Policy, Legal and Institutional Development for Groundwater Management in the SADC Member States (GMI-PLI)

Guidance Document: Operation and Maintenance of Groundwater Schemes

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GROUNDWATER MANAGEMENT INSTITUTE

This report emanates from the project Policy, Legal and Institutional Development for Groundwater Management in the SADC Member States (GMI-PLI) commissioned by the Southern African Development Community Groundwater Management Institute (SADC-GMI), and executed by Pegasys.

SADC GROUNDWATER MANAGEMENT INSTITUTE (SADC-GMI)

Dean Street, University of the Free State
205 Nelson Mandela Drive,
Bloemfontein, 9300

South Africa

E-mail info@sadc-gmi.org   Website www.sadc-gmi.org

Project team:

Derek Weston (Project Lead), Pegasys

Traci Reddy (Project Manager), Pegasys

Kevin Pietersen (Groundwater Management Expert), Pegasys

Deepti Maharaj (Project Coordinator), Pegasys

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FOREWORD

The Southern African Development Community (SADC) Member States, through the support of International Cooperating Partners have gone through a series of Water Sector Reforms which varied in terms of policy, legal and institutional development. The focus of the water sector reforms has been on Integrated Water Resources Management and aimed at achieving sustainable and equitable distribution of water resources in the respective Member States. To a large extent, the water sector reforms did not comprehensively address the sustainable management of groundwater resources, yet 70% of the population in the SADC region depend on it. Climate change continues to negatively affect the availability of surface water, placing significance reliance on the use of groundwater for both urban and rural supply throughout the region. Human wellbeing, livelihoods, food security, ecosystems, natural habitats, industries and urban centres growth throughout the SADC Region are increasingly becoming more reliant on groundwater. The SADC region in general has an abundance of groundwater resources. However, due to several factors which include the lack of an enabling policy, legal and institutional environment, only an estimated 1.5% of the available renewable groundwater resources are currently being utilised.

It is estimated that there are about 30 Transboundary Aquifers (TBAs) and 15 transboundary river systems and that these systems are central to the water security of the region. There is therefore a need for Members States to establish and strengthen existing policy, legal and institutional frameworks to achieve equitable and sustainable access to water resources through joint management of the transboundary resources. It is in view of the above and in response to the need to strengthen the sustainable use of groundwater resources conjunctively with surface water at both the national and regional level, that the Southern African Development Community – Groundwater Management Institute (SADC-GMI) was established by the SADC Secretariat, on behalf of the Member States.

The vision of the SADC-GMI is, "to be a Centre of Excellence in promoting equitable and sustainable groundwater management in the SADC region". The key focus areas of SADC-GMI are to 1)advocate, raise awareness and provide technical support in SADC around sustainable management through the dissemination of information and knowledge; 2) create an enabling environment for groundwater management through policy, legal and regulatory frameworks; 3) promote action-oriented research; 4) promote impact-oriented capacity building and training for groundwater management in the region; 5) lead and promote regional coordination for groundwater management; and 6) support infrastructure development for groundwater management.

In pursuance of the focus area of creating an enabling environment, SADC-GMI implemented the project entitled “Policy, Legal and Institutional Development for Groundwater Management in the SADC Member States, (GMI-PLI)”. The methodology for said project included the development of the Desired Future State, conducting a baseline study of best practices, and description of policy, legal and institutional frameworks which promote sustainable groundwater management. Using an in-Country Experts model, a systematic analysis of the existing policy, legal and Institutional frameworks in comparison with the Desired Future State was conducted to identify gaps that required to be addressed in order to fulfil the SADC-GMI mandate – to achieve sustainable groundwater management in all 16 SADC Member States. The analytical assessment of the gaps identified at national level culminated in the production of 16 National Gap Analysis & Action Plan Reports and the higher-level Regional Gap Analysis Report. The latter summarises the findings across the SADC region.

This guidance document focuses on the key technical and institutional aspects of O&M of groundwater infrastructure crucial for groundwater sustainability and documents best practices. The document also elaborates on monitoring and reporting requirements. It is hoped that this Guidance Document will aid the SADC Member States by developing or strengthening their own O&M guidelines based on this guidance document and ultimately advance the groundwater narrative and bring it at par with surface water in terms of policy, legal and institutional frameworks which will no doubt enhance sustainable groundwater management at a national and regional level in the SADC Region.

James Sauramba

Executive Director

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SADC – Ground Water Management Institute

Mr James Sauramba	Executive Director
Ms Nyakallo Khoabane	Administration and Finance Assistance
Mr Brighton Munyai	Technical Advisor
Mr Micah Majiwa	Governance and Institutional Consultant
Ms Mampho Ntsekhe	Grant Officer
Mr Thokozani Dlamini	Communications and Knowledge Management Specialist

Project Team

Mr Derek Weston	Project Lead and Institutional Expert
Ms Traci Reddy	Project Manager
Ms Deepti Maharaj	Project Coordinator
Ms Barbara Schreiner	Policy Expert
Dr Amy Sullivan	Knowledge Management Expert
Ms Jessica Troell	Legal Expert
Dr Kevin Pietersen	Groundwater Management Expert
Dr Pinnie Sithole	Cluster Lead
Ms Susan Byakika	Cluster Lead
Ms Pretty Ntuli	Project Administrator

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An Expert Working Group contributed to the finalisation of the guidance document: Eng Kondwani Andreah, Dr Hans Beekman, Eng Kasonde Mulenga, Eng Phillip Ravenscroft and Sam Sunguro.

DOCUMENT INDEX

Presented in the table below is a list of products developed during the GMI-PLI Project:

Phase	Document	Report No.
Country Reports	Gap Analysis and Action Plan – Scoping Report: Angola	1.1
	Gap Analysis and Action Plan – Scoping Report: Botswana	1.2
	Gap Analysis and Action Plan – Scoping Report: Democratic Republic of Congo	1.3
	Gap Analysis and Action Plan – Scoping Report: Kingdom of Eswatini	1.4
	Gap Analysis and Action Plan – Scoping Report: Lesotho	1.5
	Gap Analysis and Action Plan – Scoping Report: Madagascar	1.6
	Gap Analysis and Action Plan – Scoping Report: Malawi	1.7
	Gap Analysis and Action Plan – Scoping Report: Mauritius	1.8
	Gap Analysis and Action Plan – Scoping Report: Mozambique	1.9
	Gap Analysis and Action Plan – Scoping Report: Namibia	1.10
	Gap Analysis and Action Plan – Scoping Report: Seychelles	1.11
	Gap Analysis and Action Plan – Scoping Report: South Africa	1.12
	Gap Analysis and Action Plan – Scoping Report: Tanzania	1.13
	Gap Analysis and Action Plan – Scoping Report: Zambia	1.14
	Gap Analysis and Action Plan – Scoping Report: Zimbabwe	1.15
	Gap Analysis and Action Plan – Scoping Report: Comoros	1.16
	Tanzania GW-PLI Roadmap	1.17
	Eswatini GW-PLI Roadmap	1.18
Regional Reports	Regional Gap Analysis and Action Plan	2
Groundwater Management Guidance Documents	Development of a Groundwater Policy, Legal and Institutional Roadmap	3.1
	Operation and Maintenance of Groundwater Schemes	**3.2**
	Building Groundwater Resilience	3.3.
	Institutionalisation of Groundwater Management	3.4
	Strategic Approach to Financing Groundwater Management	3.5

EXECUTIVE SUMMARY

Failure of groundwater schemes – Poor operation and maintenance is a bigger problem than limitations of the resource

The failure of groundwater supply schemes in the Southern African Development Community (SADC) is often attributed to the failure of the resource rather than the failure of the water infrastructure. Poor operation and maintenance (O&M), however, is the key factor in failure of groundwater infrastructure. Non-functional groundwater supply schemes jeopardize the Sustainable Development Goal (SDG) of clean water for all (SDG 6). In this context, the SADC Groundwater Management Institute (SADC-GMI) developed this guidance document for groundwater managers to understand, mainstream and implement measures related to the O&M of groundwater schemes for domestic water use. The wide range of technologies adopted and different institutional arrangements in Member States mean that guidance cannot be location and technology specific.

This guidance document focuses on the key technical and institutional aspects of O&M of groundwater infrastructure crucial for groundwater sustainability and documents best practices. The document also elaborates on monitoring and reporting requirements.

Groundwater infrastructure operation and maintenance

In rural areas, a groundwater infrastructure system ranges from a handpump equipped borehole to more complex schemes consisting of a borehole, pump, disinfection system, a distribution system and storage. In urban areas the groundwater infrastructure may consist of wellfields, water treatment systems, a reticulation system, storage infrastructure and in some cases provisions for a managed aquifer recharge scheme. Compared to rural areas, urban areas need a more advanced organization to operate and maintain the complex water infrastructure which requires capable local institutions and water governance arrangements.

Operation and maintenance (preventative and breakdown) tasks which need to be carried out to keep a groundwater source or well-field functional are described such as servicing, repairs, replacement of parts, complying with pump duty cycles or maximum yields, testing, and so on.

Institutional Requirements

The effectiveness of O&M is determined to a large extent by non-technical issues. Critical institutional requirements for O&M include provision for recurrent costs, institutionalising O&M, developing human capacity and stakeholder involvement. The institutional design needs to consider the organization of O&M and roles and responsibilities. Recurrent budgets for O&M are highly vulnerable to appropriation for emergency purposes, or for filling short-term financing gaps. Involvement of stakeholders ensures proper use of facilities, minimizes vandalism and routine non-complex repairs and maintenance.

Monitoring and reporting

Monitoring and reporting should be part of a system that includes all aspects of a water resources monitoring and water supply scheme's operation and maintenance. The monitoring should not only focus on groundwater parameters but also on the infrastructure to ensure proper functioning.

CONTENTS

FOREWORD i
ACKNOWLEDGEMENTS iv
DOCUMENT INDEX vi
EXECUTIVE SUMMARY vii
CONTENTS ix
LIST OF FIGURES xi
LIST OF TABLES xi
LIST OF BOXES xi
LIST OF ACRONYMS xii
1. INTRODUCTION 1
1.1. Groundwater and groundwater schemes 2
1.2. Operation and maintenance 3
1.3. Structure of the guidance document 5
2. GROUNDWATER INFRASTRUCTURE OPERATION AND MAINTENANCE 8
2.1. Guidelines for O&M 9
2.1.1. Components of groundwater infrastructure 9
2.1.2. Preventative maintenance 15
2.1.3. Breakdown maintenance 16
3. INSTITUTIONAL REQUIREMENTS 19
3.1. Provision for recurrent costs 19
3.2. Institutionalising O&M 23
3.3. Human capacity 25
3.4. Stakeholder involvement 27
4. MONITORING AND REPORTING 30
4.1. Groundwater parameters 30
4.1.1. Water levels 30
4.1.2. Abstractions 33
4.1.3. Water quality 33

4.2. Infrastructure deterioration 35
4.2.1. Boreholes 35
4.2.2. Pumps 36
4.2.3. Water meter and water sampling point 36
4.3. Reporting and auditing 36
5. CONCLUSION AND RECOMMENDATIONS 41
6. REFERENCES 42

LIST OF FIGURES

Figure 1: (a) Groundwater infrastructure in need of maintenance (b) vandalism of borehole............. 1
Figure 2: Root causes of O&M Issues.. 5
Figure 3: Basic components of groundwater infrastructure.. 9
Figure 4: Hardrock borehole design: (a) plain casing/open hole; (b) slotted casing 10
Figure 5: Borehole design unconsolidated formation – screened and filter packed........................... 11
Figure 6: Measuring the costs of groundwater use 20
Figure 7: From ineffective to effective O&M of water infrastructure 20
Figure 8: FundiFix financing model 23

