map) should be created and kept in project records as well as provided to guide drilling crews. Whenever possible sites should be located by GPS.

3.4.4 Site Selection Forms

In addition to the site selection report (refer Section 11), a standard form as presented in Appendix B (Form ST-1) should be completed and submitted to NGRB and the implementing agency (or the Client). For smaller scale projects (public as well as private) involving a few boreholes only, where the site selection report may not be required, these forms with appropriate attachment could alone fulfil the purpose.

Section 4: BOREHOLE DRILLING AND CONSTRUCTION

4.1 GENERAL

4.1.1 Scope and Purpose

The standards and guidelines in this section cover the drilling and construction of water boreholes to be fitted with either handpumps or motorised pumping equipment. This standard applies to all water supply and water injection wells constructed by manual or mechanical means, aside from those that meet the definition of "hand dug wells".

4.1.2 Pre-requisite for Drilling of Boreholes

1. Sites for drilling should be available for possession of site by the Contractor and all issues of accessibility, land acquisition and crop compensation (if applicable), etc. should be resolved in advance.
2. Wherever applicable, the driller should receive permission from the NGRB and should obtain the number for the borehole.

4.1.3 Supervision of Drilling

Drilling should be undertaken by qualified drillers and, wherever applicable, the driller should be in possession of proper registration/ licence to carry out the drilling. All the drilling operations should be supervised by a suitably qualified hydrogeologist or technician. Boreholes that are to be equipped with handpumps should be supervised by a Drilling Technician (TD) of level B or higher with support from a Hydrogeologist (HD) of level C or higher. For boreholes to be equipped with motorised pumps, the Drilling Contractor should be supervised by a Hydrogeologist (HD) of level D or higher, supported by the Project Manager (PM). For a full description of the qualifications of the technical personnel refer 1.3.6.

The Contractor will be directly responsible to the Borehole Owner and his site representative, i.e. the technical supervisor, for all site-related issues and will provide all information as required by the Borehole Owner and according to applicable local laws and regulations

The drilling contractor should be fully responsible for being aware of all regional and national laws and regulations regarding the drilling of water boreholes and should be fully in compliance with these laws and regulations.

4.1.4 Data Recording

A drilling form for data collection is presented in Appendix B. The form should be completed by the technical supervisor and countersigned by the driller wherever similar forms are not available at national level. In some cases it may be desirable to update the national forms. Only in cases where a technical supervisor is not available (such as private boreholes), the form should be completed by the driller and then countersigned by the owner. The Drilling Contractor should keep one copy of the drilling record in his files and provide the second copy to the owner when the technical supervisor is not available. One certified copy of the forms must be supplied to the NGRB.

4.1.5 Pre-mobilisation Meeting/Agreement

Prior to commencement of drilling activities, a pre-mobilisation meeting between the client (IA), technical supervisor (hydrogeologist/engineer/qualified technician) and contractor, is essential to ensure smooth implementation. During the meeting, the following should be discussed, agreed upon and minuted, with the minutes signed by all parties.

- Location of drilling site(s)
- Anticipated number of boreholes to be drilled
- Commencement date
- Drilling methods
- Geology of the area
- Any known drilling difficulties or possible problems in access
- Expected maximum drilling depths and diameters
- Borehole design and casing installation method
- Type and expected duration of development (including type of equipment required)
- Expected time to complete the borehole(s)
- Any other special requirement

4.2 DRILLING

4.2.1 Choice of Drilling Method

The choice of drilling method or methods is primarily site specific, and should be chosen based on geologic and hydrogeologic conditions (i.e. the nature of expected formations, aquifer type, depth to water level, anticipated yield, etc.), the intended use of the borehole, and the local environment.

The primary drilling methods for boreholes employed in the SADC region include the following:

Rotary air percussion

This technique employs down-the-hole (DTH) hammers and air compressors, which are connected to the drilling string. Drill cuttings are carried to the surface by the return air flow. Although air alone can be used, various foaming agents are also often used to improve penetration through the improved removal of cuttings. Odex type hammer bits can be used in unconsolidated or collapsible formations allowing casing to advance with the drilling bit.

Cable tool (percussion)

Drilling by this method involves the repeated up and down breaking action of a heavy steel bit attached by steel cable to the spudding mechanism on the rig. Materials are removed by various bailer arrangements. Drilling in unconsolidated formations (primarily below the water table) is also often accomplished by simple bailing of the borehole while advancing the casing.

Mud Rotary Drilling

This method uses a water-based drilling mud, which maintains an open bore during drilling (particularly in unconsolidated formations) and facilitates removal of cuttings. Rotary (tri-cone) drilling bits are generally employed, although drag bits may be used in particularly soft conditions.

Rotary Reverse Circulation

In this method the circulation of the drilling fluid (generally air or water) is in a reverse sense (i.e. removed up the drilling string) during drilling. The drilling bits used in flood reverse circulation (with water) are generally rotary (tri-cone) bits, while reverse air circulation drilling uses special DTH bits.

Other techniques that are generally used for handpump boreholes, but in some cases may also be appropriate to drill boreholes for installation of motorised pumps, include:

Jetting

A relatively technically simple and low cost method for installation of shallow, primarily small diameter boreholes in unconsolidated formations. The technique involves the circulation of water or a drilling mud through the drilling pipes via a small pump. Drilling is accomplished by the washing action of the circulated fluid, with the drill string advanced manually primarily under its own weight. Screens are incorporated in the drill string or lowered within the drill string at the completion of drilling. Well points also may be jetted into position (in addition to driving, see below).

Manual Drilling

A method involving various augering techniques, which are manually implemented to develop shallow boreholes in unconsolidated formations. Casing and screens are advanced with the auger or lowered within the auger casing at completion of drilling.

Driving (well points)

For installation of small-diameter water supply boreholes in unconsolidated formations well points are often driven into the soil. Driving is generally carried out by hammering, using a drive pipe or using a mobile powered (i.e. electric) driving device. Simple hammering is not recommended due to the possibility of glancing blows bending or damaging the pipes. Pumping is often accomplished by use of electric suction-type pumps installed at the surface.

A summary of the main advantages and disadvantages of each technique, and their applicability in conditions common in the SADC countries, is provided in the Table below.

Table 4-1 : Summary of Drilling Methods

Method	*Advantages*	*Disadvantages*	*Applicability*
Cable Tool	-Low cost of equipment -Can drill in most formations -Accessible to remote sites (i.e. when pulled by tractor) -Low maintenance -Very available in region	-Slow penetration -Often requires many casings of various diameters -May be difficult to distinguish water strikes	Most consolidated and unconsolidated formations in the SADC region except for very hard basement
Air rotary	-Can drill many formations -Rapid penetration -Clear delineation of water strikes -suitable for deep drilling -Very available in region	-High cost of equipment -Large/extensive equipment required limits accessibility -not suitable for unconsolidated aquifers -Can have difficulty with high yields or collapsing conditions.	Excellent for most consolidated formations in SADC region and dry unconsolidated (i.e. Kalahari Beds); Best in hard rock (i.e. basement, basalt)
Mud rotary	-Can drill many formations -Suitable for unstable, collapsible conditions -Can drill through high yielding water strikes or cavities	-Penetration through hard formations can be slow -Expertise, equipment not readily available in many countries -Difficult to assess water strikes -Can result in formation damage in some aquifers -Can have poor sample recovery	The primary method for drilling in Kalahari Beds and coastal aquifers; also useful for drilling in sedimentary bedrock aquifers (i.e. Karoo)
R/C rotary	-Suitable for sedimentary and unconsolidated formations -Best for large diameter	-Requires large amounts of water -Penetration through hard formations can be slow	Although R/C is not well known in the region, experience in Botswana has shown it

	boreholes -Excellent sample recovery -Little or no damage to aquifers -Less development required after drilling	-Expertise, equipment not readily available in many countries -Difficult to assess water strikes	is very effective for Kalahari Beds aquifers
Jetting	-Excellent for many shallow unconsolidated aquifers -Low cost -Highly portable -Good penetration	-Cannot penetrate consolidated (i.e. calcrete, silcrete) layers -Limited diameter of completed borehole (generally <165 mm) -Limited to shallow aquifers	Experience in Zambia has shown it is an excellent method for community water supply (HP) in Kalahari Beds aquifers as well as river alluvium
Manual	-Excellent for many shallow unconsolidated aquifers -Extremely low cost -Highly portable -Community involvement	-Cannot penetrate consolidated (i.e. calcrete, silcrete) layers -Limited diameter of completed borehole (generally <165 mm) -Limited to shallow aquifers -Slow penetration	Used extensively in Tanzania, but has potential application in many SADC countries, primarily for Kalahari Beds, alluvium
Driving (Well points)	-Relatively low cost -Highly portable -Good for river alluvium	-Only for shallow installation (<6 m) -Susceptible to damage during flood -Can clog -Requires powered pumps	Used for town water supply from riverbeds in Lesotho as well as for private sources in many countries

4.2.2 Drilling Equipment

The Drilling Contractor should provide, in good operating condition, all necessary equipment required for the specified method(s) for drilling of the borehole, as indicated in the drilling contract document. The Drilling Contractor is free to alter or suggest alternate methods of drilling if appropriate, in consultation with the Borehole Owner. However, all boreholes should be constructed in a manner that should guard against the waste or contamination of the groundwater resource. It may be necessary to drill and construct boreholes with significant additional or alternative requirements or methods or materials as defined in this document.

4.2.3 Formation Sampling and Record Keeping

Formation Sampling

Samples must be taken by the Drilling Contractor at 1 meter intervals and laid out in a neat and orderly fashion at the drilling site for inspection by the technical supervisor. Prior to drilling, the contractor should be sure (and demonstrate to the supervisor) of the length of the various components of the drilling string to ensure that the sample depths are correct. Any change of drilling equipment after drilling has commenced should similarly be accurately measured. To avoid inadvertent mixing of samples or disturbance by natural factors (rain, wind, animals), it is desirable that drilling samples be set out in a sample box or equivalent which has separate compartments for each sample. The specific interval represented by the sample (i.e. 30-31 meters) should be clearly indicated, particularly for collected samples. The Drilling Contractor should take every possible precaution against sample contamination due to poor circulation, caving or hole erosion. A guide to sampling methods is presented in Table 4-2 below:

Table 4-2 :Guidelines on Sampling Method

Drilling Method	*Sample Collection and Handling*
Air rotary	Container placed next to the borehole (a shovel is not acceptable) such that cuttings are collected; a representative sample from this container should then be taken; cuttings from consolidated formations can be rinsed to remove fluids as required; cuttings from unconsolidated formation should not be washed.
Cable tool	A representative sample of the cuttings recovered from the bailer to be collected over each meter of drilling; cuttings from consolidated formations may be washed if required, cuttings from unconsolidated formation should not be washed.
Mud rotary, Jetting, Fluid Reverse circulation	Samples collected in a bucket from the borehole (mud rotary, jetting) or from the discharge pipe (fluid reverse); a representative sample from the interval should be taken and excess drilling fluid squeezed out. The sample should not be washed.
Air reverse circulation	Cuttings collected from the discharge; a representative sample collected for the interval; cuttings from consolidated formations may be rinsed to remove fluids as required; cuttings from unconsolidated formation should not be washed.
Manual	Samples should be collected from the bucket auger or sampling tube; a representative sample for the interval should be taken.
Driving	Sampling not possible.

Although not mandatory, a sample splitter is recommended to accurately obtain a representative sample when sample volume is high. Samples may then be collected, marked and preserved if prescribed in the contract document by the owner/supervisor. If required by national regulations, the necessary samples will also be submitted to the respective national borehole archive by the Drilling Contractor.

Basic Drilling Data

In addition to any reporting required by the contract document or owner/supervisor, the Drilling Contractor should keep at least two copies of the following records while drilling activities are underway. The records should include but may not be limited to:

- The name and address of the Drilling Contractor and the Borehole Owner.
- Drilling Location (including an accurate sketch map with at least one significant landmark and estimated distances). GPS coordinates are recommended as the best method of locating the borehole.
- Reference number for the borehole (official number or temporary number).
- Dates of drilling.
- Drilling methods employed.
- Total depth of completed borehole.
- Drilling diameter and depth of changes in diameter.
- The depth of the sanitary seal, if applicable.
- Rate of penetration per meter.
- Depth to first water strike and any subsequent yield increase (when drilling method allows this).
- Depth and description of well casing and screens.
- The type, installation interval and quantity of gravel pack if installed.

- The type and installation interval of any other materials installed in the annular space (i.e. backfill).
- A clear description of the reference point (datum) for all depth measurements.
- Depth to static water level on each day of drilling and after final completion of the borehole, with reference to the specified measuring point.
- Estimated borehole yields, where possible, and a description of the method employed (i.e. air blowing, bailing, etc.).
- Quality of water. For motorised boreholes a minimum of an EC meter for field testing is required. Additional field instrumentation (i.e. pH, fluoride kit, etc.) can be included as appropriate. For handpump boreholes, if no field testing instrumentation is available, at least qualitative descriptions should be included (i.e. fresh, tasteless, odourless, salty, turbid, etc.).

The above information should be recorded on the standards forms (refer 4.1.4). In some cases additional sheets may be required to record additional information.

4.2.4 Drilling Fluids

Drilling fluids are utilised during drilling to stabilise the bore and improve the removal of cuttings. There are two major types of drilling fluids used in the SADC region: fresh water based fluids and air based drilling fluids. The primary types of fluids for both fresh water based and air based fluids are summarised below:

Table 4-3: Types of Drilling Fluids

Fresh water-based	*Air-based*
Clean, fresh water	Dry air
Water with clay additives	Mist: water droplets in the airstream
Water with polymeric additives	Foam: use of surfactant and water in the airstream
Water with clay and polymeric additives	Stiff foam: foam with polymers and/or bentonite

Water-based fluids are mixed and stored in either pits excavated at the site or in manufactured tanks transported to the site. When using water-based fluids, excavated pits should be lined with plastic sheeting or other material that does not allow mixing of natural materials with the drilling fluid. Surfactants (detergents) and water used in air-based fluids are generally injected into the airstream from a container mounted on the drilling rig.

Types of Fluid Additives

The acceptable types of additives for drilling of water boreholes are as follows:

1) Dissolved additives.
   -Surfactants, drilling detergents and foaming agents.
   -Mud thinning agents and inorganic phosphates.
2) Non-dissolved additives.
   -Biodegradable polymers
   -Native solids (sand, clay)
   -Bentonite

It is important to note that the use of some of these fluid additives (such as bentonite and native clays) must be used with care and ideally only under supervision by a Professional Person, due to their ability to permanently damage productive aquifer horizons.

Monitoring of Fluid Properties

In order to ensure that drilling fluids are fully removed from the bore after completion of drilling, and to avoid significant permanent damage to formation or water quality in aquifer horizons, it is necessary to monitor and adjust their properties during drilling.

The following table indicates the properties that are generally monitored during drilling. For motorised pump boreholes, monitoring of fluid density and viscosity are required (filtration and sand content being optional). For handpump boreholes, monitoring is still desirable to ensure efficient drilling and maximum yields. Fluids should be monitored and tested as per the following table.

Table 4-4 : Monitoring of Fluid Properties

Fluid	*Monitoring Period*	*Test*	*Standard*	*Comments*
Air based fluids	n/a	n/a	n/a	Must be developed at borehole completion until water is clear
Natural / Fresh water based fluids	4 hours or every 20 m	Fluid density (Mud balance)	1.1-1.3 kg/l	Unless aquifer is under flowing artesian conditions
		Viscosity (Marsh funnel)	30-85 s	Unless aquifer is under flowing artesian conditions
		Filtration (Filter press)	2.4 mm, max. 20 ml water loss	
		Sand content >200 mesh (sand content set)	≤ 5%	

Source: Driscoll, 1986

A description of the required testing equipment and testing procedures is provided in Appendix D.

4.2.5 Drilling Diameter

The minimum drilling diameter should take into account the possible requirement for screening and gravel packing of the borehole, the planned pump size and the anticipated yield of the targeted aquifer. The diameter for boreholes should also be sufficient for the insertion of a small diameter access pipe to allow monitoring of static and dynamic water levels with the pumping equipment in place. For wellpoints, the casing diameter should be sufficient for the expected yield as well as for any pumping equipment that may be inserted if a suction type manifold is not to be used. For motorised pump boreholes, the minimum completed open borehole (not cased/screened in the aquifer horizon) diameter should be 152 mm.

4.2.6 Monitoring During Drilling Activities

As drilling progresses, various observations should be recorded and measurements taken to assist borehole design as well as to be included as part of the borehole record. The data collected should be recorded on forms as provided in Appendix B.

Yield

Whenever the drilling method allows, borehole yield should be estimated and recorded during drilling. When drilling by air rotary methods (DTH), blowout water should be channelled to a 90^o V-notch weir for measuring of blow out yield. Drilling will be halted during yield measurements and the yield measurement should be taken only when the discharge has stabilised. Data for conversion of V-notch measurements to yield are provided in Appendix

C. During cable tool drilling, the yield will be estimated by bailing of the borehole during a set period of time.

Yield measurements will be made periodically after water has been struck, with attention to increasing yield or as specified by the Borehole Owner/Supervisor. The total estimated yield at the completion of drilling should be recorded.

Water Quality

When possible (depending on drilling technique), water quality should be monitored during drilling after groundwater has been encountered. Groundwater quality will be monitored for boreholes drilled by air rotary, cable tool and manual methods. For motorised pump boreholes the minimum requirement is that either electroconductivity (EC) or directly measured TDS be monitored at a minimum of 6 meter intervals, or more regularly if appropriate. Other parameters that may be important to monitor in the field include pH, temperature and fluoride content.

For boreholes that are to be used for water supply, at least one sample should be collected at the completion of drilling and construction (i.e. after development) for analysis by a suitable laboratory.

Special care should be taken during drilling in coastal areas and inland salinity areas (e.g. Kalahari). Prior to drilling, the driller as well as drilling supervisor should have a preliminary idea about the depth of saline water and/or depth of various aquifer layers with different salinity. This information should be available from the existing data and hydrogeological model of the area or from the geophysical survey. During the drilling EC should be carefully monitored and recorded. A high level of care is also required to avoid contamination of fresh water aquifers from the saline water.

General Drilling Information

In addition to the basic information recorded about the borehole during drilling (4.2.3), significant details of the drilling process should also be recorded. The types of information that may be significant include collapsible zones, lost circulation zones, penetration rates (per meter), and drilling behaviour ("chattering", uneven advance, jamming).

4.2.7 Borehole Geophysical Logging

Geophysical logging is often desirable or required to properly drill and construct a borehole. Depending on the type of sondes utilised, it may be required to log the borehole prior to installation of casing and screens. In these cases drilling must be stopped and the drilling string removed to allow logging of the borehole. If the borehole is being drilled with a drilling mud, circulation and conditioning of the mud should be completed prior to removal of the drill string such that cuttings are fully removed and the sand content of the mud is acceptable. A description of the typical sondes used for geophysical logging and their characteristics are presented below:

Table 4-5 : Characteristics of Sondes

Sonde	*Data collected*	*Application*	*Can be used in cased borehole*
Caliper log	Diameter of borehole	Location of collapsing zones, fractured zones	No
Resistivity (single point, normal, lateral)	Resistivity of the formation;	Lithology interpretation (i.e. clay-sand, contacts); water quality (dissolved solids)	No
Spontaneous Potential	Natural electrical potential	Lithologic contacts	No

Gamma	Natural radioactivity	Lithology interpretation (primarily clay-sand)	Yes
Gamma-gamma	Backscatter radiation from source	Bulk density of formation	Yes
Neutron	Backscatter neutrons from source	Total porosity under saturated conditions	Yes
Temperature	Temperature	Vertical flow conditions	Yes
Acoustic	Attenuation of signal from acoustic source	Interpretation of fracture patterns, perched water tables, quality of casing grouting	Yes

4.3 BOREHOLE CONSTRUCTION

4.3.1 Casings

The standards described herein refer to permanent casing installed in the borehole. The selection of temporary casing used only for the construction of the borehole (and thence removed) is left to the Drilling Contractor unless otherwise specified.

Casing Types

The selection of a particular casing type will reflect expected subsurface conditions, financial constraints, available materials and available drilling equipment. The primary types of casing used in the SADC region are steel casing and uPVC casing. Other types of casing which can be used include stainless steel, fibreglass and, in some cases, concrete. All casing installed should be continuous and watertight along its full length. Plain PVC.

Casing Diameter

Casing diameters will be as required for efficient completion of the borehole. For motorised production boreholes the minimum diameter should be sufficient for installation of the planned pumping equipment and such that the uphole velocity during pumping does not exceed 1.5 m/s. For handpumps, final cased diameter should be sufficient for easy installation and removal of the chosen handpump type (refer Section 9).

For motorised pump boreholes, the uphole velocity should be calculated. The uphole (vertical) velocity within the screen/casing barrel is calculated by the following equation:

$$V = Q / \pi * r^2$$

With

V = the design entrance velocity (m/s)
Q = the planned pumping rate or yield of the borehole (m^3/s)
r = the radius of the screen (m)

Casing Characteristics

The required characteristics (i.e. wall thickness') for casing should reflect the anticipated subsurface conditions, including formation and hydrostatic pressures. Under normal conditions, the minimum standard characteristics for steel casings should be as per SABS 719 (1971) and for uPVC casings as per SABS 966 (1998).

Casing should also be selected in consideration of the expected water quality of the targeted aquifer (i.e. the corrosive nature of the water). In some cases this may require the use uPVC or stainless steel screens (primarily for motorised pump boreholes). If aquifer chemistry is not known but corrosive conditions are expected (i.e. based on previous borehole failure), uPVC casing and screens should be used at a minimum until groundwater samples can be analysed.

Other characteristics (relative density, tensile strength, yield strength and impact strength) are left to the discretion of the Drilling Contractor and Borehole Owner, but should be sufficient to ensure necessary performance under the expected conditions.

Drive Shoes

In situations where casing is to be driven (using downward mechanical force) into the borehole or formations beneath the borehole a casing shoe should be attached to prevent distortion of the leading edge of the casing. The casing shoe should consist of hardened steel and be sized to fit the casing correctly.

Sealing of the Bottom of the Casing Assembly

When casings with screens are installed in a production borehole, a short section of plain casing will be installed at the base of the lowest screened interval (the sump). This section should be a minimum of two meter (2m) in length to allow the collection of any formation material or foreign matter that may enter the borehole and settle beneath the screened section.

The base of the casing and screen assembly for production boreholes should be sealed such that no material may enter the casing from beneath. This seal normally consists of a plate welded to the base of the steel casing, a threaded cap, or a bonded cap (uPVC casing). In some cases it may consist of a drillable plug if further deepening of the borehole is anticipated in the future.

4.3.2 Screens

Borehole screens should be installed when subsurface conditions in the aquifer horizon are such that the Drilling Contractor or Technical Supervisor considers that the bore will not remain open during the planned operational life of the borehole (i.e. due to collapsible formations). Screens are required in unconsolidated formations. The choice of type and placement of screens will be based on evaluation of all available information on the aquifer unit. The major types of manufactured borehole screens are summarised below:

Table 4-6 :Screen Types

Screen type	*Design*	*Applications*
Slotted	Slots cut horizontally or vertically in casing	Primarily consolidated formations
Louvered and bridge slot	Openings are mechanically punched into steel which forces a lip of steel outwards	Primarily consolidated formations
Continuous slot screen (wedge wire)	Wedge shaped wire wrapped around longitudinal supports	Primarily unconsolidated formations
Composite	Screens with filter packing material integrated.	Primarily unconsolidated formations
Well points	May be continuous slot type, slotted or wire gauze covered openings	Unconsolidated formations

In some cases the borehole screens can be produced by the Drilling Contractor either on site or at his workshop. Two methods of making this type of screen are possible:

- Screens produced at the surface and lowered into the borehole.
- Screens produced by mechanical perforation of plain casing within the borehole.

Methods of producing screens at the surface include cutting of holes with a cutting torch (steel casing) or slotting of plain casing by a saw (steel and uPVC casing). This method however, should be discouraged, as it is not possible to cut slots of uniform size. The screens should be uniformly cut by machine to specifications.

Screens created by perforation of plain casing (steel) within the borehole can be effected by mechanical devices lowered into the borehole, which perforate the casing at specific points or cut continuous slots vertically along the casing. This is a very specific case and should only be conducted by an experienced driller after consultation with a qualified hydrogeologist.

In either situation, screens produced by the above methods should be constructed such that the aperture openings are regular and consistent in size, effectively block the entrance of excessive loose material into the borehole during pumping and do not reduce the strength of the screened casing such that collapse may occur.

Screen Length and Diameter

The length of screen installed and its diameter should be guided by hydrogeologic conditions. For motorised pump boreholes, screens should be chosen such that the calculated entrance velocity at the apertures is less than 0.45 m/s and the calculated vertical velocity within the screen barrel of not greater than 1.5 m/s (see 4.3.1). The design entrance velocity is defined by the following equation:

$$V = Q/A$$

With

V = the design entrance velocity (m/s)

Q = the planned pumping rate or yield of the borehole (m^3/s)

A = the total open area of the apertures along designed length of the screen (m^2)

The open area for the chosen screen will be defined by the manufacturer's specifications or estimated in the case of screens produced on site.

Other Design Factors

Other considerations that may be critical to proper borehole screen design, such as turbulent versus laminar flow, approach velocities and velocity distribution, are not addressed by the above criteria. Ultimately, the borehole should be designed such that:

- Borehole efficiency, specific capacity and control of sand and turbidity (if applicable) should be optimised;
- Materials chosen for construction should be sufficient to last throughout the planned lifetime of the borehole;
- Any existing or potential contaminated sources or aquifers, or zones of undesirable water quality, should be sealed off from the borehole.

Boreholes in Coastal Areas

Special care and design is often required for boreholes that are drilled in coastal areas and inland salinity areas. If the target aquifer is unconfined or is the first layer of confined aquifer then care should be taken to avoid drilling into the brackish a water/saline water zone. In a multi-layered aquifer system where fresh water is present in a deeper layer below a saline water aquifer unit then, during the drilling, the top saline water unit should be sealed off to avoid contamination of fresh water units and then a telescopic borehole should be drilled to tap the lower fresh water units. In many cases the depth of boreholes may have to be limited even in fresh water zone to avoid upcoming of the saline water interface. The general design of these boreholes varies with the formation type and may fall into any of the categories as detailed in the following sub-sections.

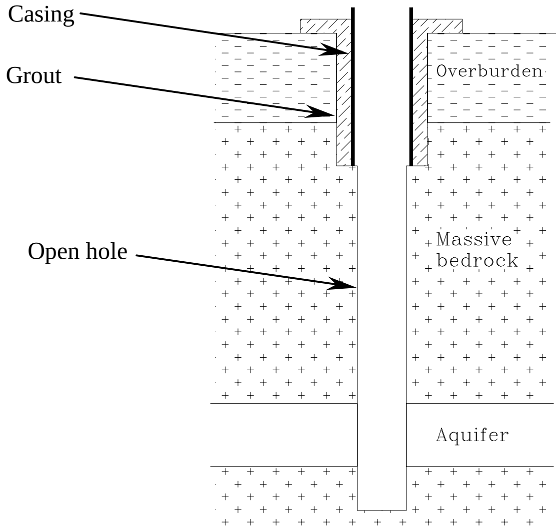
4.3.3 Typical Borehole Designs

Although the specific borehole design is site specific and it is impossible to describe every type of possible borehole design that may be utilised in the SADC region, a summary of the most prevalent types is provided below as a guide. Although all the examples showing screens are for a single aquifer zone, additional screened intervals are always possible within the framework of the example. For handpump boreholes, the first two designs (type 1 and type 2) are primarily applicable and in some cases type 5.

Type 1: Basic Open Borehole Construction

This is perhaps the most common design found in SADC countries for motorised boreholes. It is appropriate in consolidated formations where both the aquifer and surrounding bedrock is stable and shows no evidence of collapse. After a surface casing is set through the overburden and grouted (to form an appropriate seal), the remainder of the hole is left open. Advantages of this design include low cost, maximum efficiency and pump setting options. Disadvantages are primarily associated with the use of this design in unstable formations where collapse or sand pumping can occur.

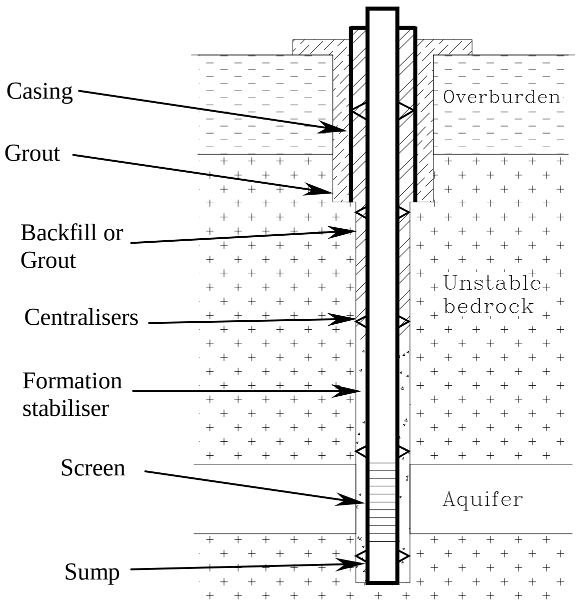
Figure 4-1 : Type 1 Design



Type 2: Cased Borehole in Consolidated Formation

This type of design is common where overlying or aquifer formations are unstable. In addition to the sanitary seal, an assembly with a screened interval set adjacent to the primary aquifer horizon is installed in the borehole. Gravel pack (formation stabiliser) is installed surrounding the screens, with the upper section of the annular space backfilled or grouted. Centralisers are installed above and below the screen and at intervals to the surface.

Figure 4-2 : Type 2 Design



Type 3: Multiple Casing Borehole

This design is required where an unstable zone(s) is encountered above the targeted aquifer. This zone may or may not be water bearing. The inner casing is installed during drilling and the borehole diameter is reduced after installation. Although only one inner casing is shown in this example, more than one may be required where several unstable zones are encountered. The inner casing may or may not be required to be grouted in place. The remainder of the borehole (including the aquifer horizon) is completed as an open hole.

Figure 4-3 : Type 3 Design

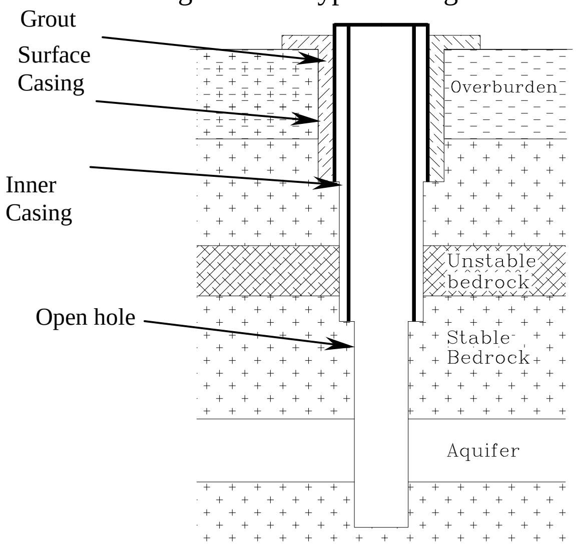
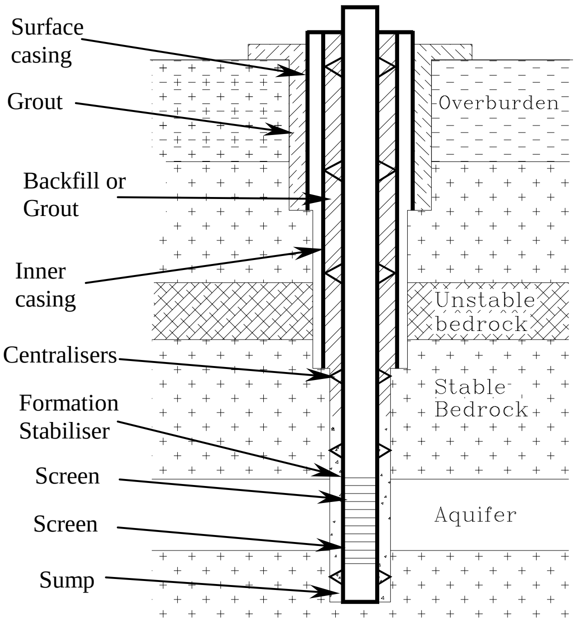


Figure 4-4 : Type 4 Design

Type 4: Multiple Casing with Screens

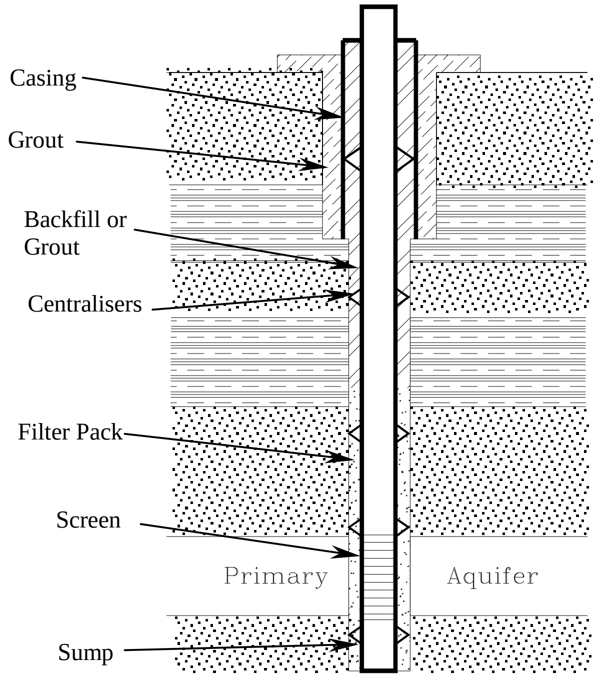
This type of borehole is required where unstable formation overlies an aquifer, and the aquifer itself is unstable. Similar to Type 3, casing must be installed during drilling to address unstable formations. Drilling then continues to the targeted aquifer. An assembly with screens is lowered and gravel pack (formation stabiliser) is installed surrounding the screened interval. The remaining annular space is backfilled or grouted.



Type 5: Filter Packed Borehole in Unconsolidated Formation

In unconsolidated formations (i.e. coastal plain sediments, river alluvium), boreholes must be screened. This design is for an aquifer where the grain size and grading is such that filter packing is required. After a surface casing is installed and grouted, drilling is completed through the targeted aquifer horizon. An assembly with screens and centralisers is lowered into the borehole and properly sized and graded filter pack installed surrounding the screen(s). The remaining annular space is backfilled or grouted.

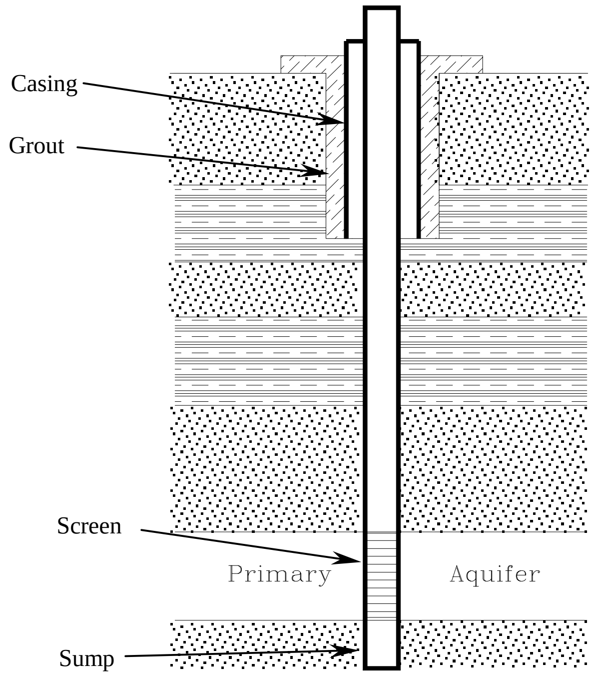
Figure 4-5 : Type 5 Design



Type 6: Naturally Developed Borehole in Unconsolidated Formation

In some unconsolidated aquifers, grain size and grading may allow natural development of the borehole surrounding the screens. This means that no filter pack is installed, but the screen is chosen so that a stable zone is created during development surrounding the screen, which effectively filters out fine material. For this design, the screen assembly is lowered in the open hole and the aquifer material allowed to fill the annular space. Extensive development then follows to remove the fines from the aquifer region surrounding the screen.

