GROUNDWATER MANAGEMENT INSTITUTE

Training manual for operation and maintenance of groundwater infrastructure in SADC

L2K2 Consultants (Pty) Ltd

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FOREWORD

The development of infrastructure in the Southern African Development Community (SADC) region is critical to job creation, economic growth and poverty reduction. Unfortunately, there has been chronic underfunding of infrastructure, resulting in an infrastructure gap. To close the infrastructure gap, an important lever is to optimise existing assets through proper operation and maintenance. In this regard, the SADC Groundwater Management Institute (SADC-GMI) has commissioned this training manual for operation and maintenance of groundwater infrastructure in SADC. The SADC-GMI is established as a regional centre of excellence on groundwater management on behalf of and under the strategic guidance of the SADC Secretariat, Directorate of Infrastructure and Services – Water Division, in Gaborone, Botswana.

In the SADC region there are a large variety of groundwater schemes and technologies, ranging from relatively simple spring protections and hand-dug wells equipped with ropes and buckets, to more sophisticated handpumps and mechanised boreholes. At the upper level of complexity are multi-borehole schemes with storage buffers and extensive reticulation serving large areas, with complex operation and maintenance characteristics. Groundwater forms an important life sustaining resource which most rural communities, about 70% of the population, in the SADC depend on. It is thus imperative that the infrastructure that brings the water to communities is always kept functional. It has become clear that limited accessibility to groundwater resources in most areas is more frequently a function of the functionality of the infrastructure than the physical availability of groundwater resources. Non-functionality of the infrastructure is also related to infrastructure vandalism which is prevalent through the SADC. This non-functionality of groundwater supply schemes affects the achievement of the Sustainable Development Goal (SDG) of clean water for all (SDG 6).

The purpose of this training manual is to provide support for groundwater infrastructure development solutions that can improve management of small groundwater schemes throughout SADC. This reflects our commitment to promote sustainable groundwater management and solutions to groundwater challenges in the SADC region through building capacity, providing training, advancing research, supporting infrastructure development, and enabling dialogue and exchange of groundwater information.

I sincerely hope that this operation and maintenance training manual for groundwater infrastructure becomes a catalyst to capacitate professionals throughout the region to provide essential services to their communities. This manual is suitable for water supply managers, technical staff, plant operators and water practitioners. However, the manual speaks to issues that might be of value to other staff such as personnel in Finance Departments.

James Sauramba
Executive Director
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PREFACE

Operation and Maintenance (O&M) of a groundwater source or wellfield includes all the tasks needed to keep the system functional. O&M includes regular tasks such as replacement of worn parts, refuelling, servicing, cleaning and monitoring, as well as dealing with irregular breakages, outages and malfunctions. Long-term, successful O&M needs suitably skilled and motivated personnel and depends in turn on a set of institutional and organisational systems that are viable financially and politically.

On average, well-designed O&M programs pay for themselves many times over, making O&M a sound investment. For example, Whinnery (2012) did a cost-benefit study of groundwater supplies in rural areas of developing countries and found that benefits outweighed costs more than 40 times when a groundwater supply system was properly constructed, operated and maintained. It was calculated that a 3 to 5-fold increase in net value is realised with the implementation of a suitable O&M program (Whinnery 2012).

Despite the clear need for better groundwater scheme O&M, comparatively little has been written about the subject in the SADC region. Compared with technical hydrogeological resources such as maps or drilling guidelines, O&M guidelines and manuals are scarce. A few groundwater O&M manuals and other resources are available in the international literature - e.g. GoI (2013), U.S. EPA (1988), or Schneider (2014) or from websites such as the International Water Association[1]. However, international resources for groundwater O&M are in relatively short supply – a curious situation given that it is often O&M that "makes or breaks" a groundwater scheme. There is a clear need for better guidelines on O&M, more studies on what constitutes successful O&M, and a renewed effort by planners, hydrogeologists and engineers to consider O&M in the design stages of every scheme. Sometimes it is tempting to see hydrogeological or engineering design issues as the primary impediments to installing a successful groundwater supply scheme, but it may in fact be O&M that in the long run controls scheme longevity and even viability.

O&M is sometimes thought to be a simple technical matter that is easy to solve. Yet as the persistent breakdowns in water supply systems in many smaller towns

[1] https://iwa-network.org/projects/operation-and-maintenance-network/

and villages in SADC illustrate, adequate O&M relies on a surprisingly complex set of organisational functions and competencies. Suitable human resources, access to the right tools, an inventory of spare parts, reliable transport, mechanisms for reporting breakdowns, accountability frameworks, and assured, regular funding are all vital. Taljaard (2008) states: “There are many factors that determine the quality of O&M. The main ones are quality of staff, access to dedicated O&M funds, and the quality of records and analysis of information”. Reducing the technical complexity of a system may only change the nature of the O&M tasks, rather than making overall O&M simpler and cheaper. For example, more complex and higher yielding water supply systems (e.g. a large groundwater wellfield or a managed aquifer recharge (MAR) scheme) may have technically more demanding O&M requirements but may be logistically (or institutionally) simpler (Gibson 2011). In contrast, lower-yielding single boreholes in a distributed network may only need basic and less frequent mechanical attention, but the logistical challenge of monitoring them from a distance and visiting them regularly can be surprisingly high. O&M is anything but simple.