LIST OF TABLES

Table 1: Key factors for improved efficiency of groundwater infrastructure maintenance.................. 4
Table 2: Structure of the O&M guidance document 7
Table 3: Commonly used pumps and energy sources 13
Table 4: Trouble shooting guide 17
Table 5: Roles and responsibilities of various actors in supporting the community 23
Table 6: Job descriptions for staff tasked with groundwater project O&M 25
Table 7: Analytical requirements and frequency 33
Table 8: Common contaminants found in groundwater 34
Table 9: Sanitary inspection checklist 35
Table 10: Sample monitoring form for a manually operated pump.. 37
Table 11: Sample monitoring form for an automatically operated pump... 37
Table 12: Drinking water standards 38

LIST OF BOXES

Box 1: Operation and maintenance 2
Box 2: Piezometer tube for water level monitoring 12
Box 3: Water meter for measuring abstraction 15
Box 4: Sample tap for water quality sampling 15
Box 5: Community empowered O&M of water points in Diti communal land, Zimbabwe................. 29
Box 6: Recommended specifications for manual water level measuring instruments 30
Box 7: Groundwater monitoring of the Nyamandlovu Aquifer 32

LIST OF ACRONYMS

Acronym	Definition
DRC	Democratic Republic of Congo
EC	Electrical Conductivity
GIS	Geographic Information System
HDPe	High-Density Polyethylene
LDPe	Low-Density Polyethylene
NORAD	Norwegian Agency for Development Co-Operation
mm	Millimetres
Mm^3/a	Million Cubic Metres per Annum
O&M	Operation and Maintenance
RCWMP	Rural Community Water Management Plan
SADC	Southern African Development Community
SADC-GMI	Southern African Development Community – Groundwater Management Institute
SANS	South African National Standards
SDG	Sustainable Development Goal
WHO	World Health Organisation

1. INTRODUCTION

The failure of groundwater supply schemes in the Southern African Development Community (SADC) is often blamed on the resource rather than on the failure of infrastructure associated with poor operation and maintenance (O&M).

The above argument was shown to be incorrect as Cobbing et al. (2015) found that O&M of groundwater infrastructure is more important to groundwater scheme sustainability than primary or "physical" groundwater availability in several municipalities in South Africa. Similarly, in Lesotho, poor O&M resulted in extensive failure of water supply systems, especially as most of the infrastructure outlived its economic life of 25 years and was overused and damaged, and the O&M systems that might remedy this are absent (Pegasys 2019). In Malawi, a survey in 2016 on boreholes equipped with hand pumps indicated that only 74% of boreholes were functional at any one point in time (Mkandawire et al. 2018). Work by Chowns (2015) in Malawi revealed that community management models for rural groundwater supply schemes do not deliver the necessary maintenance, and that more professional approaches may be required. In summary, together with vandalism and inadequate capacity, the lack of O&M are key challenges affecting groundwater infrastructure in most SADC countries (Figure 1; Pegasys 2019).

Figure 1: (a) Groundwater infrastructure in need of maintenance (b) vandalism of borehole

The undesirable consequences resulting from poor O&M are:

- Intermittent water supplies due to wastage and depletion
- Poor water quality due to inadequate treatment and contamination
- Deterioration of pipes, equipment, and service
- Increased cost of maintenance

These lead to:

- Frequent breakdowns/extended down times
- Shortened life of infrastructure
- Prevalence of water borne diseases due to use of unprotected and unsafe water sources
- School dropouts particularly for the girl child
- Abandonment of schemes and water facilities

Taking the above into account, the Southern African Development Community Groundwater Management Institute (SADC-GMI) developed this guidance document for groundwater managers to understand, mainstream and implement measures related to the O&M of groundwater schemes for domestic water use (Box 1). Knowledge of O&M requirements by groundwater managers will facilitate proper operation of groundwater schemes. The wide range of technologies adopted and different institutional arrangements in Member States means that guidance cannot be location and technology specific but rather focus on the O&M issues crucial for groundwater sustainability and document best practices.

Box 1: Operation and maintenance (World Bank 2012; Government of India 2013; Dillon 2019)

The objective of an efficient operation and maintenance of a water supply system is to provide safe drinking water as per designed quality and quantity, with adequate pressure at a convenient location and time with a competitive cost on a sustainable basis.

Operation refers to timely and daily operation of the components of a water supply system such as pumping, treatment, transmission and distribution of drinking water.

Maintenance is defined as the act of keeping the structures, plants, machinery and equipment and other facilities in an optimum working order. Maintenance includes preventative /routine maintenance and also breakdown maintenance for instance painting of steel reservoirs, and repair of leaking pipes and worn out pumps. Corrective maintenance is replacing or repairing something that was done incorrectly or needs to be changed; an example is the reallocation of a pipe route or replacement of a faulty pump

1.1. Groundwater and groundwater schemes

As stated above, some operation and maintenance issues are location-specific, but urban and rural projects differ fundamentally in the complexity of the technologies involved (Dillon 2019). Basic rural groundwater supply schemes consist of single point systems with a dug well, spring or borehole equipped with a hand pump, e.g. Afridev Pump. In some settings the boreholes may form part of a water treatment and distribution system. Most rural communities in SADC are dependent on groundwater resources. About 60% of the Mozambican population which is mostly rural, relies on groundwater resources (Pavelic et al. 2012). Similarly, a significant number of rural communities in Angola are dependent on groundwater resources with groundwater being the main source of drinking water outside the larger towns. The same applies to Zambia (Pavelic et al. 2012). In the Democratic Republic of Congo (DRC), more than 90% of the rural population relies on groundwater resources (Partow 2011). Rural Botswana and Namibia is even more reliant on groundwater resources due to the scarcity of surface water (Krugman and Alberts 2012; Republic of Botswana 2016). In Malawi the groundwater in basement and alluvial aquifers serves about 60% of Malawian population (Mapoma and Xie 2014).

Urban groundwater supply is mostly from wellfields (multiple boreholes). The City of Tshwane in South Africa obtains a significant portion of its water supply from boreholes and springs, which is blended with surface water within the bulk water distribution system (Dippenaar 2013). Lusaka, the capital of Zambia, obtains about 60% of its water requirement from groundwater resources (Nussbaumer et al. 2016). Current abstraction of groundwater in Lusaka is estimated at 90 million cubic metres per annum (Mm^3/annum) (Bäumle and Kang'omba 2013). Dodoma, the capital city of the Tanzania, mainly depends on groundwater (Elisante and Muzuka 2017). Many urbanites, e.g. for Bulawayo, Harare and Lusaka, are now relying on private boreholes for their domestic requirements due to the failure by the municipalities to supply water as result of inadequate O&M of water infrastructure.

1.2. Operation and maintenance

Table 2 lists a number of key factors that have been identified in the area of groundwater infrastructure maintenance for improved efficiency.

Table 1: Key factors for improved efficiency of groundwater infrastructure maintenance ((after Foster et al. 2000)

Factors	Remarks/Consequences
Technical	
Quality of design, construction and commissioning	• increases reliability of supply • reduces need for major maintenance and rehabilitation
Complexity of boreholes and pumps	• increases need for personnel training • reduces opportunity for local maintenance and spares manufacture
Accessibility of area and wellheads	• complicates logistics of energy supply, spares etc. • constraints on vehicle access
Institutional requirements	
Ownership and responsibility	• accountability needs to be clearly established • Strong local government • community or user ownership preferred
Operational supervision and organisational aspects	• ensure systematic monitoring and diagnosis • procedures for supply of basic spares critical • incentives for operational performance
Personnel training	• essential, especially for water users • encourages user participation • resolves cultural barrier

Non-functional groundwater supply schemes jeopardize the Sustainable Development Goal (SDG) of clean water for all (SDG 6). There is a need for SDG investment planning to move from concentrating on covering targets to focusing on quality infrastructure and proactive monitoring to reduce the future burden placed on communities (Truslove et al. 2019). To achieve SDG 6, considerable financial resources are required for expanding and modernizing groundwater infrastructure and O&M (World Bank 2018). Compared with the resources available for determining primary groundwater availability such as hydrogeological maps, there are very few resources for institutionalising O&M procedures, and few guidelines for the O&M tasks themselves (Cobbing et al. 2015).

WEF (2014) identifies 3 broad causes of shortage of high-quality and sustainable O&M (Figure 2)

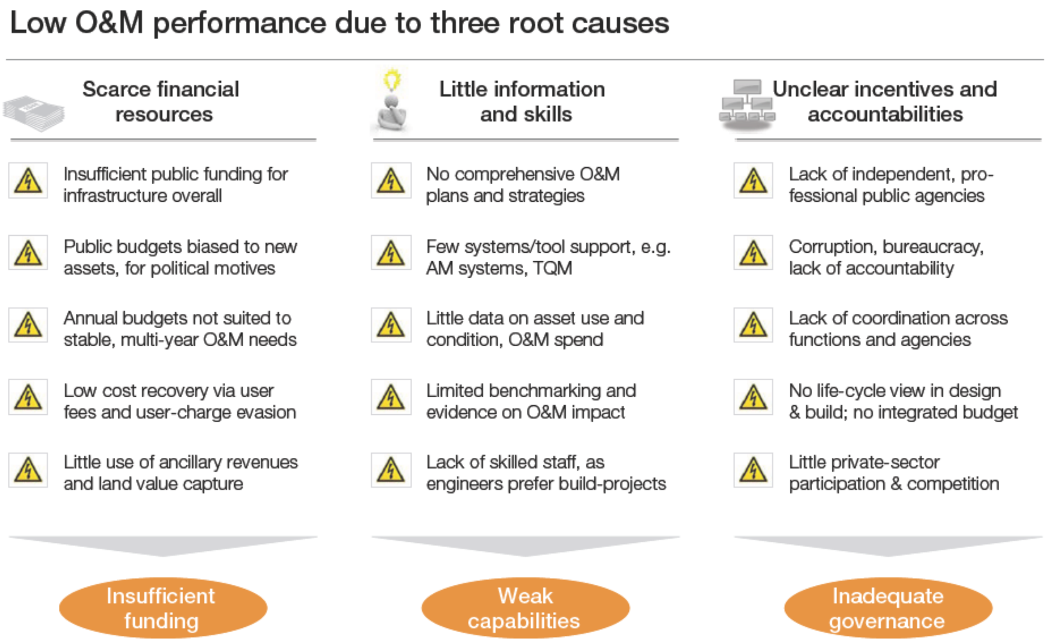


Figure 2: Root causes of O&M Issues (WEF 2014)

One also needs to consider the choice of technology in light of the above, e.g. motorising boreholes instead of installing hand pumps or piped water schemes in some rural settings.

1.3. Structure of the guidance document

This document has 6 chapters (

Table 2). Besides the introduction in Chapter 1, the first part of the document addresses technical issues related to groundwater infrastructure O&M in Chapter 2. The second part deals with institutional issues related to O&M as discussed in Chapter 3. The third part in Chapter 4 deals with monitoring and reporting requirements. Conclusions and recommendations are given in Chapter 5.