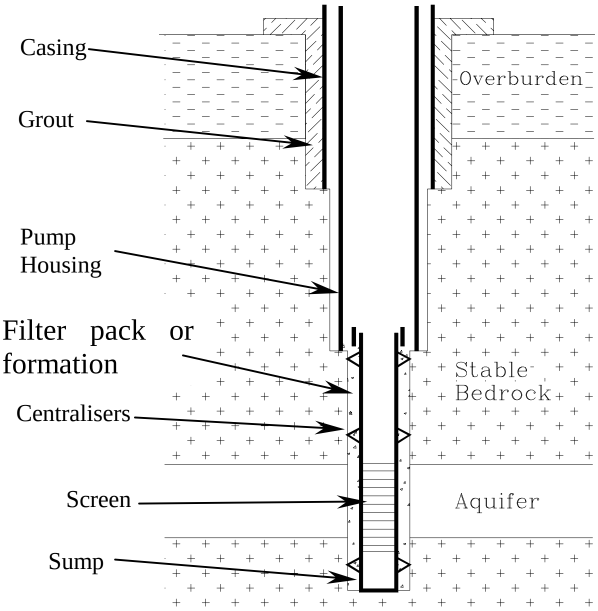
Figure 4-6 : Type 6 Design



Type 7: High Yielding Borehole with Telescoped Screen Assembly

The Type 7 design is a relatively complicated and special purpose design, but can be important in some cases. It is applicable for high yielding boreholes that have deep water strikes and relatively shallow static water levels. It would generally be used to replace an exploration borehole where information on the aquifer has previously been collected. The design uses a large diameter casing (as the pump housing) set to the depth of the planned long term pumping drawdown. The remainder of the borehole is drilled and constructed at a smaller diameter (designed to meet uphole flow requirements). The lower casing is telescoped through the pump housing. The major advantage of the design is significant cost reduction by allowing the installation of high capacity pumps (with large diameters) while maintaining a smaller diameter for the majority of the borehole.

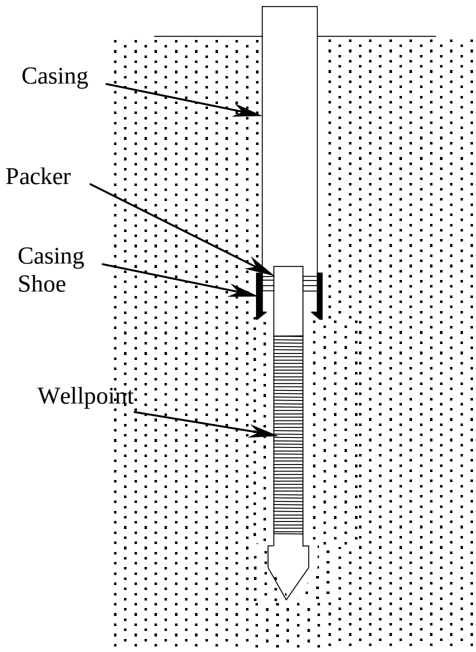
Figure 4-7 : Type 7 Design



Type 8: Wellpoint Design

Wellpoints are generally installed through a casing which has already by driven or jetted into the appropriate position in the shallow aquifer. The wellpoint serves as the screen for this type of borehole. The wellpoint is actually emplaced either by inserting the wellpoint to the base of the casing and then pulling back the casing to expose the wellpoint, or the wellpoint may be driven beyond the base of the casing through use of a special driving pipe. The latter method is generally employed when friction of the casing is too great to allow easy retraction to expose the wellpoint. In either method, the wellpoint is in direct contact with the aquifer material without filter packing. As a result, proper selection of the screen type and slot size of the well point is essential to avoid silting of the wellpoint. A typical well point installation is indicated in Figure 4-8.

Figure 4-7 : Type 8 Design



4.3.4 Installation of Casing and Screens

Steel casing and screens should be joined by welded or threaded joints that are watertight, maintain the straightness of the assembly and are a minimum of 50% of the strength of the casing or screen. Welds should be fully penetrating and continuous (see Appendix D for diagram of appropriate weld). If uPVC is used in the construction of the borehole, threaded couplings are required and should be tightened sufficiently to create a watertight seal and avoid loosening over time. Joints should be sufficiently strong to support the entire weight of the casing string during installation.

Casing and screen assemblies should be lowered into the open borehole under the force of gravity and under no circumstances should be pushed or driven downwards.

For boreholes that will be gravel packed, centralisers should be attached to the casing both above and below the screened sections and at a minimum of every 6 meters above the screened section. A minimum of three (3) centralisers should be installed at each location, equally spaced around the casing at 120^{o} (90^{o} if four are used) and should be aligned so that water level access pipes or tremie pipes can be subsequently installed in the annular space.

Permanent casing should extend a minimum of 25 cm above ground level or above the cement pad if one is installed (for all handpump boreholes). If a pitless adaptor type completion of a motorised pump borehole is utilised, then the requirement for a superelevation of 25 cm should be waived.

4.3.5 Gravel Pack

Gravel pack is installed in the annular space between the borehole casing and screens and the borehole wall. It can serve to stabilise formations and/or filter fine-grained material from entering the borehole. There are two main types of gravel pack: formation stabiliser and filter pack.

Formation Stabiliser

Formation stabiliser is required for screened boreholes, where there are collapsible formations or aquifer horizons, or where the borehole is more than 50 mm larger than the casing and screen assembly. The major purpose of formation stabiliser is to keep the borehole open and prevent caving in of overlying clays or other fine material into the screened portion of the borehole. Formation stabiliser is primarily used in consolidated formations, but can also be used with naturally developed boreholes in unconsolidated formations.

Formation stabiliser is more rarely required in handpump boreholes. Clean drill cuttings may be utilised for handpump boreholes if the material is such that the gravel pack material will not enter the borehole through the screens (i.e. proper average size, lack of shaley/clayey material, lack of fine friable sandstone or loose sand, etc.). Otherwise a similarly suitable purchased or locally obtained natural aggregate may be used.

For motorised pump boreholes, grading of the formation stabiliser used in consolidated formations should be chosen such that none of the gravel pack should pass through the chosen screen slot opening size during development.

For formation stabiliser used with naturally developed boreholes it is desirable that approximately 50 to 60% of the stabiliser is removed during development and grain size is equal to or slightly larger than that of the formation.

For all boreholes, the formation stabiliser should never reduce the hydraulic efficiency of the borehole. It is generally desirable for the formation stabiliser to extend above the screened interval by 9 to 15 meters.

Filter Pack

Filter packing is used in unconsolidated formations or sometimes in poorly consolidated (friable) sandstone aquifers, where the grain size and grading of the aquifer material is such that natural development is not possible. This is generally the case with very uniformly graded sands (as is often the case in the Kalahari Beds). Filter packing is commonly used with continuous slot screens, although it can also be used with slotted screens as well. The specific size and grading of filter pack in unconsolidated formations is chosen such that a acceptable amount of the material will be drawn into the borehole and removed during development (up to 60%). A common method of designing a filter pack is outlined in Appendix C.

The thickness of filter pack should be a minimum of 70 mm. The maximum recommended thickness is 200 mm.

The filter pack should be installed adjacent to the screened sections and should extend at least 6 meters above the screen.

Material

For motorised pump boreholes, formation stabiliser material used in consolidated formations should be sub-angular to sub-rounded, whilst formation stabiliser and filter pack used in unconsolidated formations should be well rounded. Gravel pack materials should be non-soluble (i.e. primarily quartz). It is desirable that gravel pack contains less than 5% calcareous material. The gravel pack should be graded such that the uniformity coefficient is less than 2.5. The material should be free from shale, mica, clay, dirt or organic impurities of any kind. The material should not contain iron or manganese in a form or quantity that will adversely affect the quality of the water.

As mentioned above, clean drill cuttings or a similarly suitable purchased or locally obtained natural aggregate may be utilised for handpump boreholes. If local materials are used (i.e. local sand) care must be exercised that the material is clean and free from foreign matter. For handpump boreholes, it is recommended that locally derived materials be sieved through a mesh, such that a relatively uniform grading is achieved. Washing with water of locally derived gravel pack is recommended.

For motorised pump boreholes, whenever possible it is recommended that gravel pack be purchased from a supplier that can provide analyses of the average gravel pack content. If local materials are used (i.e. local sand) care must be exercised that the material is clean and free from foreign matter. Locally derived materials should be sieved through a mesh such that the required grading (uniformity coefficient <2.5) is achieved. The method of calculation of uniformity coefficient from sieve data is described in Appendix C. Washing of locally derived gravel pack is again recommended.

Gravel pack should be stored in bags or on plastic or cloth sheeting such that it does not come in contact with the ground.

Installation

Gravel pack should be installed such that there is continuity without bridging, voids or segregation. In general, use of tremie pipes for installation of gravel pack is recommended. Methods of gravel pack installation are summarised in Appendix C.

If water based drilling fluids have been used, prior to introduction of the gravel pack the fluid should be circulated such that sediment and drill cuttings are removed. Unless required to maintain an open bore, the water based drilling fluid should be reconditioned to a viscosity of

30 seconds (Marsh funnel). If sand content testing equipment is available, it is recommended that sand content be less than 1%.

4.3.6 Grouting and Sealing

For all boreholes a sanitary seal should be installed.

Sanitary Seal Requirements

The sanitary seal should be installed in the annular space between the outmost casing and the borehole wall. The space should be a minimum of 40 mm. When cement based grouts are used, a minimum of 24 hours setting time after installation should be observed during which no other activity will be undertaken on the borehole.

Materials

The following materials are acceptable for the sanitary seal:

Neat cement:	Neat cement should consist of a mixture of ordinary portland cement or slow hardening portland cement (i.e. ASTM C150, Type 2) and clean water in a ratio of 22 liters of water to 50 kg of cement.
Bentonite:	Either bentonite pellets or a premixed bentonite slurry.
Sand-Cement Grout:	Sand-cement grout should consist of a mixture of portland cement, clean sand and water in a weight proportion of no more than 2 parts sand to 1 part cement.

Methods of Installation

The seal should be installed such that a complete seal of the annular space is effected along the complete length of the seal. Granular bentonite or pellets should in no circumstances be installed by simply pouring into the annular space. Methods of grout installation are summarised in Appendix C.

The sanitary seal should extend from ground surface to a minimum depth of 3 meters. In areas of thick overburden or identified contamination potential, a minimum seal depth of 15 meters is recommended.

4.3.7 Verticality and Alignment

All motorised pump boreholes should be tested for verticality and alignment. Handpump boreholes should be tested for alignment only. The test should be carried out in the presence of the Borehole Owner or his representative. The testing method described below is adapted from the American Water Works Association Well Drilling Standards.

Testing

Unless otherwise specified, both the alignment and verticality testing should be carried out to the anticipated depth of pump setting (generally the top of the first screen). It is not recommended to lower dummies through screened sections of the borehole.

The alignment of the borehole is tested by the lowering of a 6 m section of pipe or a dummy with an outside diameter 10 mm smaller than the inside diameter of the section of casing to be tested. If a dummy is used it should be constructed of a rigid center spindle with a minimum of three truly round rings (one on each end) each being 30 cm wide.

The dummy or pipe section should move freely throughout the tested section.

The verticality should be tested by the lowering of a plumb bob that is 6 mm smaller than the casing section to be tested. It should be suspended from the exact centre and should be heavy enough to keep the wire cable used for lowering taut and straight. The plumb bob should be suspended from the drilling rig or a tripod so that it hangs directly over the centre of the top of the casing. The pulley from which the cable is suspended, or a guide block, should be arranged so that it is at least 2.4 meters above the top of the casing. A device of accurately measuring the deviation of the cable from the centre of the borehole should be provided. The plumb bob should be lowered in 3 m intervals and measurements made of the deviation of the cable from the centre point of the casing. The depth, magnitude and direction of deviation (N, S, W, etc.) should be recorded. Drift will be calculated from the deviation data (method described in Appendix C). The maximum allowable horizontal deviation of the borehole from vertical should not exceed two thirds (2/3) of the smallest inside diameter of the section of the borehole being tested per 30 meters of depth.

4.4 BOREHOLE DEVELOPMENT

Development of boreholes is the process of removing loose materials, both in the borehole and in the formation, such that the suspended solids are thoroughly removed and the yield maximised. All boreholes should be developed until the water is clear and free from sediment or evidence of drilling fluids. The specific requirements for borehole development are set out in Section 5.

4.5 BOREHOLE DISINFECTION

All water supply boreholes should be disinfected. This should be accomplished by addition of chlorine or chlorine yielding compounds into the borehole. Typical products of this type are calcium hypochlorite, sodium hypochlorite and chlorinated lime. Liquid sodium hypochlorite is recommended. The amount of disinfectant added will be sufficient to establish a concentration of approximately 1000 mg/l of active chlorine within the borehole. The equation that allows determination of the required amount of disinfectant to add is given by:

$$V_s = V_w * (C_d / C_s)$$

with

V_s = amount of disinfectant required (liters)
V_w = volume of water in the borehole (liters)
C_d = desired concentration of available chorine (mg/l)
C_s = concentration of available chlorine in the disinfectant (mg/l)

The borehole should remain unused for a minimum of 24 hours after the disinfectant has been added. After this the chlorine-rich solution should be pumped to waste.

4.6 SITE COMPLETION

At the completion of all drilling activities the borehole should be securely capped to prevent accidental or unauthorised opening or contamination of the borehole. This may include a welded or lockable cover. The borehole number should be permanently marked by welding on the borehole cap and by deep and clear marking in the cement slab surrounding the borehole. Paint is not acceptable.

In the case of a borehole finished at the surface with uPVC casing, a suitable lockable cover should be fitted and the number cut clearly into the plastic cap or marked in the cement pad. However, a steel cover surrounding the casing firmly set in a concrete pad is recommended for completion of boreholes cased with uPVC. The ground surface should be sloped away to divert runoff away from the borehole.

The site will be left clean and acceptable. All excavations shall be filled up and heaps levelled. No rubbish, unused material or equipment should be left at the site. Refer section 1.3.2 for environmental regulations.

4.7 MISCELLANEOUS

4.7.1 Drilling Site

If not specifically addressed by the drilling contract document, local laws or regulations, the Drilling Contractor is required to maintain a reasonable aesthetic appearance and environmentally sound condition at the drilling site, both during and at the completion of drilling and construction activities. An aesthetic appearance is defined as a lack of loose or unorganised rubbish, supplies or equipment that may result in any environmental degradation of the site or hazard to those working at the site.

At the completion of drilling and construction activities, the site should be restored as far as possible to the condition found on arrival at the site. This implies that settling pits, trenches, etc. should be backfilled with clean material, and rubbish collected and disposed of properly. Maintenance of environmentally sound conditions at the site should include, but not necessarily be limited to, the following issues. Spent containers for oil, hydraulic fluid, drilling fluids/additives, etc. should be stored in such a way as to not allow any leakage or spillage until removal from the site (to an appropriate facility which accepts such waste). All motorised equipment should not leak any oils, coolants or other fluids such that they infiltrate the ground at the site. If the site is in a town or urban area, fencing may be required to ensure that spectators do not become accidentally injured. Toilet facilities should be provided at the site or be accessible at a reasonable distance for workers at the site. If no suitable facilities can be made available, workers should utilise natural areas at a minimum of 100 meters distance from the drilling site and should bury all waste.

4.7.2 Abandonment of Boreholes

If a borehole is unsuccessful (no or insufficient yield, poor quality, etc.) it may be completed by appropriate capping and site completion as described in 4.7.1 above. However, should a borehole be required or desired to be abandoned, methods must be followed to accomplish the following:

- Eliminate physical hazards
- Prevent contamination of groundwater
- Preserve the yield and hydrostatic head of aquifers (if applicable)
- Prevent the intermingling of desirable and undesirable waters from different aquifer horizons (if applicable)

Prior to sealing operations, the borehole must be checked to ascertain that there are no obstructions that may interfere with effective sealing. This can be accomplished by lowering of a suitable dummy to the base of the borehole. The minimum requirement for abandoning boreholes should be the replacement of the drill cuttings back into the borehole such that the borehole is completely filled to surface with the material. To avoid bridging of the fill, it may be required to pour clean water periodically into the borehole during this operation. The material will then be compacted by tamping it down manually and fresh backfill poured on top. This will be compacted and the process repeated until reasonable assurance is obtained such that no further subsidence will occur. A concrete collar should be installed over the filled borehole. The collar will extend approximately 0.5m beneath ground surface and have a radius of 300 mm. A diagram of the design of a collar as well as a summary of other abandonment methods are presented in Appendix C.

Section 5: BOREHOLE DEVELOPMENT

5.1 GENERAL

5.1.1 Scope and Purpose

The standard and guidelines in this section cover the development of water boreholes that are to be fitted with either handpumps or motorised pumping equipment. These standards and guidelines apply to all water supply and water injection wells constructed by manual or mechanical means, aside from those that meet the definition of "hand dug wells".

5.1.2 Principles

To some degree, all methods of borehole drilling alter the hydraulic characteristics of the formations they penetrate. In general these alterations tend to reduce the hydraulic conductivity in adjacent aquifer zones, which in turn reduces borehole yield and efficiency. Development consists of procedures (implemented after drilling is complete) to maximise borehole yield. Additionally, development is often required to remove loose or fine-grained material in the aquifer that may result in sand pumping or turbid water quality. Development is generally carried out by the drilling rig that has completed the borehole although, in some cases, a specific development rig (e.g. jumper rig) may be brought in solely for this purpose.

All newly completed successful boreholes should be developed prior to testing and production use. Development should be carried out until water is clear and sediment free, the borehole is stable (open hole and gravel pack designs) and borehole yield has been optimised. Additionally, development of existing boreholes may be considered as part of rehabilitation of production boreholes where yield has decreased over time.

5.1.3 Choice of Development Method

The choice of development method is largely controlled by the specific type of drilling rig on site, the drilling method employed, the hydrogeological conditions and financial constraints (affecting possible duration of development). However, whatever method(s) are utilised, they should be effective in accomplishing the three primary objectives of development:

1. To remediate unavoidable damage (clogging of pores/fractures, compaction, etc.) done to the aquifer as a result of drilling, restoring to the greatest degree possible its natural hydraulic properties;
2. To improve permeability of the aquifer surrounding the borehole so that groundwater can more freely flow to the borehole.
3. To ensure sand, silt, and clay free water during abstraction.

An important aspect to consider prior to drilling a borehole is to attempt to use a drilling method that will create the least damage to the targeted aquifer to begin with. Repairing formation damage through development will always be more time consuming and costly than reducing the amount of damage incurred during drilling in the first place. For example, when drilling a borehole with a cable tool rig, it may be beneficial to specify that casing should be installed by the bailing method below the water table as opposed to drilling and driving of casing (which can compact the sediment and mix stratified layers). By minimising compaction and mixing of clayey or fine-grained material with the aquifer formation, the development required for the borehole will be minimised.

5.2 MECHANICAL DEVELOPMENT METHODS

Mechanical development methods range from extremely simple to relatively complex and requiring special tools. For handpump boreholes, the simplest methods will be sufficient. However, as yield is a key issue for motorised boreholes, use of more than one method of development may be warranted to maximise yield and specific capacity. Whatever development method(s) is chosen, the implementation (and particularly the decision on development completion) should be supervised by a Hydrogeologist (level D or higher) for motorised pump boreholes and by a Drilling Technician (level B or higher) for handpump boreholes (same as the one for drilling supervision as described in 4.1.3. In all cases the supervisor will carry out development until he is confident that development is complete (water quality is constant, turbidity/sediment content is minimal).

As mentioned above, the choice of development method will be constrained to a certain degree by the type of drilling rig used for drilling the borehole. In some cases for high capacity boreholes, it may be desirable to bring a separate rig solely for development. Specific development methods are generally used for certain types of aquifers, although there are not set rules as to which methods are used with which types of aquifers. The major development methods appropriate for aquifers in the SADC region are summarised in the table below.

Table 5-1 : Borehole Development Methods and their Applicability

Method	*Rig or equipment required*	*Comments*
Blowing	Any rig with air compressor	Most common method in SADC region, particularly for handpump boreholes, effective in a variety of environments
Bailing	Cable tool, bailer	Also common for handpump boreholes
Air lift pumping	Any rig with air compressor; appropriate air lift piping	Similar to blowing, can be more effective in very porous aquifers and large diameter boreholes
Pumping	Any rig (including jetting, manual drilling) with pump	Can be used by jetting rigs or for manually drilled wells, by a power or hand operated pump
Backwashing, air surging	Any rig with air compressor or borehole pump	Creates surging action without requiring surge blocks or special tools
Air lift pumping / Surging	Any rig with air compressor, air lift equipment with valve	Effective for boreholes in sandstone aquifers
Surging	Cable tool or rotary rig, surge block	Not recommended for aquifers with clay layers
Swabbing	Cable tool or rotary rig, swab	Not recommended for aquifers with clay layers
Surging/Air lift pumping	Cable tool rig, air compressor, isolation tool	Very effective in unconsolidated aquifers; only for screened boreholes
Jetting (air)	Rotary, air compressor, jetting tool	Best with wire wrap screens; only for screened boreholes
Jetting (water)	Rotary, mud pump, jetting tool	Best with wire wrap screens; only for screened boreholes
Jetting/Air lift pumping	Rotary, mud pump, jetting tool, air compressor	Best with wire wrap screens; only for screened boreholes

A brief description of the methods and requirements of each method is presented below.

5.2.1 Pumping Methods

Blowing

A very common form of development, particularly with air rotary drilling rigs. The basic principle is the over-pumping of the borehole through the injection of compressed air. The air may be injected through the DTH drilling bit (development of water strikes during drilling) or through simple drill rods after drilling. Wherever static water levels are sufficiently above the water strikes or screened sections, blowing should be carried out above the water strike or screens to limit air entering these zones. In some porous and fractured rock aquifers, air blowing below the water strike/screen can result in little or no yield (due to air locking) inhibiting development or creating the impression that the borehole is unsuccessful.

The water is blown out of the casing at the surface and should be channelled to a V-notch weir (or other appropriate device) for yield measurement. A bucket should be placed to collect the blown out water so that water quality and sediment content can be monitored. The final activity should be blowing from the base or sump (for screened boreholes) to remove and clean any material that has entered the borehole during development.

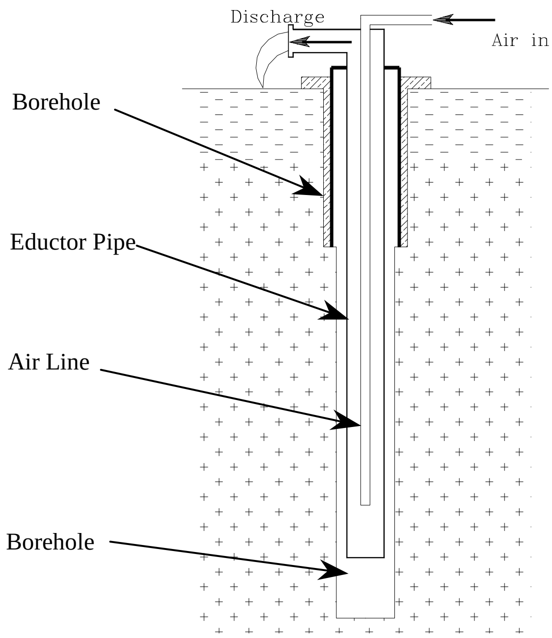
Bailing

This is a development method primarily used by cable tool rigs. A large volume bailer (usually with a dart valve at the bottom for rapid release at the surface) is repeatedly lowered below the water level and removed from the borehole to be emptied at the surface. Rough estimates of yield can be determined by recording volume of water removed during a given time period, if possible supported by drawdown measurements made between bailing. Water quality and sediment content should be measured periodically.

Air Lift Pumping

Air lift pumping is similar to blowing, but allows more effective pumping and sediment removal from the borehole. It is accomplished by installation of an eductor pipe within which a smaller diameter air line is installed. The air line terminates at least one meter above the base of the eductor pipe. Air is injected (by compressor) into the air line and exits into the eductor pipe where, similar to blowing it moves the water upward. Since the air does not come out into the borehole itself the pressure does not affect the aquifer or screens adversely. It can also be effective in boreholes with large diameters or low yield where blowing alone is not effective. The method also allows water levels to be measured (outside of the eductor pipe) during development to assess improvements in specific capacity.

Figure 5-1 : Air Lift Pumping



A surging action can also be created during air lift pumping by periodically turning off the air flow, lowering the air line below the eductor pipe, then releasing a sudden surge of air. This air will tend to enter the screens and/or aquifer pores and fissures. Immediately afterwards, the air line is brought back into the eductor pipe to continue regular air lift pumping, reversing the flow through the screens and aquifer and removing loosened material.

Pumping

This method is often the only method possible for development of boreholes drilled by jetting or manual means. It is implemented by pumping the borehole at a suitable rate (over-pumping if possible) by either a powered pump (possibly the jetting pump) or a manually operated pump. Water quality and sediment content should be measured periodically. Yield is commonly measured by a bucket of known volume, and drawdown can be measured during pumping to assess specific capacity.

5.2.2 Surging Methods

Development using surging creates a flow into and out of the borehole screens or aquifer formations. It is often accomplished using a tool (surge block or swab) specifically designed for the procedure. Fine-grained material and drill cuttings are then freed and pulled into the borehole where they can be removed. Since the method involves inducing flow into the aquifer, the borehole must be cleaned initially prior to surging to remove loose sediment and turbidity in the water. Cleaning may be accomplished by blowing, bailing, pumping or air-lift pumping.

Backwashing and Air Surging

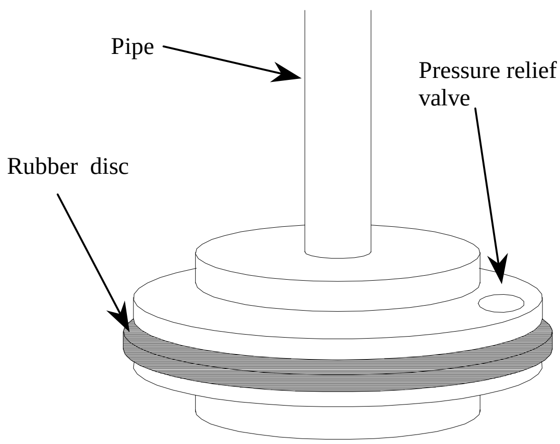
This development method involves intermittent pumping of a borehole such that the raised column of water is forced back through the screen and/or aquifer pores and fissures. It can be accomplished using a pump (with non-return valve removed) installed in the borehole by immediately stopping the pump as soon as water comes to the surface. The water column then rapidly flows downward and out into the aquifer. The process is then repeated rapidly. The same action can also be created during blowing by cutting off the air flow immediately as the water arrives at the surface. With either method, periodically during the process a period of pumping should be initiated to remove any material that has entered the borehole.

Air Lift Pumping/Surging

This method is similar to backwashing and has been shown to be effective in sandstone aquifers characterised by alternating cemented/uncemented zones or thin clayey layers (i.e. Ntane Sandstone of Botswana). It is particularly effective in eliminating sand pumping. The method involves the installation in the borehole of an air lift system equipped with a gate valve on the discharge of the eductor pipe. Air lift pumping is first initiated with the air line raised in the eductor until the water is clear. The valve on the eductor discharge is then closed while air continues to be injected. With the discharge closed, the air displaces the water in the eductor pipe and forces it to the surface in the surrounding casing. When the water clears, the valve is quickly opened and the column of water in the casing falls downward surging the formation and air lift pumping begins again.

Surging (Surge Block)

Figure 5-2 : Surge Block



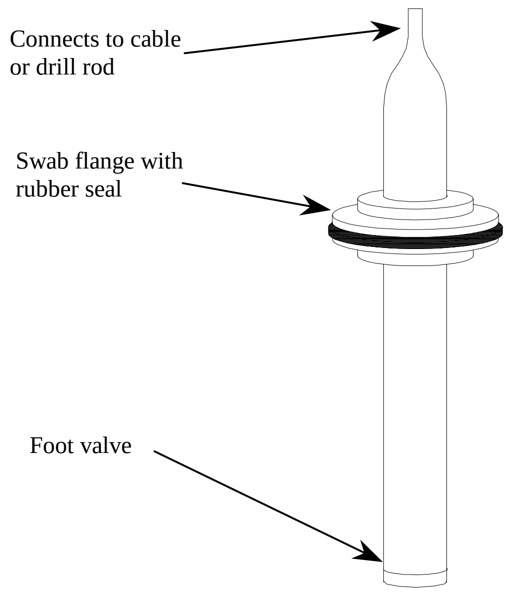
Surging using a surge block can be used with rotary and cable tool rigs as well as using a large diameter bailer with cable tool rigs. Prior to surging, the borehole should be blown or bailed to ensure that water is able to enter the borehole (to avoid damage to screens). The tool is initially set approximately 5 meters below the static water level. The basic principle is to create a surging action in the water column by moving the surging tool up and down, initially gently, then increasing the length and speed of the stroke. After several minutes of surging, the tool is removed and the sediment collecting in the well removed (i.e. by blowing or bailing), then the process repeated. The tool is gradually slowly moved down the borehole to the top of the borehole screen or base of the cased section (open borehole design).

The method is not recommended for aquifer formations characterised by thin clay layers as the method may actually result in clogging of the aquifer.

Swabbing

Swabbing is similar to surging and it is carried out by a specific tool (line swab or double flanged swab) or sometimes simply by a bailer within the screens of the borehole or within the bore of unscreened boreholes. In contrast to surging, the tool (or bailer) is lowered into the borehole or screen then pulled upward at approximately 1 meter/second. Pressure is developed above the tool which forces water out into the formation, while behind the tool the low pressure zone pulls the water back into the borehole. No surging motion is utilised and the length of the stroke is generally much greater than that used during surging. After one stroke, the tool is allowed to sink back to its original position

Figure 5-3 : Line Swab

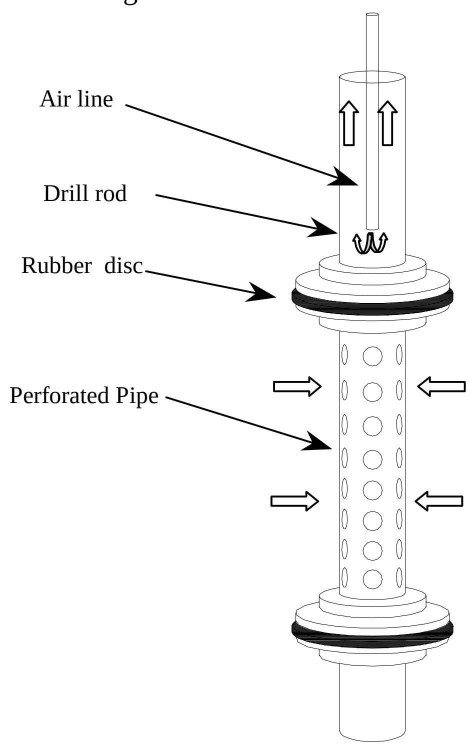


The method is particularly effective in consolidated formations with open borehole designs. For screened boreholes, swabbing can only be used in aquifers that are sufficiently transmissive (such that they can yield sufficient water to keep pressure differentials in reasonable limits) otherwise it can lead to screen collapse in tight formations. Additionally, swabbing should not be utilised in boreholes with uPVC screens or in screens in silty formations with screen slot sizes around 0.25 mm or less. Similar to surging, this method should be avoided in aquifers characterised by thin clay layers.

Surging/Air Lift Pumping

A specially designed surge block (isolation tool) allows surging to be undertaken at the same time as air lift pumping. Material freed by the surging motion is then immediately removed from the borehole. A net inflow from the aquifer is also maintained. The method is primarily applicable for screened boreholes in unconsolidated formations and is particularly effective in developing filter packed boreholes. The tool is best utilised with a cable tool rig, although acceptable results can be obtained using a rotary type rig. The tool is utilised in the screened portion of the borehole and is begun at the top of the screened interval to avoid sand locking (from sand entering the borehole above the tool).

Figure 5-4 : Isolation Tool

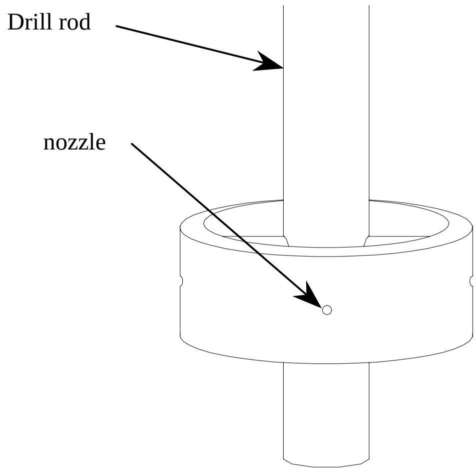


The tool is surged and pumped in approximately a one meter intervals until no more material is removed. It is then lowered to the next meter and the process repeated until the base of the screened section is reached.

5.2.3 Jetting Methods

Jetting involves the direction of a high pressure stream of air or water horizontally at the borehole screen. By focussing the energy on a limited area the effectiveness and penetration into the formation of development energy is maximised. The method is primarily used with screened boreholes and is most effective with wire wrap type screens. The jetting tool for both air and water jetting is similar and consists of a tool with four nozzles equally spaced around its diameter. The tool diameter should be such that the jets are as close to the screen as practically possible, with the space between the jets and screen generally less than 25 mm. A check valve can be fitted at the bottom to allow periodic pumping during water jetting.

Figure 5-5 : Jetting Tool



The size of the nozzles should be such that a high velocity is maintained. The lowest velocity for effective jetting is 30.5 m/s. The table below gives the jet velocity and discharge per nozzle for common nozzle sizes and at various pressures.

Table 5-2 : Orifice Size and Nozzle Pressure

Size of nozzle orifice (mm)	*Nozzle pressure*									
	690 kPa		*1,030 kPa*		*1,380 kPa*		*1,720 kPa*		*2,070 kPa*	
	v	Q	v	Q	v	Q	v	Q	v	Q
4.8	30.5	44	36.6	55	42.7	65	47.3	71	51.8	82
6.4	30.5	82	36.6	98	42.7	114	47.3	131	51.8	142
9.5	30.5	185	36.6	223	42.7	262	47.3	289	51.8	316
12.7	30.5	327	36.6	398	42.7	458	47.3	512	51.8	561

v = velocity (m/s) *source: Driscoll, 1986*
Q = discharge (m^3/d)

Jetting is initiated at the base of the screen and the tool is rotated slowly while moving it upwards at a rate of 15 to 45 minute per meter. When jetting with water alone, material entering the borehole collects in the sump below the screen and should be cleaned periodically (i.e. by air lift pumping or bailing).

Jetting (air)

The simplest form of jetting involves the use of compressed air with the jetting tool. The technique is common with air rotary rigs as large compressors are already on site. An additional advantage of air jetting is that air lift pumping is accomplished during the jetting procedure, which removes any material entering the borehole immediately. Sometimes air jetting can cause air locking of some formations. This can be alleviated by drilling of several small holes in the bottom of the jetting tool. This enhances the air lift pumping and tends to avoid air locking. The tool can also periodically be pulled above the screens to just air lift pump and induce flow from the formation.

Jetting (water)

Jetting with water is generally accomplished with the mud pump of a drilling rig (i.e. Orbit type pump). Relatively large amounts of water are required and should be stored in a water tank or lined pit. The water should be clean and relatively free of suspended sediment (which can erode the nozzles or screen). Water jetting in uPVC screens should be done with care to avoid damaging the screens and with a maximum pressure of 690 kPa. Material should be periodically removed from the sump.

Water Jetting/Air Lift Pumping

The most effective method of water jetting is accomplished when it is combined with simultaneous air lift pumping. In this method a separate air line is installed above the jetting tool and air injected (by compressor) during the jetting operation. As the jetting tool removes material, the air lift pumping action removes it from the borehole. An additional advantage is that the water can then be re-circulated, as long as suspended sediment is allowed to settle out prior to re-injection.

5.3 CHEMICAL METHODS

A variety of chemicals can be utilised with mechanical development methods to improve the results. The most common additive is polyphosphate. Although less common, some aquifers may respond well to certain acid treatments, which may open up fractures or dissolve cements. Acid treatment can also be important in rehabilitation of existing boreholes.

Chlorine

Perhaps one of the simplest chemical treatments to assist in development is the addition of chlorine. Chlorine can be added in dry form but is most commonly added as a liquid to the borehole or combined with water used in jetting. Chlorine is particularly effective in breaking down polymer based (biodegradable) drilling muds. The addition of chlorine serves a dual purpose of disinfecting the borehole as well (see Section 4.5).