Technical O&M considerations must, in turn, be fitted to the institutional environment in which the O&M will take place. There is still too little guiding material on the institutional arrangements necessary to implement and sustain O&M of groundwater schemes in the SADC region, and it is often up to local authorities or even communities to devise and sustain O&M of water supply schemes once the initial scheme construction is completed and the construction company has departed. Development experts working on groundwater schemes in many parts of SADC recognise this, and favour “appropriate technology” solutions such as the Afridev handpump or basic spring protections that are repairable by local people with limited resources. Ironically, it is often in those environments where there is little outside support for O&M, that O&M requirements may be taken most seriously at the scheme planning stage. There are lessons to be learned from such rural water supply schemes with a measure of self-sufficiency “built-in” to the design. On the other hand, if it is assumed that O&M will only be carried out by community members at low cost, the available technology options and the potential yield of the scheme may be limited.

Successful O&M of larger groundwater schemes often requires collaboration between different entities or organisations, and any breakdown in the relationship between collaborating partners can derail O&M as effectively as a lack of funds or personnel. Difficulties with cost-recovery may also complicate matters. Routine O&M functions are often the first to be cut from budgets when funds grow short, since pressing and immediate needs naturally take budgetary priority. Unfortunately, temporary budget cuts often become permanent. Without strong institutional systems, as roles and personnel change the final responsibility for O&M may become obscure. Routine tasks may slowly become rare and exceptional. Trained personnel may resign or be hired elsewhere, with the most valuable skills being the hardest to retain and the first to leave. A key factor in O&M success is management recognition of the essential need for O&M. In some circumstances it is more difficult to ensure institutional continuity of O&M than it is to carry out the tasks themselves, and it may even be more difficult and expensive to establish systems for O&M than it is to install the infrastructure in the first place.

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LIST OF ACRONYMS

AC	Alternating current
CBM	Community based maintenance
DC	Direct current
IBTs	Increasing block tariffs
M&E	Monitoring and evaluation
NRW	Non-Revenue Water
NGO	Non-Government Organization
OECD	Organisation for Economic Co-operation and Development
O&M	Operation and maintenance
RCWMP	Rural Water Supply Management Plan
REST	Representational State Transfer
RWSN	Rural Water Supply Network
SADC	Southern African Development Community
SADC-GMI	SADC Groundwater Management Institute
SDG 6	Sustainable Development Goal of clean water for all
SKAT	Swiss Centre for Appropriate Technology
SWOT	Strengths, Weaknesses, Opportunities and Threats
VLOM	Village level operation and maintenance
WASH	Water, Sanitation and Hygiene

WSUP Water and Sanitation for the Urban Poor

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Photo credit: SADC-GMI

1. INTRODUCTION TO THE OPERATION AND MAINTENANCE TRAINING MANUAL

- Explain the purpose of the operation and maintenance (O&M) training manual
- Understand the challenges of O&M of groundwater infrastructure in the Southern African Development Community (SADC)
- Identify the target group for the training manual
- Understand the strengths, weakness, opportunities and threats for O&M of groundwater infrastructure in SADC Members States
- Set-out the structure for the O&M training manual

1.1. About the manual

This O&M training manual (O&M manual) is a guide to assist water supply managers, technical staff, plant operators, water practitioners and others to manage groundwater infrastructure. O&M activities ensure that the infrastructure delivering potable water to consumers is always operational. The information in this manual is derived from International Standards and best practices, as well the authors' experience in the SADC region.

The SADC Groundwater Management Institute (SADC-GMI) has commissioned this O&M manual. The SADC-GMI is established as a regional centre of excellence on groundwater management on behalf of and under the strategic guidance of the SADC Secretariat, Directorate of Infrastructure and Services – Water Division, in Gaborone, Botswana.

The vision of the SADC-GMI is to ensure the equitable and sustainable use and protection of groundwater in the SADC region, as well as to be a centre of excellence in the areas of groundwater management and management of groundwater dependent ecosystems. The role of the SADC-GMI is to:

Promote sustainable groundwater management and solutions to groundwater challenges in the SADC region through building capacity, providing training, advancing research, supporting infrastructure development, and enabling dialogue and exchange of groundwater information Conduct and support SADC Member States in groundwater research, and serve as a focal interlocutor with national, regional and international groundwater initiatives.

The term O&M as used in this manual means operation and maintenance. Maintenance can be further subdivided into preventative and corrective maintenance (Box 1-1).