Table 2: Structure of the O&M guidance document

Chapter	Contents
1. Introduction	This chapter presents the introduction to the O&M guidance document.
2. Groundwater infrastructure O&M	The chapter focuses on O&M tasks and preventative maintenance of groundwater infrastructure
3. Institutional requirements	Discusses the effectiveness of O&M as determined to a large extent by non-technical issues.
4. Monitoring and reporting	The chapter deals with monitoring and reporting. Groundwater monitoring should be part of a monitoring system that includes all aspects of a water supply scheme’s operation and maintenance. The monitoring should not only focus on groundwater parameters but also on the infrastructure to ensure proper functioning.
5. Conclusions and recommendations	The chapter presents the conclusions and recommendations.
6. References	Presents the references cited in the O&M guidance document

2. GROUNDWATER INFRASTRUCTURE OPERATION AND MAINTENANCE

In rural areas, a groundwater system often consists of a borehole, pump, disinfection system, a distribution system and storage. In urban areas, the borehole configuration becomes more complex and may consist of wellfields, water treatment systems, a reticulation system, storage infrastructure and in some cases provisions for a managed aquifer recharge scheme. In urban areas, a more advanced organization is needed to operate and maintain (complex) wellfield configurations with capable local institutions and water governance arrangements in place. Ensuring the appropriate use and longevity of groundwater infrastructure requires (Mannix et al. 2018; World Bank 2018; Dillon 2019):

- Standards for borehole drilling and construction: Most problems observed are caused by sub-standard construction of water points prior to commissioning for use. These are typically permanent and irremediable, and this contributes to increased service delivery costs through (i) extended down times; (ii) disproportionate maintenance requirements; and (iii) abandoned infrastructure. The resulting burden increases the challenge for community-based management approaches. The costs of addressing poor construction are usually much higher than any initial savings. Standards need to be supported by a legal instrument such as regulations that are part of a Water Act.
- Guidelines for O&M: This includes routine tasks which need to be carried out to keep a groundwater source or well-field functional such as servicing, repairs, monitoring, replacement of parts, complying with pump duty cycles or maximum yields, testing, and so on. Many of these tasks are routine and can be planned and budgeted for, but O&M programmes also need to be able to efficiently and effectively respond to breakdowns and other unforeseen events. For example, the NORAD-Assisted Programme for the Sustainable Development of Groundwater Sources in South Africa developed a Toolkit for Water Services that include guidelines for O&M of groundwater infrastructure that are useful in this regard (DWAF 2004), but these have not yet found practical application (DWS 2016) due to financial limitations, legislative and social constraints or political interference.
    - **Preventative maintenance**: This includes work that is planned and carried out on a regular basis to maintain and keep infrastructure in good condition, such as flushing of the borehole, cleaning and greasing of mechanical parts and replacement of items with a limited lifespan. It sometimes also includes minor repairs and replacement when observed through routine examinations.
    - **Breakdown maintenance:** Repair broken infrastructure and bring it back into operation.

This guideline document does not focus on standards for borehole drilling and construction but on O&M tasks of groundwater infrastructure. Stakeholder involvement is critical in ensuring timely maintenance of infrastructure and prevention of vandalism of the infrastructure.

2.1. Guidelines for O&M

The O&M of a water supply system starts from understanding the general components that physically make up the system. Groundwater infrastructure as part of a water supply system comprises boreholes, pumps and the transmission line connecting the boreholes with the distribution network (**Figure 3**). It is recommended to prepare a schematic layout of the water supply system in a Geographic Information System (GIS) for planning and carrying out O&M.

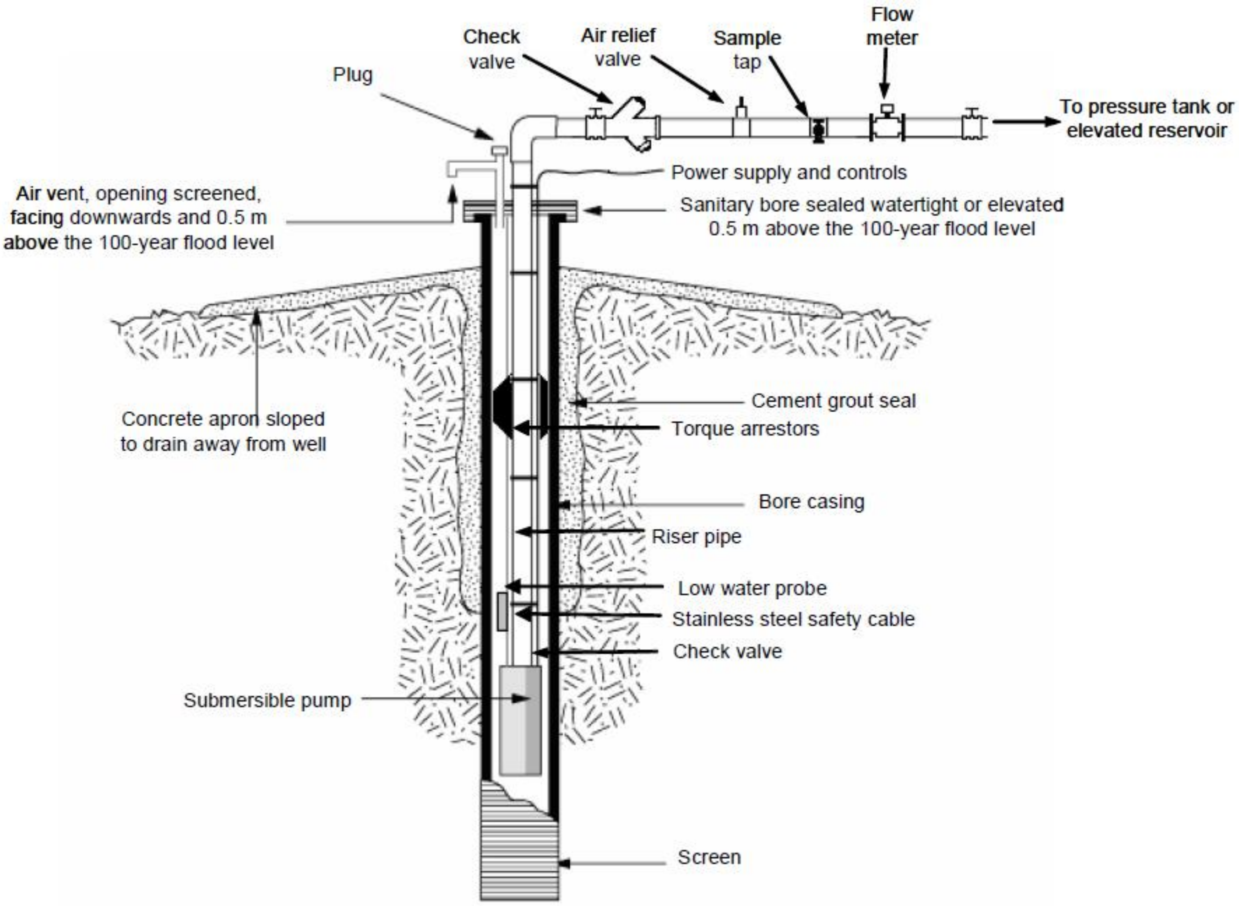


Figure 3: Basic components of groundwater infrastructure (Ministry of Health 2010 - New Zealand)

2.1.1. Components of groundwater infrastructure

2.1.1.1. Boreholes

There are different borehole designs for hard rock formations (crystalline and sedimentary consolidated formations – Figure 4) and for unconsolidated formations (Figure 5; SAZ 2012).

The hard rock design involves a simple open hole construction, with plain casing inserted to protect the borehole from collapsing material above a water bearing horizon. Where the crystalline and sedimentary formation is collapsing below the water strike level, the installation of perforated (slotted) casing is necessary. The design for unconsolidated formations includes plain casing and screens covering the entire depth of the borehole.

In the annular space between the casing's slotted section or screen and the borehole sidewall usually a gravel pack is placed to provide a permeable zone between the formation and the casing, while at the same time protecting the slotted casing or screen from clogging due to collapse of the formation.

To prevent the inflow of potentially polluting surface water into the borehole via the annular space between the borehole sidewall and the outside of the casing a sanitary seal is placed. Each borehole must also be completed with a concrete slab to protect the sanitary seal.

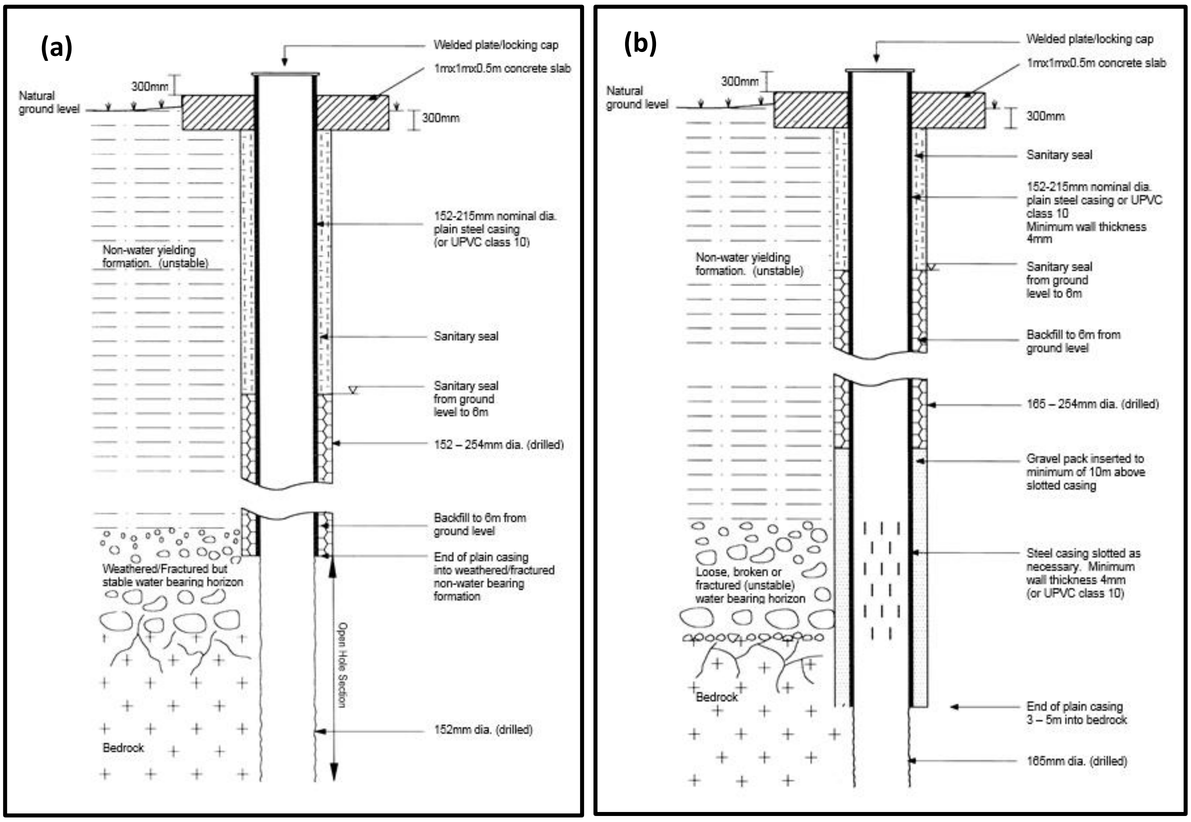


Figure 4: Hardrock borehole design: (a) plain casing/open hole; (b) slotted casing