Polyphosphate and Surfactants

Polyphosphates as well as surfactants (detergents) can assist mechanical development by dispersing and separating clay particles. The clay particles are then more easily removed from the borehole. Common forms of polyphosphate are sodium acid pyrophosphate, tetrasodium pyrophosphate, sodium hexametaphosphate and sodium tripolyphosphate. They are generally supplied in crystalline form. Treatment is carried out by mixing approximately 7 kg of dry polyphosphate with 400 liters of water. The solution must then be chlorinated to 125 mg/l and injected into the borehole using a tremie pipe to ensure placement in the aquifer horizon. Dry polyphosphate should never be directly added to a borehole. Chlorination is critical as bacterial growth can be promoted by the presence of polyphosphates.

Surfactants are used at low concentrations (250 - 500 mg/l) and enhance the dispersing efficiency of polyphosphates in removing silt and clay. Acid treatment may also be enhanced when used in conjunction with a surfactant.

After adding the polyphosphate and/or surfactant solution, time must be allowed to let the chemical treatment take effect, usually overnight. The borehole can then be developed to mix the solution and free clay material (i.e. by surging, backwashing). The solution can also be injected during development by water jetting.

Acid Treatment

Acid treatment is primarily effective in limestone and dolomite aquifers or in sedimentary formations that are cemented by calcium carbonate. During treatment with acid the carbonate minerals are dissolved, which can open up fractures and connect voids and fissures, thereby increasing the hydraulic conductivity in the vicinity of the borehole. The use of acid is complicated and highly site specific. It should only be undertaken under the supervision of a Hydrogeologist (level A) experienced in its use.

5.4 TESTING COMPLETENESS OF DEVELOPMENT

In handpump boreholes, motorised pump boreholes which are relatively lower yielding (i.e. less than 5 or 10 m^3/hr) or in aquifer types that do not generally require significant development (i.e. fractured basement aquifers), the completeness of development can be well assessed by monitoring water quality, sediment content and turbidity of the water during development. However, for high capacity boreholes such as those for urban supply, borehole rehabilitation, or boreholes completed in aquifers that require considerable development (i.e. unconsolidated sands), it may be beneficial to assess the completeness of development by more quantitative methods. Additionally, should any development activity actually begin to lead to reducing specific capacity (i.e. mobilising clays which are clogging aquifer pores), on-going testing can allow termination before significant yield reduction can occur.

The most practical and effective method of monitoring the development of a borehole is through the use of repeated short duration pumping tests. The basic objective of the testing is to monitor the changes in borehole specific capacity during development. The tests require some method of pumping water from the borehole at a reasonably constant rate and a dipper to measure water levels. Whatever method is chosen, the format of the testing should remain consistent throughout development to allow comparison of the data.

A baseline test should always be completed prior to development activities. After a period of development has been completed, the test is repeated and the specific capacity (or specific capacities if the test allows) compared. Development is generally continued until the specific capacity remains constant, with due consideration of other monitored parameters (water quality, sediment content, turbidity). Whenever possible, step drawdown tests should be utilised for both baseline testing as well as development assessment (before and after development). The table below indicates the types of tests that are possible to quantify development progress.

Table 5-3 : Testing Methods to Assess Degree of Development

Method	*Equipment Required*	*Comments*
Air lift pumping	Air lift pumping equipment, discharge measuring device, dipper, access pipes	Fairly crude system, but can give information on larger changes in specific capacity
Short constant rate test	Borehole pump, dipper	Useful if pump is not capable of variable discharges
Short step test	Borehole pump capable of variable discharge rates, dipper	Most accurate method

5.4.1 Air Lift Pumping

In situations where a borehole pump is not available, estimates of specific capacity can be obtained during air lift pumping. In addition to the air lift pumping equipment, a dipper access pipe is installed between the eductor pipe and the borehole casing to a depth approximately 1 meter below the eductor if possible (to avoid turbulence). As air lift pumping is begun, air flow is adjusted to achieve the smoothest pumping action possible. Water levels are then recorded regularly (similar to pumping test), at least at 5 minute intervals. Due to the uneven action of air lift pumping, the water level will be variable, but should remain within a given range at a particular time. The approximate average reading is recorded. The discharge is simultaneously measured, preferably by a large enough container to allow at least one minute filling time (to average the uneven rate). The test is generally continued until it appears that the water level has stabilised. The specific capacity is determined based on the estimated yield and drawdown at the end of the test.

5.4.2 Short Constant Rate Test

When a pump is available during development, repeated short constant rate tests to determine specific capacity can be valuable to assess development progress. For baseline and subsequent tests the pump is installed and the borehole is allowed to recover to near the original static water level. Electric submersible pumps are recommended because of the rapidity and ease of installation and removal. Pumping is initiated and drawdown measured at intervals similar to a regular constant rate test (i.e. every 2 minutes). A duration for the test is chosen that is long enough to account for well bore storage effects (as little as 20 minutes may be sufficient). Discharge is measured and specific capacity at the end of the test is calculated for comparison.

5.4.3 Short Step Test

The short step test method is the best method for testing development completeness. The test uses a pump to actually carry out a short step drawdown test. Again an electric submersible pump is recommended. For baseline and subsequent tests the pump is installed and the borehole is allowed to recover to near the original static water level. Pumping is initiated and drawdown measured at intervals similar to a regular step test (i.e. every 2 minutes). Discharge is measured. After a set duration, the yield is increased to begin the next step. The step duration is chosen based on the discharge range of the pump in relation to the yield of the borehole and should be long enough to surpass well bore storage effects during the test. Step duration may be as short as 15 minutes and the number of steps may be as few as two (three is recommended if possible).

While development is continued, specific capacities for each step can be calculated and the data plotted to determine specific drawdown. In addition to the specific capacity data, degree of development may also be assessed using the plot of specific drawdown versus discharge rate.

5.5 BOREHOLE ACCEPTANCE

Development is generally the final activity completed by a driller during the drilling and construction of a borehole. As such, the acceptance by the supervisor or borehole owner of the quality of works carried out by the driller must be assessed during development. After completion of development, the borehole water during pumping should be fully acceptable to the supervisor in terms of its intended use and as per any specifications in the contract document.

The most effective method of assessing changes in water quality during development, in addition to visual monitoring of sediment/turbidity, is to monitor the electroconductivity (EC) or TDS (total dissolved solids) with a hand held portable meter. In most aquifers and hydrogeological conditions, the EC (and TDS) will tend to reduce and eventually stabilise as borehole development is completed. However, other factors such as a minimum specific yield or borehole efficiency might also be specified in a contract document and will need to be verified at the completion of development. If required (primarily for motorised pump boreholes), sand content can be quantitatively tested using a Rossum type sand sampler (or equivalent), which separates sand and silt from the pumped water and allows a volumetric measurement. Turbidity can be qualitatively assessed in the field or analysed quantitatively by a laboratory.

The Table below could be used as a checklist of items essential for borehole acceptance. After customising the checklist to particular client need and project, it should be made mandatory. It should be noted that natural water quality and quantity problems (such as low yields, high

TDS etc.) should not be used for borehole acceptance unless, of course, where it is established beyond doubt that these problems have occurred or aggravated due to drillers negligence.

Table 5-4 : Borehole Acceptance Criteria

Item	Criteria
Water Quality	
Turbidity	Should be within the limit as set by the local water quality standards/guidelines
Sand Content	The water should be sand free (use a Rossum type sand sampler or equivalent to check)
Yield	
Specific Yield	Refer Section 5.4
Borehole Construction	
Verticality	Refer Section 4.3.7
Alignment	Refer Section 4.3.7
Casings and Screen Placement	Should be correctly placed as provided in the design, refer Section 4.3.2
Gravel Pack	Should be correctly placed as provided in the design, refer Section 4.3.5
Grouting and Sanitary Seal	Should be correctly placed as provided in the design, refer Section 4.3.6
Borehole Cap	Borehole cap must be installed and locked.
Identification Number	Borehole number must be marked, refer Section 1.5.3
Site	
Cleaning of Site	Refer Section 4.6

Section 6: GROUNDWATER SAMPLING

6.1 GENERAL

6.1.1 Scope and Purpose

The standards and guidelines covered under this section are for groundwater sampling. Groundwater samples may be collected from boreholes, hand dug wells, springs or other groundwater outlets. The samples are collected for analysis at an appropriate laboratory.

The purpose of groundwater sampling is to collect a sample that is representative of the groundwater as it is present in the aquifer, to preserve it as necessary and to delivery it within an acceptable time period to a laboratory for analysis. Groundwater analyses are critical to characterise groundwater type, potability (for drinking water supplies) or other characteristics pertinent to other uses (i.e. irrigation, industrial). Samples may also be taken for analysis of isotopes, natural and man-made tracers or noble gasses as part of in-depth groundwater investigations or research.

6.2 THE SAMPLING PROGRAMME

Groundwater sampling may involve the collection of a single sample at the completion of borehole drilling or a large-scale programme for sampling of many water points. In either case, it is important to first clearly define the purpose (or purposes) that are to be addressed by the sampling. The issues should be considered prior to the sampling so that necessary equipment is available and sampling is conducted in the appropriate manner, sample volume, time and frequency.

6.2.1 Single Water Point Sampling

When the sampling programme consists of sampling a single water point the following issues should be addressed to ensure the quality of the sample and allow interpretation of the data when the analysis if complete.

- What parameters are to be analysed.
- What type of container(s) and preservation method are required.
- When can the best sample be collected (i.e. after development for a new borehole, at the end of pumping for an existing production borehole, after rains to assess contamination of a spring, etc.)
- Will additional equipment be required (pump or bailer to purge the borehole or well).
- Can access be obtained for the water point site (existing water points).
- How will the borehole be opened (existing boreholes).
- What is the borehole design (i.e. at what depth is the water strike or screened section, are there multiple water strikes, etc.)
- Is depth specific sampling required (boreholes).

6.2.2 Multiple Water Point Sampling

When a sampling programme is planned for an area or as part of a long term monitoring programme, further issues (in addition to those listed above) may be pertinent to be considered.

- Avoidance of cross-contamination between sites.
- Will samples need to be sent to the laboratory while sampling is underway (to ensure effective preservation).
- Are the same procedures to be followed during each sampling period (long term monitoring programmes).

6.2.3 Laboratory Liaison

For any type of sampling it is important to have effective liaison with the laboratory that will undertake the analyses. The laboratory staff can advise on the types of preservation they require for specific analyses, the required sample volumes, submission procedures, the time they will require to complete the analysis and the analysis data format (digital or hardcopy).

Additionally, if erratic results or inaccurate analyses are detected, discussion with the testing laboratory can facilitate locating the source of errors.

6.3 GROUNDWATER SAMPLING METHODS

Proper collection of a groundwater sample is imperative to allow meaningful interpretation of analyses. Outlined below are the basic equipment and procedures required for successful groundwater sampling. However, site and aquifer specific conditions may be important and should always be considered in addition.

6.3.1 Sample Collecting Devices

Containers

Appropriate collection containers should always be utilised. In some cases these may be available from the testing laboratory. Groundwater sample containers are commonly polyethylene or glass bottles. The cap should seal the bottle completely with no leakage even when overturned or squeezed. The volume should be sufficient for the analysis type (generally 1 liter). Reusing soft drink bottles or similar containers is not acceptable. The bottles must be sterilised when microbiological analysis is to be carried out.

Bailers

For boreholes or hand dug wells a bailer may be used to purge and sample. The bailer should be cleaned thoroughly before and between sampling events. It should be fitted with a foot valve at the base.

Pumps

Pumps generally allow more rapid purging and sampling of boreholes and hand dug wells. There are various types depending on the application and planned determinands.

> *Portable Submersible*. This type is most commonly a 12 volt system which allows use of the vehicle battery. They are particularly effective when sampling a large number of boreholes/wells, especially for basic chemical analysis. It may be difficult to fully clean pump parts between sampling events for environmental sampling.
>
> *Foot Valve Pump.* A very simple system that utilises a foot valve attached to the base of a sampling tube. The sampling tube is lowered below the water level and the opposite end placed in the sample container. The tube is then moved up and down repeatedly which creates a flow up the tube into the container. The system limits the loss of volatile organic substances and, if the tube is replaced after each sample, eliminates the possibility of cross contamination.
>
> *Peristaltic Pumps.* These pumps are primarily for sampling for very low concentration constituents (i.e. pollutants). They operate by progressively squeezing the sampling tube with a series of pressure rollers mounted on a rotating wheel. When the sampling tube is installed in a bracket around the rollers, they then create a pumping action as they rotate. The device can be operated manually or by an electric motor. The sampling tube can be replaced after each sampling event to prevent cross contamination.

Filters

In some cases it may be necessary to filter a groundwater sample prior to collection. This is often the case for spring or hand dug well samples where floating or suspended material may be present. Filters may consist of either a filter holder with exchangeable membranes or disposable filters. The normal filter size is 0.45 micron, although a 0.1 micron filter may be required if iron or aluminum oxyhydroxides are present.

Sampling Pipe

A sampling pipe is often required for sampling undeveloped springs. The pipe is simply a straight section of pipe (PVC is recommended) of approximately 25 to 50 mm diameter. The pipe is used to allow the spring flow to be directed into the sample container.

6.3.2 Spring Sampling

As springs are flowing sources, there is no need to undertake any type of purging activity. However, collecting a representative sample requires careful procedures. If the spring is developed by a spring catchment, a sample should be collected at the catchment itself or as near as possible in the supply pipeline. Undeveloped springs can be more difficult to sample. In most cases it will be required to dig away as much of the surrounding soil as possible (if applicable) to attempt collect a sample from as near to the spring eye as possible. A sampling pipe can then by placed at the spring outflow in such a way as to allow flow to the sample container. To the greatest degree possible, the spring flow should not be allowed to contact the soils surrounding the eye, as this may contaminate the sample.

6.3.3 Existing Borehole and Hand Dug Well Sampling

When an existing borehole or hand dug well is to be sampled, the first activity is to remove the water that has been standing in the casing/bore or well such that water directly from the aquifer can be sampled. This is called purging. It can be accomplished by bailing or pumping the borehole or well prior to sampling. The amount of water that must be removed varies based on the volume of water in the borehole or well, borehole construction and hydrogeology.

The most effective method of determining when purging is sufficient is by monitoring water quality parameters (EC, temperature, Eh, and pH) in the field. As purging is undertaken, the parameters will tend to vary until they stabilise, indicating that purging is complete. In general it has been found that effective purging is complete after removal of between 2 to 10 borehole or well volumes. The borehole or well volume is calculated by measuring the diameter of the well or borehole (using the drilled diameter with a screened borehole) and the depth of the water column, using the equation for the volume of a cylinder:

$$\text{Volume (m}^3\text{)} = \pi \text{ radius}^2 \text{ (m)} * \text{height (m)}$$

A minimum of 2 well or borehole volumes should be removed for purging if no field water quality meters are available.

After purging a sample can be collected (after filtering if required).

6.3.4 New Borehole Sampling

When a newly completed borehole is to be sampled (either after drilling or during testing) or when an existing borehole is being re-developed or re-tested, purging is completed by the drilling or testing rig. For a newly drilled borehole, samples should be collected at the end of development. During testing, samples should be collected at the end of the test if only one sample is to be collected. However, during testing it is recommended that samples be collected at several times during the test as a cross check and to evaluate water quality changes under pumping conditions.

Groundwater samples collected during borehole development should be collected from as near to the borehole as possible. During air blowing for example, a clean bucket may be placed next to the borehole to collect the sample. During air lift pumping, water may be collected from the eductor discharge pipe. Samples should not be collected from a V-notch weir or after the water has flowed over the ground.

6.3.5 Multiple Horizon Sampling

In some layered aquifer systems, the individual aquifer layers may have different hydrochemical characteristics although they are tapped by a single borehole (i.e. a borehole with a screen crossing several aquifers or separate screens at individual aquifers). Also in some cases, water quality or specific chemical parameters may vary with depth in a single aquifer unit. In these instances, if may be necessary to collect groundwater samples at specific depth intervals within the borehole. This may be of importance in more detailed groundwater studies where identification of small variations in hydrochemistry or isotopic characterisation are the goal of the sampling programme.

The implementation of multiple horizon sampling within a borehole requires specialised equipment. Each type of sampling system has specific procedures to be followed in order to obtain satisfactory results. In general, this equipment operates by allowing specific intervals to be physically isolated within the borehole and sampled individually. The degree of isolation and accuracy in depth sampling will largely be guided by the specific objectives of the sampling programme. Due to the relatively complex nature of both the design of the sampling programme as well as the interpretation of the data collected, as well as the greater cost, it is desirable that an experienced hydrogeologist supervise the activity (i.e. Level B or higher, Section 1.3.6).

6.3.6 Preservation Methods

When time elapses between sample collection and analysis, the groundwater chemistry may change. As soon as it is brought to the surface, a sample is exposed to physico-chemical conditions different from those in the subsurface. As a result, equilibria change which can affect the chemistry. For example, oxidation of Fe^{2+} and H_2S can result from exposure to the atmosphere, or degassing of CO_2 can occur resulting in changes in pH. As such, some form of sample preservation is required.

At a minimum, the sample should be transferred quickly to the sample container, filled completely and tightly capped. Samples for microbiological analysis are collected in laboratory-supplied sterile bottles with protected capping to avoid contamination during handling. In general, for microbiological analysis the sample must be analysed within 6 hours of sampling if not refrigerated and within 24 hours if refrigerated.

Samples for groundwater analysis involving determination of dissolved metals (such as iron ands manganese) are preserved through acidification. In this procedure, two samples are collected, with one sample acidified with a small amount of acid (normally HCl). Determination of what preservation technique is applicable is best decided after discussion with the testing laboratory.

6.3.7 Labelling and Documentation

Sample containers should be clearly and indelibly labelled in the field after collection. Polyethylene bottles may be marked on directly using a permanent marker, while labels must be affixed to glass bottles. When paper labels are attached to containers it is desirable that a covering of clear packaging tape be used after marking. At a minimum the label should contain the following information:

- Sample number or code;
- Waterpoint number or description
- Date and time of collection
- Preservation method (if applicable)
- Measured field parameters (pH, EC, etc.)

6.3.8 Analysis

Once collected the samples should be send for analysis with a requisition form. The form should clearly mention the constituents which are to be analysed. For groundwater to be used for human consumption, a list of the minimum constituents that must be analysed for, irrespective of the hydrogeologic conditions, type of borehole or implementation programme, are presented in Table 6-1. This list represents a bare minimum level of analysis, primarily reflecting the primary water quality problems common in the SADC region. However, if any other constituents which may be harmful to public health have been previously reported in or near the project area, these should always be included.

Whenever funding and available laboratory facilities available are sufficient, it is always desirable for a broader range of constituents to be analysed. A more comprehensive list of constituents for analysis in this case is presented in Table 6-2 : Guidelines on Constituent Analysis.

Table 6-1 : Minimum Requirements for Constituent Analysis

Constituents	*Unit*
Chloride (Cl)	*mg/l*
Nitrate	*mg/l*
Faecal Coliform	*Count/100ml*
Temperature (field measurement)	^{o}C
pH (field and laboratory measurement)	
Electrical Conductivity (field and laboratory measurement)	*mS/cm or µS/cm*

Table 6-2 : Guidelines on Constituent Analysis

Constituents	Unit	Regular[1]	Additional Desirable[2]	Additional Special[3]
Suspended solids	mg/l	√		
Colour	TCU		√	
Turbidity	NTU		√	
TDS	mg/l	√		
pH		√		
Hardness ($CaCO_3$)	mg/l	√		
Calcium (Ca)	mg/l	√		
Magnesium (Mg)	mg/l	√		
Sodium (Na)	mg/l	√		
Potassium (K)	mg/l	√		
Chloride (Cl)	mg/l	√		
Total Alkalinity	mg/l	√		
Bicarbonate	mg/l	√		
Carbonate	mg/l	√		
Sulphate	mg/l	√		
Nitrate	mg/l	√		
Flouride	mg/l	√		
Iron	mg/l	√		
Manganese	mg/l	√		
Zn	μg/l			√
Copper	μg/l l			√
Arsenic	μg/l			√
Lead	μg/l			√
Aluminium	μg/l			√
Cadmium	μg/l			√
Cyanide	μg/l			√
Mercury	μg/l			√
Ammonia	μg/l			√
Hydrogen Sulphide	μg/l		√	
Faecal Coliform	Count/100ml	√		
Total Plate Count	Count/100ml		√	
Field Measurements				
Temperature	^0C	√		
pH		√		
Electrical Conductivity		√		

1. Regular analysis that should be carried out on all newly drilled/ exiting boreholes for any purpose
2. Additional desirable constituents that could also be tested, unless there is already problems reported in the area in which case it becomes regular.
3. Special requirements for any specific purpose or reason.

Section 7: PUMPING TEST OF BOREHOLES

7.1 GENERAL

7.1.1 Scope and Purpose

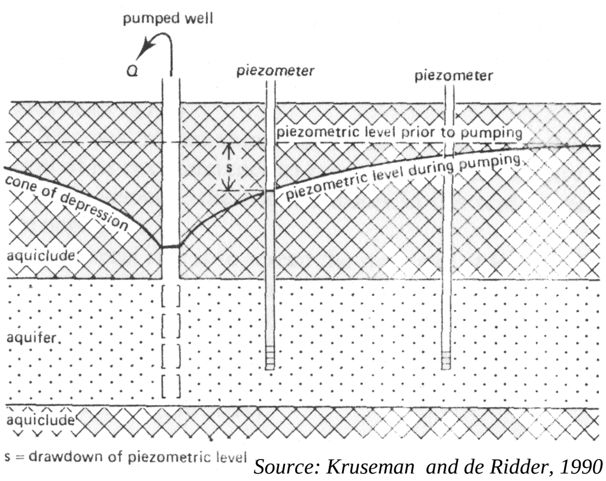
The standard and guidelines in this section cover the pump-testing of water boreholes that are to be fitted with either handpumps or motorised pumping equipment. These standards and guidelines apply to all water supply and water injection wells constructed by manual or mechanical means, aside from those that meet the definition of "hand dug wells".

Pumping test of water boreholes is carried out to meet two main objectives:

1. Establish Borehole Potential. Estimation of 'apparent optimum yield' and hydraulic performance of individual boreholes for water supplies (domestic and non-domestic).
2. Establish Aquifer Potential. Assessment of hydraulic characteristics of the aquifer to determine groundwater resources, sustainable yield of individual boreholes and/or wellfields and groundwater flow characterisation (also referred to as Aquifer Test).

Pumping test consists of pumping a borehole at a specified rate and recording the water level (and therefore the drawdown) in the pumping borehole as well as in nearby observation boreholes at specific time intervals (see Figure 7-1. When these measurements are substituted in appropriate flow equations, certain hydraulic parameters can be calculated. These parameters, together with qualitative assessment of discharge-drawdown characteristics, are used for the assessment of the sustainable yield of borehole/s and the aquifer. In some cases, numerical modelling methods may also be effective in analysis and interpretation of pumping test data.

Figure 7-1 : Pumping Borehole and Drawdown



Source: Kruseman and de Ridder, 1990

7.1.2 Conducting And Supervising the Pumping Test Operations

Only a qualified and experienced Contractor or Operator should carry out pumping test that is recognised and/or registered by the relevant national authority and, is well equipped with all the necessary equipment and facilities as described in this section. An independent Technical Supervisor must supervise the pump-testing operations. The Technical Supervisor must be a Technician of level B or higher for motorised boreholes, and a Technician of level D or higher in case of a handpump borehole, with proper support from a qualified Hydrogeologist (refer Section 1.3.6).

During the pumping test operations, all the basic measurements such as water level, discharge etc. should be taken by the contractor's/operator's personnel. The chief operator should be appropriately qualified and experienced (refer Section 1.3.6 and the Protocol on Quality Assurance for the Contractors). The Technical Supervisor should be responsible for quality control, overall supervision and on-site decision making.

7.2 TYPES OF TESTS

There are three primary types of borehole yield test (step-drawdown, constant rate and recovery tests) as well as other less common and more specialised tests. Prior to any test, a calibration exercise (sometimes also referred to as a test) is carried out to adjust and calibrate the pumping equipment at various discharges.

Step-drawdown Test

A step test involves pumping a borehole at variable discharge rates. Typically discharge is successively increased in several steps at increasing rates after a certain time interval that may range from 60 to 120 minutes. Each period during which discharge is held constant is known as a 'step'. During each of these steps, discharge is maintained constant and duration is normally kept the same. In some cases a period of recovery also follows the end of each step prior to beginning a new step.

Drawdown is recorded at certain time intervals during the test. Although of debatable use for fractured rock aquifers, analysis of the step test data quantifies the hydraulic performance of the borehole. Nevertheless, the test is extremely useful for qualitative assessment of borehole performance over the discharge range and in turn for selecting an appropriate discharge for the follow up Constant Rate Test.

Constant Rate Test

In a Constant Rate Test (CRT), the borehole is pumped at a constant discharge rate over a selected period that typically ranges from 12 to 72 hours. The discharge is kept constant during the entire duration of the test, and water levels are recorded in the pumping borehole and observation boreholes (if available) at certain time intervals that are logarithmically distributed.

Time-drawdown data obtained from the CRT is analysed for quantitative (estimation of Transmissivity, Storativity, hydraulic boundaries) and qualitative analysis of borehole and aquifer response to pumping. The analysis provides useful input to assess the sustainable yield of individual boreholes and the potential of aquifers as well as susceptibility to groundwater pollution and contamination.

In most cases quantitative estimation of parameters (except transmissivity) is limited to cases where drawdown data from the observation boreholes are available. Time-drawdown data from the pumping borehole alone has numerous limitations and only allows limited parameters to be calculated. However, useful qualitative and semi-quantitative insight is still gained from this data that is extensively used for the assessment of sustainable yield of the individual borehole.

Recovery Test

In this test recovering water levels are measured in the pumping borehole immediately after the end of CRT when the pump is switched off.

Recovery data from the pumping borehole are useful for quantitative assessment of Transmissivity. Data from observation boreholes also allows quantitative determination of transmissivity and storativity in addition to other parameters depending on the type of aquifer. The recovery test is very useful in qualitatively assessing the pumping effect and possible dewatering of the aquifer that may result due to the limited extent of aquifer.

Other Tests

Interference Test. This is not very common and is carried out only in certain cases on boreholes in a wellfield. It is normally conducted on two or more boreholes when it is suspected that the drawdown patterns of these boreholes will interfere with each other. Boreholes are pumped simultaneously at a specified rate and drawdown in the pumping and observation boreholes is recorded.

Slug Test. This test is not really a pump test in the true sense and is normally conducted in very low yielding boreholes. In this test a specific volume of water is either introduced or removed from the borehole and the subsequent water level rise or decline is measured so as to give an indication of the aquifer transmissivity. Use of this test is subjective and is not recommended for borehole yield assessment, other than for the preliminary assessment.

7.3 CHOICE OF TYPE AND DURATION OF TEST

The choice and duration of test depends primarily on the intended use of the borehole and the aquifer type that it taps. In cases when the primary objective is to assess the sustainable yield of an individual borehole (which is mostly the case within the SADC Region), the duration of the test could depend on the confidence level required in the determination of sustainable yield and the risk factor associated with failure of the borehole.

A general guideline on the type of test and the required duration is compiled below. The table provides minimum durations of a particular test under given conditions. The duration could be increased or decreased based on the site-specific requirements by the Technical Supervisor or the Client.

Table 7-1: Choice and Duration of Test

*Test Type and Duration**	*Yield Range (m^3/h) (Blow-out)*	*Intended Use*	*Hydrogeological Environment/ Aquifer*
Step Test			
No Test	< 3*	n/a	n/a
Minimum 4 steps; each of 100 min duration	> 3	All types	All types
Constant Rate Test			
8 hours	0.5 to 1.5*	Private, livestock, agricultural and all handpump and windmill boreholes	All types
12 hours	1.5 to 4	Private, livestock, agricultural and all handpump and windmill boreholes	All types
24 hours	1.5 to 4	Urban and rural water supply	All types
24 hours	> 4	All types	Established confined aquifer conditions
48 hours	> 4	All types	Aquifer is semi-confined/ unconfined or uncertain
> 48 hours	> 4	Special cases where the test is performed for parameters estimation and/or greater degree of confidence is required	Any
Recovery Test			
In all cases recovery should be taken to a minimum of 1/3 of the CRT pumping duration or until 95% of the pre-test water level is recovered, whichever is later. In any case, duration of recovery should not be less than 6 hours. The measurement should also not exceed the CRT duration.			

* Although, in most general cases, it may not be worthwhile to conduct the test below these limits, the Technical Supervisor/Hydrogeologist in charge may still make a decision to conduct the test based on their judgement and site specific conditions.

7.4 PUMPING EQUIPMENT AND MATERIAL AND THEIR INSTALLATION

A range of equipment and material is required to carry out pumping-test and this together constitutes a pumping-test unit.

7.4.1 Pumps

A pump of suitable type, design and capacity that satisfies the following requirements is essential for pumping-test:

- The pump should be capable of continuous operation to a minimum of 100 hours within the discharge ranges and heads expected during the test.
- The pump should be able to handle the full discharge range over the expected heads pertaining during the test. The end points of the discharge range are defined as 75% of the lowest discharge required for the step-test and 125% of the maximum discharge required for the step-test.
- The pump should be equipped with a non-return valve to prevent back-flow from the rising main into the borehole on cessation of pumping.
- To allow trouble-free installation in the specified borehole, the maximum pump diameter should not be more than 80% of the finished diameter of the borehole at the depth where pump installation is planned.

There are two types of pumps that are most frequently used for pumping-test: centrifugal type submersible pumps and positive displacement pumps. While the submersible type pumps are commonly used for testing and are easy to install, they often pose problems of varying discharge over the wider range of discharges required for step tests as well as in maintaining the constant discharge during the constant rate test. Although not essential, it is desirable that wherever possible, positive displacement type pumps are used for testing as these are more suited to handle wider discharge ranges and maintain constant discharge. The positive displacement pump should be equipped with a suitable pump head, gearbox and clutch so that varying the speed of the motor (rpm) can control the discharge. In no case should the maximum rpm of the pump exceed 2/3 of the maximum speed of the motor.

Suction pumps may also be used for pump-testing, however, they are only suitable for specific cases where a quick assessment of specific capacity is to be made and the head is very limited (e.g. in shallow alluvial aquifers or in river bed aquifers). The primary limiting factor with these pumps is the difficulty to maintain constant discharge.

7.4.2 Delivery Pipes

Rising Main

This is the discharge pipe that carries the water from the pump to surface. It can be a flexible hose of suitable strength (only in case of centrifugal submersible pump) or steel pipes with suitable joints capable of carrying the specified discharge range with a minimum of frictional head losses. The diameter of the pipe shall also be such that to minimise the frictional losses.

Discharge Line

This is the pipe that carries the water away from the borehole head to a sufficient distance to avoid recharge to aquifer. The discharge pipe should not have leakage of more than 2% of the discharge along its full length. The “safe distance” to which water could be discharged varies according to the aquifer type and surface conditions. Unless instructed or specified, the water should be discharged at a minimum distance of 100 m away from the borehole. At all times the unit should be equipped with an additional 100 m of discharge pipe/hose. The Technical Supervisor on site should make the final decision on the distance and direction of discharge line. However, for any length greater than 200 m, the indicative length of discharge pipe required should be specified in the pre-mobilisation meeting. In some cases a booster pump of suitable capacity may also be required to pump the water to longer distances.

7.4.3 Discharge Control and Measuring Equipment

A suitable valve must be fitted at the end of the rising main near the borehole head to provide flow control. At all times during the test, the valve should not be opened to more than ¾ as it becomes difficult to maintain the constant discharge with the valve opened more than this limit.

Measurement of discharge is one of the most critical parameters of the test. There are two basic elements of discharge measurement: the point at which discharge is measured and the means and equipment for measurement.

The most common method of measurement is the volumetric method using the stopwatch and a container of suitable capacity. This method is most accurate and should always be used as a minimum for discharges of up to 30 m^3/h. The stopwatch should be capable of time measurement to accuracy of 1/10 of a second. A guideline on the size of container to be used for measurement is presented in Table 7-2. Volume measurements should be taken at the end of the discharge pipe. Only in cases where a site reservoir and booster pump is available, measurement could be taken near the wellhead wherein the water is discharged into the reservoir at the wellhead and then from there either gravitates (negative head) or is pumped (positive head) to a “safe distance” through the discharge line. Arrangement should be made to keep the container in a horizontal position and level markings for various volumes should be clearly marked.

Table 7-2 : Guidelines on Container Capacity for Discharge Measurements

Discharge range (l/s)	*Discharge range (m^3/h)*	*Container volume required (litres)*
Less than 2	Less than 8	20
2 to 5	8 to 20	50
5 to 10	20 to 40	100
10 to 20	40 to 80	200
20 to 30	80 to 120	500
More than 30	More than 120	Other methods

While the volumetric method is essential, one of the following methods is also desirable for discharge measurement (in addition to volumetric method, wherever applicable, which then serve as a calibration).

Flow Meter

This is a very useful method of discharge measurement. A variety of flow meters are available. A suitable flow meter capable of measuring the discharge required with an accuracy of +/- 2.5% should be used. Manufacturer’s instructions should be followed for instructions to assure accuracy and to limit the turbulence at the metering point. Care must be taken in installing the flow meters to ensure near laminar flow through the meter. The meter must be calibrated and should be installed at least 10 pipe diameters from any bend.

Orifice weir

This is also a useful method for indirect measurement of discharges utilising the head loss through an orifice. The equipment consists of a circular steel plate and manometer tube. For a given configuration of the orifice plate, the water level in the manometer tube is directly proportional to the square of discharge through the pipe. Unlike the volumetric method, the orifice plate can be installed at any place in the discharge line, although it is preferred to install it near the wellhead. A detailed discussion of this method is provided in Driscoll (1987).

Other Methods
In addition, there are also other suitable methods for discharge measurement. However, use of these methods should be carefully scrutinised by the Technical Supervisor prior to approval.

7.4.4 Water Level Measurement Equipment

Water level measurement is the second most critical parameter to be recorded during the test.

Battery operated electric dip tapes (or dipper) capable of giving light signals and/or audible signal on contact with water (through its sensor) and providing an accuracy of 0.01 m must be used as a minimum for water level measurements. The electric wire along the tape should not be exposed at any point. The length of the tape should be sufficient to reach the pump intake level. The number of dippers should be same as the number of boreholes/ piezometers where water level measurements are to be recorded. Sufficient spare batteries should be available and there should be at least one standby dipper available during the test.

For the purpose of measuring the water level in the pumping well, a minimum of a 25 mm conduit pipe (or dipper pipe) should be installed. The dipper pipe should be perforated over the bottom 1 m length and all lengths should be suitably jointed.

While water level measurement using dippers is essential, whenever possible it is desirable to make use of pressure transducers (data loggers) with a fully automatic microcomputer controlled system or other automatic devices and data loggers that use chart recorders (for observation boreholes). Use of data loggers has numerous advantages:

- accurate data can be recorded with a higher frequency, particularly at the early stages of the test;
- it eliminates human error such as loss of data points during the night, difference in measurement from person to person etc;
- the reference point does not change as the transducer remains at a fixed position throughout the test;
- it can reduce the cost of pumping test in certain cases (such as when number of observation boreholes are to measured), if planned carefully; and
- data can be easily downloaded to computers (when using pressure transducers) and graphs can be plotted in real time on the site.

It is desirable that data loggers be installed, operated and maintained by the Technical Supervisor on site and not by the Contractor/operator as it provides an indirect and independent check on the discharge variations. However, if the Contractor is in possession of his own data logger, he should be allowed to use it under a close supervision of the Technical Supervisor.

7.4.5 Water Quality Monitoring Equipment

It is desirable to monitor certain water quality parameters during the test. These parameters should be recorded on site using field kits. The kit should include:

1. A conductivity meter or total dissolved solid (TDS) meter.
2. A thermometer for the measurement of water temperature.
3. A pH meter.

7.5 PRE-TEST PREPARATIONS

7.5.1 Information to be collected

Prior to the test, the following information should be collected:

- Borehole number, location, geographical coordinates, depth, diameter, water strike, casing, lithology and screen positions, blow out yield, date of drilling and other related information on the borehole to be test pumped.
- Status of the borehole to be pumped i.e. whether the borehole is in use or not. If it is in use, then the information on the pump and installation and whether the existing pump can be used for testing purpose.
- A site map (preferably topographical map sheet).
- Location, depth and design details of nearby unused boreholes that can be used as observation boreholes. If pumping boreholes are present, information on their pumping schedule is essential as it may interfere with the test.
- Location, depth and design details of any piezometer specially constructed for the test.

7.5.2 Pre-mobilization Meeting

A pre-mobilisation meeting is essential. The meeting should be held between the pumping-test contractor/in-charge, the Technical Supervisor (Hydrogeologist/ engineer/ qualified technician) and the Client. The following should be discussed and agreed upon and provided to contractor/operator:

- Location of borehole
- Commencement date
- Borehole details such as depth, design etc.
- Discharge range for which the borehole is expected to be tested
- Duration of test
- Depth of pump installation
- Length of discharge line
- Number of observation boreholes where measurements are to be taken
- Any other special requirement

The meeting should be minuted and the minutes signed by all parties involved.

7.5.3 Mobilisation and Installation of Test Unit

The following should be observed during the installation:

1. Rest water level, RWL (or Static Water Level, SWL) in the pumping well must be recorded prior to installation of any equipment in the borehole.
2. A 6 m dummy with an outside diameter 10 mm smaller than the inside completed diameter of the borehole should be lowered in the borehole prior to installation of pump to check the alignment and ensure that there is no obstruction in the borehole that may create problems during pump installation.
3. In case of submersible pump, a steel security cable should be firmly attached with the pump and during lowering and removal of pump to ensure accidental drop of pump.
4. Maximum care should be taken during lowering and removal of pump to prevent any damage to screens and casings.
5. In hard-rock and/or unscreened boreholes, the pump inlet should be installed 2 m to 3 m below the lowest water strike. In the case of unconsolidated aquifers where the lower one-third of the aquifer is screened, the pump inlet should be just above the screen. In cases where no information is available or there is an ambiguity, the pump inlet should be 3 m to 5 m from the bottom of the borehole.

6. The dipper pipe should be firmly secured at the top to avoid any vertical movement during the test. A reference point should be marked on the dipper pipe in relation to the top of the casing to detect any vertical movement during the test. A rope should be tied along the whole length of the dipper pipe to avoid the pipes dropping accidentally in to the borehole. The dipper pipe should not be attached to the rising mains and should be installed separately up to 1 m above the point where the rising main joins the pump.
7. The direction of the discharge line shall be such that water flows away from the borehole (refer section 7.4.2 for more details). The Technical Supervisor on site should make required final decision on the direction and length of discharge line.
8. A proper lighting arrangement should be made at and around the wellhead during the test to facilitate the measurements and other operations during the test.
9. A continuous supply of fuel/electric power should be maintained during the test to ensure uninterrupted testing.
10. The pumping-test unit should be equipped with a suitable mechanism for the installation of pumps and rising mains. It is desirable that a hydraulic system be used for the installation. The unit should also be equipped with suitable welding and cutting equipment and tools to open and secure the borehole casing, if required.
11. The pumping test unit should be equipped with a sufficient number of measuring tapes; at least one 100 m tape is essential.
12. Although not always possible, the Technical Supervisor should ensure that all the boreholes in the vicinity of the pumping test borehole that are suspected to interfere with the water level in the pumping well should be shut down prior to and during the test.

7.5.4 Observation Boreholes/ Piezometers

Water level data from the observation boreholes provides useful information including storage coefficients, leakage, interference effect etc.

In cases where the primary purpose of testing is to assess the sustainable yield of an individual borehole, every effort should be made to locate existing boreholes in the vicinity of the pumping test borehole and use them as observation boreholes, provided they are not in operation during the test and have been shut down for a sufficient time prior to testing. If no observation boreholes are available and the yield of the borehole to be tested is very high compared to the average yield in that area (more than 5 times), it is desirable that at least one piezometer should be specially constructed at an appropriate location prior to testing for water level measurement. The distance of this piezometer from the pumping borehole should be based on the local and site specific hydrogeological conditions.

In case where the primary purpose of the test is to estimate aquifer parameters, observation boreholes are essential. The selection and/or construction of observation boreholes/ piezometers in these cases is site specific and should be decided by the Technical Supervisor.

7.6 PUMPING TEST

7.6.1 Data and Records to be collected

During the test, a range of information and data are collected and recorded. Standard forms for recording are presented as Appendix C.

1. If no forms are available or the existing forms are inadequate (i.e. they do not contain the minimum required information as described in this section) then all the information and data that are to be collected during the test must be recorded on standard forms as presented in Appendix B (Form TP-1 to TP-4).
2. Measurements of water level and discharge should be taken by the contractor's/operator's personnel and recorded on appropriate data forms and supplied to the Technical Supervisor from time to time during the test. The Technical

Supervisor should record the measurements on his own forms that should serve as the master copy and bears the counter signature of the contractor.

3. A cover sheet or main form (Form TP-1) recording the general information on the site must be completed.
4. RWL should be recorded in the pumping borehole as well as in all the observation boreholes prior to installation of equipment and start of the test.
5. Water level measurements should be recorded to within an accuracy of 0.01 m using the equipment as described in section 7.4.4 on the pumping well as well as in selected observation boreholes, if available. A reference point should be clearly marked for the measurements. The frequency of measurement should be as indicated in appropriate forms for the applicable test. Wherever transducers are used for water level measurements, data sheets should still be completed manually by periodically checking the measurements on the data logger.
6. Discharge measurements should be recorded using suitable equipment and method as described in section 7.4.3. Each measurement should be repeated at least three times and average reading should be recorded, provided discharge is not adjusted between these readings and that fluctuations are within 5%.
7. It is desirable to record certain water quality parameters such as conductivity and /or TDS, temperature and pH. Frequency of measurements should be as indicated in the appropriate forms for the applicable test. Although recording of these parameters, in general, does not fall under “minimum or essential” requirement for the test, in certain cases recording of water quality parameters may be essential e.g. in coastal areas where saline water intrusion is expected. Decision on making the recording of these parameters essential should be taken by the Technical Supervisor prior to start of the test.
8. In coastal areas or inland salinity areas if EC increases considerably during the pump testing then the test should be stopped, as it may be an indication of saline water intrusion.
9. Wherever possible, it is desirable to record the water level twice daily for a week prior to the test in the borehole to be test pumped as well as selected boreholes from the surrounding area.
10. It is desirable to keep a record of rainfall occurring during the test.
11. Any other observation such as change in colour of water etc. should be recorded.
12. It is also desirable to keep a record of barometric pressure on site.

7.6.2 Testing

Step-drawdown Test

1. It is desirable to conduct a Calibration Test prior to the Step Test to calibrate the pumping equipment and the discharge ranges that are required. This is achieved by recording the corresponding rpm (for positive displacement pump) and valve positions (for centrifugal submersible pump).
2. The test should be for a minimum of 4 steps; each step of 100 minutes duration.
3. the planned discharge for 4 steps should be 50, 70, 100 and 130% of the reported blow-out/expected yield respectively. This is only a guideline and discharges could be changed on site by the Technical Supervisor based on the responses obtained, thus ensuring that the four steps are completed without drawing the water level down to the pump level. Adjustment in discharge should be such that at the end of the last step, the water level approaches the pump intake level. It is desirable to continue the test for further steps 5 and 6, as long as drawdown is still available and the funds permit. The key is to obtain the discharge – drawdown relationship over the whole range and observe the pattern when water strikes are dewatered. This information is critical to select the optimum pumping rate for CRT.

4. Discharge during a particular test should always remain constant within a permissible limit of 5%.
5. Measurement of discharge, time and drawdown should be recorded for time intervals according to Form TP-2.
6. A time-drawdown plot of the test should be plotted on graph paper on the site as the test progresses. This enables to assess the drawdown pattern and make necessary adjustment on planned discharge for the next step.

Constant Rate Test

1. The Technical Supervisor, based on the results of the step-drawdown test, will decide the discharge rate at which the test should be carried out. The selected discharge should be such that the estimated drawdown at the end of the planned pumping duration (based on the drawdown pattern obtained from the step-drawdown test by estimation and extrapolation of appropriate drawdown curves) during the test remains at between 60 to 80% of the available drawdown. The expected hydrogeological environment also plays an important role in selecting this discharge, e.g in cases where negative boundaries exist, drawdown can be nearly double or more than the expected, while on the other hand, when recharge boundaries or leakage occurs, the drawdown could be much less then expected resulting in under-pumping. In general, great care should be taken to ensure that the borehole is not under-pumped during the test.
2. Discharge during the test should always remain constant within a permissible limit of 5%. However, the operator should make every possible effort to keep this limit even lower during the test.
3. Measurement of discharge, time and drawdown should be recorded for time intervals according to Form TP-3.
4. The time-drawdown plot of the test should be plotted on graph paper on the site as the test progresses. It is desirable to increase the pumping duration if a change in the slope of the time-drawdown plot is observed towards the end of the test in order to ascertain the continuing pattern. The Technical Supervisor on site should take such a decision.

Recovery Test

1. Recovery measurement should follow immediately when the pump is shut down at the end of CRT, for duration as stipulated in Table 7-1.
2. Measurement of time and drawdown should be recorded for time intervals according to Form TP-4.
3. It should be ensured that the pump is fitted with a non-return valve so that water from the rising main does not return to the borehole to affect the water level measurement, especially at the early part of the test.

7.7 MISCELLANEOUS

1. The Technical Supervisor should conduct an inspection of all the equipment and measuring devices to be provided by the contractor/operator prior to mobilisation to site.
2. The borehole should be well developed prior to the pumping test.
3. In case a breakdown occurs during the step drawdown test, the particular step during which it occurs should be repeated again after fixing the problem.
4. Sufficient time should be allowed between the two tests for the water level to recover. It is recommended that the step test should start in the morning so that it is completed by the evening. CRT should then start the next morning. This not only allows sufficient time for the water level to recover prior to the test, but also ensures that during the night time the time interval between measurements is at least one hour.
5. Water samples should be collected for water quality analysis during the CRT. Sample procedures are outlined in more detail in Section 6.

6. In case a breakdown occurs during the CRT, recovery measurements should immediately be initiated. Thereafter, the test should be repeated if the duration of pumping has been less than 12 hours. If the breakdown occurs after 12 hours of pumping and can be rectified within 5% of elapsed time, the test should be allowed to continue. For any test where breakdown occurs after 12 hours of pumping for more than 5% of elapsed time, the decision to repeat or accept the test should be taken by the Technical Supervisor on site based on the data obtained up to that stage.
7. If, at any stage during the CRT, the water level reaches the pump suction then the pump should be shut down immediately and recovery measurements should be initiated. A cut-off switch should also be provided to avoid damage to the pump.
8. There should always be proper communication facilities available on site for back up support on all matters related to the test.

Section 8: RECOMMENDATIONS ON PRODUCTION PUMPING

8.1 GENERAL

8.1.1 Scope and Purpose

The standard and guidelines in this section cover the recommendations on production pumping applicable to single boreholes that are to be fitted with either handpumps or motorised pumping equipment. These recommendations include sustainable yield of the borehole, pumping hours, pumping schedule, pump installation depth, groundwater quality and suitable equipment for pumping. These apply to all water supply and water injection wells constructed by manual or mechanical means, aside from those that meet the definition of "hand dug wells".

8.2 REQUIRED PARAMETERS

A variety of data and information is required to provide adequate recommendations on production pumping. These are detailed below.

8.2.1 Pumping test Data and Aquifer Parameters

Pumping test of boreholes is carried out to obtain the aquifer parameters and time-drawdown characteristics for pumping boreholes (Section 7). For the purpose of recommendations on production pumping for a borehole, pumping-test data (together with aquifer parameters that are obtained from the analysis and/or from other methods) are primarily used for estimating the drawdown in a pumping well at a specified discharge and time.

Analysis of pumping test data is a complex subject requiring proper understanding and experience. There are various methods available for the analysis of different types of tests and it is beyond the scope of this document to discuss these methods. A number of books and publications are available in this regard and the reader is particularly referred to Kruseman & de Ridder (1990) and Driscoll (1986) for details. There are also a number of computer software applications available for the analysis some of which are listed in Appendix C.

It is important to note some critical limitations associated with the analysis of pumping test data. Analysis for the more accurate assessment of critical parameters for drawdown prediction (such as Storativity, Leakage Coefficient etc.) is only possible when:

- time-drawdown data from the observation borehole/s is available;
- the nature and position of barrier/recharge boundaries are known; and
- aquifer geometry (thickness of aquifer, position and width of fractures, etc.) is known.

In most cases, however, data from only the pumping borehole is available and aquifer geometry is poorly constrained. In single borehole tests, analysis of test data is generally limited to determination of transmissivity and qualitative analysis of time-drawdown curve for drawdown predictions. The analysis is particularly complex for heterogeneous and fractured aquifers (secondary aquifers) that are more commonly present in the SADC Region.

In some cases values of hydraulic parameters are also available from previous studies in the particular area of investigation. These assessments (particularly on the storage coefficient/specific yield) are also very useful in the absence of any other information and could be used for assessment of sustainable yield after a careful review of site-specific situations.

8.2.2 Groundwater Recharge

Groundwater recharge is the component of precipitated water that reaches an aquifer through infiltration. This direct recharge, together with the induced recharge with pumping, strongly influences the sustainability of the aquifer.

Groundwater recharge is also one of the most difficult parameters to estimate. The main factors influencing the groundwater recharge are:

- Precipitation;
- Evapotranspiration;
- Soil/regolith properties;
- Geology;
- Topography; and
- Landuse and vegetation.

In the SADC region where majority of the aquifers are fractured, recharge distribution is expected to vary significantly in space and time, even over relatively small areas, due to preferential flows along the high transmissive zones.

Various methods are available for recharge assessment at regional and site specific level, with their inherent advantages and disadvantages. A useful detailed description of the various recharge methods and their applicability is provided by Bredenkamp, et al. (1995). Some of the useful methods for recharge assessment are:

<u>Unsaturated Zone:</u>

Lysimeter studies
Soil moisture flow and balance
Tritium profiling
Chloride profiling

<u>Saturated Zone</u>

Water Balance Method
Saturated Volume Fluctuation Method (SVF)
Chloride Mass Balance Method
Hydrograph Analysis Method
Cumulative Rainfall Departure Method
Isotope Balance Method (^{18}O, ^{2}H)

8.2.3 Groundwater Quality

The quality of groundwater to be extracted from the borehole is also a critical parameter in relation to production pumping recommendations. It is essential that water quality analysis results are available prior to making recommendations, except where it is established beyond reasonable doubt that the quality is suitable for the intended purpose.

8.2.4 Abstraction Data from Nearby Production Boreholes

Information should be gathered on the abstraction rate and water levels in the other boreholes that exist within the vicinity of the borehole for which recommendations are to be made. This is particularly important in assessing any interference effects.

8.2.5 Monitoring Data

Historical groundwater level monitoring data are also extremely useful in assessing the sustainable yield of a borehole. This provides an important indication on water level fluctuations that should be accounted for while making predictions on expected drawdown in the pumping borehole.

8.2.6 Available Drawdown (s_{av})

Available drawdown is the maximum allowable drawdown in a pumping borehole. Drawdown beyond the available drawdown may negatively impact on borehole life, reduce the specific capacity (and thus the yield of the borehole), impact negatively on water quality and damage the pumping equipment. Therefore, sustainability of an individual borehole for a given discharge is mainly controlled by this available drawdown.

In most cases, available drawdown is the difference between the dry season rest water level and the upper level of the first screen or the water strike or the pump intake, whichever is shallower. During the construction of the borehole, optimisation of available drawdown is an important consideration in the placement of screens (refer 4.3.4). Woodford from DWAF, RSA suggests that the available drawdown is also limited to the point at which an inflection point occur for the corresponding drawdown in the semi-log plot of the time-drawdown. It may result due to dewatering of the aquifer.

8.3 PRODUCTION PUMPING RECOMMENDATIONS

A number of variables are involved in the assessment of sustainable yield and associated pumping hours. In most cases, the majority of the variables are either not known or there is considerable ambiguity (or uncertainty) in their values, and therefore a number of assumptions are made in that regard to achieve the estimates of sustainable yield.

8.3.1 Sustainable Yield

The term 'sustainable yield' is critical to sustainable groundwater use, but it has a variety of definitions both in the SADC region and internationally. Sustainable yield is the amount of water that can be extracted from a borehole or an aquifer (normally expressed as volume per unit time) for a given duration in a sustainable manner over a long period (normally 5 to 15 years) whilst maintaining the life of the borehole and without depleting the aquifer beyond an acceptable level and without causing adverse environmental impacts.

There are two distinct element of this sustainable yield:

1. The <u>aquifer sustainability</u> that refers to the sustainability of the whole aquifer in general for a given yield in terms of its exploitation potential without depleting or contaminating the aquifer beyond an acceptable limit; and
2. The <u>borehole sustainability</u> that refers to the sustainability of an individual borehole for a given yield in terms of ensuring the life span of the borehole, optimising the running cost, limiting the negative impact on screens/casings as well as the equipment by limiting the drawdown in the borehole within an acceptable limit,

On a longer term, borehole sustainability depends on aquifer sustainability. For example there may be a case where a borehole itself, located in a highly transmissive zone in an aquifer of limited extent, can sustain a given yield (for a short period) without any adverse effect on its own life span or equipment, but the aquifer may not sustain that yield. On the other hand, there may be a case when the aquifer can sustain much higher rate of abstraction but a borehole tapping this aquifer may not sustain this abstraction. Therefore, the sustainable yield of a borehole is determined by both factors and the recommendations on production pumping should be based on an assessment of both these elements.

It should also be noted that monitoring data (in terms of discharge, water level, water quality) during the production pumping stage provide a useful insight into the aquifer and borehole sustainability. Therefore, it is imperative that production recommendations should be reviewed once the monitoring data is made available.

Aquifer Sustainability Assessment

Sustainability of aquifer for a given abstraction (in terms of quantity of water) at a particular site depends on the following components:

- Extent of the aquifer and/or the catchment size;
- Aquifer recharge and throughflow;
- Storativity/specific yield of the aquifer;
- Presence of a surface water body or river and its connectivity to the aquifer; and
- Connectivity of the aquifer with underlying and/or overlying aquifers/aquitards (multilayerd or semi-confined aquifers).

Interrelationship of the above components has direct impact on aquifer sustainability. In most cases the interrelationship is very complex and can only be established by groundwater flow modelling, particularly in terms of the aquifer recharge (direct and induced) and throughflow. Therefore it is recommended that groundwater flow modelling should be carried out where the risk of failure is high or where a large volume of water is to be abstracted. The modelling can also simulate the effect of induced recharge or inflow as a result of pumping – the components that are difficult to establish using analytical methods. For smaller supplies and low risk cases, a simplified assessment of groundwater recharge and 'intake area' should be made based on site-specific conditions and taking a more conservative approach.

In its most generalised form groundwater recharge represents the renewable resource that can be safely abstracted from the aquifer on a long-term basis although, abstraction beyond this limit may also induce recharge from surface water bodies. In addition to recharge, aquifer throughflow (the volume of water passing through the entire cross section of the aquifer, perpendicular to groundwater flow, under the prevailing hydraulic head) also contributes to the volume of water that can be abstracted, particularly for deeper and confined aquifers. More sophisticated methods are required to assess this throughflow.

One of the simplified ways of assessing the direct recharge is by defining the 'intake area' which is the area of the aquifer that contributes to the flow in a borehole over a longer period of time due to recharge. It depends on the extent of the aquifer and on the local geological and physiographical conditions. In most cases of shallow fractured rock aquifers and/or unconfined aquifers, it is the same as the area of the surface water catchment (bounded by surface water divides and natural outflows) in which the borehole is located. In aquifers bounded by impermeable boundaries and in linear aquifers, the intake may be restricted by the hydraulic boundaries (such as dykes) or zones of extremely low hydraulic conductivities. More details on defining the intake areas or 'recharge areas' can be found in Bredenkamp et al. (1995). However, in cases where the intake areas are too large (such as topographically flat area or aquifers of greater extent) the intake area is difficult to assess and a conservative figure could be adopted based on the site specific conditions. This should, in general, not exceed more than 10 km^2.

It should be noted that not all the water that is recharged to aquifer may be available for exploitation and therefore a clear distinction should be made between the recharge and 'net inflow' to aquifer, as some proportion of the recharge may be lost to other aquifers and as throughflow. It is imperative to assess the proportion of recharge that could actually be abstracted, based on the intake area, locally from the aquifer on a sustainable basis.

The total simplified estimate of recharge for a given 'intake' area of a site can be defined by:

$$R = AR_r$$

Where,

A = Intake area
Rr = Recharge rate in m/day
R = Recharge volume for the intake area in m^3/day

Once the recharge volume is calculated, the proportion of this that can be abstracted has to be estimated. DWAF of South Africa (1993) suggests 50% of this volume can be abstracted. In case of absence of more information, this value could be considered. Based on modelling studies, Sami et. al. (1998) have also suggested a method of estimating the proportion of recharge that could be abstracted. The method takes into account the maximum and the minimum transmissivity values in the area where the borehole is located.

In some cases limited dewatering of the aquifer is also permissible for a short period within an allowable limit of decline in water level/ piezometric head. In such cases aquifer storativity also plays an important role. The volume of water that can be available from the aquifer is represented by:

$$V = S_s B A h$$

Where,
V = Volume that can be abstracted from the aquifer
S_s = Specific Storage coefficient/Specific yield
B = Thickness of aquifer
A = Intake area
h = Decline in piezometric head/water level

Once the sustainable volume from the aquifer (represented in volume/per day basis) is estimated, the total abstraction volume that is planned from the number of boreholes considered in the area (i.e. 'intake area') should not exceed this limit. The sustainable yield of the individual borehole (borehole sustainability) is then estimated from the pump test results of the individual borehole.

Borehole Sustainability

<u>Basic Principle</u>

Sustainability of a borehole for a given abstraction rate depends on:

- Aquifer sustainability;
- Geological and hydrogeological conditions in the immediate vicinity of the borehole, including distances from hydraulic boundaries;
- Onsite transmissivity of the aquifer;
- Saturated thickness, hydraulic head and/or depth of water strike which, in turn, limits the available drawdown; and
- Construction of the borehole and its hydraulic efficiency.

Borehole sustainability has two sub-elements, the sustainable discharge rate and the sustainable pumping hours. It is not good practice to represent the sustainable borehole yield by the volume of water per day alone because, although the borehole may sustain the volume, it may not sustain the higher pumping rate required to abstract that volume (as it may lower the water level below the optimum level and cause pump failure and/or borehole damage).

Sustainable discharge (or yield) is controlled by the drawdown in the pumping boreholes. Therefore estimating reasonably accurately the drawdown (or predicting, as it is commonly referred to) is critical to making proper recommendations, as this drawdown should not exceed the available drawdown.

Drawdown in a pumping well is a function of discharge (Q), time (t), transmissivity (T), storativity (S), linear and non-linear well losses and aquifer geometry (including the barrier and/or recharge boundaries). If these parameters are available, drawdown could be calculated using the following formula:

$$S_{pred} = \frac{Q}{4\pi T} W_f + S_{loss} \pm S_{bound} \pm S_{other}$$

Where,

S_{pred} =	Predicted Drawdown at given time
Q =	Discharge
T =	Transmissivity
W_f =	Well function, as applicable to the appropriate particular aquifer type such as the W(u) – Theis well function for confined aquifer, W(u,r/L) for leaky aquifer, $w(u_A, u_B, \beta)$ for unconfined aquifer etc.
S_{loss} =	Drawdown due to linear and non-linear well losses in the borehole
S_{bound} =	Additional drawdown due to barrier and/or recharge boundary, interference effect etc.
S_{other} =	Any other drawdown

As long as S_{pred} remains less than or equal to S_{av}, the corresponding discharge becomes the sustainable discharge ($Q_{sustain}$) of the borehole. For a continuous pumping the time for S_{pred} should be high enough (2 to 10 years, as appropriate). For intermittent pumping, the rate could be adjusted further (refer guidelines on pumping hours further in this sub-section).

<u>Methods for Estimating Sustainable Borehole Yield</u>
The most common mean of assessing borehole sustainability is pump testing that provides the yield drawdown characteristics of the particular borehole resulting from the combined effect of aquifer characteristics surrounding the borehole and hydraulic efficiency of the borehole itself.

A variety of methods are available that use pump-testing data and are broadly based on the basic principle outlined above, with various assumptions and additional mathematical treatment to estimate the sustainable yield. Some of the methods applicable within the context of the SADC region, are outlined below. For more details on these methods the references are provided. These methods are:

- Subjective Method
- Maximum Drawdown Method
- Transmissivity Method
- FC Method (Flow Characteristics Method)
- Double Slope Method
- Drawdown Calculation Method
- Drawdown Projection Method

Subjective Method is based on the qualitative analysis of pump test data, shape of the drawdown curve and, more significantly, on the judgement of the hydrogeologist utilising his experience of geological and hydrogeological environment. The method is more commonly used for boreholes equipped with handpumps. Although the method can be effective at times, depending on the quality of judgement, it has no set procedures and logical background. More often then not it results in incorrect recommendations. It is recommended that this method should only be used as a supportive method to other more established quantitative methods.

Maximum Drawdown Method (Enslin and Bredenkamp, 1963) is another popular method for estimating individual borehole sustainable yield, particularly in South Africa. In this method the pump is placed near the bottom of the borehole and then pumped at a high rate until the water in the borehole is drawn down to the pump. Thereafter, the abstraction rate is reduced until the water level in the borehole rises above the pump and does not reach back to pump intake for 4 - 12 hours of pumping at that rate. Then the sustainable yield is assessed as 60% of this rate for an 8 - 12 hour pumping per day. The method was evaluated by Sami et.al. (1998) on a limited number of boreholes in fractured rock and it was found that generally the yields are overestimated. The method does not have any theoretical reasoning and is not recommended for reliable use.

Transmissivity Method is used by Geological Survey of Swaziland and is described by the Canadian Development Agency (CIDA) in course notes (Sami et.al.,1998). According to this method the sustainable discharge is estimated as:

$$Q_{sustain} = 0.068\, T\, s_{av}$$

Where,
$Q_{sustain}$ = Sustainable discharge
T = The transmissivity of aquifer
s_{av} = The available Drawdown

While the method does take into account the two most critical parameters for the sustainable yield of an individual borehole (i.e. the T and s_{av}), the actual theoretical justification of this method is not available and evaluation results are also not available to assess the effectiveness of the method.

FC Method (Flow Characteristic Method) (van Tonder et.al., 1998) is developed by the Institute of Groundwater Studies, Bloemfontein in association with the Directorate of Geohydrology, Department of Water Affairs and Forestry, South Africa. The method is fairly comprehensive, has a proper theoretical and mathematical justification, and takes into account the effects of no-flow boundaries and uncertainties of transmissivity, storativity and distances to the boundaries for risk assessment. In principle the available drawdown is corrected for uncertainties in aquifer parameters using:

$$s'_{av} = s_{av} - 2s_s \qquad \text{(for 95.5\% confidence level)}$$

and

$$s'_{av} = s_{av} - s_s \qquad \text{(for 68.3\% confidence level)}$$

Where,
s'_{av} = Corrected available drawdown
s_{av} = Available drawdown as described in 8.2.6
s_s = Uncertainty of the extrapolated drawdown

An MS Excel® code is also developed to aid the estimation of sustainable yield using the above method. The code and the manual is in the public domain and can be downloaded from the IGS website at www.uovs.ac.za/faculties/igs/software.htm. Two levels of solution are possible:

1. A more conservative *Basic Solution* in the absence of boundary information and late stage T and S; and
2. A more comprehensive *Advanced Solution* that requires prior knowledge of distances to boundaries and late stage T and S.

Double Slope Method is used by the Department of Water Affairs (DWA) in Botswana with associated in-house developed software, *Test Curve,* for the calculation of recommended yield based on estimated drawdown at five years and the available drawdown in the borehole. The method is based on the conservative assumptions that an impermeable boundary is encountered at the end of the test causing the drawdown slope to double in gradient from that point onward and no recharge to aquifer occurs for a period of 5 years. Based on this assumption the drawdown during the CRT is projected beyond the end of test point by doubling the slope for a 5-year period (s_{proj}). The sustainable discharge is then estimated using the following equation:

$$Q_{sustain} = Q_{test} \frac{s_{av}}{s_{proj}} \quad \text{while } Q_{sustain} \leq Q_{test}$$

The Double Slope method is based on the conservative assumption that at least one impermeable boundary is encountered immediately after the end of CRT. The method does not have flexibility to accommodate the site-specific geological and hydrogeological conditions that may vary. It tends to take a fairly conservative approach and therefore, tends to underestimate the sustainable yield in some cases.

Drawdown Calculation Methods are primarily based on basic principle described previously in this sub-section with various simplifications and assumptions suited to specific hydrogeological environment. In most cases, the methods are based on estimating drawdown (in an infinite aquifer with no recharge) from the Cooper-Jacob equation that states that:

$$Q = \frac{4\pi T s_{av}}{2.303 \log(2.25Tt / r^2 S)}$$

Where,
Q = Discharge
T = Transmissivity
t = Time, usually long enough (1 year or more)
S = Storativity
s_{av} = Available drawdown
r = Borehole radius

Transmissivity values that are used in the equation are mostly for the late stage and are obtained from the CRT analysis of the late stage curve. Storativity values are normally not available unless the observation borehole data are available and therefore assumptions have to be made based on the general S value in the area.

Drawdown Projection Method is similar to the above method but has an advantage over the calculation method in terms of simplicity. It uses the projection of drawdown in the pumping well (which is a function of all the parameters in the calculation method as well as non-linear losses in the well). The method may be less accurate but is useful in cases where most of the parameters are unknown and it can be easily applied using the simple manual calculations. It basically combines elements of the FC Method and Double Slope Method, with some additional and simplified assumptions based on site-specific conditions.

In this method the time-drawdown curve (on a semi-log plot) of the CRT is linearly projected to a period of 5 years and the corresponding drawdown is noted (S_{extra}). Thereafter the following adjustments are applied to this drawdown:

1. While extrapolating the curve, the slope of the last segment should be doubled in the semi-log plot of time drawdown (based on the assumption that an impermeable boundary may be encountered with prolonged pumping) starting from the point at which the test ends. This should only be done in cases where:
   - The borehole is located in an aquifer of limited extent (small catchments);
   - impermeable boundaries exist around the borehole but the effect has not shown on the time-drawdown data within the test duration (for example in Karoo Aquifers in southern Africa where there are numerous dyke intrusions);
   - the nature of the aquifer is very complex and can have a negative impact on drawdown; and
   - there are uncertainties and very little is known about the aquifer.
2. The extrapolated drawdown should also be adjusted (S_{adj}) for water level fluctuations, if these are known. The adjustment could be subjective, by adding the approximate head or, more appropriately, be based on standard deviation (add standard deviation to extrapolated drawdown). In cases where fluctuation records are not available, a best estimate should be made based on experience and data from a similar hydrogeological environment. It should also be noted that if this adjustment is applied to available drawdown then there is no need to apply it to extrapolated drawdown as well.
3. If there is a nearby existing pumping borehole that could interfere with the proposed pumping borehole, then necessary adjustment should be made. In case of any ambiguity, extrapolated drawdown should be obtained by doubling the slope as explained earlier.

Once the adjusted drawdown (S_{adj}) is estimated based on the above approximations and extrapolations, sustainable yield can then be calculated using the following equation:

$$Q_{sustain} = Q_{test} \frac{s_{av}}{s_{adj}} \qquad \text{while } Q_{sustain} \leq Q_{test}$$

Where,
$Q_{sustain}$ = Sustainable discharge
Q_{test} = Discharge during the pump test (CRT)
s_{av} = The available Drawdown
s_{adj} = The adjusted drawdown as described above

This estimate is an approximation and is based on 24 hours of pumping a day and can be adjusted for the actual pumping hours. It should also be noted that in any case $Q_{sustain}$ should not exceed Q_{test}.

Pumping Hours

Similar to the discharge, the setting of pumping hours is also critical to the sustainability of production pumping. Pumping discharge estimates based on the principles and methods detailed earlier are mostly applicable to continuous pumping (i.e. 24 hours of pumping a day). Continuous pumping is often advantageous to borehole life and ease of operation. However, in most cases where aquifer geometry and flow behaviour is poorly understood it is far safer and practical to limit the pumping hours.

To a certain extent, estimation of pumping hours is subjective and depends on recovery pattern, aquifer type and aquifer geometry. Some of the general considerations that should be considered in such estimations are listed below:

1. Recovery data are very useful in making assessment of pumping hours (Kirchner & Tonder, 1995). Theoretically the recovery curve should intercept the zero residual drawdown line at t/t'=2 (t is the time since the start of pumping and, t' is the time since pumping stopped) which means that time taken for recovery is equal to total time of

pumping (for aquifers of infinite extent). In practice this is often not the case (unless a recharge boundary is encountered) and for any intercept less than 2, there are indications that either the aquifer is of limited extent or the storativity value is different during the pumping and recovery phases (requiring longer for recovery).

2. In most cases, where the aquifer is not recharged or there is no through flow (a conservative assumption that is often considered in estimating sustainable yield), a certain residual drawdown always remains at the end of each pumping cycle. There are methods to calculate this residual drawdown and adjust the sustainable yield that is estimated for continuous pumping to the required pumping hours (DWA-Botswana, 1997).

3. In a complex fractured aquifer environment where aquifer extent and continuity is poorly understood, unknown impermeable boundaries and lower transmissivity zones may increase the drawdown rate as the cone of depression propagates continuously with time. In such cases, by limiting the pumping hours and allowing for sufficient recovery, the effect can be minimised.

4. In cases where an interference effect is expected from nearby pumping boreholes, pumping hours need to be regulated and scheduled properly. If the borehole is located in a wellfield, interference tests should be conducted and preferably a groundwater model used to regulate the pumping hours.

5. In some cases, detailed groundwater management plans exist for aquifers and/or catchments to protect against overexploitation. These plans provide useful information and conditions that should be considered, especially in regard to volumetric abstraction.

It is desirable that detailed determination of pumping hours should be made on the basis of the above factors. In cases where detailed assessment is not possible, Table 8-1, which provides a broad guideline on pumping hour recommendations taking into consideration the above factors in a simplified manner, should be used. The table should only be used as a guideline and site specific conditions must be considered.

Table 8-1 : Guidelines on Pumping Hours

Recommended pumping hours per day	*Adjustments on calculated yield for 24 hours pumping*	*Applicability and conditions*
Continuous Pumping	No Adjustments	• Unconsolidated homogenous aquifer of wide extent located in large catchments. • Reasonably good understanding of hydrogeological environment and aquifer extent. • Established recharge from the nearby source and/or through precipitation
18 to 24 hours	No Adjustments	• Heterogeneous/fractured aquifer of much wider extent located in large catchments with flat to gentle topography and without dyke intrusions • Unconsolidated homogenous aquifer of unidirectional extent (such as valley flats) • Reasonably good understanding of hydrogeological environment and aquifer extent. • Established recharge from the nearby source and/or through precipitation • t/t' intercept at zero drawdown should be more than 2
12 to 18 hours	$Q_{sustain}$ =	• Heterogeneous/fractured aquifers extending to one

	$(1.1)xQ_{24}$ (As long as $Q_{sustain} < Q_{test}$)	direction only (such as valley flats) located in medium to smaller catchments with gentle to moderate topography • Moderately good understanding of hydrogeological environment and aquifer extent. • Established recharge from the nearby source and/or through precipitation • t/t' intercept at zero drawdown should be more than 2
10 to 12 hours	$Q_{sustain}$ = $(1.2)xQ_{24}$ (As long as $Q_{sustain} < Q_{test}$)	• Heterogeneous/fractured aquifers of limited extent, dyke intrusions, smaller catchments and moderate topography • Reasonable understanding of hydrogeological environment and aquifer extent. • t/t' intercept at zero drawdown should not be less than 1.6
8 to 10 hours	$Q_{sustain}$ = $(1.2)xQ_{24}$ (As long as $Q_{sustain} < Q_{test}$)	• Heterogeneous/fractured aquifers of limited extent, dyke intrusions, weathered basement aquifers with lower recharge, smaller catchments and moderate to extreme topography • Limited understanding of hydrogeological environment and aquifer extent. • Uncertain recharge • t/t' intercept at zero drawdown less than 1.6

8.3.2 Pump Installation Depth

Pump installation depth is very critical in order to optimise the available drawdown and to ensure the life of the pump and the borehole. The following considerations should be taken in selecting the installation depth:

1. The maximum pump intake depth should be such that it is at least 5 m above the bottom of the borehole in case of an open borehole and 3 m in case of a fully cased borehole.
2. The pump intake should not be placed adjacent to the slotted casing/screens or the water strike (point of inflow).
3. The pump intake should be placed at least 1 m above the major water strike. In case the water-yielding zone is spread over a larger depth, care should be taken during construction to provide at least 3 m plain casing at an appropriate place to house the pump intake.
4. In case of hand pumps and windmills, the minimum pump intake installation depth should such that it is 3 m below the expected pumping water level for a constant discharge of 1 m^3/h. The maximum installation depth should be such that it is at least 5 m above the bottom of the borehole in case of an open borehole and 3 m in case of a fully cased borehole. In addition the maximum installation depth is also controlled by the pump type (refer Section 9.6).