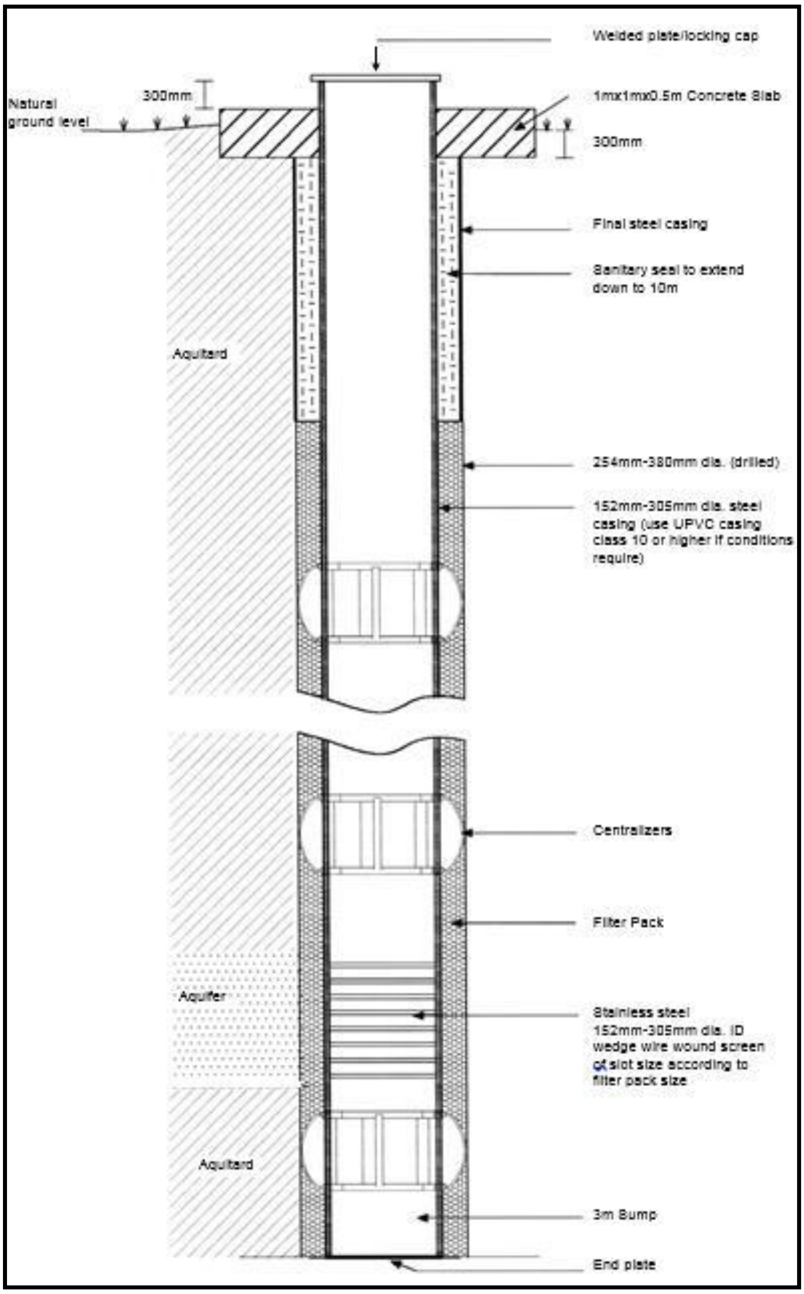


Figure 5: Borehole design unconsolidated formation – screened and filter packed

Furthermore, a piezometer tube should be installed to allow for measurement of the water level (Box 2).

Box 2: Piezometer tube for water level monitoring (after DWAF, 2004)

- A piezometer of 32 millimetres (mm) or 40 mm diameter must be installed in the borehole to allow for measuring water levels.
- If one wants to install a data logger in the borehole, the piezometer tube must be able to accommodate for the diameter of the data logger.
- A dip meter or data logger stuck in a piezometer tube is a costly problem that can be prevented, and all the following points are aimed at avoiding that.
- It is best if the piezometer tube is attached to the outside of the borehole rising main pipes with broad clamps or zip ties, but one must take care that the pipe is not constrained by the clamps or zip ties.
- For the same reason, a pipe of more rigid material is better than one of soft material. High-density polyethylene (HDPe) is better than low-density polyethylene (LDPe), and if one uses LDPe then class 6 should be used.
- The piezometer tube must have no joints, restrictions, bends or twists in it.
- The bottom of the piezometer must be closed so that the monitoring equipment cannot fall out of the bottom. Slits must be cut in the bottom one metre of pipe, to allow water to enter the tube.
- The top of the piezometer tube must be positioned such that it is secure, so that readings can be taken safely and easily. The top end must be clear of any belts or moving parts and must be secure and tamper proof.
- After the pump and piezometer tube have been installed, the piezometer tube must be tested for openness, i.e. insert a dip meter probe to the bottom of the tube. If it is not open for the full length, the pump and piezometer tube must be re-installed, until they are correctly positioned.

2.1.1.2. Pumps

Pumps are critical components of a water supply system and are subject to wear, tear, erosion and corrosion due to their nature of functioning. Failures or interruptions in water supply are more often attributed to pumping machinery than any other component of the water supply system. Downtime can be reduced by maintaining an inventory of fast-moving spare parts.

Various types of pumps (Table 3) are commonly installed in boreholes and these include:

- Positive displacement pump
  - Rotor stator (e.g. Mono pumps)
  - Piston and cylinder (e.g. Afridev)
- Centrifugal submersible pump

The pump type must be compatible with the borehole yield as determined from pumping tests, the intended use and site conditions. In areas of shallow groundwater other types of pumps may be used such as windlass and treadle pumps.

Table 3: Commonly used pumps and energy sources (references for the pictures are given Chapter 6)

Energy source	**Pump type**	
Diesel Standalone diesel motor connected to the pump drive head by belts	Rotor Stator Also called progressive cavity pump, the rotor turns inside the stator forcing pockets of water upwards. The motor and drive head are above ground and connected to the pump with rods located inside the riser pipe.	
Electrical Normally from to the electricity supply network but can be from generator or inverter. Medium to large pumps require 3 phase 400V supply	Centrifugal submersible pump Most commonly used. The pump and motor are coupled together and submerged in the borehole. Multistage – more stages are required for higher pumping head. Rotor Stator – as above but driven with electric motor with belts or direct drive.	 
Manual Hand pumps	Piston and cylinder Reciprocating pump with piston and cylinder below water level and connected to the drive lever handle with rods. Each stroke lifts the water until it flows from the spout. Rotor Stator. As above but driven with geared head. Generally used where water table depth is too deep for piston and cylinder type pump	 
Solar	Centrifugal submersible pump As above	

Energy source	Pump type	
If direct solar power then pump is normally running on Direct Current (DC)		
Wind	Piston and cylinder As above but the reciprocating motion of the rods generated by the rotation of the multi-blade rotor	

Pump installation

In boreholes completed in hard rock and consolidated aquifers, motorized pumps must be set 0.5m - 1m above the main water strike level to avoid potential overheating of the centrifugal pump motor and ingress of aquifer material. In boreholes drilled within unconsolidated formations with only one screened section, the pump must be set above the top of the uppermost screen. Where multiple screen sections are present, the pump may be set within plain casing (pumping chamber) between any screened sections. In this case the dynamic water level must not be drawn below the top of the uppermost screen. Failure to observe this will result in the inflow of fine material and/or encrustation of the uppermost screen.

In the case of hand pumps the installation is governed by the type of pump. For the Afridev, for example, the recommended maximum installation depth is 45m.

Abstraction rate and duration of pumping

The abstraction rate of the production pump must not exceed the yield as determined from pumping test data and preferably, it should not exceed 2/3 of the largest discharge which caused minimal drawdown during the pumping test. The duration of the pumping cycle depends upon the capacity of the aquifer to sustain the yield with time and reflects the storage and recharge characteristics of the aquifer. The optimal pumping rate can be obtained after a period of intensive monitoring of abstraction, water levels and water quality.

2.1.1.3. Water meter and water sampling point

Production boreholes should have a water meter and water sampling point on the transmission line close to the wellhead. The water meter needs to be recorded regularly and maintained and also have a scour near the pump or a sample tap for taking samples for physico-chemical and microbiological analyses (**Figure 3**). Boxes 3 and 4 provide critical information on the water meter and a sample tap respectively.

Box 3: Water meter for measuring abstraction (DWAF 2004)

- A water meter installed at the borehole is the most effective way of measuring abstraction.
- It must be positioned so that it is easy and safe to read and must be well clear of any belts or moving parts.
- The meter must be sized to suit the maximum flow from the borehole (it is not correct to specify a meter that is the same size as the pumping main). The valve manufacturers have specifications for minimum and maximum flows for meters, and normally a meter would need to be of a smaller diameter than the pumping main.
- To eliminate the effects of turbulence, a water meter must be preceded (in flow direction) by a length of pipe of the same diameter as the meter, and also followed (out flow direction) by a length of pipe of the same diameter as the meter. The lengths of pipe required before and after the meter, are specified by the meter manufacturer.
- Meters can easily be blocked if the water flowing through them contains sand or other large particles. Generally, groundwater is clear of particulate matter. However, badly constructed boreholes in sandy or poorly consolidated aquifers will pump a mixture of water and sand, which can block water meters. Installing an in-line strainer will protect the water meter from blockage. Preferably install a water meter which allows debris to flow through.
- Water meters and in line strainers require regular checking and maintenance. This needs to be part of the O&M schedule of the project.

Box 4: Sample tap for water quality sampling (DWAF 2004)

- A sample tap must be supplied close to the borehole (but after the water meter) for taking samples to monitor water quality.
- The sample tap must be positioned so that it is easy and safe to take samples and must be well clear of any belts or moving parts.
- Ensure that all taps and fittings are rated for the maximum design pressure at the borehole head.
- Many boreholes have a scour a short distance from the borehole, which can also be used for taking water samples (and for pumping to waste on start-up).

2.1.1.4. Equipment and spares

An equipment inventory of all the components of the water supply system is recommended. There is also need for critical spare parts to be readily available. A water supply entity tends to hold the more common items in stock so that repairs don't have to wait until the item can be purchased and delivered. The equipment and spares should be standardised for project implementation.

2.1.2. Preventative maintenance

Planning for preventative O&M requires:

- Baseline information on the water supply system (status quo of components and operation)
    - Overview of the water supply
    - Contacts list

  - Details of site access and security
  - Drawings
  - Manufacturers manuals for system components
- A programme for implementation
  - Standard operating procedures
  - Log sheets
  - Maintenance schedules
  - Water quality monitoring schedule, procedures and reporting requirements
  - Emergency response plan
  - Asset inventory and asset data sheets
- A project budget, including monitoring and evaluation

2.1.2.1. Routine / scheduled

Regular operation and planned (preventative) maintenance of equipment ensures that the expected service life of equipment is achieved (NZ Ministry of Health 2010). Regular preventative maintenance should be carried out on mechanical components such as the pumps and valves and involves making adjustments, cleaning, lubricating and replacing minor components at regular intervals before a failure occurs. These activities and intervals are usually given in the manufacturer's recommendations. How frequently they are actually done is a matter of judging the cost-effectiveness of the maintenance. In addition, operators should check the condition of the above-ground structure, including the concrete apron and fence, to ensure it is in good condition. Where equipment is essential to the operation of the water supply, or where failure would lead to a personal safety or a water quality issue, then cost should not be the only consideration. Some planned maintenance activities are based on a measure of the condition of the asset rather than the date on the calendar. This might include measures such as pump vibration, oil condition and operating efficiency. There are sophisticated instruments for assessing the condition of equipment, but simpler methods are likely to be used in small supplies. These would involve making regular observations such as listening and feeling for excessive vibration and looking for signs of corrosion.

2.1.3. Breakdown maintenance

It is not unusual for the yield or discharge from a borehole to decline over time. Causes and remediation could be (NZ Ministry of Health 2010):

- Mechanical failure of pumps – repair the pump
- Chemical encrustation: precipitation of calcium carbonate, iron and manganese hydroxides on screens – wire brushing or scraping or alternatively application of acid
- Clogging of screens and aquifer pores by biofouling (bacterial growth) – clearing by flushing, brushing, chemical treatment, etc.

- Corrosion of pumps and structural elements of borehole in case of aggressive chemistry of groundwater and bio-fouling - need for proper selection of materials for construction of borehole
- Ingression of sand due to a too high pumping rate or failure of gravel pack/screens – raising pump and/or reducing abstraction rate

In general, only limited preventative maintenance can be done on the borehole itself as most of the structure is inaccessible. Table 4 presents a trouble shooting guide for common problems. With regards to the other components of a water supply system, there needs to be a plan for having both people and equipment available to undertake repairs.

Table 4: Trouble shooting guide (after NZ Ministry of Health 2010)

Indicator	Possible problem	Solution
E Coli detected in borehole water that has been assessed to have secure status	Water contaminated by poor sampling technique	Take more samples to see if further positives are detected. Positive results must be reported to the appropriate regulatory and action taken, e.g. chlorination.
	Contaminated water is entering the borehole from the surface or a shallow depth	Check the borehole to make sure water is not getting in from the surface through the casing.
	Contamination of the aquifer	Seek advice from the regulator or a local authority. Check for activities in the area that could affect the water quality
Change in turbidity or colour	Damaged screen, wellhead or casing	Check wellhead security. In some cases, a drilling contractor may be able to replace the screen or repair the casing
	Drawing in water from a different part of the aquifer	Seek advice from the regulator or local authority
Change in turbidity or colour after rainfall	Surface water intrusion into bore	Check wellhead security. Can the intrusion be prevented? Is it necessary to take water when the quality if poor?
Water is turbid during the first stages of pumping	The rising main within the borehole is corroding	Can the first flush of water be diverted to waste? Inspect the rising main in the borehole. Examine the inlet screen, check valve and pipe connections. Replace badly corroded pipes
Sand in well discharge and/or excessive pump impeller wear	Damaged well screen or gravel envelope	In some cases, a drilling contractor may be able to replace or repair the screen or gravel envelope
	Flow is drawing sand into the borehole	Throttle back the flow rate to reduce the problem. A drilling contractor may also need to redevelop the

Indicator	Possible problem	Solution
		borehole to flush out the sand around the borehole screen (or take other measures) as appropriate
	Rapid stop/start pumping agitating the borehole and not flushing out the sand	Look at the pump controls. Install storage or a variable speed drive (not always appropriate)
Pump vibration	Cavitation caused by adequate pump submergence.	The flow rate should be throttled back to reduce the draw down.
	Unbalance pump or worn pump components	Have the pump serviced
Pump cutting out on high temperature or high amps	Pump needs repairing	Have the pump serviced
	Pump cycling too quickly between start and stop	Look at pump controls. Install storage or variable speed drive (not always appropriate).
Sudden change in flow rate	The position of a flow-restricting valve has been changed.	Find the problem and fix as appropriate
	A leaking pipe	
	A damaged pump	
Gradual decline in pump flow rate	Pump wear or flow constriction in delivery pipework	Check pump shut-off pressure against previous values to see if this is falling. Do not run a borehole pump for any longer than necessary against a closed valve (check manufacturer's instructions). Have the pump serviced
The borehole drawdown increases	Water demand in increasing in relation to the capacity of the bore	Is another borehole needed?
	The aquifer is becoming depleted	Are other borehole users in the area noticing increased drawdown? Investigate water extraction in the local area and consider the effect of recent weather
	Clogging of borehole screen	Consider screen corrosion, chemical encrustation, biological fouling and fine material build-up. A drilling contractor would normally undertake any remedial action
	Gradual blockage of the area around the bore is affecting water recharge	A drilling contractor may be able to re-develop the borehole

3. INSTITUTIONAL REQUIREMENTS

The effectiveness of O&M is determined to a large extent by non-technical issues. Good O&M is based on proper planning, adequate staffing, budgeting, monitoring and other functions, as well as sufficient intra- and inter-organisational collaboration (Cobbing et al. 2015). Institutional requirements for O&M include (Kiparsky et al. 2017; World Bank 2018):

- **Provision for recurrent costs:** There is need to estimate the total cost of groundwater development by considering expenditures associated with the discrete components of infrastructure investment, operation and maintenance, and secondary factors. Within each of the discrete components are multiple elements which need to be considered, from investigation and exploration costs to energy costs to applicable taxes and subsidies. There is evidence to suggest that groundwater schemes have lower up-front costs, but higher ongoing costs, compared with surface water schemes of similar size. This has implications for budgeting and scheduling.
- **Institutionalising O&M:** The institutional design needs to consider the organization of O&M and roles and responsibilities. Recurrent budgets for routine O&M are highly vulnerable to appropriation for emergency purposes, or for filling short-term financing gaps.
- **Human capacity:** Human capacity is the ability of individuals and teams to successfully carry out O&M tasks that enable a sustained provision of water services to communities. This includes the training and equipping of staff members, as well as the organisational systems and protocols that enable trained personnel to carry out their duties.
- **Stakeholder involvement:** Involvement of stakeholders ensures proper use of facilities, minimizes vandalism and routine non-complex repairs and maintenance.

3.1. Provision for recurrent costs

Implementing a revenue management system is an important aspect of any water supply system as it governs the financial sustainability (Government of India 2013). Financing of major maintenance works remains challenging without outside assistance as major repair and rehabilitation works are often beyond the financial capabilities of the community organisations and users (Egloff 2016). In most cases, the user of the groundwater resource (in effect) receives all the benefits of groundwater use but (at most) pays only part of the costs (

Figure 6) —usually the recurrent cost of pumping (providing the energy input is not subsidized) and the capital cost of well construction, but rarely the external and opportunity costs leading to economically inefficient resource use (Kemper et al. 2004) and many small-scale systems being ineffective not long after their inception (Jagals and Rietveld 2011).

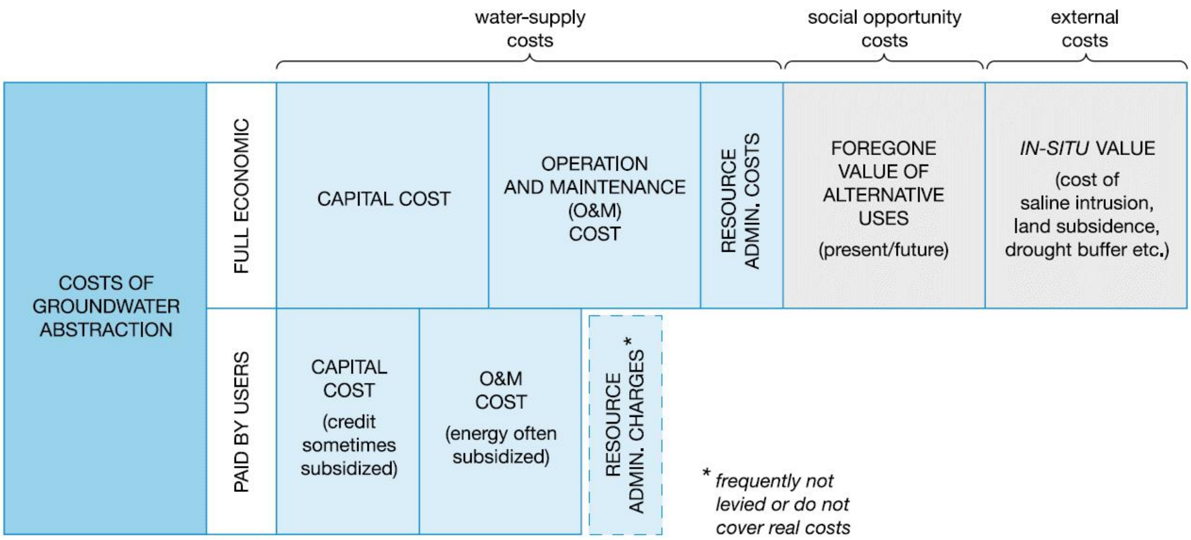


Figure 6: Measuring the costs of groundwater use (Nanni et al. 2004)

The close linkages between cost recovery and sustainable O&M are characterised by the vicious and virtuous circles shown in Figure 7. In a vicious circle, one issue leads to the other and eventually back to issues of poor health.

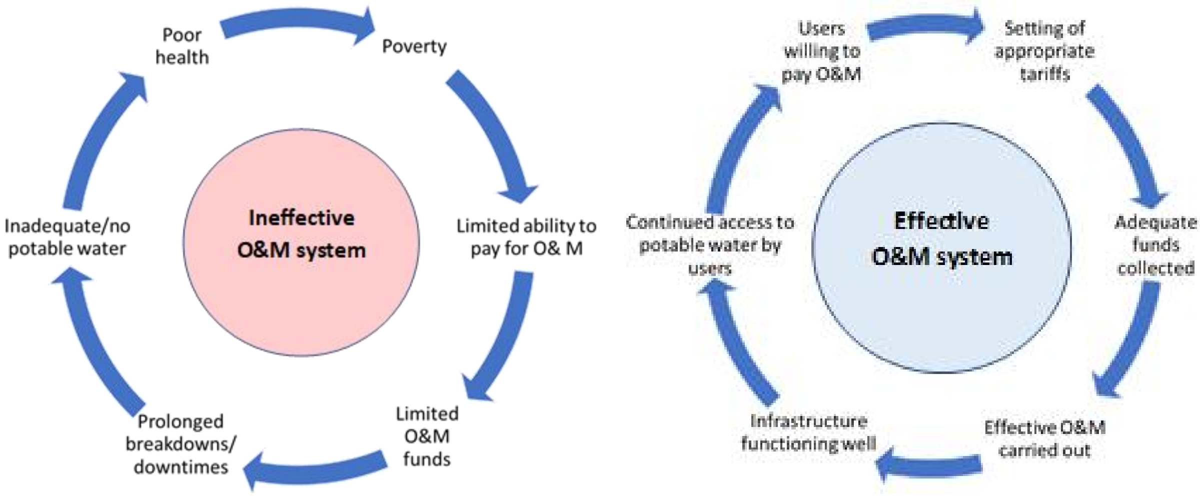


Figure 7: From ineffective to effective O&M of water infrastructure

From the vicious cycle the water supply service will improve once the revenues are collected to sustain the system leading to better health and lessen poverty amongst communities (Angwec 2015).

Recurrent costs comprise all expenditures (staff, parts and materials) that are required to keep a system operational and in good condition after installation has been completed (Jagals and Rietveld 2011). The following is a list and description of what is generally included as O&M cost items (WHO; World Bank 2012):

- Materials (consumable chemicals, energy, tools, spare parts and equipment)
- Works personnel (operation, maintenance, routine preventative maintenance, routine repairs, unanticipated repairs, construction for minor rehabilitation)
- Management personnel (planning, supervision, financial management, administration, monitoring)
- Follow-up (training support, technical assistance, institutional strengthening, monitoring and evaluation)
- Financial costs (interest, amortization, depreciation, exchange rate variations, inflation)
- Environmental costs (water source protection and conservation, wastewater treatment)
- Other costs (transport; services paid to a private contractor; unaccounted for water, both due to leakage in system and bad administration; and vandalism - they become a cost to the community if not prevented)

Franceys et al. (2006) found that regardless of the institutional framework, the strategies for improving the financial performance of utilities should concentrate on two aspects: one is controlling costs and making the best use possible of the facilities and manpower; the other is to raise revenues through tariffs. This means that users need to see that all efforts are made to curtail costs and receive value for their money.