8.3.3 Water Quality

The quality of water must conform to the local standards for the purpose for which the borehole is intended to be used. Any tendency for degradation in water quality with time due to flow regime induced by pumping from the borehole must be assessed. In case of unavailability of sufficient data, reasonable judgment should be made on the basis of hydrogeological set-up and experience.

There may also be instances where water quality from the particular borehole may not conform to standards but where it could be mixed (blended) with better quality water in an integrated supply to achieve the desired standards.

8.3.4 Water Quality Protection

Production pumping recommendations should also include recommendations on water quality protection.

Protection of aquifers and the water quality of pumping boreholes against pollution and contamination is a very wide and complex issue and cuts across the groundwater development as well as management aspects. Ideally the area around a borehole should be categorised (i.e. zoned) according to the potential for, and level of, pollution and contamination, that in turn depends on the type of aquifer and groundwater flow regime. A large volume of literature is available in this regard.

During groundwater development at the level of a single borehole or a group of boreholes, there are certain general criteria that must be followed to protect the groundwater quality and avoid pollution and contamination. These principles are applicable to domestic water supply boreholes.

1. If available, the existing map on groundwater pollution vulnerability for the area in question should be referred to, in order to get an overview of potential pollution and other baseline information that might be useful in making necessary arrangements/ recommendations on protection for a particular borehole(s).
2. The allowable horizontal distance between the borehole and pit latrines, or any pollution point source, depends on a number of factors such as the pollution type, soil type, aquifer heterogeneity, groundwater flow regime etc. Wherever the risks are high and information is available, protection zones should be defined utilising the available data and numerical groundwater modelling techniques. In case details on these are not available, the borehole should be placed at least 50 m away from any pit latrine, graveyard or similar pollution source under normal conditions and 75 m in case the borehole is located in down gradient (groundwater flow) of the source (Braune, 1997).
3. There should be no activity that may create pollutants within 75 m of the borehole once the borehole is constructed. In case of a wellfield, or very high yielding borehole with high risk of supply failure, it is desirable to define such zone more precisely after estimating the capture zone and allowing for at least 50 days travel time (the time required to attenuate most pollutants).
4. An area of 10 m radius around the borehole should be fenced and no other activity than the collection of water should be allowed within this area.
5. Water quality should be frequently monitored and compared to base line information to assess any pollution that might be taking place. In case there are specific threats of contamination or pollution that may not be part of regular monitoring and analysis, then these should be specified (e.g any trace element).
6. Other considerations on protection (such as sanitary sealing and backfilling of abandoned borehole) are presented in Section 4. The reader is also referred to IAH publication on groundwater quality protection.

8.4 SPECIAL CONSIDERATIONS IN COASTAL AND INLAND SALINITY AREAS

In coastal areas and inland salinity areas a careful analysis of pumping effects should be undertaken as the risks of contamination of fresh water aquifer units may be high, depending upon the location. Once the fresh water is contaminated the remedial measures could be extremely expensive and, at times, nearly impossible.

It is desirable that in most cases the lateral and vertical distribution of the fresh water – saline water interface should be identified in single or multi-layered aquifer environments. Similar to the basic principles of sustainability outlined in the previous sub-sections, aquifer as well as borehole sustainability should be considered. At aquifer level the pumping effect for a given volume should be simulated. The special consideration is given on various possible configurations of pumping points and methods to optimise the fresh water abstraction. At borehole level, the available drawdown is an important factor to keep the head gradient within the limits to avoid saline water intrusion.

Some of the methods to optimise the fresh water abstraction could be (elaborated after Todd, 1959):

- Reducing the pumping rate and hours to keep the head gradient low. Cyclic pumping could be a useful.
- Using a higher number of boreholes, with low discharge and cyclic pumping, to maintain a shallow and consistent head gradient.
- Artificially recharging the aquifer to maintain the hydraulic gradient.
- Developing a pumping trough in the region adjoining the coast in order to limit intrusion.
- Using a combination of injection and recharging wells.
- Using shallow tunnels or infiltration galleries.

8.5 ADJUSTMENTS IN PRODUCTION YIELD AND PUMPING HOURS AFTER COMMISSIONING

It is very important to monitor the performance of a borehole under production conditions for at least 14 months immediately after commissioning, although it is desirable to perform monitoring throughout the production. This should be done, wherever possible, in terms of:

- Water level in the borehole prior to shutting down the pump every day (i.e. pumping or dynamic water level);
- Average discharge per day;
- Average pumping hours per day;
- Instantaneous pumping rate;
- Water quality (randomly); and
- Rainfall.

It is often the case that many assumptions are made in estimating the sustainable yield. The above monitoring data provide an extremely valuable feedback on these assumptions so that the production discharge and time can be adjusted upward or downward accordingly. The monitoring data should be forwarded to the relevant authorities.

Additionally, monitoring of water quality over time may indicate the need for alteration of the original pumping recommendations (i.e. due to TDS increase with time) during the lifespan of the borehole.

Section 9: RECOMMENDATIONS ON EQUIPPING OF BOREHOLES

9.1 GENERAL

9.1.1 Scope and Purpose

The standards and guidelines in this section cover the recommendations on equipping production borehole for water abstraction. These recommendations include the selection of appropriate pumping equipment and installation for production pumping applicable to single boreholes that are to be fitted with either handpumps or motorised pumping equipment. These apply to all water supply boreholes constructed by manual or mechanical means, aside from those that meet the definition of "hand dug wells".

9.2 BOREHOLES EQUIPPED WITH MOTORISED PUMPS

9.2.1 Design Requirements

To optimise the selection of pumping equipment the following information is required:

1. Borehole information including the location, depth, design (casing and screens) etc.
2. Recommendations by the hydrogeologist on sustainable yield, pumping hours, pumping schedule, depth of installation and expected pumping water level below the top of the screen (supplied on Form PR-1 or similar).
3. Altitude of the top of casing of the borehole.
4. Altitude at the location (end point) to which the water is to be pumped (e.g. reservoir).

The above information is supplied to the design engineer/ pump supplier to select an appropriate pump and associated pumping equipment. Only a competent engineer or pump supplier should design the pumping system, and an equally competent pump supplier/ contractor should perform the installation. It is also desirable to involve in the process the hydrogeologist who has provided the recommendations on production pumping.

9.2.2 Pump Selection

A variety of pumps suited to specific conditions is used for motorised pumping. The three broad categories according to the source of energy are:

- The solar pump.
- Diesel driven positive displacement pumps.
- Electric submersible pumps.

Various Member States in the SADC region have standardised on pumps for specific uses. In case these standards do not exist the Table 9-1 below should be used as a broad guideline on the type of pump to be used. The Table only provides guidelines on the most common types of pumps. In certain cases different types of pump may be more suitable and these should be investigated.

Table 9-1 : Guidelines on Pump Types

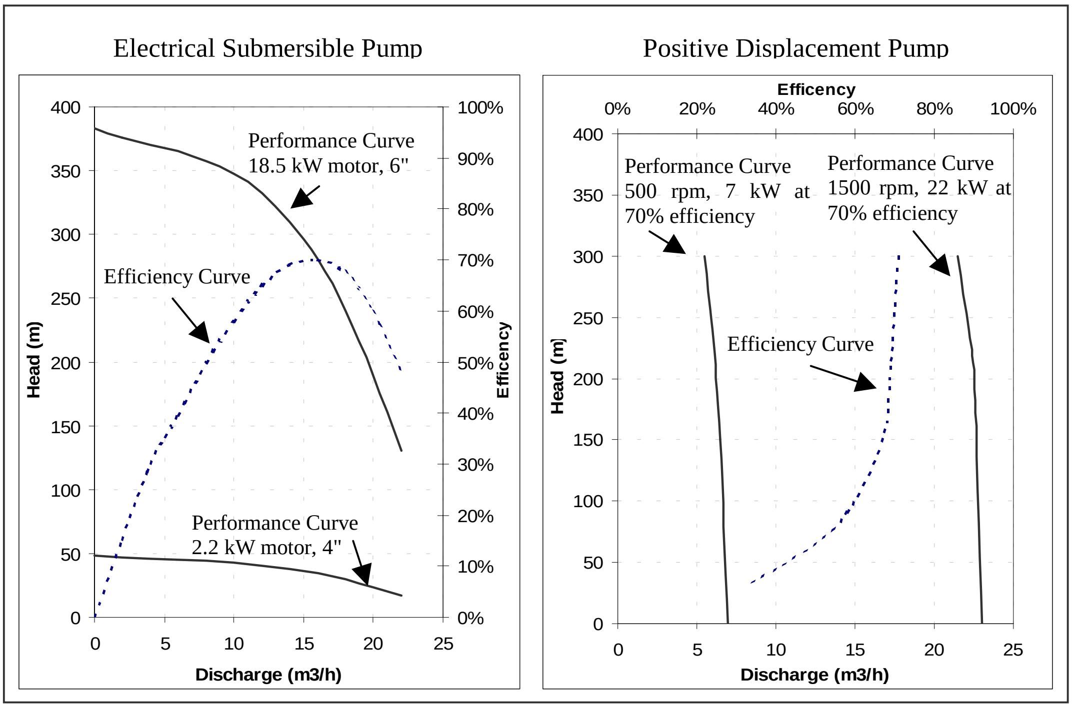
Pump Type	*Guidelines on Suitability*
Electrical Submersible Pumps (Centrifugal type)	• Most economical and convenient pumps in cases where electrical supply is available – normally the first choice for borehole pumps • Lower maintenance and running cost. • More efficient at higher volumetric capacity and lower heads • Less prone to vandalism as most of the assembly is housed inside the borehole. • Can function satisfactorily even in boreholes that are not straight and vertical. • Less suitable when the head fluctuations are high as it has direct impact on discharge. • Not suitable for electrical supply with more than 10% voltage fluctuations
Diesel-Driven Positive Displacement Pumps	• Economical for rural and remote areas where electrical supply is not available • More suited for higher discharge and head (head x volume factor more than 1,300 m^4 – for factors less than that normally solar pumps are more suitable) • Not very suitable for long hours of pumping • More efficient at higher heads • Higher running and maintenance cost • Not very suitable for boreholes that are not straight and vertical
Solar Pumps	• Ideal for places where sunshine hours are high • More economical under lower pumping head (normally less than 50m) and volumetric abstraction (20 to 25 m^3/day) • Prone to vandalism and therefore may not be feasible in remote areas with no attention • Technology still developing
Electric-Driven Non-submersible type Pumps	• Also commonly referred to as Turbine Pumps and are used for higher discharges • Not preferred over the submersible types (provided their motor size is suitable for installation) for a similar set of conditions
Electric-Driven Positive Displacement Pumps	• These may be used, where electrical power is available, in the same supply applications as for the diesel-driven variety and offer the advantage of lower capital and running costs. However, it is critical to ensure that the motor chosen can supply the torque required to start the pump, bearing in mind that the starting torque usually exceeds the running torque for this type of pump

Irrespective of the type of pump, there are certain general principles that should always be followed with regard to pump selection:

- Maximum diameter of pump and motor for submersible pumps should not exceed 90% of the finished diameter of the borehole at the depth where the pump is to be installed.
- While selecting the size of the pump, the total head (or a head range) against which the pump may be operating, should always be calculated.

  Total Dynamic Head (H_T) = Expected Pumping Water Level in the borehole (H_{PWL})- normally a range
  + Static Head from the top of the borehole to the point of discharge (H_S)
  + Frictional Head Losses along the line (H_F)
- The optimum pump size should be selected using the performance curves and the calculated total head such that the pump operates within its maximum efficiency range. A typical (hypothetical) pump curves for positive displacement pumps and electrical submersible pumps are presented in Figure 9-1.

Figure 9-1 : Comparison of Performance Curves of Electrical Submersible Pump and Positive Displacement Pump



- The pump manufacturer's instructions on installation and operating conditions should always be followed.
- The pump should be capable of operating under the specific water quality conditions pertaining, such as temperature, suspended solids load, pH, conductivity and other constituents, without unacceptable degradation.
- Pumps, motors and cabling should always comply with established national, regional or international standards.
- Engines, wherever used as prime movers, should be of appropriate size and type with regard to power output and torque characteristics, including reference to altitude and ambient temperature effects on performance. Start-up devices, such as centrifugal clutches, may be considered. The ambient temperature capability and cooling requirements should be verified.

9.2.3 Rising Mains

The size, type and material of rising mains depend on the type of pump and discharge. The following general principle should be followed:

- The rising main must be of steel for positive displacement pumps and non-submersible centrifugal pumps (associated with rotating drive shaft), whilst for submersible pumps it could be of steel, uPVC or flexible hose type. The material and type must comply with local national standards. In case applicable local standards are not available, then equivalent SABS and other international standards should be followed in the order of priority (e.g. SABS 533-2 for plastic rising mains).
- All the couplings and joints should be such that the rising mains is capable of supporting its entire weight, and that of the pump, including the weight of the water column.
- The rising mains and drive shaft (wherever applicable) should follow pump manufacturer's specifications.
- The rising mains should be capable of withstanding water pressure at least 25% in excess of that expected during the pumping operations, allowing for the pressure due to the discharge altitude and friction head losses in the case of a remote discharge point.

9.2.4 Other Mechanical and Electrical Components

Other mechanical and electrical equipment necessary for the installation is covered under Installation.

9.2.5 Installation Of Pumping Equipment

1. General guidelines and instructions of the manufacturer on the installation of pumping equipment should always be followed. All material and equipment should conform to local national standards. If local standards do not exist, equivalent standards of SABS, or other international standards, should be followed in the same order of priority.
2. A general layout of equipment to be installed is presented in Figure 9-2 & 9-3.
3. A Dipper pipe (or access tube or conduit pipe) for water level measurements must always be installed in the pumping borehole to a depth where the pump is connected to the rising mains. It should be of plastic material of minimum 15 mm ID, although it is desirable to install 25 mm dipper pipe to facilitate the use of larger diameter sensors/ transducers. The lower 1 m of the dipper pipe should be perforated. The dipper pipe should be freely hanging (it should not be attached to the rising mains) and all lengths should be properly jointed. It should also be firmly secured at the top and should be supported by a suitable rope (such as nylon) throughout its entire length to avoid accidental dropping in the borehole.
4. When a combination of drive shaft and steel rising mains is used then the borehole straightness and verticality must be considered.
5. Wherever the motor of a submersible pump is housed in the sump and there is no water strike/water inlet below it, a flow inducer (or shroud) must be installed to induce the flow of water upwards past the motor to keep it cool during operation.
6. To protect the pump from running dry (that can damage the pump and the motor) a Run-dry protection should be provided that trips off the pump before the water level reaches the pump intake. It should also have an upper level control to re-start the pump once the water level recovers to an appropriate level.
7. A tap should be installed at the discharge line to collect water sample.
8. All the electric cables must comply with established standards. Electrical cable used for submersible pumps must be able to withstand underwater conditions inside the borehole for that specific water quality and the submerged cable joints should be of the encapsulated epoxy type, or similar watertight standard.
9. During the installation of pumps and operations any direct introduction of oil, grease, fuel etc. should be avoided in the borehole.
10. The equipment and assembly at the borehole head should be protected by a concrete structure of suitable design and size, according to the guidelines in the following table.

Table 9-2 : Guidelines on Borehole Protection Structure

Pump type	*Structure details*
Electrical submersible pump	A concrete structure (in cases where the borehole is in the open and in an unprotected area) divided into two chambers; one to house the electrical panel and the other to house the base plate, water meter, valve etc. The two chambers should have separate access lockable doors/manholes.
Electrical turbine pumps or positive displacement pump	Similar to the above but the second chamber to house the mechanical assembly should be of a suitable size.
Diesel Driven Pumps	A concrete or masonry structure with cemented flour (to avoid the risk of oil seepage through the ground to contaminate the aquifer) and proper ventilation. The size of the housing should be sufficient to provide storage facilities for the diesel fuel oil. The ceiling could be of corrugated iron or equivalent but firmly secured to the structure.
Solar pumps	Solar pumps require open space and, as such, can be housed in any structure. The area around the solar panel and the borehole should be fenced and protected to secure against vandalism. The fence should be at least 5 m away from any edge of the solar panel.

Figure 9-2 : General Layout of Pumping Equipment Installation at the Wellhead – Electrical Pump

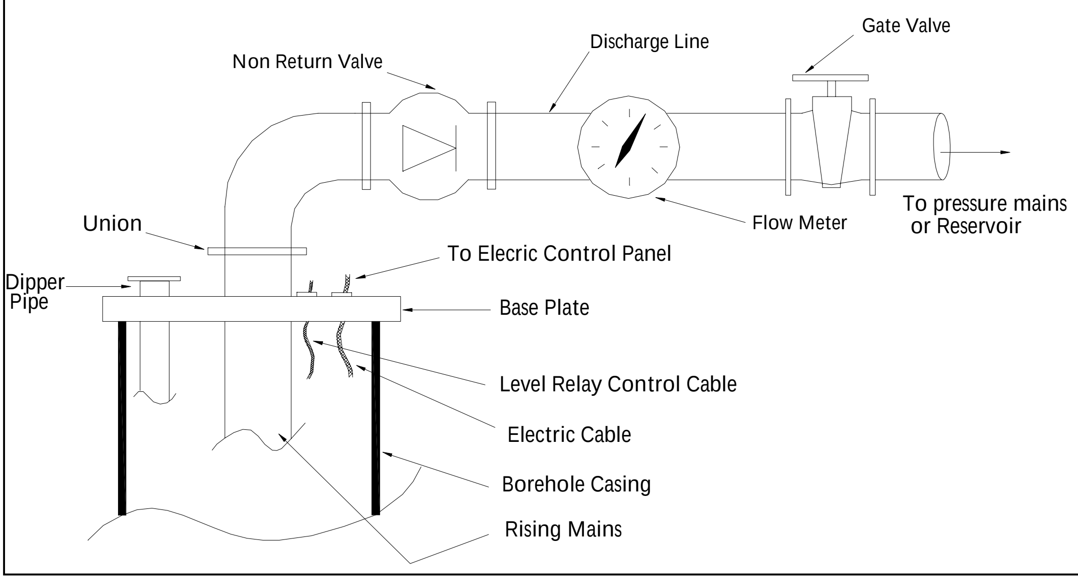
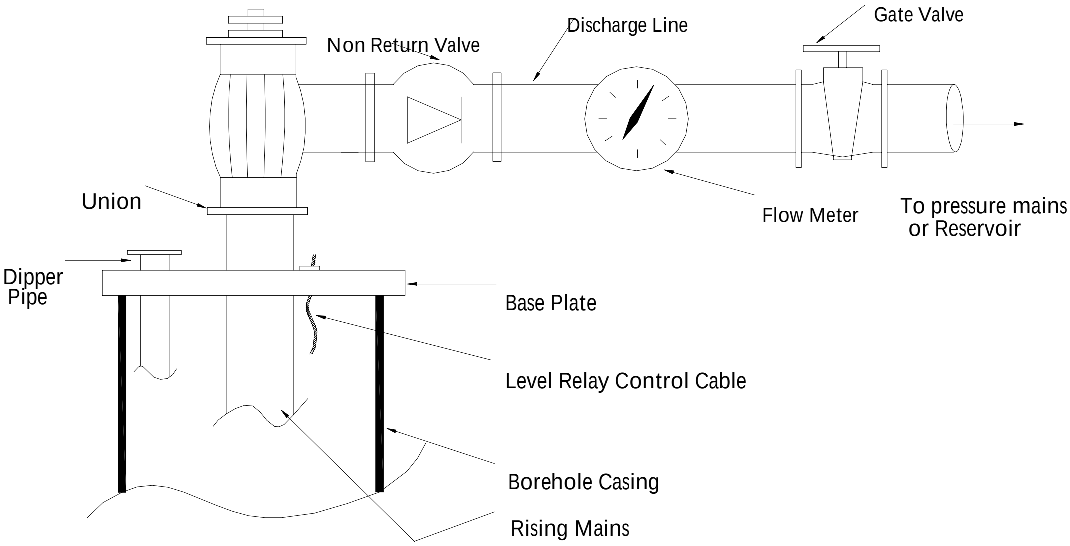


Figure 9-3 : General Layout of Pumping Equipment Installation at the Wellhead – Non-submersible Pump



11. Two non-return valves must be fitted; one at the pump and the one at the surface where the rising mains joins the discharge line.
12. A flow meter must be fitted immediately after the non-return valve. Manufacture's instructions should be followed for instructions to assure accuracy and to limit the turbulence at the metering point. The meter must be calibrated and should be installed at least 1.2 m from any bend. The flow meter should be capable of measuring instantaneous discharge and cumulative volume within an accuracy of 5%.
13. A gate valve should be installed after the flow meter to control the discharge.
14. A running hour meter should be installed on the electrical control panel to keep a record of the number of hours the pump has run.
15. Installation of appropriate lightning protection mechanism (for electrically driven pumps) should be considered in areas that are prone to lightning damage.
16. The make, model & serial number, type, motor capacity and pump capacity should be marked on a steel plate and permanently installed at an appropriate place at the borehole head.
17. Although not essential, it is desirable to install a pressure gauge in order to give indication of any obstruction in the delivery line (where applicable) and to facilitate diagnostic equipment testing against various heads where the performance of the pump is in doubt.

9.3 BOREHOLES WITH NON-MOTORISED PUMPS

9.3.1 Handpumps

Based on the mechanism of operation, there are broadly two types of handpumps that are commonly used; reciprocating pumps and positive displacement rotating type pumps. Characteristics of these pumps are summarised in Table 9-3 below.

Table 9-3 : Guidelines on Handpump Selection

Pump Type	*Applicability and Remark*
Direct Action Reciprocating Pump	Ideal for shallower installation (less than 10 to 15 m depth range), easier to maintain at village level, largely based on SKAT specifications.
Deep Well Reciprocating Pump	Ideal for deeper installation up to 90 m depth range, easier to maintain at village level, largely based on SKAT specifications.
Direct Rotary Action	For installation up to 45 m deep, robust design but relatively more complicated in maintenance.
Geared Rotary Action	For installation up to 120 m, robust design but relatively more complicated in maintenance.

There are some general principles that must be followed regardless of the choice of the pump:

- Design requirement should be the same as 9.2.1.
- The minimum sustainable yield of the borehole should be at least 1 m^3/h (approximately 0.3 l/s or 18 l/min) on an 8 hours pumping basis.
- Manufacturers instructions on the installation must be followed.
- All the material used for construction and installation should comply with national standards and, in case local standards are not available, then equivalent SABS and other international standards should be followed in the order of priority.
- Once installed, the handpump should be operated continuously for at least 30 minutes during which it should deliver at least 450 litre of water.
- Pump cylinder size should be according to the borehole water depth and sustainable yield and the manufacturer specifications.
- Guidelines on installation depth should be as detailed in Section 8.3.2.
- Water quality consideration must be taken in choosing appropriate material (i.e. uPVC, Mild Steel or Stainless Steel) for the rising main, connecting rods and cylinder.

- Maximum outside diameter of the cylinder should not be more than 90% of the finished diameter of the borehole at the depth where the cylinder is to be installed.
- All the couplings and joints should be such that the rising mains is capable of supporting its entire weight including the water column.
- Borehole straightness must be considered.

9.3.2 Windmills

Windmills in water supply are commonly used for pumping water from a borehole to a surface reservoir or elevated tank utilising the wind energy. Windmills are suitable for water supply to isolated and small rural settlements and for livestock watering.

The major advantages of windmills, particularly in remote areas, are their low maintenance requirement and long life, utilise an unpaid energy supply and that they can function in the absence of an operator. Disadvantages of windmills are high capital cost, relative to a diesel or electric prime mover offering the same output, loss of supply during win-still period and the possibility of wind damage in areas prone to high winds or strong gusts.

The wind energy is converted into rotational mechanical energy, which is transmitted through a gearbox into drive shafts or rods communicating with a pumping device inside the borehole. A tail vane on the head of the windmill keeps the turbine wheel facing directly into the wind direction under normal conditions, whilst under conditions of high or gusty winds a furling device is used to rotate the turbine wheel side-on to the wind direction to prevent damage.

Since the windmill relies on wind speed that is variable and often unpredictable, sufficient water storage (such as reservoir or elevated tank) is always required that is normally larger than that required for a supply powered by diesel engine or electric motor.

A windmill installation comprises the following major components:

- Windmill head mechanism and wheel
- Tower
- Down-the-hole pumping equipment

The pumping equipment includes the piping constituting the borehole rising main, the drive rods (reciprocating action) or shafts (rotational action), and the borehole ‘cylinder’ or other type of pump.

The windmill tower is of three (tripod) or four legged (pyramid) arrangement, of height between 6m and 15m, and is usually constructed of angular mild steel (‘angle iron’), with cross-bracing of round mild steel bar to impart added rigidity. The tower usually comprises about half of the cost of the windmill and the height should be carefully selected according to the available and optimum wind speed above ground level. This, in turn, is determined by the local topography and wind pattern and consideration should also be given to local obstructions to the wind, particularly the dominant tree types and buildings.

The down-the-hole equipment comprises the rising column, drive rods or shafts and pump and is determined by the type of pump action. The most common mechanism is a reciprocating action in which a string of drive rods transmits an up and down motion to a positive displacement ‘mushroom’ cylinder, although rotational drive to a pump of progressive cavity type has also been used.

The cylinders are normally made of brass, with piston ‘leathers’ of nitrile rubber, for maximum working pressures up to 150m water column, although cylinders are manufactured of more wear-resistant materials and with different valve actions for working pressures of up to 300m for very deep boreholes. Borehole cylinders are generally available in diameters of 50mm to 115mm and with a stroke (working displacement) of around 150 to 300mm.

The drive rods for borehole cylinders are manufactured of mild steel of diameter between 12mm and 20mm, depending on the load to be transmitted. The rods are screwed and socketed in 3m lengths and are consecutively connected inside the rising column in a drive 'string', extending from the windmill head down to the cylinder. Where the water delivery is close to ground level a standpipe of sufficient length extends above the borehole baseplate, but where delivery is to a higher hydraulic level a 'forcehead' arrangement is installed with the drive shafts working through a borehole 'leather' as a mechanical seal.

The borehole rising column is also of screwed and socketed mild steel and is manufactured in exact 3m lengths in order to facilitate the installation and removal of piping and rods. An alternative form of drive that has been used is the rotary action, such as the Mono pump. In this case the drive shafts operate in a rotational action within rubber 'bobbin' bearings inside the water column. The pipes and shafts are connected as before, but the drive shafts are manufactured in 1.5m lengths. Plastic piping normally does not possess the axial or torsion strength to withstand the cyclical compression and tension or rotational torque that accompanies the drive motion.

The rates of flow available from a windmill pump are constrained by the prevailing wind speeds and by the yield and depth of the borehole. If required, and where borehole yield allows, the delivery may be increased by the use of a larger wheel diameter in conjunction with a higher tower, where necessary. As the yield of a windmill pump is wind dependent and cannot be guaranteed, power head drives using secondary prime movers are sometimes installed in conjunction width windmills, particularly in regions with significant wind still periods.

A conventional windmill can provide 300-450 l h^{-1} at a pumping head of approximately 30 m and an average wind speed of 10 km h^{-1}. This translates to an average daily discharge of 4.3 - 6.5 m3 d^{-1}, assuming the wind blows 60% of the time.

9.4 OPERATION AND MAINTENANCE

Operation and maintenance is an important aspect and should be carefully considered during the selection of type of pumping and other equipments for installation, particularly for the water supply in rural areas. Hand pumps are in most cases the priority choice for rural water supply. However, it is realised that one of the major problem with hand pumps relates to operation and maintenance and for this reason, emphasis should be given to VLOM (Village Level Operation and Maintenance) concept and all the operation and maintenance should be done on Community Based Management (CBM) principles.

To make operation and maintenance effective it is imperative that:

- majority of the maintenance should be done at village level;
- the spares should be inexpensive and should be available locally and easily;
- the community at village level should be trained to develop basic skills to maintain/repair the handpumps and an illustrative and easy to understand manual for maintenance and repair should be provided by the pump manufacturer;
- women should be involved at all levels;
- the community should have an organisation structure at village level (such as water committee, pump committee) with clearly defined responsibilities;
- a proper attitude should be developed within the community by involving them throughout the borehole drilling and installation programme;

- development of professional private caretaker/repairers should be encouraged and trained under supervision of pump manufacturer/sales company and regulatory body.
- the community should contribute and maintain a maintenance fund for expenses incurring towards the maintenance;
- the community should contribute in cash or kind towards the programme to develop the sense of belonging and ownership of the system; and
- a community representative should keep all the records pertaining to the installation and maintenance of handpumps.

The implementing agency and/or the department responsible for rural water supply at national level has a very crucial role as facilitator and technical assistant in community based operation and maintenance. They should provide the necessary guiding framework, training and technical assistance to community. These agencies should also standardise at national and district level on selected pumps in order to assure the availability of spares. This standardisation should be based on sound design principles and local manufacturing of pumps and spares (or easily accessible pumps and spares within the region). It should also be guided by a sufficient number of pumps installed to justify and optimise the operation and maintenance in terms of spares and manufacturers/suppliers. Some of the SADC Member states have already done this for handpumps and have successfully minimised the maintenance related problems.

Section 10: GUIDELINES ON HAND DUG WELLS AND SPRINGS

10.1 HAND DUG WELLS

Hand dug wells are a common source of water supply in many of the SADC countries. Hand dug wells include both traditional structures that are constructed by local inhabitants with simple materials, as well as wells constructed by IAs or NGO's, which incorporate pre-manufactured parts and are often equipped with handpumps. A hand dug well is a large diameter (generally greater than 1 m) excavation for water supply, constructed by manual labour, which is completed to the depth of the water table. It may be lined or unlined. An *improved or upgraded well* is a well that has been constructed (or modified in the case of existing wells) to create a durable structure and ensure a safe (uncontaminated) supply of water for the users.

The construction of hand dug wells requires only limited equipment and relies primarily on human labour, and as a result, they represent a very inexpensive method of obtaining groundwater supplies. However, poorly constructed or maintained wells can easily become contaminated and there are only certain hydrogeologic environments where they can be successfully installed.

Hand dug wells are possible in areas underlain by unconsolidated or highly weathered terrain where overburden and (at least) the uppermost portion of the aquifer can be excavated by manual means. Additionally, in some areas where water levels fluctuate between the weathered overburden and the underlying fractured but solid basement rock formation, blasting has been utilised to deepen wells into the bedrock (i.e. southeastern Zambia, southwestern Zimbabwe) to ensure a sustainable supply.

10.1.1 Siting

Even a relatively shallow hand dug well requires a considerable amount of labour and time to construct. As such, locating an appropriate site for the well is important to ensure success and sustainability. In general, well siting should address the following issues:

1. Proximity to users;
2. Underlying formations suitable to manual excavation;
3. Year round water table present in the 'unconsolidated' zone;
4. Areas where water table is present at shallowest depth;
5. Areas where contamination potential is minimised;
6. Areas where water quality (i.e. salinity) is acceptable.

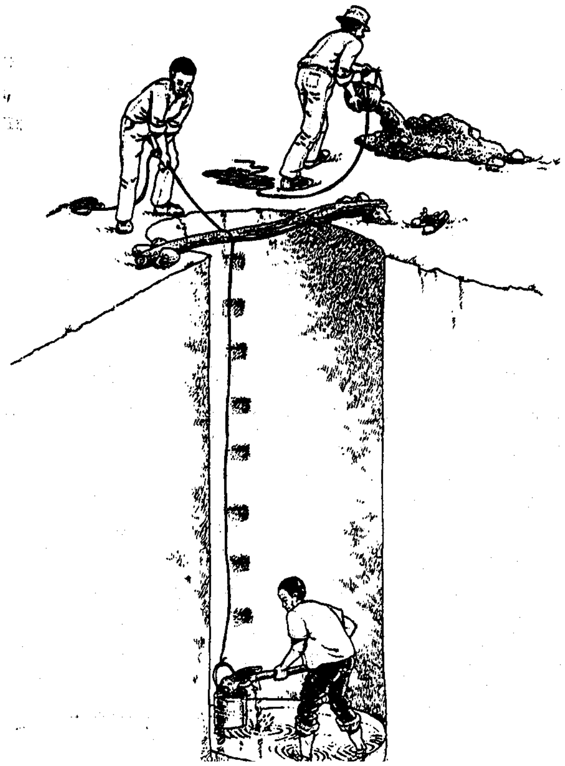
The easiest situations for well siting are in situations where hand dug wells are already present and there is considerable local experience. In these cases, siting may consist primarily of consulting with local community members who have been involved in previous well construction activities. In areas with known complexity or where little existing information is available on the shallow groundwater environment, a more detailed siting programme is desirable. In these cases, a Desk Study and Reconnaissance Survey is recommended (Section 2). Of particular importance can be the use of hand augers to survey the depth to groundwater, depth to bedrock, and soil and regolith conditions. Also the proximity of a site to existing surface water bodies (particularly dams, lakes and perennial rivers) should be carefully considered. Similarly to boreholes, in some cases geophysical methods may be appropriate.

In terms of contaminant sources, a well should not be sited less than 30 meters away from latrines, cattle kraals or refuse pits. When the well is between 30 to 75 meters from these sources, it should always be up slope from the contaminant sources. After a well is installed, no polluting activities should be allowed within 30 meters of the well.

10.1.2 Well Excavation

After a site has been chosen, a 1.5 meter circle (may be larger if required) is marked on the ground. A diameter of 1.2 meters is sometimes used in particularly hard or rocky conditions. The excavation process is then begun within the circle, taking care to maintain vertical sides (Figure 10-1). If upper layers are particularly loose or liable to collapse, a larger excavation can be undertaken and side reinforcement (i.e. logs, stones) can be installed as digging continues. As the well is deepened beyond 2 or 3 meters, it is necessary to install a bucket and windlass suspended from a tripod (or some equivalent means) to remove the material from the well. Workers should always pay close attention to the stability of the surrounding formations and work should be halted if collapsing formations cannot be safely controlled. Steps can be cut in the well sides to allow workers to enter and exit the excavation. If this is not practical, ladders should be provided.

Figure 10-1 : Well Excavation



Source: Morgan, 1988

When the water table is reached, digging must continue into the water bearing formation. In most cases, the water level can be controlled by bailing the water (together with the sediment if possible) with buckets. When the rate of inflow into the well exceeds the capacity to remove the water, digging must generally stop. In unconsolidated aquifers (especially clean sands) it may be impossible to penetrate the aquifer (due to continuous collapse of the sand) without the used of concrete well liners (or equivalent). In these cases a well liner of slightly smaller diameter than the excavation is lowered to the bottom. Workers re-enter and dig primarily from under the edges of the liner, which will move downward under its own weight. When required a second liner can be lowered and fitted to the top of the first as digging continues.

Although local hydrogeologic conditions and previous experience will largely determine exactly how much effort is expended to deepen the well into the aquifer, in general it is desirable to penetrate the saturated aquifer by at least 2 to 3 meters.

10.1.3 Well Lining

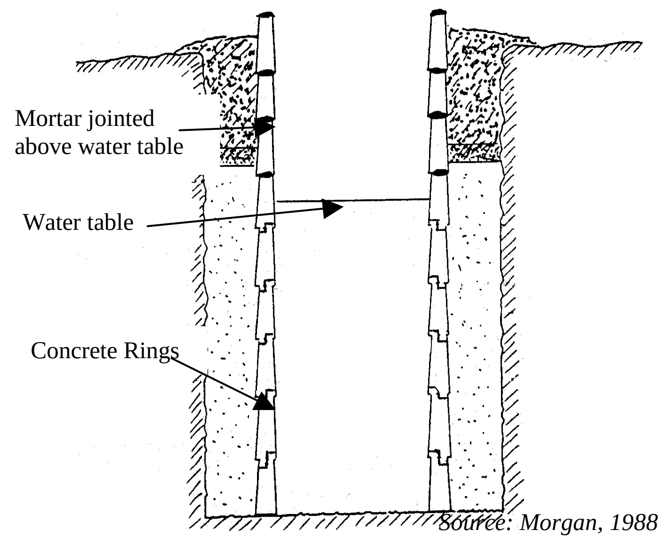
Well linings are used to ensure the stability of the well walls and reduce the potential for contamination of the well. In unconsolidated formations, the full depth of the well should be lined. In hard rock terrain, where the deeper portion of the well extends into solid rock, only the soil and regolith must be lined. The following are the primary acceptable materials used for lining wells in the SADC region:

1. Natural stones. The stones are carefully stacked along the sides of the well. Above the waterline, the stones should be mortared to form a seal and maintain the stability of the wall. If it is not possible to fully seal the walls (above the aquifer) with the mortar, the

annular space between the wall and the excavation should be filled with clay or clayey soil as construction progresses to ensure the seal.