Basic recurrent costs can be determined in the following way (WHO):

a. List all O&M activities needed, and their frequency
b. According to each activity, list all human resources, materials, spare parts, energy, tools and equipment required
c. Estimate the quantity or volume needed for each requirement
d. Define the activity cost
e. Sum up all costs of all activities

There are a number of factors to consider in O&M costs:

- Revenue streams: number of consumers, taxes, grants from national government, overseas development assistance
- Expenses: wages, debt, infrastructure funding/replacement
- Sophistication of groundwater infrastructure and treatment system: requiring outside assistance

An example of a model for maintenance service provision is the FundiFix model which was developed based on prepaid user contributions, performance-based contracts and remote monitoring, providing a professional and rapid maintenance service for community water supplies (initially serving handpumps) and implemented in Kenya (Katuva et al. 2016). The FundiFix model blends flows of finance from users (Figure 8), governments and development partners with the key components of the model (Katuva et al. 2016):

- A local company acts as a **maintenance service provider** as opposed to a water service provider such that they are not responsible for a legacy of poor installation or changing environmental conditions. The maintenance service provider can monitor water quality metrics as required but in cases of health risks the burden for action would be with mandated government agencies.
- **Working at scale pools risk** across multiple systems and is a core principle underlying the model. Water security risks to individual communities and households are reduced, and a high-quality maintenance service becomes viable with pooling of revenue and costs.
- Regular **prepaid user contributions** are made through a mobile money service, and registered users (up to ten community and committee members) are sent notifications of payment and reminders via SMS (text message). This provides an efficient and transparent mechanism for financial flows from rural water users to the maintenance service provider, one element of sustainable finance (tariffs).
- **Affordable tariff** - Observed handpump usage data allow variable tariffs to be designed with provision for regular, low or special cases. Most communities fall in the former; low users are monitored with a reduced tariff; and 'special' cases, including schools, clinics or other facilities with handpumps benefit from a reduced rate. The latter provide a basis for government support through taxes.
- **Transfers** (the third element of sustainable finance) are also necessary to sustain water services to the rural poor and can feed into the model through performance-based payments from a coordinated financing mechanism.
- Providing a professional service is linked to **performance-based contracts**. The service provider is responsible for providing repairs within an agreed timeframe. For example, if a handpump repair takes longer than three days, communities receive a free month of service, so building in penalties for poor performance.
- **Remote automated monitoring** occurs through transmitters fitted to pump handles that monitor movement (usage and functionality) and send data to a central server using the mobile phone network. The status of handpumps in the system can be remotely monitored via a web-based interface. This is essential for validation of repairs and information sharing in remote rural areas, keeping the service accountable to government, donors and other stakeholders.
- **Unit of analysis**. As each handpump is managed differently related to group size, water demand, access rules, alternative water sources and other factors, the decision was made to collect a 'community payment' per handpump rather than individual payments to reduce the complexity and transaction costs of cost recovery at scale.

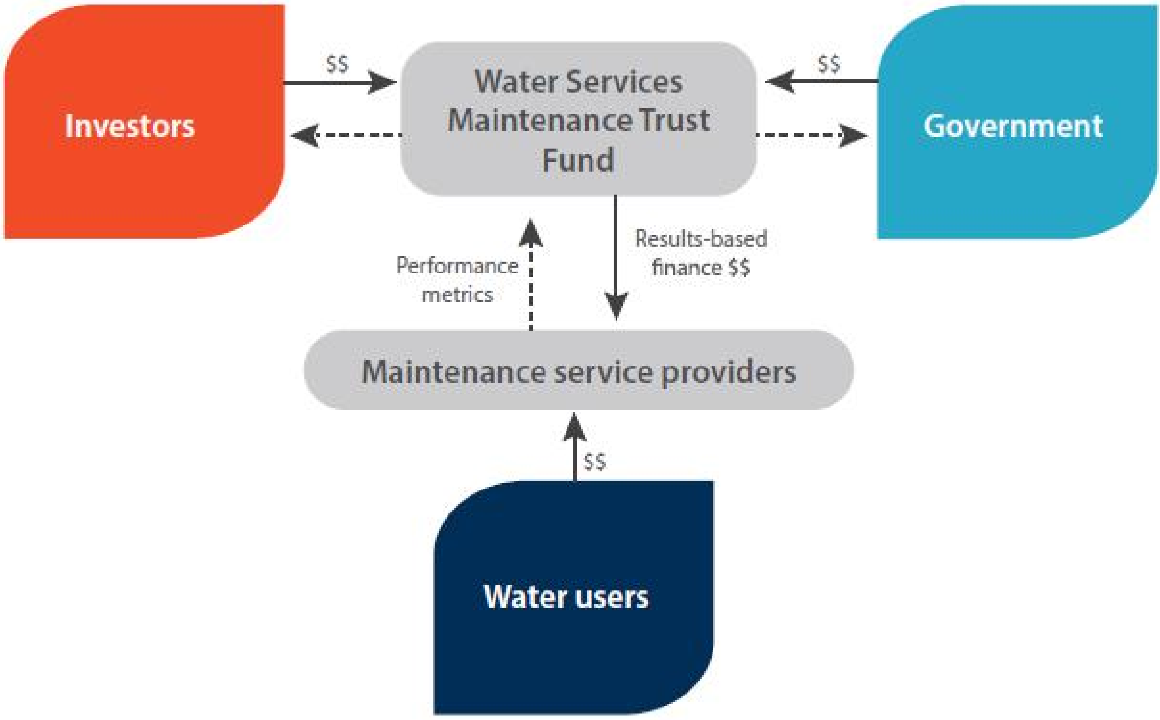


Figure 8: FundiFix financing model (REACH)

In the Kibibi Water Supply in Uganda, which is a pumped water supply, the water bills are issued door to door to the users. The revenue is collected by the operator 'door to door' at the operator's office or at the bank. The revenue collected was kept in an account in a commercial bank. The signatories to the account were the operator, sub-county chief and the sub county accountant. The users paid any amount of money during the course of the month (Angwec 2015).

3.2. Institutionalising O&M

In rural settings, groundwater schemes are handed over for communities to operate and maintain, emphasising community ownership and authority. In urban settings the groundwater infrastructure for public water supply are managed by a local authority or a public water utility. Normally the institutional roles and responsibilities for O&M are poorly defined and executed with minimal follow-up support. The community that can adequately manage its own water supply system during its life time without any form of external assistance is the exception rather than the rule (Ministry of Water Irrigation and Electricity 2018). Table 5 lists the responsibilities of the different institutions in O&M.

Table 5: Roles and responsibilities of various actors in supporting the community (Directorate of Water Development 2004; Government of India 2013)

Institutions	Roles and responsibilities
Transboundary institution/ River Basin Organisation	• guidelines production • best practice support • policy harmonisation
National Government	• policy decisions about water tariff, O&M, undertaking major repairs, augmentations, etc. • regulation and monitoring • review of O&M of strategic aquifer systems and associated wellfields • review of aspects of sustainability of water supply schemes • revision of policies, strategies and guidelines periodically for post construction support • establishment and dissemination of norms, manuals and standards related to O&M • coordination with various department of national and state governments like Rural Development, Agriculture, Energy and Health, etc. • allocating special funds to execute contingent plans so that the water supply schemes are not affected by inadequate power supply, adverse seasonal conditions like droughts and natural calamities like earthquake, tsunami, cyclone, etc.
Water Utility	• training capacity and follow-up support • availability of technical assistance to the communities • budgets for O&M activities that include replacement and rehabilitation costs • regular monitoring visits and preventative maintenance • monitor water quality
Local authority/Municipality	• set municipal bylaws • training capacity and follow-up support for preventative maintenance • availability of technical assistance to the communities • budgets for O&M activities that include replacement and rehabilitation costs • monitor water quality
Village Committee/Water User Association	• plan for & oversee O&M; report problems • collect and utilise O&M funds
NGO and others	• O&M financing, tools • equipment

Institutions	Roles and responsibilities
	• capacity building
Private sector	• ensure availability of spare parts • provision of specialist services for system repair and/or upgrading • provision of design services for system expansion • provision of legal advice and representation, • water quality monitoring service

3.3. Human capacity

In many countries, the key constraint to implementing all of O&M best practices is the shortage of skilled staff (WEF 2014). Staff tasked with groundwater project O&M should include at least (after DWAF 2004); Table 6):

- Pump operator
- Pump operator supervisor
- Data capture clerk
- Mechanic
- Electrician
- Technical manager
- Water quality manager

Table 6: Job descriptions for staff tasked with groundwater project O&M (after DWAF 2004)

Staff	Functions
Pump operator	• operate groundwater infrastructure according to operational guidelines • measuring water levels and abstraction volumes • maintaining a borehole logbook and recording the water levels, abstraction volumes and other significant information in the logbook • ensuring that the borehole monitoring equipment is kept clean, stored in a secure place and is not misused by unauthorised people • implementing recommendations by the technical manager and communicated via the pump operator supervisor, e.g. how the pump is operated
Pump operator supervisor	• support to the pump operator in monitoring activities • regular assessment of the pump operator's performance • on the job follow-up training for the pump operator as and when required • collection of data from the pump operator, and transferring this data to the data processor located within the technical management office

Staff	Functions
Data capture clerk	• entering monitoring and water quality data from log sheets into a computer database • maintaining a filing system for completed log sheets • printing out reports and ensuring that the reports are supplied to the technical manager
Mechanic	• preventative & breakdown maintenance on mechanical components • trouble shooting of faults
Electrician	• preventative & breakdown maintenance on electrical components • trouble shooting of faults
Technical manager	• overall responsibility for maintaining the groundwater scheme, including ensuring that all role-players fulfil their responsibilities • reviewing groundwater operational reports • consulting with groundwater specialists, where required • reporting to local authority or regulator • making changes to the operation of the borehole. This includes instructing the pump operator supervisor to implement changes, and checking to ensure that the changes have taken place • liaison with the health manager on water quality sampling and testing • using monitoring info in the planning of new infrastructure development
Water quality manager	• ensuring regular sampling and testing for potability • providing water quality data to the data capture clerk • reporting to local authority or regulator • liaison with technical manager on projects with water quality problems • co-ordinating remedial action and new infrastructure planning

Communities and their organisations that will undertake O&M of local infrastructure will need training in technical matters, accounting and simple financial management, basic contract procedures, and monitoring and reporting. Hands-on training is desired in order to ensure the full understanding and the implications of the new system. Private operators or local engineering companies, which will take care of the maintenance of the systems, should also be trained in the type of maintenance activities that have to be carried out periodically (Dillon 2019). To set up external support is challenging in a long-lasting manner. In many cases, this support by external agencies is bound to stop at some point in time as project cycles end. Instead of coaching and supporting communities directly, development agencies may consider building the capacity of cooperative local governmental agencies (Egloff 2016).

3.4. Stakeholder involvement

Stakeholders are people or organisations who or which are involved or affected by a project or an effort of a project or outcome of a project. Beneficiary communities are primary stakeholder groups. Other stakeholders with specialised capacities and responsibilities are also essential in O&M of water infrastructure.

Stakeholder involvement is very critical in ensuring long-term sustainability of water infrastructure. The identification of relevant stakeholders should be done during the early stages of a project planning phase as this will allow them to buy into and own the project. Communities could carry out preventative maintenance of water infrastructure and prevent its vandalism thereby ensuring the infrastructure's sustainability in delivering potable water. Other stakeholders such as church organisations could assist with provision of spare parts or even cover costs for major repairs.

Empowerment of a village community to self-maintain its infrastructure can take a variety of forms. A common one is the appointment of a water committee which in turn might chose to elect a keeper of community wells or boreholes (SADC 2009). Some small tariff might be applied against income within the village which allows the purchase of spare parts for pumps and pays the local mechanic to undertake repairs as required. Such structures are widespread throughout many of the semi-arid rural areas of the SADC region.