2. Burnt bricks. Locally produced bricks are often used to line wells. Bricks should always be burned (not merely sun-dried) so that they maintain their strength even when wet. The walls are built up similar to the process for natural stones.
3. Cement bricks or blocks. Installation similar to above.
4. Pre-cast concrete liners (Figure 10-2). These are liners cast at the surface (at the site or transported to the site) and lowered into the well. The liners should be a minimum of 70 mm thick and each liner should have at least 3 reinforcing wire rings (3 mm) integrated within the liner wall.
5. In situ cast concrete liners. The concrete is mixed on surface and liners are constructed within the well with suitable steel forms.

Figure 10-2 : Well Lined with Pre-cast Rings

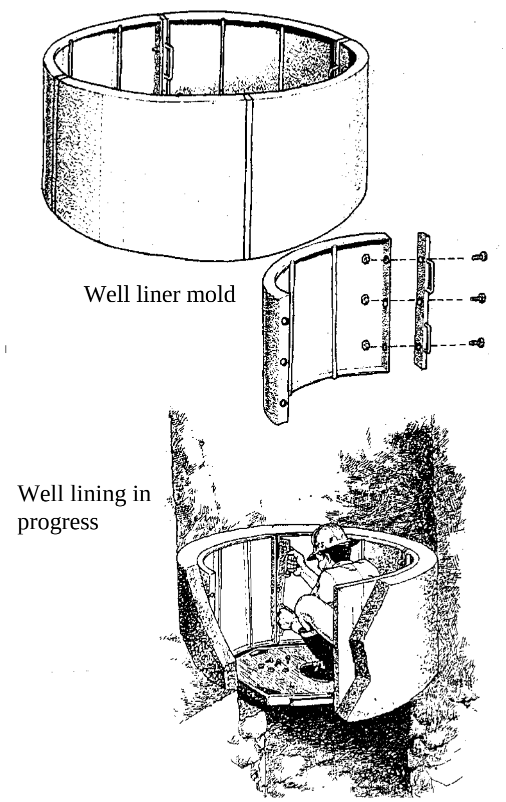


Source: Morgan, 1988

10.1.4 Installation of Liners

Natural stones, burnt bricks and cement bricks are installed using regular wall construction practices. Cement mortar is required and above the water table should form a continuous seal between the building materials. If the liner is begun in the aquifer (below the water table) then mortar is not required until the top of the aquifer is reached. However, in some cases mortar can be used below the water table to improve the strength of the wall. In these cases, it is desirable to use a strong cement mixture (3 parts sand to 1 part cement) and to not fully seal the wall (to allow easy inflow of water). The annular space between the wall and the excavation should be filled with clean sand or well cuttings (if it consists primarily of sand, gravel or stone) to a position above the aquifer. The remainder of the annular space up to the well head should be filled with clay or soil.

Figure 10-3 : In-situ Well Lining



Source: Morgan, 1988

Pre-cast concrete liners are lowered into place with a windlass with the broad base downwards. Care should be taken that the lowest ring is placed centrally within the excavation and is level. If the rings are step-jointed, then clean sand or well cuttings (if it consists primarily of sand, gravel or stone) can be back-filled outside the rings as they are added. If the rings do not have a step-joint, then plastic sheeting must be used around the rings prior to adding the sand/cuttings so that it doesn't run through the joint. Once the top of the aquifer is reached, then the liners joints can be cemented and a clay or soil backfill used up to the well head.

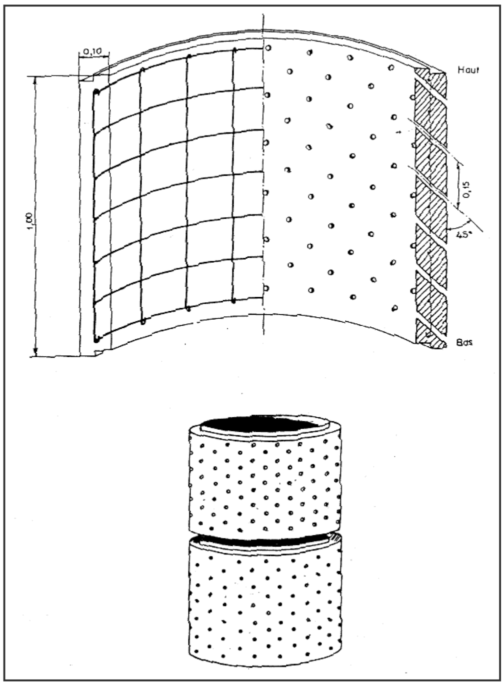
In situ cast concrete liners are primarily used in wells where blasting is required to penetrate the aquifer (Figure 10-3). After excavation at 1.5 meter diameter is completed to a zone of hard rock, the diameter is reduced to 1.2 meters. When the formation becomes too hard for manual excavation, the in situ liners are installed prior to blasting. Installation is carried out by lowering a steel form (usually in two shutters) to the base of the 1.5 meter diameter section. The shutters are assembled on the shoulder of the 1.2 meter diameter section. A concrete mixture of cement, sand and stone is then poured outside of the form. Generally, two bags of cement are required for each meter section of liner. After the form is filled, the concrete is allowed to harden at least 12 hours (usually overnight). Then the shutters are disassembled, oiled and moved upward to the next section, where the process is repeated. After lining is complete, blasting of the aquifer can commence.

10.1.5 Slotted or Perforated Pre-cast Concrete Rings, or in situ Cast Concrete Liners.

This is useful in case of flowing sediments and unconsolidated formation. The perforated rings are pre-cast concrete that are fixed together by means of right angle notches and bolts (refer Figure 10-4). As for the pre-cast well lining, lowering of the rings may necessitate mechanical leverage method. Perforated rings are of smaller diameter than the well lining and to facilitate lowering and penetration of rings into the formation, the first ring in equipped with a cutting shoe, made of reinforced concrete. Once the perforated rings are in place, a concrete slab is placed in a similar manner. A gravel pack is inserted in the annular space. An example of this construction method is illustrated in Figure 10.5. Pumping equipment is required to lower the water table while inserting the pre-cast rings. It is required as well in case of in situ cast concert liners, installed below the water table.

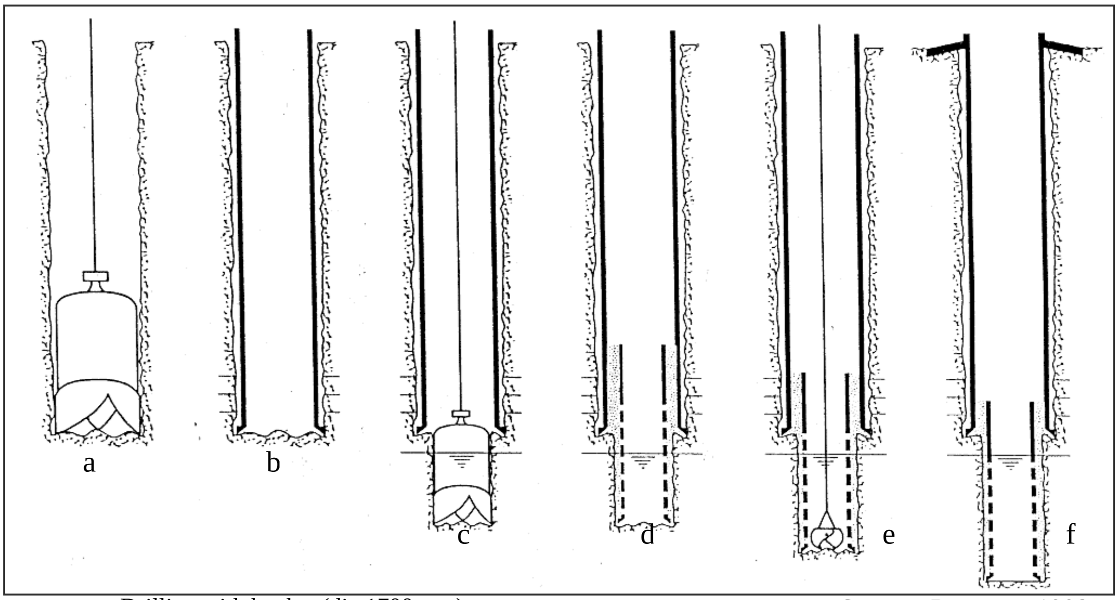
In some cases perforated corrugated iron sheets are also used as liners. The thickness of these liners varies from 2 to 4 mm, depending on the depth.

Figure 10-4 : Pre-cast Concrete Rings Assembled by Notches Lining



Source: Burgeap, 1992

Figure 10-5 : Example of a Mechanised Well Construction in Niger



a. Drilling with bucket (dia 1700 mm)
b. Well lining with 1400/1500 mm dia
c. Drilling with bucket (dia 1350 mm)
d. Perforated rings of 1000/1200 mm dia and gravel in annular space
e. Drilling with auger
f. Completed well with filter and sanitary sealing

Source: Burgeap, 1992

10.1.6 Well Head Completion

The well head is the upper section of the well generally extending at least 2 to 3 meters below ground level. This section is where the sanitary seal must be installed. When a well has been lined with stones, bricks or pre-cast liners, the annular space of the wellhead should be filled with clay or clayey soil, periodically tamped down to form an effective seal. It is desirable to fill this space with manufactured bentonite (i.e. pellets) or a cement grout to provide an impermeable seal.

With in situ cast concrete lining, no additional sealing is required.

10.1.7 The Well Cover

A well cover is required for all drinking water supply wells. A well cover forms a seal of the top of the well leaving only sufficient open space for installation of the chosen abstraction device. The well cover should be made of steel reinforced concrete, which can be constructed at the site. The cover should be of a diameter sufficient to fully cover the well opening. A mesh of 3 mm (8 gauge) wire can be used to form a square mesh with approximately 150 mm openings, which should be installed within the concrete slab. A hole should be left in the middle of the slab that is sufficiently large for the planned bucket (windless system) or pump (hand pump or motorised pump). The slab thickness should be a minimum of 75 mm and should take into account the diameter of the well and the weight of any pumping equipment. The cover slab should be sloped away from the central hole. If a windlass system is to be used, a collar is made up around the central hole after the slab has cured for at least one hour. This is generally made of bricks and plastered inside and out. The top of the collar should slope away from the hole so that any spillage will not enter the well.

After the cover has cured for at least 24 hours, it can be carefully installed on the well. Prior to installation, a continuous bed of mortar should be placed along the top liner of the well to form a water tight seal with the cover. Windlass systems should be fitted with a metal cover for the bucket opening.

10.1.8 Apron and Water Runoff Channel

All wells for drinking water supply should be fitted with an apron and water runoff channel. The apron should be made of steel (i.e. 3 mm wire) reinforced concrete and should have a diameter of at least 2 and preferably 3 meters surrounding the well. A ridge should be constructed around its edge and it should slope toward the runoff channel. The thickness of the apron should be at least 75 mm and the edge should extend at least 150 mm above the apron surface. At one side the runoff channel should be connected to the apron which channels waste water and rainfall away from the well. It is crucial that no cracks form in the apron. Therefore, careful curing of the concrete is required. After completion of the apron, the concrete should be kept wet for at least 3 continuous days. The community members should be instructed on patching cracks that may appear over time or who to contact to repair any cracks.

The runoff channel should extend a minimum of 3 meters away from the apron and have sides extending at least 150 mm above the channel. At the end of the channel a soakaway is desirable to avoid standing water in the vicinity of the well.

The ground surrounding the apron should be generally sloped away from the well to the greatest degree possible and soil should be used to fill any depressions in the immediate vicinity of the well where standing water can collect.

10.1.9 Upgrading existing wells

Existing wells which are not are not constructed to standard can often be easily upgraded without having to construct a new well. Generally upgrading involves two tasks, deepening of the well (if required) and lining/wellhead completion. Although existing wells may have water and be in use, some deepening of the well may be worthwhile prior to upgrading to assure the water supply and/or improve yield. Methods are as described in Section 5.2. Most unimproved wells are unlined or incompletely lined and many do not have proper wellhead and cover completion. Upgrading simply consists of lining the well with an appropriate method, installing a proper sanitary seal at the wellhead, and fitting a cover with apron and runoff.

In some cases, radial horizontal drains can also be drilled inside the well towards the bottom through the reinforced concrete liners. The technique is particularly useful in stratified aquifer where radial drains can be drilled along the high transmissive layers (such as gravel). Similarly it can also be used for high transmissive horizontal fracture zones or along the base of a weathered zone.

10.2 SPRINGS

Springs are the natural outlet of groundwater on the surface where the water table intersects the ground surface. In hydraulic terms these are the points/areas where groundwater head equals or exceeds the atmospheric pressure.

Springs are an important component of water supply in the SADC Region as the cost of source development is often low and normally does not require pumping (depending on spring location relative to point of use).

10.2.1 Spring Discharge (or Flow) and Water Quality Measurements

The flow of a spring determines its potential in terms of a potential supply source. If the flow is sufficient (relative to the intended use) and consistent throughout the year, springs form important sources of water supply. The flow of a spring depends on:

- The intake (or recharge) area of the spring;
- The magnitude and frequency of groundwater recharge; and
- The spatial extent, storage capacity and saturation level of aquifer(s).

For lower discharges, the flow in the spring should be measured by using a bucket or container of suitable capacity, a pipe to direct the flow and a stop watch/ normal watch. If the flow is high, use of a V notch could be considered.

In most cases the flow of springs varies considerably over a season and for this reason it is essential that flow measurements over at least one season are available to assess the maximum and minimum discharges. It is also essential that flow measurements be taken at least once in a month. Each measurement should be taken at least five (5) times and the average reading should be recorded after discarding any anomalous readings. It is desirable that, wherever applicable, the community should be trained in taking spring measurements.

Water quality samples should be taken and sent for analysis at least twice a year, once during low flow period and the other at the high flow period. In case any microbiological contamination/ pollution is suspected then proper samples for microbiological analysis should also be taken and analysed.

10.2.2 Excavation of the Eye

In order to minimise the possibility of contamination of a spring and to ensure that all the spring flow is harnessed, the 'eye' of the spring must first be excavated. Effectively capturing the spring 'eye' (i.e. the main outlet point, zone or structure) is a crucial part of spring development. In some cases this may involve a relatively shallow excavation to a single eye. In other cases, it may be found that a single spring (at the surface) is fed by a series of eyes spread over a relatively large area.

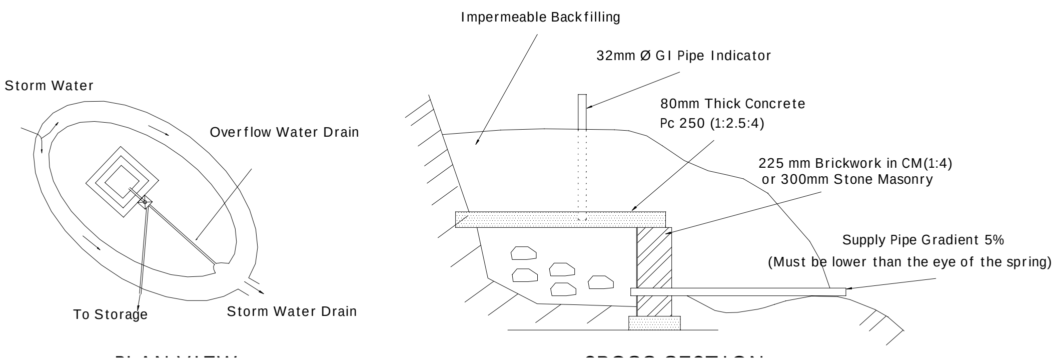
The main objective of excavation is the location of the point(s) where the spring issues from solid rock. Removal of all overlying soil and weathered regolith is crucial to allow construction of a proper catchment (described below). In areas of a 'spring line' or large seepage zone, this may require a relatively large excavation. In other areas, the spring eye is already exposed at the surface.

10.2.3 Spring Intake (Catchment)

Once the eye(s) has been located and exposed, springs are captured by building a spring intake structure or catchment (refer Figure 10-6 & 10-7). A spring intake consists of a sealed structure which encompasses the spring eye(s) and directs the spring flow to the outlet pipe. It may be constructed of a variety of materials (i.e. stone, cement block, brick) but it is essential that it be well sealed, both to the base rock as well as its walls and cover. The actual shape of the catchment will largely be dictated by the topography of the base rock and geometry and location of the eye(s).

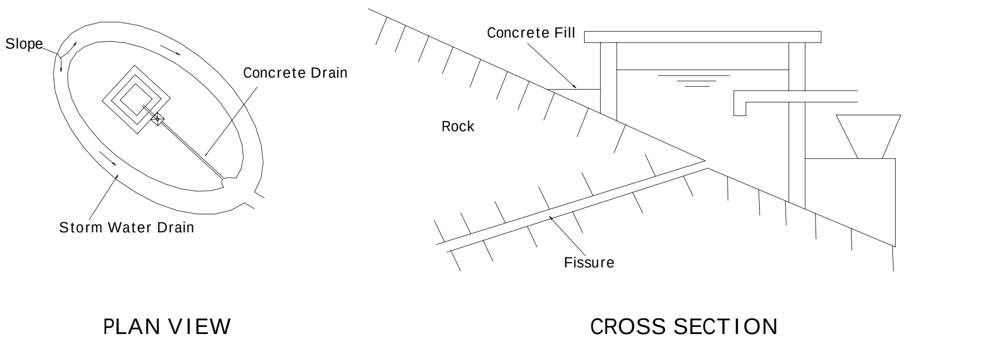
First the walls are built up, incorporating the outlet pipe at the lowest point. In cases of high discharge springs, the walls may have to be built in two (or more) sections to allow the spring flow to be diverted away from the construction area. The walls should be vertical and solidly constructed, with a minimum thickness of 230 mm. The outlet pipe should be a minimum of 50 mm galvanised pipe (larger if discharge is high) and should be sealed well into the wall such that no leakage occurs around it. The discharge pipe should be sloped downward at a minimum gradient of 5%.

Figure 10-6 : Typical Spring Catchment Design - 1



Modified after DRWS, Lesotho

Figure 10-7 : Typical Spring Catchments Design-2



after E H Hofkes

After the walls are constructed and the cement allowed to harden (minimum 24 hours), the cover can be installed. Although a steel reinforced concrete cover can be fitted over a catchment with an open interior, it is recommended that the interior be filled with a suitable material first to better support the cover (and soil if it is re-buried). The interior fill should consist of clean rocks or coarse gravel. Clean stones of approximately 10 to 20 cm size are the best fill material for the catchment. The stones should be fresh and not weathered or friable and washed prior to installation. In some cases a coarse gravel (i.e. river bed gravel) may be more available. If coarse gravel is used, it must be of a large enough size so that it cannot enter the outlet pipe or the outlet pipe may be required to be fitted with a perforated section within the catchment to screen the gravel. When the catchment is filled, a cover can be constructed in situ, by installing concrete over the top of the fill material. The consistency of the concrete should be such that it does not invade the fill material to any significant degree. The concrete should then be sloped outward toward the edges.

If this completed structure is below the ground level then the top of the concrete slab should be re-covered with soil with an indicator (i.e. metal rod) firmly secured to the concrete cover that extends above the surface. This allows the catchment to be easily found later if maintenance is required. At a relatively close distance to the catchment, the outlet pipe should be connected to a constructed silt trap. The silt trap is a small water tank that allows the water flowing from the spring to stand and release any entrained silt or sand. The size of the silt trap is based on the rate of flow from the spring, with larger discharges requiring a larger silt trap to ensure sufficient standing time and lack of turbulence in the silt trap. The silt trap should be equipped with an overflow diverted away from the trap. The outlet (main supply line) from the silt trap can then be sized according to the flow from the spring.

In area where springs are located in local depressions, it is advisable to construct a structure similar to a dug well. Depending on the head, the dug well:

- can be equipped with hand pump (covered from the top),
- can be equipped with a motorised pump to pump the water to a reservoir (covered from the top), or
- can be used as open dug well, or
- the water can be gravitated to another point depending on the head and topography (covered from the top).

10.2.4 Water Supply System based on Spring Source

Both developed and undeveloped springs form important sources of water supply in the SADC region. Developed schemes can be as simple as a water point next to the spring fed by gravity or it may be a pumping system that pumps the accumulated water to a storage reservoir. In favourable topographical conditions, large-scale gravity fed water supply systems are designed that are sourced from the springs. Although the infrastructure cost of such gravity systems (in terms of long distance pipelines) can be high, the maintenance is simple and running costs are often low – ideally suited to rural water supply.

During the design of the water supply system fluctuations in spring discharge should be duly considered. The lowest spring discharge should be used to assess the secure water availability while the maximum discharge should be used to size the pipes. In addition a ‘safety’ factor of 20% should be allowed on the measured discharge records. This safety factor could vary from area to area and availability of previous records (which could more accurately establish the fluctuations).

10.2.5 Spring Catchment Protection and Monitoring

Although springs have the advantage of low running and maintenance costs as sources of water supply, springs tend to be vulnerable to pollution and the denuding of local recharge areas. The following general principles should be followed with regard to protection of springs against pollution:

1. Any existing map(s) on groundwater pollution vulnerability should be referred to (if available) to get an overview of identified pollution potential and other baseline information that might be useful in making necessary arrangement/ recommendations on the protection of the spring.
2. Any spring that is within 75 m down gradient of any pit latrine, graveyard or similar pollution source should not be used for water supply. This distance is intended only as a guideline based on the most general cases and could vary in specific cases. If for any reason this distance is reduced then a hydrogeologist should assesses the pollution potential.
3. There should be no activity within 100 m of the spring intake that may create pollution such as animal grazing, pit latrines, waste disposal sites etc. If the spring is located in a remote area, fencing may be required. This is also a general criterion and in specific cases this distance requirement may be more based on the local geological formation.

4. An area of 10 m around the spring intake should be fenced and no other activity than the maintenance of the spring should be allowed within this.
5. Soil erosion can have a significant and long-term effect on the yield of the spring and may also create siltation problems. The area surrounding the spring, most particularly upslope, should be protected and maintained in its natural state to the greatest degree possible. In some cases where a spring is located below an ephemeral stream, small check dams may be appropriate to slow runoff and enhance local recharge.
6. If there are a number of springs in a catchment with significant contribution to water supply then a catchment management plan should be specifically designed to protect the springs.
7. Spring discharge should be monitored regularly on a monthly basis. Wherever applicable, the community should be trained in discharge measurement and keeping the appropriate records.
8. Water quality should be frequently monitored and compared to base line information to assess any pollution that might be taking place.

10.2.6 Miscellaneous

1. Water rights must be established for the spring, particularly if it is to be used for communal water supply.
2. Nearby pumping boreholes can also impact the yield of the spring. Consideration should be taken when siting a borehole near to a spring that is already in use.

Section 11: GUIDELINES ON REPORTING

11.1 GENERAL

11.1.1 Scope and Purpose

Proper reporting of groundwater development activities is extremely important to optimise the future programmes. Data and information generated during a groundwater development project should be effectively reported with analysis and synthesis to convert in to a knowledge base.

11.2 REPORTING

In a typical groundwater development project the following types of reports are produced:

1. Inception Report
2. Borehole Siting Report
3. Progress Report (including drilling and pumping test reports)
4. Final Technical Report.

11.2.1 Inception Report

This is a very critical report on any groundwater development project. The report is produced at the end of the initial desk study and target delineation phase (refer Section 2 for more details). A preliminary/reconnaissance field visit to the project area must be undertaken prior to compilation of the report. The report should summarise first detailed assessment on various technical and management aspects of the project.

The report should include, but not be limited to the following:

1. Verifications of the results of the feasibility study including the assessment of water demand.
2. An overview of existing water supply sources with special reference to groundwater supplies.
3. Listing of all available literature, including the maps, reports, memoirs for the area, that are relevant to groundwater resources
4. A detailed inventory of existing groundwater sources such as boreholes, springs, dug wells and compilation of verified information and data on these sources (boreholes, springs, dug wells) that are either collected during the field visit or from existing reports, databases etc.
5. An analysis and description of the geology of the area supported by field observations and aerial photo/ satellite imagery analysis, if applicable.
6. A synthesis of the expected hydrogeological environment constructed from the data and information collected and verified till that stage. This should include (with reasoning) expected water level, aquifer type and extent, expected yields, recharge regime, expected groundwater quality and groundwater flow direction.
7. Identification of target areas for groundwater development with reasons for selection and most cost effective siting method.
8. A geophysical survey layout map with suggested methods if ground geophysical survey is recommended as theb optimum siting method.
9. A tentative borehole design and drilling method.
10. Map/s showing topography, project location and area, drainage, geology, inferred geological and water bearing structures, groundwater source location, water chemistry, groundwater levels, groundwater flow direction and target areas for siting. If possible, it is desirable to integrate all this information in a single map as long as clarity is maintained.

11. Recommendations on whether it is feasible to carry on with the proposed groundwater development.
12. Further scheduling of the project for follow-up stages and cost estimates.

Inception report could be fairly comprehensive on large-scale groundwater development projects and may even be integrated with other components of an overall water supply project. For smaller scale projects and individual borehole it may be less comprehensive although the content and analysis should not be compromised.

A typical Inception Report should be produced within approximately the first 10% of the total project duration. This, of course, may vary based on other logistical and technical factors

11.2.2 Siting Report or Site Selection Report

The siting report is produced at the end of the geophysical survey and analysis that leads to selection of sites for drilling. If geophysical survey is not required then the siting report could be merged with the Inception Report.

The report should include, but not be limited, to the following:

1. A map showing the location of sites duly numbered.
2. Priority of selected sites.
3. Expected yield, water strikes, water level and geology at the particular site.
4. Justification on site selection described individually for each site.
5. Any changes in proposed borehole drilling method and design given in the Inception Report.

In addition the following should also be included if geophysical survey is conducted for siting:

1. A map showing the layout of geophysical profile lines and survey points.
2. Plots of geophysical survey profiling data, showing integrated plots for a particular profile line if more than one method is used, with locations of point surveys (such as resistivity sounding), groundwater sources, exposed geological features, drainage and topographical features clearly indicated on profile line plots.
3. Plots of point survey or depth profiling.
4. Interpretation plots of geophysical data, wherever relevant and applicable, showing quantitative estimates and/or modelled features with all the relevant inferred parameters.
5. Wherever possible, an essential interpretation on how geophysical response is correlated to geological and/or hydrogeological features that may be of significance to groundwater occurrence and movement.

11.2.3 Progress Reports

Progress reports may be rendered weekly or monthly and outline the physical progress for a particular duration. The purpose of these reports is to monitor the project progress. When drilling and pumping test activities are ongoing, these reports should include these activities.

11.2.4 Final Report

The Final Report should be submitted at the end of the project and should be compiled in such a manner so that it serves as a standalone report to summarise all the activities of the project, technical information, data, synthesis and experience gained.

The report should include, but not be limited to, the following:

1. The basic elements of the Inception Report such as overview of existing supplies, existing groundwater resources and inventory, geological and hydrogeological description and analysis, target delineation etc.

2. The basic elements of the site selection report such as geophysical survey layout (if carried out), rationale behind the site selection etc. with interpretations and plots of survey results presented as annexure.
3. Results of drilling activities, with all the relevant information collected during the drilling activities.
4. A graphical representation of borehole design and associated information presented separately for each borehole and presented preferably as annexure. The information should include borehole number, depth, location, coordinates, site reference, water level, penetration rate graph, litholog, geological description, water strikes, yield variations, casing and screen details and design.
5. Correlation and synthesis of drilling results with geophysical results is also essential to gain experience and to optimise future groundwater development programmes under similar conditions.
6. Results of pumping test activities with data plots and interpretation. Apart from the quantitative assessment of parameters, the analysis should also include qualitative interpretation of the results and correlation of the hydraulic behaviour of the aquifer with its physical nature.
7. All the interpretation plots of pumping test data and analysis attached as annex.
8. Descriptions of the hydrogeological environment of the project area based on previous knowledge and additional information gained during the project.
9. Assessment of the sustainable yield of pumped boreholes with rationales and methodology used, together with other recommendations on equipping of boreholes.
10. Results of water quality analysis.
11. Any other relevant information, analyses and recommendations.
12. Map/s showing topography, project location and area, drainage, geology, inferred geological and water bearing structures, groundwater source location, locations of groundwater sources developed during the project, water chemistry, groundwater levels, groundwater flow direction, target areas for siting, etc.
13. All the raw data collected during the project. This should include all geophysical data, drilling data, pumping test data and water chemistry data on standard prescribed forms.

It is essential that, irrespective of the implementing agency or the purpose, a copy of the final report must be submitted to the respective national agency responsible for regulating groundwater development and management.

11.2.5 Community Report

A community report should also be prepared wherever applicable as a simplified version of the final report. This report should aim at community and should explain various processes involved in the project in an illustrative manner. Aspects relating particularly to locating borehole sites, abstraction and maintenance should be covered in this report.

APPENDICES

APPENDIX A

REFERENCES

Appendix A: REFERENCES

Banda, K.M.; 1992; Development of Comprehensive Water Department Water Well Development and Rehabilitation Standards; for Ministry of Works (Water Department), Malawi.

Blankwaardt, B.; 1984; Hand Drilled Wells: A Manual on Siting, Design, Construction and Maintenance; Rwegarulila Water Resources Institute, Tanzania.

Bredenkamp, DB, Botha LJ, van Tonder GJ, Rensburg, HJ; 1995; Manual on Quantitative Estimation of Groundwater Recharge and Aquifer Storativity; Prepared for Water Research Commission of South Africa.

Braune, E, Xu, Y; 1997; On-site Sanitation and Groundwater Protection; WISA First Symposium on Sanitation Technical Options, Pretoria, Republic of South Africa.

Burgeap; 1992; La Construction des Puits en Afrique Tropicale, Ministere de la Cooperation et du Development, 3ieme edition mise a jour, ISBN 2-11-086742-6. (Well Construction Manual, manily based on West African Experience, French Ministry for Cooperation and Development, Third Edition)

Department of Water Affairs and Forestry, The Department of Health, Water Research Commission; 2000; Quality of Domestic Water Supply: Volume 1: Assessment Guide & Volume 2: Sampling Guide. WRC No. TT 117/99, Republic of South Africa.

Department of Water Affairs and Forestry; 1997; A Protocol to Manage the Potential of Groundwater Contamination from On-Site Sanitation, Republic of South Africa.

Department of Water Affairs and Forestry; April 1997; Minimum Standards and Guidelines for Groundwater Resource Development for the Community Water Supply and Sanitation; Chief Directorate: Community Water Supply and Sanitation, Republic of South Africa.

Department of Water Affairs and Forestry; February 1999; Guide to Communities and their Water Services; Water Services: Macro Planning and Information System, Republic of South Africa.

Department of Water Affairs, 1993, Protection zones and guidelines for major wellfields, aquifers and dams in Botswana, Water Surveys (Pty), Ltd., Gaborone, 2 vols, Botswana

Department of Water Affairs, 1997, Manual for "Testcurve", Programme Package for Test Pumping Interpretation and Calculation of Recommended Yield, Gaborone, Botswana.

Department of Water Affairs, 2000, Contract Document: Drilling and Test Pumping of Boreholes, DWA, Gaborone, Botswana.

Department of Water Affairs, Practical Guidelines for Rehabilitation of water points to be carried out under the CBM programme, Directorate Rural Water Supply, Namibia.

Department of Water Affairs, Standard Drilling Contract, Namibia.

Driscoll, F.G., 1986; Groundwater and Wells; Johnson Division, St. Paul Minnesota, 2nd Edition.

Groundwater Consultants; 1998; Draft Regional Groundwater Management Programme for SADC Region- Final Report; for SADC Water Sector Coordination Unit, Lesotho.

Guião de Fiscalização para Construção de Furos, DGRH 1998.

Kang'omba, S., 2000, Investment Guidelines for Rural and Peri-Urban Water Supply and Sanitation, Water Sector Reform Support Unit, 75 pages, Zambia.

Kruseman, G.P., De Ridder, N.A.; 1991; Analysis and Evaluation of Test pumping Data; ILRI Publication 47; The Nederland.

Kirchner, J., Tonder, G.J., 1995; Proposed Guidelines for the Execution, Evaluation and Interpretation of Pumping Tests in Fractured Rock Formations; Water SA, Vol.21 No.3.

Lysonski, J., Vilakati, A., Ngwenya, O., Negash, T., 1991, Geophysics Procedure Manual for Well Siting in Swaziland, 120 pages, Swaziland.

MASAF; 1998; Tender Documents for Construction of Boreholes, Malawi.

Métodos de Análise de Água, 1997, Ministério da Saúde, Laboratório Nacional de Higiene dos Alimentos e Água.

Ministry of Health, 1995, Upgraded Well Manual for Field Workers, Mvuramanzi Trust, 27 pp., Zimbabwe.

Ministry of Water Development; ??; Technical Specifications for Drilling, Siting and Pump Installation, Malawi.

Ministry of Water Development; 1999; Community Based Rural Water Supply, Sanitation and Hygiene Education, Malawi.

Ministry of Water Development; 2000; Design and Technical Specifications for the Construction of Groundwater Supply Facilities in Rural Areas, Malawi.

Molapo, P., Pandey, S.K., Puyoo, S; 2000; Groundwater Resource Management in the SADC Region: A Field of Regional Cooperation; IAH 200 Conference, Cape Town

National Environmental Secretariat (NES); 1998; Proposed Water Quality Guidelines for Lesotho – Domestic (Drinking) Water Guidelines, Lesotho

Normas Gerais para abertura de poços e furos, projecto de regulamento, DGRH 1995.

SABS 0299; 1998; *Standards on* "The Development, Maintenance and Management of Groundwater Resources" (8 Parts - published and unpublished), Republic of South Africa.

Sami, K., Murray, EC; 1998; Guidelines for the Evaluation of Water Resources for Rural Development with an Emphasis on Groundwater; Final Report to the Water Research Commission of South Africa.

SKAT-HTN; 1997; Malda Direct Action Handpump Specifications Revision 0-1997; Swiss Centre for Development Cooperation in Technology and Management; Switzerland

SKAT-HTN; 1998; Afridev Handpump Specifications Revision 3-1998; Swiss Centre for Development Cooperation in Technology and Management; Switzerland

Standards Association of Zimbabwe, 1995, Zimbabwe Standard Specification for Natural Mineral Water, Zimbabwe Standard No. 457:1995, ICS 13.060.10, ISBN 0-86928-310-3, Zimbabwe.

Standards Association of Zimbabwe, 1997, Zimbabwe Standard Specification for Water for Domestic Supplies, Zimbabwe Standard No. 560:1997, ICS 13.060.20, ISBN 0-86928-469-X, Zimbabwe.

Tonder Gerrit van, Kunstmann, H., Xu, Y.; 1998; Estimation of Sustainable Yield of a Borehole Including Boundary Information, Drawdown Derivatives and Uncertainty Propagation; CSIR Report, Republic of South Africa.

UNDP; 1982; A Manual for Integrated Projects for Rural Groundwater Supplies, Malawi

United Nation; 1989; Groundwater in Eastern, Central and Southern Africa; Natural Resources/Water Series No. 19, Botswana

Village Water Supply; 1992; Manual on Borehole Construction & Maintenance and Handpump, Lesotho

Water and Sewerage Authority; 1996; Design Guidelines for Planning of the Capital Program of the water Sector Projects, Lesotho

Weaver, J M C; 1992; Groundwater Sampling: A Comprehensive Guide for Sampling Method; WRC Report No. TT 54/92, Republic of South Africa.

Xu, Y, Braune, E,; 1995; A Guide for Groundwater Protection for the Community Water Supply and Sanitation Programme; DWAF; ISBN 0-621-16787-8, Republic of South Africa.

Zambia Bureau of Standards, 1997, Zambian Standard for Water Supply Systems - Consumption Figures for Design – Guidelines, ZS 361:1997, ISO91.140.60, Zambia.

REPORTS

GENERAL/REGIONAL

British Geological Survey; Radial Collector Wells in Alluvium Project: Progress Report 1 on Trenchless Moling Trials at Corner Wood, Laughton, Lincoln

Groundwater Consultants; 1998; Draft Regional Groundwater Management Programme for SADC Region- Final Report; for SADC Water Sector Coordination Unit, Lesotho.