Box 5 presents an example of a community empowered operation and maintenance of water points in Diti Zimbabwe.

Box 5: Community empowered O&M of water points in Diti communal land, Zimbabwe (SADC 2009)

Diti communal land [Zimbabwe)

Location Diti village is located about 41 km east of Beitbridge town and has an estimated population of 6091. The area is accessed by gravel road from the main Mashvingo Road.

Physiography Weathered basement gneiss terrain with relatively shallow depths of weathering as evidenced by shallow outcrops strewn around the focal point.

Infrastructure Clinic, stores, school

Livelihoods Employment in Beitbridge, local agriculture, small irrigated gardens and rainfed crops.

Water Supply Situation One hand-dug well supplies the school, the clinic, shops and the surrounding community. A diesel engine powered borehole used to supply the clinic, however this borehole and the engine had broken down which resulted in a critical water shortage. Two boreholes which used to supply water for the community and the school were also no longer in use (no longer equipped and were blocked).

A water point committee being advised on proper handling of a water point

A Rural Community Water Management Plan (RCWMP) was formulated in response to the critical water shortage for improved utilisation of groundwater during periods of drought and specific to the Diti community's needs, abilities and aspirations to:

- Facilitate better community management of the water sources
- Improve community well being
- Build linkages with stakeholders
- Measure intervention success
- Serve as guidelines for replication elsewhere in the SADC Region

The RCWMP provides guidance to the community in times of drought. It offers background information and action advice which the community members can relate to and make decisions on. The anticipated essential outcome for the rural community was enhanced livelihood security through the provision of a better managed and a more secure water supply. A water point committee comprising community members was trained in O&M of the water supply infrastructure to ensure sustainability. The training included preventative maintenance and minor repairs.

4. MONITORING AND REPORTING

Monitoring should be part of a monitoring system that includes all aspects of a water supply scheme's operation and maintenance. Key to documenting the status quo of a water supply scheme is to identify and prioritise monitoring sites keeping in mind (DWAF 2004):

- The need to prevent pump failure (i.e. those sites where it is suspected that water levels are regularly drawn down to the pump intake. Note that surging flow from the discharge pipe indicates this)
- The need to ensure that the aquifer is not being over-pumped and that it will be critical for its usage during droughts
- The need for an early warning if the aquifer is contaminated, or if the water quality is deteriorating
- The cost of emergency supplies, should the borehole fail

For each selected borehole and associated components, the monitoring objective should be defined and how one will know if the purpose for monitoring has been successful. An example of a monitoring objective is to avoid water levels reaching the pump inlet during pumping which requires monitoring of water levels and abstraction rates and may result in reducing the abstraction to meet the set objective. Another example is the prevention of salinization of an aquifer which requires the monitoring of the electrical conductivity and may result in reducing the abstraction rate.

4.1. Groundwater parameters

4.1.1. Water levels

The water level of a borehole fluctuates as a result of natural conditions and due to the abstraction of water from the aquifer. It is thus important to monitor groundwater levels over time in order to obtain valuable information such as supply levels, annual changes in levels, saline intrusion and the direction of flow. This information helps the managers gain insight into well construction and placement of a pump to assist in the efficient abstraction of the water and in the protection of the quantity and quality of groundwater and ensure a dependable and affordable supply. It also helps groundwater developers. Water levels can be measured in the following manner:

- Water levels should be measured using a decontaminated, electronic water-level probe or equivalent measuring device, accurate to the nearest (+/–) 1mm, which has been subject to regular calibration to account for stretch of suspended tape, wire or cable (Box 6)
- Ground water levels, recorded daily, can be used as an indicator of the current status of the groundwater resource. If historical data is available for ground water levels, monthly averages can be calculated, and the current groundwater level can be compared to these averages to see how the resource compares to the long-term average during any time of the year

Box 6: Recommended specifications for manual water level measuring instruments (DWAF 2004)

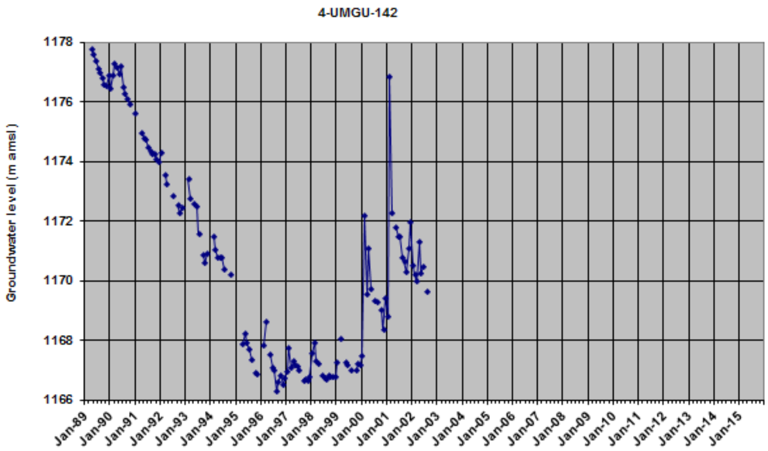
- Coax cable mounted on a strong cable reel. The length would depend on the requirements for the borehole but would normally be 50 metres or 100 metres. A coax cable is stronger than "twin flex" and it can be easily marked at one metre intervals with a permanent marker.
- The probe should be made of metal that is a good electrical conductor and be of the smallest possible diameter (to easily fit in the piezometer tube). The probe should have an insulating spacer to stop the meter giving false readings when the probe touches the metal casing of a borehole (if inserted in a non-equipped borehole without a piezometer tube).
- A microvolt meter permanently connected to a 9-volt battery gives good battery life and does not need an on / off switch. The current only flows when the probe is in water, as opposed to an ohmmeter that permanently draws current from the battery. A gauge also uses less current than a light or buzzer.
- The dip meter should be marked at 1m intervals and be issued together with a steel metre rule or tape measure, for measuring to centimetre accuracy.

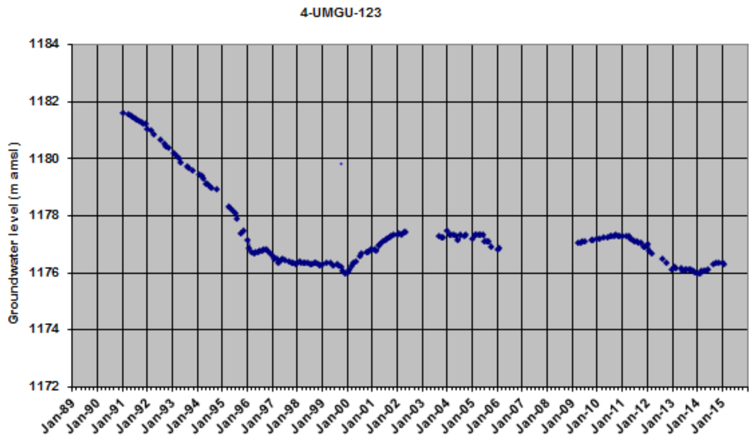
Box 7 illustrates the importance of groundwater monitoring in the Nyamandlovu Aquifer in Zimbabwe.

Box 7: Groundwater monitoring of the Nyamandlovu Aquifer (Beekman and Sunguro 2015)

Groundwater from the Nyamandlovu Aquifer (covering an area of area of ~1,500 km^2) is inordinately considered an essential source of water for the City of Bulawayo, the second largest city of Zimbabwe and for the local farming community, especially during drought periods - hence the need for thorough hydrogeological investigations and monitoring of groundwater quality and quantity (water levels and abstractions) to ensure the proper development and management of the aquifer. Under the GIZ Urban Water Supply and Sanitation Programme, part of the Nyamandlovu Wellfield was rehabilitated with the aim to increase the total wellfield abstraction to 12,000 m³ per day.

Groundwater levels of the Nyamandlovu Aquifer have been monitored systematically since 1989 on a monthly basis and provided a crucial input into the development of a groundwater model of the aquifer in terms of determining a maximum overall abstraction rate and accordingly setting limits to the extent of rehabilitation of the wellfield. The figures below show groundwater level changes over the period of 1989 to 2015 for a borehole within the wellfield (BH 4-UMGU-142) and outside the wellfield (BH 4-UMGU-123). Note that from 2000 to 2002, which includes increased rainfall from Cyclone Eline since 22nd February 2000, water levels increased ~2 m on the average.





4.1.2. Abstractions

Abstractions are measured using water flow meters. A water flow meter is an instrument capable of measuring the amount of water passing through a pipe. Several water flow meter technologies are available for selection depending on the water measurement applications, budgetary terms, and maintenance requirements. Each of these water flow meter types has a unique principle of operation, overall cost-of-ownership, and specific application benefits. There are four major types of water flow meters: mechanical water flow meters, ultrasonic flow meters, vortex volumetric flow meters, and magnetic flow meters. The amount of water abstracted and consumed should be known in order to prevent over-abstraction of the groundwater and losses due to leakages. For the mechanical water flow meter:

- The numbers on the flowmeter are the number of cubic metres that have been pumped
- For recording the abstraction in a logbook, just record the cubic metres pumped

4.1.3. Water quality

It is recommended that water samples be taken and analysed for their chemical composition and bacteriological contents according to the protocol listed in Table 7

Table 7: Analytical requirements and frequency

Frequency	Analysis
Weekly	Electrical conductivity (EC), Temperature (T), pH, Alkalinity, DO
Quarterly	EC, T, pH, Alkalinity, DO, NO_3, NH_3, SO_4, S, Cl, F, Na, Ca, K, Mg, BOD, COD
Annually	Macro-and trace constituents
Bi-monthly	Microbiological (E. coli, Total plate count, total coliforms)

- All water quality samples collected should be labelled in a clear and precise manner with the borehole name and date for proper identification in the field and for tracking in the laboratory

- During sampling, water temperature, electrical conductivity, pH, alkalinity, and dissolved oxygen should be measured using field test meters
- All field meters should be calibrated according to manufacturers' guidelines and specifications prior to beginning of the field work. Field meter probes should be decontaminated before and after use at each borehole
- Water samples are preserved as necessary and placed in ice chests to maintain a sample temperature less than 4 °C for transport back to the laboratory. Note that a special sampling method is required for bacteriological sampling and samples must reach the laboratory within 12 hours from sampling

WRC (2017) provides guidelines for sample preparation, sampling in the field, field analysis, sample storage and transportation, laboratory analysis, data processing and interpretation of results.

Pollutants may enter the aquifer with the water as it percolates from the surface, or directly via the borehole shaft itself. Table 8 lists common chemical contaminants that may be an issue in groundwater. Sources of contamination include seepage from underground fuel storage tanks, effluent discharges, septic tanks, soakaways, waste ponds, offal pits, industrial areas, leaking sewers and landfills. The choice for analysing contaminants depends on the likelihood of its occurrence.

Table 8: Common contaminants found in groundwater (NZ Ministry of Health 2010)

Arsenic and Boron	Arsenic and boron often occur at potentially harmful levels in groundwater, particularly in geothermal and hydrothermal areas. The concentration of arsenic can vary significantly in shallower boreholes between summer and winter.
Calcium and Magnesium	High calcium and magnesium concentrations can cause water to be 'hard' which can lead to problems of scale formation on hot surfaces and difficulty in getting soap to lather. This often happens in areas where limestone is part of the aquifer.
Fluoride	Epidemiological evidence shows that concentrations above guidelines carry an increasing risk of dental fluorosis and that progressively higher concentrations lead to increasing risks of skeletal fluorosis.
Iron and Manganese	Iron in drinking-water in high enough concentrations can cause an unpleasant metallic taste and a rusty colour, which can stain fixtures and clothing. Iron and manganese are often found together in groundwater. The conditions that lead to the presence of iron and manganese can be localised and may change over time. Manganese can also affect the taste of water and has potential health effects when present in the water at higher levels. When oxidised, manganese can be deposited in pipes. It also causes staining of laundry.
Nitrate	High nitrate concentrations can occur in drinking-water sources due to contamination from farming, septic tank systems and solid waste disposal. A high nitrate concentration can be toxic to bottle-fed infants.
Pesticides	In some boreholes pesticides may be present. Testing should be undertaken if it is suspected that pesticides may be present, particularly in shallow unconfined aquifers.

Radioactive elements	Groundwater can contain naturally occurring radioactive elements such as radon. Water from new underground sources must be tested for radon before they are connected to a reticulated drinking-water supply.
Salinity	Some aquifers are naturally saline (salty). Boreholes located near the coast may be affected by seawater flowing into the aquifer if excessive water abstraction causes seawater to be drawn into the aquifer to replace the fresh water.

4.2. Infrastructure deterioration

4.2.1. Boreholes

Boreholes should be visited regularly by the borehole operator to perform routine monitoring and preventative maintenance. The operator should visually check the above ground components such as the well cap, which should remain secure and watertight. Also, the performance of the borehole should be evaluated regularly (Ministry of Water and Energy 2013) as well as a sanitary inspection to reduce the risk of water contamination and water-borne illness. Table 9 presents a sample of a sanitary inspection checklist and any issues identified should be immediately attended to by the relevant authorities. Joints, cracks or any loose connections on the borehole casing should be sealed to prevent surface contaminants from entering the borehole. Boreholes should be disinfected (World Bank 2012) and sampled after repairs are made to the borehole or borehole equipment. Protective fencing around the borehole must be well maintained and breaks repaired immediately.

Table 9: Sanitary inspection checklist (after Open University 2019)

No.	Checklist	Y/N
1	Is there a latrine or sewer within 15–20m of the pump house?	
2	Is the nearest latrine a pit latrine that can pollute groundwater?	
3	Is there any other source of pollution (e.g. animal excreta, rubbish, surface water) within 10m of the borehole?	
4	Is there an uncapped well within 15–20m of the borehole?	
5	Is the drainage area around the pumphouse faulty? Y/N Is it broken, permitting ponding and/or leakage to the ground?	
6	Is the fencing around the installation damaged in any way which would permit any unauthorized entry or allow animals access?	
7	Is the floor of the pumphouse permeable to water?	
8	Is the well seal unsanitary?	
9	Is the chlorination system functioning properly?	
10	Is chlorine present at the sampling tap?	

4.2.2. Pumps

The pump manufacturer's instructions must be followed to ensure correct O&M of pumps (World Bank 2012). The pumps, pipes, and valves should be tested on a regular basis, and the cause of any changes in water quantity and quality should be investigated (ATTAC 2002):

- Pump discharge - The operation of the pump should be checked on a regular basis, at least every six months. Discharge will decrease if abrasive materials such as sand have worn the impeller, if the impeller is jammed, or if the system is air locked. Replacing a worn-out impeller and wear rings may restore a pump's performance to nearly its original output
- Vibration - Excessive vibration can be caused by loose mounting bolts, a broken impeller, worn out bearings, or a misaligned shaft. A centrifugal pump should run smoothly. If it vibrates, it is imperative to shut it down and determine the cause. Vibration may also be the result of cavitation. Cavitation produces distinct erosion marks on the volute and impeller similar to those left by hitting a hard surface with a ballpeen hammer. A cavitating pump may make a loud pinging noise.
- Debris - Is there sand and sediment in the water? Submersible pumps often pump sand. If the screen is missing or damaged, the sand may reach the pump. Sand will damage the impeller and impede the flow. Reduced pump discharge or unusual noise may indicate debris in the pump.

4.2.3. Water meter and water sampling point

The water meter for monitoring abstraction rates and the water tap for sampling water along the transmission line needs to be checked and maintained regularly and/or replaced once beyond repair.

4.3. Reporting and auditing

A flow chart needs to be developed of who provides whom with what information at what intervals, and ensure that all the role-players understand their functions within the reporting system, which includes but is not limited to (DWAF 2004):

- Data from the pump operator to the pump operator supervisor
- Data from the pump operator supervisor to the data capture clerk
- Data reports from the data capture clerk to technical management
- Field reports from the pump operator supervisor to technical management
- Recommendations from technical management to the pump operator supervisor and the pump operator
- Feedback reports to the pump operator on borehole data

Logbooks should be kept for all components of the groundwater supply system, but detailed analyses of the data are only necessary where there is a potential for failure, over-abstraction or for water quality problems. Table 10 and Table 11 show samples of monitoring forms for manually and automatically operated pumps. Reporting in the context of groundwater management requires summarized information on:

- The type of data available for each borehole
- Daily and annual total abstractions per borehole
- Water levels recorded, and the dates recorded per borehole
- Borehole water quality data

Table 10: Sample monitoring form for a manually operated pump (DWAF 2004)

Settlement name:				**Borehole number:**			**Operator name:**		
Date	**Before pumping**		**Time pumping starts T1**	**Pumping water level (m)**	**Time pumping stops T2**	**Flow meter after pumping (kl or m³) F2**	**Total hours pumped (T2-T1)**	**Volume pumped (kl or m³) (F2-F1)**	**Comments include EC measurements; flow measurement; breakdowns and repairs; servicing (e.g. oil changes); water sampling, etc.**
	Flow meter before pumping (kl or m³) F1	**Water level below datum (m)**							

Table 11: Sample monitoring form for an automatically operated pump (DWAF 2004)

Settlement name:				**Borehole number:**		**Operator name**		
Date	**Time of reading**	**Pump on or off**	**Totals**					**Comments include EC measurements; breakdowns and repairs, servicing (e.g. oil changes), water sampling, etc.**
			Water level below datum (m)	**Water meter reading (kl or m³)**	**Hour meter reading (hrs)**	**Volume pumped (kl or m³)**	**Total hours pumped**	

Water quality monitoring measures the physical, chemical, and microbiological parameters to ensure suitability for its intended use. Each country might have own standards for the various uses of water. With regards to drinking water quality standards, an example is provided in Table 12 in the form of the South African National Standard (SANS) 241:2015. SANS sets limits to concentration levels for various constituents and associated risks for domestic water and these can be used as a guideline for evaluating observed concentration levels. Countries could use own standards, preferably aligned to the WHO Guidelines on drinking water quality (WHO 2017).

Table 12: Drinking water standards (SANS 2015)

MICROBIOLOGICAL DETERMINANDS		
	Risk	**Limit**
E.coli or Faecal coliforms count/100ml	health	Not detected
Cryptosporidium species count/10mL	health	Not detected
Giardia species count/10mL	health	Not detected
Total coliforms count/100ml	operational	< 10
Heterotrophic plate count/1ml	operational	< 1000
PHYSICAL, AESTHETIC, OPERATIONAL AND CHEMICAL DETERMINANDS		
Free chlorine mg/L	health	≤ 5
Monochloramine mg/L	health	≤ 3
Colour Pt-Co	aesthetic	< 15
Conductivity at 25degC mS/m	aesthetic	≤ 170
Total dissolved solids mg/L	aesthetic	≤ 1200
Turbidity	operational	≤ 1
	aesthetic	≤ 5
pH at 25degC	operational	≥ 5 and ≤ 9.7
Nitrate as N mg/L	health	≤ 11
Nitrite as N mg/L	health	≤ 0.9
Nitrate-Nitrite ratio		≤ 1
Sulphate as SO4- mg/L	health	≤ 500
	aesthetic	≤ 250
Fluoride as F- mg/L	health	≤ 1.5
Ammonia as N mg/L	aesthetic	≤ 1.5
Chloride as Cl- mg/L	aesthetic	≤ 300
Sodium mg/L	aesthetic	≤ 200
Zinc mg/L	aesthetic	≤ 5
Antimony µg/L	health	≤ 20
Arsenic µg/L	health	≤ 10
Barium µg/L	health	≤ 700

Boron µg/L	health	≤ 2400
Cadmium µg/L	health	≤ 3
Chromium µg/L	health	≤ 50
Cobalt µg/L	health	≤ 500
Copper µg/L	health	≤ 2000
Cyanide µg/L	health	≤ 200
Iron µg/L	health	≤ 2000
	aesthetic	≤ 300
Lead µg/L	health	≤ 10
Manganese µg/L	health	≤ 400
	aesthetic	≤ 100
Mercury µg/L	health	≤ 6
Nickel µg/L	health	≤ 70
Selenium µg/L	health	≤ 40
Uranium µg/L	health	≤ 30
Vanadium µg/L	health	≤ 200
Aluminium µg/L	operational	≤ 300
Total organic carbon mg/L	health	≤ 10
Chloroform µg/L	health	≤ 300
Bromoform µg/L	health	≤ 100
Dibromochloromethane µg/L	health	≤ 100
Bromodichloromethane µg/L	health	≤ 60
Trihalomethane ratio		≤ 1
Microcystin µg/L	health	≤ 1
Phenols µg/L	aesthetic	≤ 10

A data management system should be established which consists of a physical filing system and an electronic data system such as GIS. The data capture clerk needs to maintain a physical file with the log sheets for each borehole filed. This must include a cover sheet indicating what data has been received for each borehole, as well as recording what data has been captured electronically. Physical copies of the reports generated by the electronic management system, water quality sample analyses and field reports must also be stored in the physical filing system. The electronic data management system would either be a spreadsheet or dedicated groundwater management software. For example, groundwater management plan for the Chris Hani District Municipality, South Africa which included a groundwater information management system. The groundwater management information system allows storing static point information and time series data.

The static point information is background information about a waterpoint, and is arranged in four categories (DWAF 2004):

- **Location and Identity** – covers where the waterpoint is located, under whose responsibility it is, and the details of the operator.
- **Borehole Information** – includes details of where water was found during drilling, and information on the size and depth of, and equipment installed in, the borehole.
- **Yield and Pumping Information** – covers recommendations (normally from a hydrogeologist) for how the borehole is to be used.
- **Monitoring** – covers what must be monitored, at what intervals, and who has recommended the monitoring.

The time series data is the actual monitoring information collected regularly by the scheme operators. It is called "time series" because it enables viewing how information changes over a period of time. The data that can be stored includes (DWAF 2004):

- **Groundwater Level** – the level of the groundwater below the ground.
- **Abstraction** – how much water has been pumped from the source.
- **Monthly Rainfall**
- **Water Quality Determinands** – all commonly sampled determinands for drinking water quality and groundwater quality.

5. CONCLUSION AND RECOMMENDATIONS

All groundwater schemes are likely to fail, whatever the underlying groundwater resource, if provisions for O&M are lacking. Such failures are often blamed on the resource itself (i.e. “the groundwater dried up”), making groundwater a less attractive option for domestic water supply to policy makers and beneficiaries. Resource planning needs to consider the recurrent (O&M) costs in addition to groundwater infrastructure capital costs. For many parts of Africa, groundwater is the most obvious and potentially most viable water supply source. To succeed however, water supply schemes should not only rely on good aquifers but also on appropriate functioning institutions and infrastructure.

In order to ensure efficient and effective O&M in the SADC Region, it is recommended that individual Member States develop or strengthen their own O&M guidelines based on this guidance document.

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CONTACT DETAILS:

205 Nelson Mandela Drive
University of the Free State, Dean Street
Bloemfontein, South Africa

Tel: +27 51 401 7734
E-mail: info@sadc-gmi.org

GROUNDWATER MANAGEMENT INSTITUTE