Ground Water Monitoring & Remediation: Spring 1995 Seasonal Journal

Hotmail to Sanjeev; HTML 4.0 Specification

Hotmail to Sanjeev; 16 Frames

Molapo, P., Pandey, S.K., Puyoo, S; 2000; Groundwater Resource Management in the SADC Region: A Field of Regional Cooperation; IAH 2000 Conference, Cape Town

SKAT-HTN; 1997; Malda Direct Action Handpump Specifications Revision 0-1997; Swiss Centre for Development Cooperation in Technology and Management; Switzerland

SKAT-HTN; 1998; Afridev Handpump Specifications Revision 3-1998; Swiss Centre for Development Cooperation in Technology and Management; Switzerland

United Nation; 1989; Groundwater in Eastern, Central and Southern Africa; Natural Resources/Water Series No. 19

UNDP; 1992; Low Cost Groundwater Development: An African Regional Seminar held at Lilongwe, Malawi during 6 – 8 December, 1982

SADC; 2001; SADC 16th expert group meetings on standardization, Quality Assurance and Metereology (SQAM), 4th meeting of SADC Cooperation in Standardization (SADCSTAN) Maseru , Lesotho-23 April 2001

SADC; Development of Minimum Common Standards for Groundwater Development in the region, Contract Document

Scientific Software Group; 2000; Environmental Software: Groundwater, Surface Water Bioremediation Geotechnical, Air Pollution and Others

Water Distribution Modeling for Autocad, User’s Guide for Cybernet for Windows, Version 3.0

ANGOLA

Regulamentação das actividades de prospecção, pesquisa e exploração dé água subterrânea, IGEO, 1998

Proposta de reforma do Curso de Geologia, Universidade Agostinho Neto, Faculdade de Ciências, Departamento de Geologia.

Normas de Potabilidade, EPAL.

Projecto de Lei de Águas, documento para apreciação e discussão.

Boletim da República, I Série - nº 11 - 17 de Março de 2000.

Posição Geológica Geral das Nascentes localizadas, mapa Geológico de Angola à Escala 1: 1 000 000, IGEO, em execução.

BOTSWANA

Botswana Geoscientists Association, June 1999, Botswana Journal of Earth Scientists

Department of Water Affairs, 1991, Natioanal Water Master Plan, Snowy Mountains Engineering Corporation (Australia), SGAB (Sweden), 12 vols.

Department of Water Affairs, 1993, Protection zones and guidelines for major wellfields, aquifers and dams in Botswana, Water Surveys (Pty), Ltd., Gaborone, 2 vols.

Department of Water Affairs, 1993, Some Comments and Considerations Regarding the Calculation of Recommended Yield for a single Production Borehole

Department of Water Affairs, 2000, Contract Document: Drilling and Test Pumping of Boreholes, DWA, Gaborone.

Department of Water Affairs, 2000, Groundwater Monitoring, Geotechnical Consulting Services (Pty) Ltd., Gaborone, 25 vols.

Dwamena M, 1998, The Water Bill,1998,

Geotechnical Consulting Services: May 2000; Groundwater Monitoring: Review of Monitoring performed by DWA and DGS, Assessment of Water Resources nad Suggestions for Improvements, Phase 1 of the National Groundwater Information Systems; Volume 1: Main Report Executive Summary

Geotechnical Consulting Services: May 2000; Groundwater Monitoring: Review of Monitoring performed by DWA and DGS, Assessment of Water Resources nad Suggestions for Improvements, Phase 1 of the National Groundwater Information Systems; Volume 1: Main Report Executive Summary

Geraghty & Miller ; October 1989,AQTESOLVE; Aquifer Test Solver Version 1.00 Documentation

Masedi O.A.; 1999; southern African Vision for Water, Life and Environment in the 21st Century ; Perception from Botswana.

Water Resources Consultants;1995; Comments on DWA's Uniform Rates Programme: Contract Document for Consultants and Contractors

DEMOCRATIC REPUBLIC OF CONGO

Etude Nationale du plan de développement du secteur de l'eau potable et de l'assainissement, CNAEA / Louis Berger International, December 1994.

Tender Document for the 3rd World Bank Project, Water Supply for 18 semi-rural centres and the town of Likasi.

Shéma d'Orientation Hydrogéologique, SOGREAH, 1993

Department Des Mines et Energie; *No Specified year;* Alimentation en Eau Patable de 18 Centres Semi-Ruraux et la Ville de Likasi; Regie de Distribution D'eau REGIDESO; Dossier D'appel D'offres, Lot 1; Volume 2

LESOTHO

No Specified Author; 1998; Proposed Waste Water or Industrial Effluent Discharge Standards; 2nd Draft

Aleobua BOY; 1993; Training Workshop on Borehole Rehabilitation; Volume 2: Workshop Notes for VHSS

Department of Rural Water Supply; *No Specififed Year*; Technical Guidelines Volume 2 – Drawings

Department of Rural Water Supply; Tender Notice and Tender Documents; Tender No B99GOL1 'Borehole Drilling 1999 –2000' to be approved by Central Tender Board

Development Unit, MICARD Village Water Supply; 1992, Manual on Borehole Construction & Maintenance and Handpumps

Environmental Bill 2000; 2000; Government of Lesotho.

GKW Consult/Kfw; 1998; Two Town Water Supply Project Evaluation, Butha-Buthe Upgrading ;Stage 2 Final Report

Groundwater Consultants/ GKW Consult; 1998; Butha-Buthe Water Supply Borehole Evaluation (Stage 2); Interim Progress Report.

Groundwater Consultants/ GKW Consult; 1998; Two Town Water Supply Project Evaluation, Butha-Buthe Upgrading (Stage 2 Report)

Groundwater Consultants; 1999; Southern African Vision for Water Life and Environment in the 21st Century – Lesotho Perspective

Groundwater Consultants; 1999; Southern African Vision for Water Life and Environment in the 21st Century – Lesotho Perspective, Report

Groundwater Division; 1988; Borehole Siting for Dilli Dilli Clinic (Quthing)

Kessler, S; 1994; Design of Pumping Systems: Diesel Engine or non-submissible, grid connected Electric Motor for Village Water Supply

Martinelli, E and Associates; Masianokeng and Ha Motloheloa Irrigation Schemes Phuthiatsana South River Hydrological Feasibility Study

Ministry of Natural Resources: Invitation to Bid: Construction of Boreholes and Test pumping of Production boreholes at "Ha Nyenye Industrial Estate"

National Environmental Secretariat (NES); 1998; Proposed Water Quality Guidelines for Lesotho – Domestic (Drinking) Water Guidelines.

National Environmental Secretariat (NES); 1998; Proposed Waste Water or Industrial Effluent Discharge Standards; 2nd Draft

National Environmental Secretariat (NES); 1998; National Environmental Policy for Lesotho (Revised)

Protocol; 1995; Shared Watercourse Systems in the Southern African Development Community (SADC) Region

Southern Africa Environment Project; 1999; Draft: A practical guide for understanding the Environmental Impact Assessment Requirements of the Kingdom of Lesotho, prepared for Lesotho National Environment Secretariat.

Tams Consultants, Sechaba Consultants & Groundwater Consultants; 1996; Water Resources Management: Policy and Strategies – Final Report Prepared for Department of Water Affairs.

Village Water Supply; 1992; Manual on Borehole Construction & Maintenance and Handpump.

Water and Sewerage Authority; 1996; Design Guidelines for Planning of the Capital Program of the water Sector Projects

Water Resources Act 1978; Act no. 22 of 1978; Government of Lesotho.

Water Resources Policy; 1999; Government of Lesotho.

MALAWI

Canadian International Development Agency & UNDP-World Bank; 1998; Water and Sanitation Sector Programme up to the Year 2020.

Community Based Management Unit, Malawi Government; *No Specified Year*; Community Handbook on Water and Sanitation Afridev Version

Director of Mines; 1999; Malawi Annual Report 1999; Volume 2 No.1

Kafundu R.D.; Case Study on Groundwater Quality of the Weathered Basement of Dowa

Ministry of Water Development; 1997; The country Situation Report on Water Resources Malawi.

Ministry of Water Development; 1998; Tenders for Borehole Construction Component #3 Pump Installation and Civil Works Construction, part 1

Ministry of Water Development; 1999; Community Based Rural Water Supply, Sanitation and Hygiene Education.

MASAF; 1998; Tender Documents for Construction of Boreholes.

MASAF; 2000; Water Projects as at February 2000

Water Resources Act 72:03; 1972; Government of Malawi.

Water Act (Draft); 1998; Government of Malawi.

Ministry of Water Development; 2000; Design and Technical Specifications for the Construction of Groundwater Supply Facilities in Rural Areas.

Ministry of Water Development; 1998; Construction & Test Pumping of Boreholes: Draft Document; Detailed Design for New Urban and Rural Gravity Fed Water Supply Schemes

Banda, K.M.; 1992; Development of Comprehensive Water Department Water Well Development and Rehabilitation Standards; for Ministry of Works (Water Department).

Environmental Affairs Department; 1997; Guidelines for Environmental Impact Assessment

Ministry of Water Development; ??; Technical Specifications for Drilling, Siting and Pump Installation.

UNDP; 1982; A Manual for Integrated Projects for Rural Groundwater Supplies.

MAURITIUS

Water Resources Unit, Ministry of Public Utilities; March 2000; Water Resources of Mauritius.

Water Resources Unit, Ministry of Public Utilities; November 1999; Water Resources of Mauritius: Fact and Figures.

Groundwater Act, September 1970; Government of Mauritius.

Groundwater Act (Amendment) Regulations 1992.

Geolab; July 1999; Geological and Hydrogeological Map of Mauritius (1:50,000); Joint Cooperation of Government of Mauritius and Government of France.

Geolab; March 1998; Geological and Hydrogeological Map of Rodrigues (1:25,000); Joint Cooperation of Government of Mauritius and Government of France.

Loic Giorgi, French Company; 2001; Geology-Geohydrology, Mauritius Island

Water Resources Unit, Ministry of Public Utilities, July 1998, Instruction to Tenderers,Tender & Apprentices to Tender Forms of Bonds & Agreement Conditions of Conditions of Contract – Part II, Specification, Bill of Quantities,Drawings

MOZAMBIQUE

Critérios para Construção de Furos a Serem Equipados com Bombas Manuais em Moçambique, DGRH 1997.

Guião de Fiscalização para Construção de Furos, DGRH 1998.

Normas Gerais para abertura de poços e furos, projecto de regulamento, DGRH 1995.

Métodos de Análise de Água, 1997, Ministério da Saúde, Laboratório Nacional de Higiene dos Alimentos e Água.

Ficha de Inventário Geohidrológico, DGRH

Boletim da República 1996, I Série- Número 52.

Boletim da República 1991, I Série I- Número 31.

Política Nacional de Águas, DNA, 1997.

Revista da Hidrogeologia do Baixo Limpopo e Baixo Incomati, SdG, 1985.

BURGEAP, (1961), Rapport de Mission dans le District de Cabo Delgado, relatorio 288.

BURGEAP, 1962, Hidrogeologia do Sud do Save.

ZIMBABWE

Ministry of Water Resources, 1985, National Master Plan for Rural Water Supply and Sanitation, InterConsult (Norway) and E. Martinelli and Associates (Zimbabwe).

Ministry of Health, 1995, Upgraded Well Manual for Field Workers, Mvuramanzi Trust, 27 pp.

Mvuranzi Trust, Annual Report 1998 Supported by: Sida, Norad, Unicef, Oak Zimbabwe for IPA, Rotary Club of Harare.

Mvuranzi Trust, A builder’s Manual for the 4 Bag Model and Hand Washing Tank , The Latrine Blair.

Standards Association of Zimbabwe, 1997, Zimbabwe Standard Specification for Water for Domestic Supplies, Zimbabwe Standard No. 560:1997, ICS 13.060.20, ISBN 0-86928-469-X.

Standards Association of Zimbabwe, 1995, Zimbabwe Standard Specification for Natural Mineral Water, Zimbabwe Standard No. 457:1995, ICS 13.060.10, ISBN 0-86928-310-3.

Institute of the Scientific & Industrial Research & Development Centre SIRDC, *No specified year,* Environment and Remote Sensing Institute

Institute of the Scientific & Industrial Research & Development Centre SIRDC, *No specified year,* Technology for Sustainable Development

APPENDIX B

DATA RECORDING FORMS

List of Contents – Appendix B

STANDARD BILL OF QUANTITY FOR SERVICES

Activity :					
Item	*Description*	*Unit*	*Rate*	*Qty*	*Amount*
Manpower					
I.A.1	Project Manager/Team Leader	Day			
I.A.2	Hydrogeologist A	Day			
I.A.3	Hydrogeologist B	Day			
I.A.4	Hydrogeologist C	Day			
I.A.5	Hydrogeologist D	Day			
I.A.6	Geophysicist A	Day			
I.A.7	Geophysicist B	Day			
I.A.8	Geophysicist C	Day			
I.A.9	Geophysicist D	Day			
I.A.10	Technician A	Day			
I.A.11	Technician B	Day			
I.A.12	Technician C	Day			
I.A.13	Draftsperson	Day			
I.A.14	Specialists (Socio-economist, modelling etc.)	Day			
	Sub Total Manpower				
Direct Cost					
	Office, Transport and Communication				
I.B.1	Office Set-up (running and establishment)	Day			
I.B.2	Radio/Wireless Communication	Day			
I.B.3	Vehicle hire	Day			
I.B.4	Vehicle mileage - Tar Road	km			
I.B.5	Vehicle mileage - Other Roads	km			
I.B.6	Other Travel (Specify)	---			
I.B.7	Other (Specify)	---			
	Geophysical Survey and Sampling				
I.C.1	Magnetic Profiling	Km			
I.C.2	Resitivity Profiling	Km			
I.C.3	EM Profiling	Km			
I.C.4	Vertical Resitivity Sounding (AB/2<600)	No.			
I.C.5	Vertical Resitivity Sounding (AB/2>600)	No.			
I.C.6	Water Quality Sampling and Analysis	No.			
I.C.7	GPS Unit Hire	Day			
I.C.8	Other (Specify)	---			
	Reports				
I.D.1	Inception Report	No			
I.D.2	Progress Report (Monthly, Quarterly)	No			
I.D.3	Site Selection Report	No			
I.D.4	Draft Final Report	No			
I.D.5	Final Report	No			
I.D.6	Others (Drilling, Testing etc.)	---			
	Sub Total Direct Cost				
Reimbursable					
I.D.1	Purchase of Maps, Aerial Photo	No.			
I.D.2	Others (Specify)	---			
	Sub Total Reimbursable				
	Sub-Total Activity ----				

Note: 1. Complete separately for each activity such as Desk Study, Siting, Drilling Supervision Etc.
2. Remove the item that is not required for a particular activity

STANDARD BILL OF QUANTITY FOR WORKS

Activity :						
Item	*Specs*	*Description*	*Unit*	*Rate*	*Qty*	*Amount*
Drilling						
Dl.1		Mobilization and demobilization (Tar Road)	Km			
Dl.2		Mobilization and demobilization (Other Road)	Km			
Dl.3		Rigging and Unrigging	No.			
Dl.4		Drilling --- mm dia through Regolith	m			
Dl.5		Drilling --- mm dia through consolidated/ fractured rock	m			
Dl.6		Drilling --- mm dia through Unconsolidated Formation	m			
Dl.7		Reaming to --- mm dia through consolidated/ fractured rock	m			
Dl.8		Reaming --- mm dia through Unconsolidated Formation	m			
Dl.9		Supply and installation of -- mm dia plain casing of ------ material and -- mm thickness	m			
Dl.10		Supply and installation of -- mm dia screen of ----- material ----- type and -- mm thickness	m			
Dl.11		Borehole development using ---------- method	hr			
Dl.12		Supply and installation of Formation Stabliser/Gravel of --- size	kg			
Dl.13		Supply and installation of cement grouting	m3			
Dl.14		Supply and installation of well head cap	no			
Dl.15		Construction of concrete slab	no			
Dl.16		Water quality analysis	no			
Dl.17		Standing Time	Hr			
Dl.18		Borehole Straightness Test	No.			
Dl.19		Borehole Verticality Test	No.			
Dl.20		Others (Specify)	---			
		Sub Total Drilling				
Testing						
Tp.1		Mobilization and demobilization	site			
Tp.2		Preliminary and calibration test	hr			
Tp.3		Step test pumping and measurements	hr			
Tp.4		Constant rate test pumping and measurements	hr			
Tp.5		Recovery test measurements	hr			
Tp.6		Observation hole measurements (<500 m)	hr			
Tp.7		Observation hole measurements (>500 m)	hr			
Tp.8		Pump installation, rigging and unrigging	m			
Tp.9		Removal and welding of borehole cap	no			
Tp.10		Water quality analysis	no			
Tp.11		Others (Specify)	---			
		Sub Total Drilling				
		Grand Total Works				

Note: 1. Add more rows if more than one diameter/type of drilling, casing, screens etc. are required
2. Make a reference to specifications in column 2

Form ST-1

BOREHOLE SITING DETAILS

(Information to be supplied by the hydrogeologist/Geophysicist)

Site No. ______________________ Owner ______________________

Village ______________________ District ______________________

Coordinates *Lat/Long* ______________ S ______________ E

UTM ______________ S ______________ E

Map Sheet No. ______________

Sketch Map

Project ______________ Client ______________

Consultant/Hydrogeologist Incharge ______________ Geophysicist ______________

Consideration	Check	Remark
Ownership	*OK/Objection*	
Community informed	*Y/N*	
Rig accessibility	*Y/N*	
Community accessibility	*Y/N*	
Environmental problem	*Y/N*	
Aerial photo used	*Y/N*	
Geological map used	*Y/N*	
Hydrogeological map used	*Y/N*	
Geophysical Survey	*Y/N*	
Geophysical methods used *(Specify methods)*		

Recommended drilling depth ______________ Expected yield (range) ______________

Reason for the selection of site

Attachments with this sheet:
Geophysical plots, further elaboration on any of the above point (if required)

Form DR-1

BOREHOLE DRILLING DETAILS

(Main/Cover Sheet)

BH No. ____________________ Owner ____________________

Village ____________________ District ____________________

Coordinates *Lat/Long* ______________ S ______________ E

UTM ______________ S ______________ E

Map Sheet No. ______________

Sketch Map

Project ______________ Client ______________

Consultant/Hydrogeologist Incharge ______________ Technical Supervisor ______________

Contractor ______________ Driller ______________

Date of Commencement ______________ Date of Completion ______________

Total Depth of Borehole ______________ Drilling Method ______________

Blow-out Yield/Expected Yield ______________ Water Level ______________

Drilling Diameter ______________ Completed Diameter ______________

Casing

Material ________ Diameter ________ Thickness ________

Screen

Material ________ Diameter ________ Thickness ________

Type ________ Slot Size ________ Open Area % ________

Gravel

Type ________ Size ________ Used Volume ________

Water Quality

Temperature ________ TDS/EC ________ pH ________

Attachments with this sheet:
Form DR-2, DR-3 and DR-4

Form DR-2

LITHOLOGICAL LOGGING

BH No. **Logged by:** **Page** **of**

Depth (m)	Description	Colour*	Grainsize*	Texture*	Degree of weathering*	Stratigraphic unit (if known)*	Remarks (e.g. mineralogy, drilling, water etc.)	Penetration rate (min/m)	Discharge	EC/TDS

Data to be recorded at a minimum of 1 meter intervals- add more sheets if required

* See attached sheet for codes

Form DR-3

BOREHOLE CONSTRUCTION DETAILS

BH No. ________

Drilling

From	To	Diameter	
m	m	Inches	mm

Casing

From	To	Material/ Thickness	Diameter	
m	m		Inches	mm

Screens

From	To	Diameter		Type	Material	Thickness	Slot Size	Open Area
m	m	Inches	mm			mm		%

Gravel/Cement Grout

From	To	Material	Size	Thickness	Remark
m	m				

Borehole Cap

Y/N ________

Cement Slab

Thickness ________ Size ________

Alignment/Verticality Test Remark

General Remarks

Form DR-4

ABBREVIATIONS FOR LITHOLOGICAL LOGGING

Colour (use combinations if needed)			
Gr - grey	Gn - green	Br-brown	Or - orange
Bg-beige	Rd-red	Pk- pink	Wt - white
Shade			
L-light	M-medium	D-dark	
Grainsize			
VF - very fine	F - fine	M - medium	C - coarse
VC - very coarse			
Texture (use more than one as applicable)			
D - Dense, hard	F - fractured	U- unconsolidated	PC- partly consolidated
L - laminated	H- homogeneous	C - clast supported	M- matrix supported
Degree of weathering			
F-fresh	L-light	M-moderate	D-deeply
Formation / Stratigraphic unit (if known)*			

* Add codes based on the local stratigraphic nomenclature

Form SM-1

GROUNDWATER SAMPLING FORM

(Main Sheet / Covering Sheet)

Sample No. ____________________ Owner ____________________

Sample Type: (Borehole, Spring Etc.) ____________________ Borehole No. ____________________

Village ____________________ District ____________________

Coordinates *Lat/Long* ____________________ S ____________________ E

UTM ____________________ S ____________________ E

Map Sheet No. ____________________

Sketch Map

Project ____________________ Client ____________________

Sampler ____________________ Lab Send to: ____________________

Date of Sampling ____________________ Date of Submission ____________________

Depth of Sample (if Applicable) ____________________ Other Source ____________________

Sampling Method Used ____________________

No. of Samples Collected __________ Acidic Sample (Y/N) ____________________

Constituents Request Form Attached (Y/N) __________ ____________________

Field Measurements

Temperature __________ TDS __________ mg/l pH __________

Attachments with this sheet:

Form SM-2

Form SM-2

WATER ANALYSIS REQUEST FORM

Constituents	*Unit*	*Tick*
Suspended solids	*mg/l*	
Colour	*TCU*	
Turbidity	*NTU*	
TDS	*mg/l*	
pH		
Hardness ($CaCO_3$)	*mg/l*	
Calcium (Ca)	*mg/l*	
Magnesium (Mg)	*mg/l*	
Sodium (Na)	*mg/l*	
Potassium (K)	*mg/l*	
Chloride (Cl)	*mg/l*	
Total Alkalinity	*mg/l*	
Bicarbonate	*mg/l*	
Carbonate	*mg/l*	
Sulphate	*mg/l*	
Nitrate	*mg/l*	
Flouride	*mg/l*	
Iron	*mg/l*	
Manganese	*mg/l*	
Zn	*mg/l*	
Copper	*mg/l l*	
Arsenic	*mg/l*	
Lead	*mg/l*	
Aluminium	*mg/l*	
Cadmium	*mg/l*	
Cyanide	*mg/l*	
Mercury	*mg/l*	
Ammonia	*mg/l*	
Hydrogen Sulphide	*mg/l*	
Faecal Coliform	*Count/100ml*	
Total Plate Count	*Count/100ml*	
Field Measurements		
Temperature	^{0}C	
pH		
Electrical Conductivity		

Form TP-1

PUMPING TEST RECORD

(Main Sheet / Covering Sheet)

Borehole No. ____________________ Owner ____________________

Village ____________________ District ____________________

Coordinates *Lat/Long* ______________ S ______________ E

UTM ______________ S ______________ E

Map Sheet No. ______________

Sketch Map

Project ______________ Client ______________

Consultant/Hydrogeologist Incharge ______________ Technical Supervisor ______________

Contractor ______________ Foreman ______________

Date of Commencement ______________ Date of Completion ______________

Total Depth of Borehole ______________ Blow-out Yield/Expected Yield ________

Type of Pump, Size and Capacity ____________________________________

Water Level Before the Installation of Pump ________ Depth of Pump Intake ______________

Reference Point for WL Measurements ____________________________________

Step-drawdown Test

No. of Steps ________ Duration of Each Step ________ Discharges ______________

Constant Rate Test

Duration ________ Discharge ________ Max Drawdown ________

Recovery Test

Duration ________ Recovery % at the end ________ Residual Drawdown ________

Water Quality

Temperature ________ TDS ________ mg/l pH ________

Attachments with this sheet:

Form TP-2, TP-3 and TP-4, Field Plots of time-drawdown (if available), Any other extra information

Form TP-2

STEP DRAWDOWN TEST

BH No ____________________ Location ____________________

WL Before the Test ____________________ Pump Intake ____________________

Reference Point ____________________

Step No. _______ ***of*** __________ ***Discharge*** __________ *(units)*

Time			Water Level		Discharge		Remark
Real Time	Hrs	Min	Depth of Water	Drawdown	Container Method	Flow Meter	TDS, Temperature, pH and any other observation
			m	m	l/s or m^3/h	l/s or m^3/h	
		0					
		0.5					
		1					
		2					
		3					
		4					
		5					
		6					
		7					
		8					
		9					
		10					
		12					
		14					
		16					
		18					
		20					
		25					
	0.5	30					
		35					
		40					
		45					
		50					
	1	60					
		70					
		80					
	1.5	90					
		100					
		110					
	2	120					

* Use separate sheets for each steps

Contractor/Operator ____________________ Technical Supervisor ____________________

(Name and Signature) *(Name and Signature)*

Date:

Form TP-3

CONSTANT RATE TEST

Pumping BH No ____________ Location ____________

WL Before the Test ____________ Pump Intake ____________

Reference Point ____________ Pumping Well/ Observation Well *(Tick Appropriate)*

Average Discharge ________ *(units)* Obs Well No.: Dist: *m*, Depth: *m*

Time			Water Level		Discharge		Remark
Real Time	Hrs	Min	Depth of Water	Drawdown	Container Method	Flow Meter	TDS, Temperature, pH and any other observation
			m	m	l/s or m^3/h	l/s or m^3/h	
		0					
		0.5					
		1					
		2					
		3					
		4					
		5					
		6					
		7					
		8					
		9					
		10					
		12					
		14					
		16					
		18					
		20					
		25					
	0.5	30					
		35					
		40					
		45					
		50					
	1	60					
		70					
		80					
	1.5	90					
		100					
		110					
	2	120					
	2.25	135					

Form TP-3

CONSTANT RATE TEST

Pumping BH No	____________	Location	____________
WL Before the Test	____________	Pump Intake	____________
Reference Point	____________	Pumping Well/ Observation Well *(Tick Appropriate)*	
Average Discharge	________ *(units)*	Obs Well No.:	Dist: *m*, Depth: *m*

Time			Water Level		Discharge		Remark
Real Time	Hrs	Min	Depth of Water	Drawdown	Container Method	Flow Meter	TDS, Temperature, pH and any other observation
			m	m	l/s or m^3/h	l/s or m^3/h	
	2.5	150					
	2.75	165					
	3	180					
	3.5	210					
	4	240					
	4.5	270					
	5	300					
	5.5	330					
	6	360					
	6.5	390					
	7	420					
	7.5	450					
	8	480					
	8.5	510					
	9	540					
	9.5	570					
	10	600					
	10.5	630					
	11	660					
	11.5	690					
	12	720					
	13	780					
	14	840					
	15	900					
	16	960					
	17	1020					
	18	1080					
	19	1140					
	20	1200					
	21	1260					
	22	1320					

Form TP-3

CONSTANT RATE TEST

Pumping BH No ____________ Location ____________

WL Before the Test ____________ Pump Intake ____________

Reference Point ____________ Pumping Well/ Observation Well *(Tick Appropriate)*

Average Discharge ________ *(units)* Obs Well No.: Dist: *m*, Depth: *m*

Time			Water Level		Discharge		Remark
Real Time	Hrs	Min	Depth of Water	Drawdown	Container Method	Flow Meter	TDS, Temperature, pH and any other observation
			m	m	l/s or m^3/h	l/s or m^3/h	
	23	1380					
	24	1440					
	26	1560					
	28	1680					
	30	1800					
	32	1920					
	34	2040					
	36	2160					
	38	2280					
	40	2400					
	42	2520					
	44	2640					
	46	2760					
	48	2880					
	50	3000					
	52	3120					
	54	3240					
	56	3360					
	58	3480					
	60	3600					
	62	3720					
	64	3840					
	66	3960					
	68	4080					
	70	4200					
	72	4320					

Contractor/Operator ____________ Technical Supervisor ____________

(Name and Signature) *(Name and Signature)*

Date:

General Remarks and Observations:

RECOVERY TEST Form TP-4

Pumping BH No ______ Location ______
WL Before the Test ______ Pump Intake ______
Reference Point ______ Pumping Well/ Observation Well *(Tick Appropriate)*
Average Discharge during Pumping ______ *(units)* Obs Well No.: Dist *m* Depth *m*

Time			Water Level		Time			Water Level	
Real Time	Hours	Minutes	Depth of Water	Residual Drawdown	Real Time	Hours	Minutes	Depth of Water	Residual Drawdown
			m	m				m	m
		0				8.5	510		
		0.5				9	540		
		1				9.5	570		
		2				10	600		
		3				10.5	630		
		4				11	660		
		5				11.5	690		
		6				12	720		
		7				13	780		
		8				14	840		
		9				15	900		
		10				16	960		
		12				17	1020		
		14				18	1080		
		16				19	1140		
		18				20	1200		
		20				21	1260		
		25				22	1320		
	0.5	30				23	1380		
		35				24	1440		
		40				26	1560		
		45				28	1680		
		50				30	1800		
	1	60				32	1920		
		70				34	2040		
		80				36	2160		
	1.5	90				38	2280		
		100				40	2400		
		110				42	2520		
	2	120				44	2640		
	2.25	135				46	2760		
	2.5	150				48	2880		
	2.75	165				50	3000		
	3	180				52	3120		
	3.5	210				54	3240		
	4	240				56	3360		
	4.5	270				58	3480		
	5	300				60	3600		
	5.5	330				62	3720		
	6	360				64	3840		
	6.5	390				66	3960		
	7	420				68	4080		
	7.5	450				70	4200		
	8	480				72	4320		

Contractor/Operator ______ Technical Supervisor ______ Date:
(Name and Signature) *(Name and Signature)*

Form PR-1

PRODUCTION PUMPING RECOMMENDATIONS

(Information to be supplied by the hydrogeologist)

Borehole No. ______________________ Owner ______________________

Village ______________________ District ______________________

Coordinates *Lat/Long* ______________ S ______________ E

UTM ______________ S ______________ E

Map Sheet No. ______________

Sketch Map

Project ______________ Client ______________

Consultant/Hydrogeologist Incharge ______________ Technical Supervisor ______________

Date of Drilling ______________ Date of Testing ______________

Total Depth of Borehole ______________ Tested Yield (CRT) ________

Reference Point for WL Measurements ______________ Water Level Prior to Testing ________

Method used for Sustainable Yield Estimate ______________________________

Computer Software Used for Sustainable Yield Estimate ______________________________

Available Drawdown ______________ t/t' intercept at zero drawdown ______________

Adjustments made on predicted/extrapolated drawdown ______________________________

Recommendations for Production Pumping

Discharge ______________ Pump Installation Depth ______________

Pumping Hours and Schedule ______________ Expected Pumping Water Level ______________

Water Quality ______________________________

Remark/ Additional Conditionality ______________________________

Attachments with this sheet:

Form PR-2, Casing/screen depth details/ borehole profile

Form EQ-1

BOREHOLE EQUIPPING DETAILS

(Information to be supplied by the hydrogeologist)

Borehole No. ______________________ Owner ______________________

Village ______________________ District ______________________

Coordinates ______________ S ______________ E

Map Sheet No. ______________

Sketch Map

Project ______________ Client ______________

Consultant/Hydrogeologist Incharge ______________ Design Engineer ______________

Date of Drilling ______________ Date of Testing ______________

Reference Point for WL Measurements ______________ Water Level Prior to Testing ______________

Total Depth of Borehole ______________ Recommended Yield ______________

Recommended Pumping Hours ______________ Recommended Installation Depth ______________

Expected Pumping Water Level ______________ ______________

Installation Summary

Pump

Type	Make	Model
Discharge Range	Head Range	Efficiency Range

Motor/Engine

Type	Make	Model
Power	Other	

Rising Main

Type, Size and Length

Dipper Pipe

Type, Size and Length

Others

Flow Meter (Y/N)	Non-return Valve (Y/N)	Gate Valve (Y/N)

Attachments with this sheet:
Performance Curve of pump and other details provided by the suppliers

APPENDIX C

REFERENCE MATERIAL

DESIGN OF FILTER PACK FOR UNCONSOLIDATED FORMATIONS

To ensure the optimal efficiency of a borehole completed in unconsolidated sand aquifers which requires a filter pack as well as to avoid sand pumping during the life of the borehole, proper filter pack design methods should be followed. A common method is discussed below.

1. SAMPLE ANALYSIS

To properly design a filter pack and select the appropriate wire wrap screen size, samples of the aquifer formation must be collected. These may be collected during drilling or from archived samples from existing boreholes. It is desirable to have existing samples for analysis, as this allows the filter pack to be designed and ordered prior to drilling. Although regular sample collection during drilling is acceptable (Section **), it is recommended that a split spoon type sampler be utilised to ensure an accurate sample of the formations.

Samples are air dried and disaggregated so that only mineral grains were present. In some cases, some proportion of the coarser fraction constitutes cemented material (such as siltstone or sandstone) or some type of duricrust (such as calcrete, silcrete). In these cases, sieving of the complete sample can create a distorted plot indicating coarser grading than the true sample. As a result, the sample can be examined and these materials removed prior to sieving. However, even large quartz grains or gravels should not be removed.

The samples should then be sieved through a standard set of sieves. Generally the sieves have mesh openings ranging from 0.09 mm to 1.40 mm. The sieves are arranged with the finest mesh opening on the bottom and the largest on top. The sample is first weighed, then sieved (using a shaking motion or electric vibrator) and the material retained on each sieve weighed.

The data is then plotted both by sample and by borehole (consisting of a series of samples) on grain size distribution curves as cumulative percentage passed versus grain size (cumulative percentage retained is also sometimes used and is equivalent). A semi-logarithmic scale (the grain size on log scale) can be used to highlight the finer proportions of the samples if they are primarily characterised by fine and fine to medium sands (i.e. Kalahari Beds).

1. FILTER PACK/SCREEN SELECTION METHODS

The methods used in design of gravel envelope boreholes generally consists of assessing the nature of the aquifer sands, choosing a filter pack with a suitable grading relative to the aquifer and selecting a screen slot size that will retain at least 90 percent of the filter pack. Assessment of aquifer materials involves determining the finest grain size interval in the zone to be screened and the application of a multiplier to that grain size curve. The specific multiplier chosen is based on the typical sediment size of the complete section. Commonly a four and six times multiplier is used. The four and six multipliers are considered appropriate for uniformly graded materials with a 60 percent passing size less than 0.25 mm.

The next step is the choice of the specific filter pack. The available filter pack grain size curves are then plotted for comparison with chosen formation material analyses. An appropriate filter pack grain size distribution falls within the 4 and 6 times plots of the formation material and has a grading similar to the formation material.

Following selection of a filter pack, a screen slot size is then chosen to allow passing of not more than 10% of the filter pack. In the provided examples, the percent of filter pack that will be passed by the screen is found at the intersection of the filter pack grain size curve and a vertical line for the size of the screen slot size.

List of Contents – Appendix C

2. CALCULATION OF UNIFORMITY COEFFICIENT

The uniformity coefficient is defined as the 60% passed size of the sediment divided by the 10% passed size when using a plot of cumulative percentage passed versus grain size. When using a plot of cumulative percentage retained, the uniformity coefficient is defined as the 40% percent retained size of the sediment divided by the 90% retained size. Larger values represent less uniform grading.

EQUIPMENT AND METHODS OF TESTING FOR DRILLING FLUIDS

NATURAL / FRESH WATER BASED FLUIDS

1. DENSITY

Control of fluid density during drilling is crucial to successful borehole drilling and minimisation of damage to the aquifer formation.

1.1 EQUIPMENT

The equipment used to measure density is generally a simple balance scale. It is portable and can be easily set up on site. Density is measured in g/cm^3 or kg/m^3. A container of known volume is also required (generally one liter) to hold the drilling fluid.

1.2 PROCEDURE

The following procedure is used to measure fluid density:

1. Set up the balance so it is stable and level.
2. Measure the mass of the clean, dry and empty container.
3. Fill the cup accurately to the necessary level with a sample of the drilling fluid.
4. Clean the exterior of the container.
5. Measure the mass of the container and fluid.
6. Subtract the mass of the empty container.
7. Convert the density either g/cm^3 or kg/m^3 as required.
8. Wash the container immediately.

If a balance specifically for fluid densities is being used, no conversion is necessary and the fluid density in g/cm^3 or kg/m^3 is read directly from the scale.

2. VISCOSITY

Viscosity describes the "thickness" of the drilling mud. Drilling mud that is too thick will retain drill cuttings, if it is too thin it will not remove the cuttings fully.

2.1 EQUIPMENT

An approximate measure of viscosity is accomplished using a Marsh funnel. It is a simple device usually made of plastic but with a set dimensions and a small filtering strainer at the top.

2.2 PROCEDURE

The following procedure is used to test viscosity with a Marsh funnel:

1. Ensure the funnel is clean and that the outlet is not blocked in any way.
2. Cover the outlet with a finger and fill the funnel to the full mark with a sample of drilling fluid, pouring through the strainer to remove any drill cuttings.
3. Remove your finger and use a stop watch to determine the time required for the funnel to be emptied. This is the Marsh viscosity.

3. FILTRATION

Filtration measures the ability of a drilling mud to form a filter cake on the borehole wall to prevent fluid loss.

3.1 EQUIPMENT

Filtration (wall cake and filtration loss) is measured using a device known as a filter press.

3.2 PROCEDURE

The general procedure is to press a known quantity of drilling fluid and then to measure the thickness of filter cake produces as well as how much water is released. The filter press instructions or manual should be followed for the specific procedure.

4. SAND CONTENT

Sand content is a measure of the amount of sand (or fine drill cuttings) entrained in the drilling fluid. Maintaining a low sand content is important to ensure proper cuttings removal.

4.1 EQUIPMENT

Sand content is best measured using a standard sand-content measuring set (i.e. API standard).

4.2 PROCEDURE

The sand and fine suspended drill cuttings are removed from a sample of the drilling fluid. Generally the amount of material larger than a 200 mesh forms the basis of the measurement. The equipment instructions or manual should be followed for the specific procedure.

INSTALLATION OF GROUT

Grouting is the filling of the annular space between the borehole casing and the drilled hole with a suitable slurry of cement or clay. The ideal result is a uniform sheath of cement (or clay) around the casing for the entire vertical distance that is grouted.

1. MIXING GROUT

The volume of the annular space should be calculated and a preliminary estimate of the volume of grout necessary determined. There should always be sufficient materials on site for mixing of additional grout as the estimate may incorrect due to irregularities in the borehole wall (i.e. zones of caving). It is important that grout be mixed thoroughly and should not contain any lumps.

2. METHODS OF EMPLACEMENT FOR CEMENT BASED GROUT

2.1 SIMPLE POURING

The simplest method for installation of grout is to simply pour the grout mixture from the surface through the annular space. This method does not ensure that the grout reaches the specified depth or that voids are not present and is not recommended for motorised boreholes.

2.2 TREMIE METHOD

The best method in most situations is the use of a tremie pipe to inject the grout mixture into the annular space. Prior to grouting the casing should be well seated on the bottom of the borehole and it is recommended that the casing be filled with water or drilling fluid to avoid grout filling the casing. This will also avoid a buoyant effect (lifting the casing) as the grout surrounds the casing. Then a tremie pipe of suitable diameter is lowered in the annular space to a point just above the base of the borehole. The grout mixture can then be placed under the force of gravity or by pumping it (pumping is recommended). If the mixture is placed by gravity or if the hole is deep, the tremie pipe may need to be periodically lifted upward as grouting progresses. However, the bottom of the tremie pipe should always remain below the level of the grout. The depth to the top of the grout can be measured by a weighted line lowered in the annular space.

2.3 OTHER METHODS

There are also other effective methods for installation of grout using specific tools such as:

- Inner String Method. Useful if it is not possible to put a tremie pipe outside the casing. The method involves putting the tremie pipe inside the casing which has an attached to a float shoe at the bottom. The grout is pumped down the tremie pipe and flows upward along in the annular space. When grout appears at the surface, the process is complete. The tremie pipe is disconnected from the float shoe and the grout washed out before removing it from the borehole. The casing can then be flushed with water.
- Casing Method. This method involves injection of the grout through the casing using two drillable plugs (which fit snugly but can slide within the casing). The first plug is installed and then the casing capped. A measured volume of grout is injected through a fitting in the cap and the casing is opened. The second plug is installed and the borehole re-capped. A measured volume of water is then injected to force the second plug to the

bottom of the casing. The borehole remains closed (under pressure) until the grout has set. Then the borehole is opened and the plugs drilled out as drilling resumes.

3. INSTALLING BENTONITE GROUT

Granular or pelleted bentonite shall in no circumstances be simply poured into the annular space. The material quickly becomes sticky in the presence of water and will tend to bridge within a meter of the water level. The best method is to prepare a bentonite slurry which is then installed by means of a tremie pipe (see above).

VERTICALITY AND ALIGNMENT TEST CALCULATIONS

1. TESTING

Testing will be undertaken with the tools described in the main report and data collected in the specified manner.

2. DETERMINATION OF DRIFT

The drift (horizontal deviation) is calculated for each depth by the following equation:

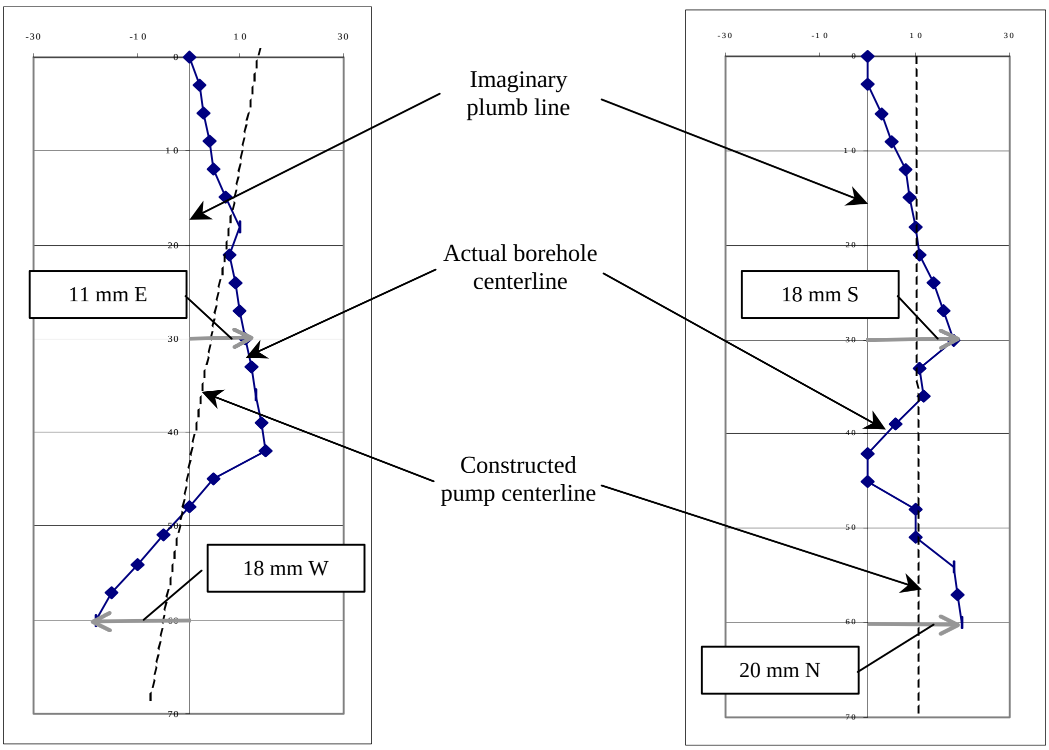
$$\text{Drift} = \frac{\text{Deflection (height + depth)}}{\text{height}}$$

with

drift = calculated horizontal deviation of casing or hole from vertical (mm)
deflection = measured horizontal deflection of the plumb line from the center of the top of casing or hole (mm)
height = height of the pulley above the casing or hole (m)
depth = depth of plumb weight below the top of casing or hole (m)

3. INTERPRETATION OF RESULTS

The deviation for each depth measured during the test should then be plotted on two cross sections at 90^{o} to each other (i.e. E-W and N-S). The plots should show deviation on the x-axis and depth on a central y-axis. An example is shown below.

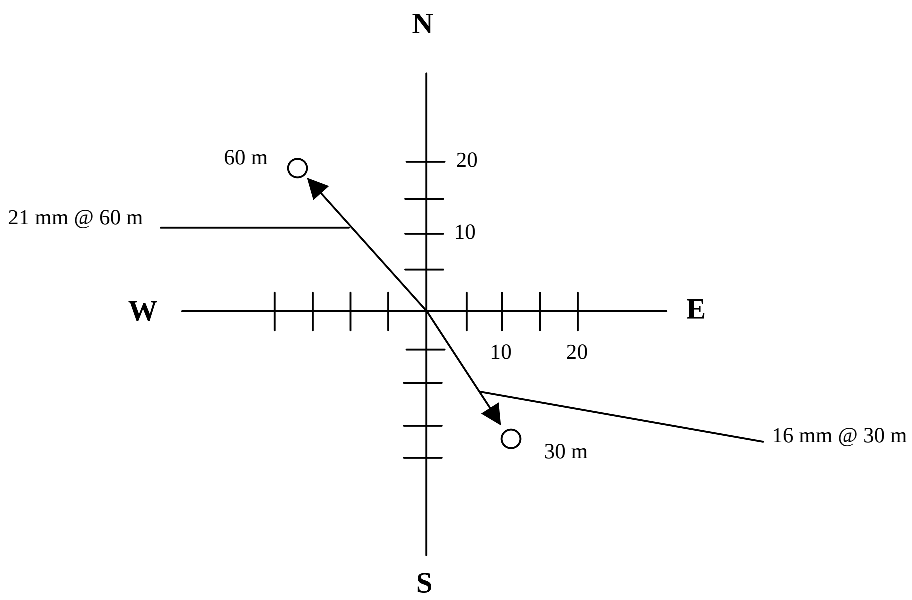


E-W Section

N-S Section

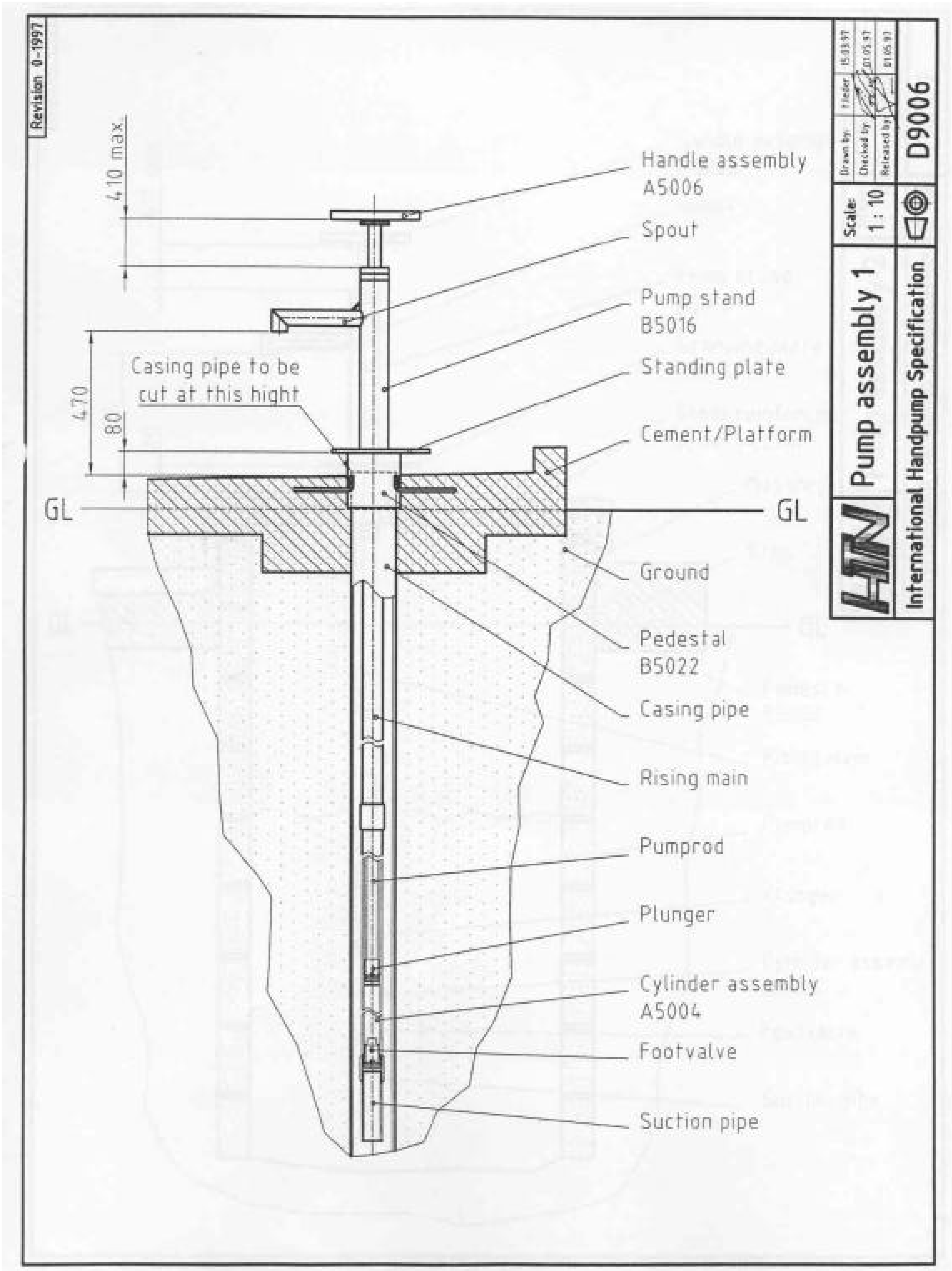
The plots show the deviation of the actual borehole center line from an imaginary exactly vertical (plumb) line at each depth. Additionally, straight lines can be constructed which represent the pump center line such that the distance from this line to any plotted point is minimised (see example). This is the optimum position and alignment of the pump and rising main in both planes.

The next step is to plot the deviations (in both planes) at depths were deviation is greatest (standard requires not more than 2/3 of the smallest inside diameter of the section of the borehole being tested per 30 meters of depth) on a circular plot. These points are indicated in the above plots (grey arrows) and the data is plotted on the alignment plot below.The data chosen to plot on this graph will be from places were the deviation from plumb is most significant.



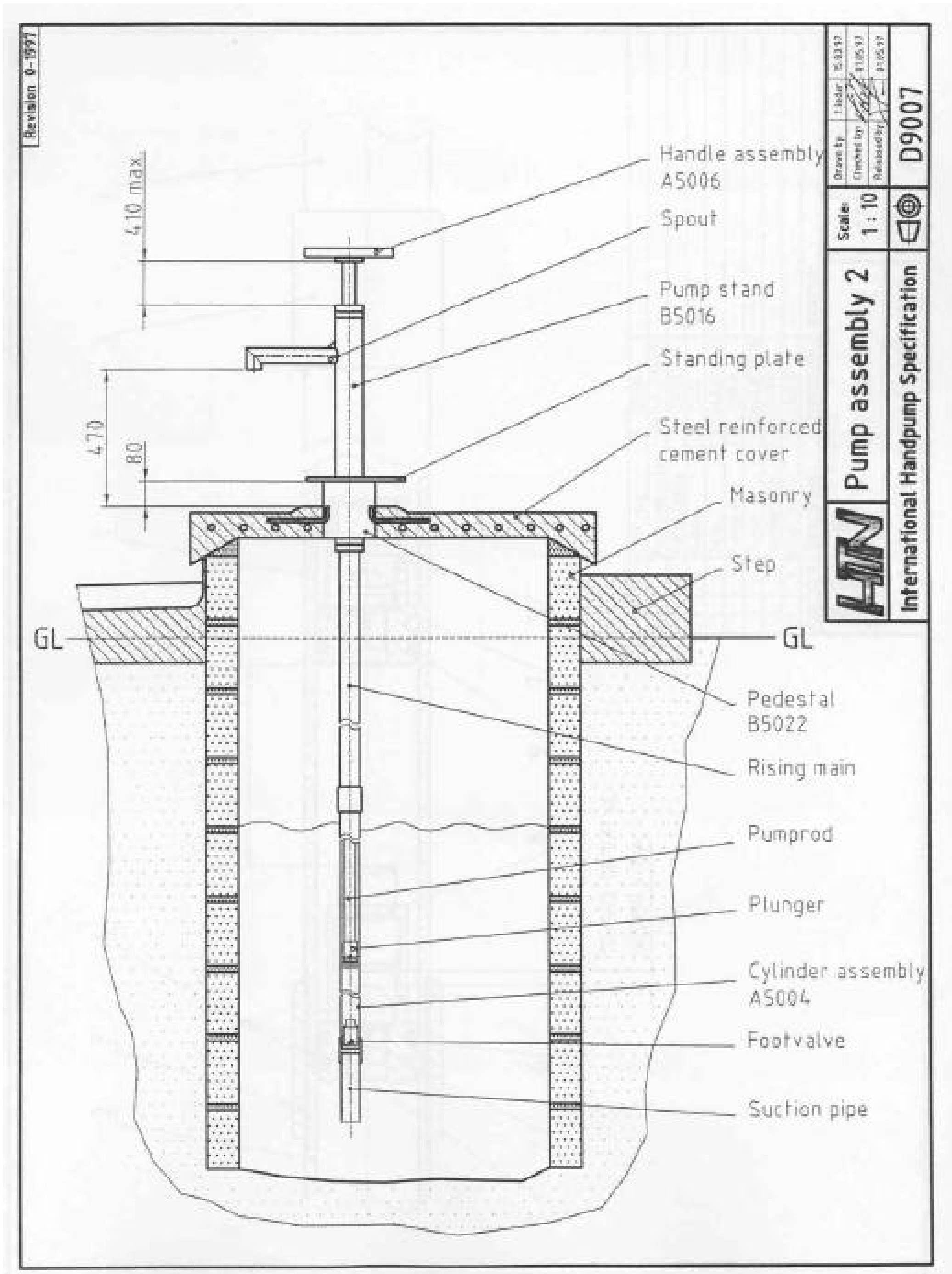
Assuming the example borehole above was cased with 165 mm casing, then the maximum allowable deviation would be 110 mm at 30 m and 220 mm at 60 m. Therefore this borehole has an acceptable plumbness.

SKAT Design for Shallow Handpump-1



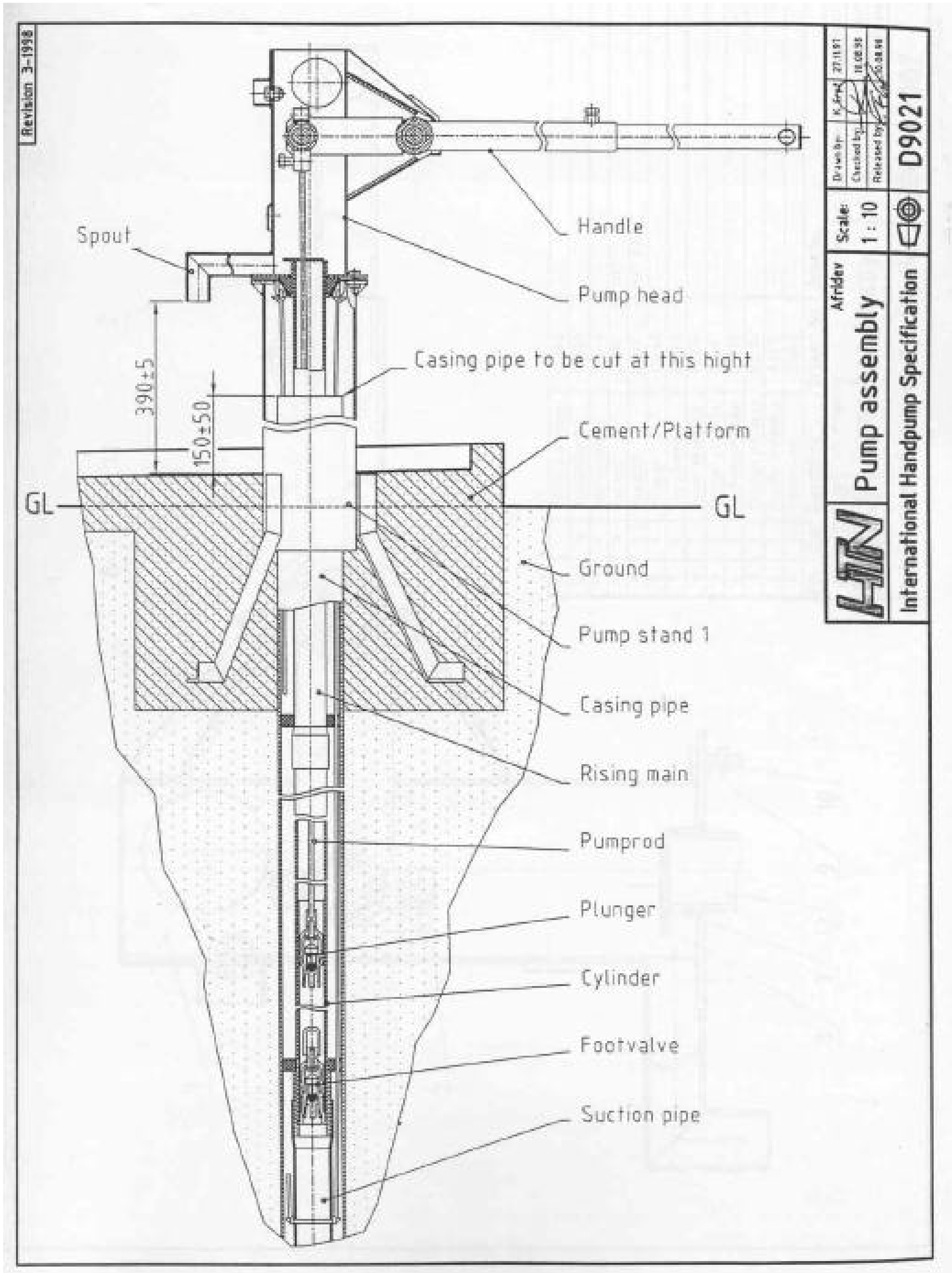
Source: Malda Handpump Specifications, Revision 0-1997
For more details: SKAT, Vandianstrasse 42, CH-9000 St. Gallen, Switzerland, tel +41 712285454

SKAT Design for Shallow Handpump-2



Source: Malda Handpump Specifications, Revision 0-1997
For more details: SKAT, Vandianstrasse 42, CH-9000 St. Gallen, Switzerland, tel +41 712285454

SKAT Design for Deep Handpump
(Afridev)

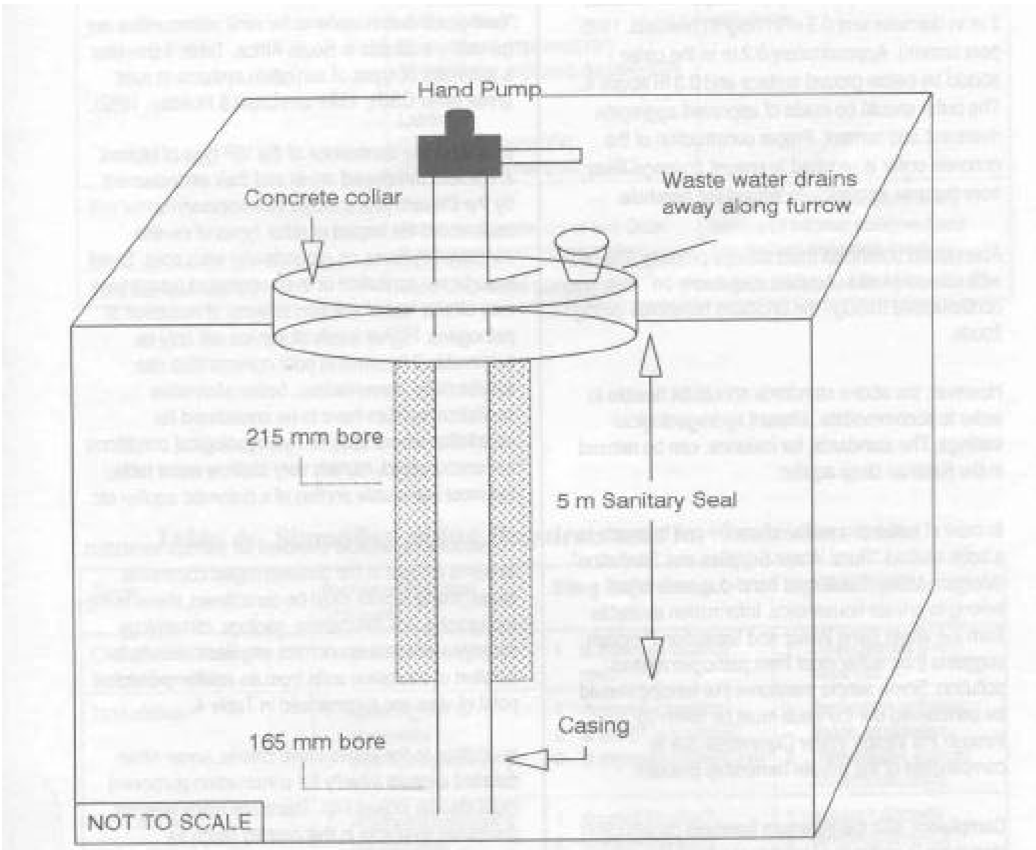


Source: Afridev Handpump Specifications, Revision 3-1998
For more details: SKAT, Vandianstrasse 42, CH-9000 St. Gallen, Switzerland, tel +41 712285454

Design of Sanitary Sealing

Source : Xu, Y, Braune, E,; 1995; A Guide for Groundwater Protection for the Community Water Supply and Sanitation Programme; DWAF; ISBN 0-621-16787-8, Republic of South Africa.

Available From : Department of Water Affairs, Pretoria, Republic of South Africa



SKETCH OF SANITARY STANDARDS FOR BOREHOLE CONSTRUCTION

FLOW RATE – 90° 'V' NOTCH WEIR

Height over Weir (mm)	Flow Rate m^3/h	Height over Weir (mm)	Flow Rate m^3/h	Height over Weir (mm)	Flow Rate m^3/h	Height over Weir (mm)	Flow Rate m^3/h	Height over Weir (mm)	Flow Rate m^3/h	Height over Weir (mm)	Flow Rate m^3/h	Height over Weir (mm)	Flow Rate m^3/h
10	0,054	48	2,581	86	10,980	124	27,180	162	52,74	200	88,920	238	136,800
12	0,0828	50	2,696	88	11,592	126	28,260	164	54,36	202	91,080	240	139,680
14	0,1224	52	3,150	90	12,276	128	29,412	166	56,016	204	93,240	242	142,560
16	0,169	54	3,456	92	12,960	130	30,564	168	57,708	206	95,760	244	145,440
18	0,227	56	3,780	94	13,68	132	32,716	170	59,436	208	97,920	246	148,680
20	0,295	58	4,14	96	14,400	134	32,94	172	61,200	210	100,440	248	151,560
22	0,374	60	4,500	98	15,156	136	34,164	174	62,964	212	102,600	250	154,800
24	0,464	62	4,860	100	15,948	138	35,424	176	64,764	214	105,120	252	157,680
26	0,565	64	5,256	102	16,740	140	36,720	178	66,600	216	107,640	254	160,920
28	0,677	66	5,688	104	17,568	142	38,016	180	68,472	218	110,160	256	164,160
30	0,806	68	6,120	106	18,432	144	39,384	182	70,38	220	112,680	258	167,040
32	0,943	70	6,588	108	19,296	146	40,752	184	72,324	222	115,200	260	170,280
34	1,098	72	7,056	110	20,196	148	42,156	186	74,268	224	117,720	262	173,880
36	1,264	74	7,560	112	21,096	150	43,920	188	76,284	226	120,240	264	177,120
38	1,447	76	8,064	114	22,068	152	45,036	190	78,300	228	123,120	266	180,360
40	1,642	78	8,604	116	23,040	154	46,512	192	80,352	230	125,640	268	183,600
42	1,854	80	9,180	118	24,012	156	48,024	194	81,360	232	128,520	270	187,200
44	2,081	82	9,756	120	25,056	158	49,572	196	84,564	234	131,400	272	190,800
46	2,322	84	10,332	122	26,100	160	51,120	198	86,724	236	133,920	274	194,040

BARNES FORMULA $Q\ (l/s) = 1337\ H^{2,48}$

INTERNATIONAL DRINKING WATER QUALITY STANDARDS
(with special reference to groundwater sources)

Parameter	Unit	EU Directive 98/83/EC	W.H.O. Guidelines, 1986[1]	R.S.A. SABS 1984 (Max.)	R.S.A. SABS 1984 (Rec.)[2]
Colour	mg/l Pt-Co	Subjective criteria	15	-	20
Turbidity	N.T.U.	1	5	5	1
Taste		Subjective criteria	-	-	-
Odour	T.O.N.	Subjective criteria	5	-	-
pH	$-\log[H^+]$	6.5 - 9.5	6.5 - 8.5	5.5 - 9.5	6.0 - 9.0
Chloride, Cl	mg/l	250	250	600	250
Sulphate, SO_4	mg/l	250	250	600	200
Sodium, Na	mg/l	200	200	400	100
Aluminium, Al	mg/l	0.2	0.2	-	0.15
Hardness, Total	mg/l	-	-	650	-
Solids, Total Dissolved TDS	mg/l	-	1,000	-	450
Conductivity (at 20°C)	µs/cm	2,500	-	3,000	700
Oxygen, dissolved	% saturation	75% min.[5]	-	-	-
CO_2, free	mg/l	-	-	-	-
Oxydisability, test by $KMnO_4$	mg/l as O_2	5	-	-	-
Nitrate, NO_3	mg/l	50	50	44	27
Nitrite, NO_2	mg/l	0.5	0.91	-	-
Ammonium, NH_4	mg/l	0.5	1.5	-	-
Hydrogen Sulphide, H_2S	µg/l		0.05	-	-
Benzene	µg/l	1	-	-	-
Pesticides, total	µg/l	0.5	-	-	-
Policyclic Aromatic Hydrocarbons	µg/l	0.1	-	-	-
Boron, B	µg/l	1,000	300	-	-
Iron, Fe	µg/l	200	300	1,000	100
Manganese, Mn	µg/l	50	500	1,000	50
Copper, Cu	µg/l	2,000	2,000	1,000	500
Zinc, Zn	µg/l		3,000	5,000	1,000
Fluoride, F	µg/l	1,500	1,500	1,500	1,000
Antimony, Sb	µg/l	5	5		
Arsenic, As	µg/l	10	10	300	100
Barium, B	µg/l		700		
Cadmium, Cd	µg/l	5	3	20	10
Chromium, Cr	µg/l	50	50		
Cyanide, CN	µg/l	50	70	300	200
Lead, Pb	µg/l	10	10	100	50
Mercury, Hg	µg/l	1	1	10	5
Nickel, Ni	µg/l	20			
Selenium, Se	µg/l	10	10	50	20
Total Coliforms[3]	MPN/100 ml	0	0[4]	5	0
Faecal Coliforms[3]	MPN/100 ml	0	0	0	0

Notes:

1. Recommended maximum allowable value for parameter (W.H.O. Guidelines for Developing Countries)
2. Parameter values supplemented by values from DWAF Guidelines (RSA) where not available in SABS 1984
3. After disinfection (as measured in distribution system). Please consult WHO Guidelines for classification of Raw Water quality
4. Not less than 95% of distribution samples to be clear on a monthly basis
5. Does not apply to groundwater. Groundwater should be aerated before use.

EXISTING INSTITUTES WITHIN THE SADC REGION PROVIDING DEGREES IN HYDROGEOLOGY

1. Institute of Groundwater Studies (IGS) associated with University of Free State in Bloemfontein – Post-graduate degree in Hydrogeology

2. Rhodes University (South Africa)- Graduate courses in Hydrogeology

3. Witwatersrand (South Africa)- Graduate courses in Hydrogeology

4. Pretoria Technicon (South Africa)- 3-year course in Geotechnologies mostly oriented towards mining, but with some focus on groundwater aspects in the third. A fourth year has been added as an advanced course in Geotechnology.

5. University of Venda (South Africa)- A course is being established on Hydrogeology

6. University of Western Cape (South Africa)- Degree level course is under development supported by UNESCO funding, on community based Geohydrology, with basic idea of linking social and technical aspects.

7. University of Botswana - Course in Hydrogeology as part of geology degree. Master programme in Hydrogeology to begin in2001. Short courses are presented regularly through the University.

8. University of Dar-es-Salam (Tanzania) - Course in Hydrogeology as part of geology degree; Post graduate degree in Water Resource Engineering and; Environmental Engineering with significant hydrogeology component

9. University Eduardo Mondlane (Mozambique); Department of Geology: 64-hour subject on Hydrogeology; Civil Engineering Department: 96-hour subject on Hydrogeology, with some emphasis on Mathematical aspects of goundwater movement

10. Agostinho Neto University (Angola); Department of Geology (DG): 5 year course in Geology, 0.5 years optional, one of the courses being Applied Geology, including Geophysical Methods, Hydrochemistry, Advanced Computation, Water Resources Management, Surface Hydrology, and Field Work

11. University of Zimbabwe - The Geology degree includes Hydrogeology courses and Honors students may purse Hydrogeology topics for their researches; The Civil Engineering Department offers an M.Sc Programme with a Hydrogeology component.

EXISTING TRAINING FOR TECHNICIANS

Rwegarulila Water Resources Institutes (RWRI) in Tanzania; Curriculum covers wide spectrum of groundwater related topics, including Geology, Grilling and Horehole Construction Technology, Hydrogeology Groundwater Modelling, Geophysics Shallow Wells Technology, Pump/Lifting Devices, Water Analysis and Computer Sciences.

ON THE JOB AND SHORT COURSES TRAINING PROGRAMME

- Groundwater divisions in Governments,
- Private sector: important role in particular to provide on-the-job training for own personnel (mainly at technician level) and for counterparts in major projects supervised government,
- Drilling Contractors Association of South Africa has a 3 year training manual to cover various drilling activities,
- REGIDESO (DRC) has two training centres, one in Kinshasa, and one in Lubumbash.i. Teaching modules for groundwater development procedures, methods and techniques are used in training,
- Groundwater Association of Botswana,
- Groundwater division of the geological Society of South Africa (Courses and confertences)

LIST OF USEFUL SOFTWARE

Software Name	***Purpose***	***Available From***	***Author***	***WebSite***
Processing Modflow for Windows (Ver 5.1)	Integrated Graphical Simulation System for 3 D Modelling using MODFLOW, MT3D, MT3DMS, MOC3D, PMPATH 98	Institute for Groundwater Studies, P O Box 339, Bloemfontein 9300, South Africa	Wen-Hsing Chiang and Wolfgang Kinzelbach	www.uovs.ac.za/faculties/igs/software.htm
Visual Modflow	3 D modelling software	Waterloo Hydrogeologic, 180 Columbia Street West- Unit 1104, Waterloo, Ontario, Canada	-	www.flowpath.com
AQUAWIN and NETGEN	For 2 D finite element groundwater modelling	Institute for Groundwater Studies, P O Box 339, Bloemfontein 9300, South Africa	G van Tonder and Eelco Lukas	www.uovs.ac.za/faculties/igs/software.htm
Recharge Estimate	An MS Excel code for groundwater recharge estimate	Institute for Groundwater Studies, P O Box 339, Bloemfontein 9300, South Africa	G van Tonder and Yongxin Xu	www.uovs.ac.za/faculties/igs/software.htm
FC-Method	An MS Excel code for calculation for sustainable yield of borehole.	Institute for Groundwater Studies, P O Box 339, Bloemfontein 9300, South Africa	G van Tonder	www.uovs.ac.za/faculties/igs/software.htm
WISH	GUI for hydrogeologists to draw maps, access data sets and perform various analysis.	Institute for Groundwater Studies, P O Box 339, Bloemfontein 9300, South Africa	Eelco Lukas and Frank Hodgson	www.uovs.ac.za/faculties/igs/software.htm

AQTESOLV	Pump test analysis	Hydrosolve Inc., 2303 Horseferryu Court, Reston, VA, USA	-	www.aqtesolv.com
StepMaster	Analysis of Step Drawdown pump test data	The Scientific Software Group, P O Box 23041, Washington, USA	-	www.scisoftware.com
Step Test v2	Analysis of Step Drawdown pump test data	Groundwater Consultants, P O Box 7885, Maseru 100 Lesotho	S K Pandey	www.ilesotho.com/mpandey/step
PLOTCHEM	Water quality data plotting software	The Scientific Software Group, P O Box 23041, Washington, USA	-	www.scisoftware.com
QuickLog/QuickCross/ QuickFence	Plotting of borehole logs, cross sections and fence diagrams	The Scientific Software Group, P O Box 23041, Washington, USA	-	www.scisoftware.com

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