Box 1-1: Operation and maintenance definitions (MoWE 2013)

Operation refers to timely and daily operation of the components of a water supply system such as pumping, transmission, treatment 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 condition. Maintenance includes preventative maintenance and corrective maintenance.

- **Preventative maintenance** includes actions carried out according to a regular schedule to keep equipment or structures operating effectively and to minimize unforeseen failures. It involves activities such as network inspection, cleaning and greasing of mechanical parts and replacement of items with a limited lifespan. It sometimes includes minor repairs and replacement of certain components/parts as informed by routine examinations.
- **Corrective maintenance** includes actions to either repair or restore malfunctioning equipment or structures to ensure effective operating conditions through either scheduled or unscheduled work. These actions may result from problems discovered during preventive maintenance or because of failures during operation

Potable and readily available water is important for public health, whether it is used for drinking, domestic use, food production or recreational purposes. Absence of or inadequate potable water supply services exposes citizens to preventable health risks including diseases such as cholera, Covid-19, diarrhoea, dysentery, hepatitis A, typhoid, and polio. Figure 1-1 shows vicious and virtuous cycles of ineffective and effective O&M systems, respectively. An ineffective O&M system perpetuates a vicious cycle of poverty.

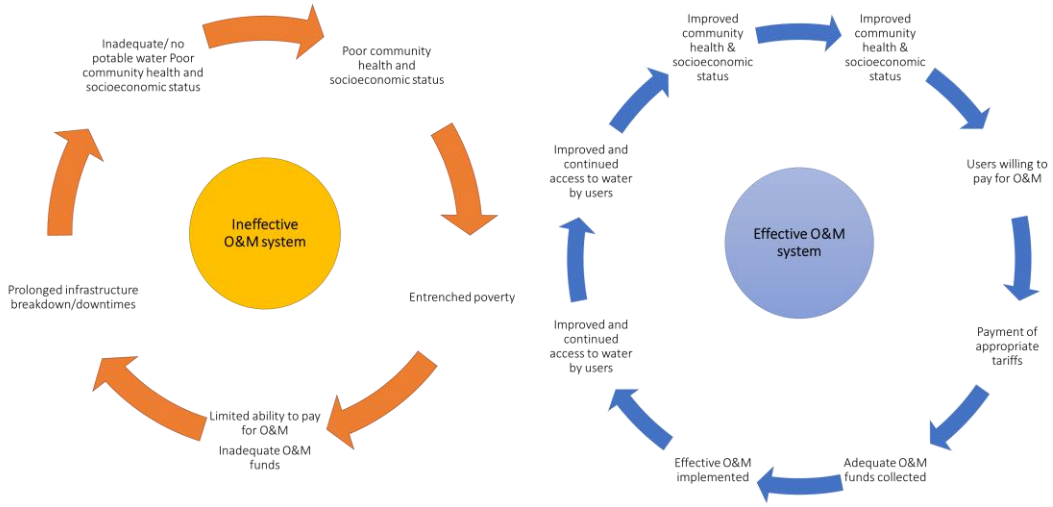


Figure 1-1: Vicious and virtuous cycles of ineffective and effective O&M systems (SADC-GMI 2019b)

There are several undesirable consequences resulting from poor O&M, some of which are (SADC-GMI 2019b):

- Intermittent water supplies due to wastage and depletion
- Poor water quality due to contamination and inadequate treatment
- Deterioration of pipes, equipment, and service
- Increased cost of maintenance which could ultimately result in abandonment of water supply schemes
- Vandalism of non-functioning systems

These lead to (SADC-GMI 2019b):

- Frequent breakdowns/extended down times
- Shortened life of infrastructure
- Dry and collapsed boreholes
- Water scarcity resulting in the prevalence of water borne diseases due to use of unprotected and unsafe water sources
- School dropouts particularly for the girl child (Box 1-2)
- Abandonment of schemes and water facilities
- Impaired livelihoods: most rural communities rely on groundwater for gardening activities to produce vegetables for subsistence and as a source of income through selling the vegetables, and ineffective O&M will have a negative impact

Box 1-2: Sanitation and water supply in schools and girls' educational progression in Zambia (Agol et al 2018)

There is much anecdotal evidence related to the importance of Water, Sanitation and Hygiene (WASH) in schools for girls' educational progression, yet there is a lack of comprehensive quantitative studies on linkages between WASH and educational indicators disaggregated by gender and grade. Agol et al. (2018) aimed to fill that gap by testing the hypothesis that the presence of water and sanitation facilities in schools can increase female-to-male enrolment ratios and reduce repetition and drop-out-ratios for girls, especially at ages when they menstruate. Quantitative analyses were undertaken of Education Management Information System data collected from over 10,000 schools in Zambia, to explore relationships between WASH facility provision in schools and enrolment, repetition and drop-out ratios disaggregated by gender and grade. Results indicated that improved sanitation provision in schools was correlated with high female-to-male enrolment ratios, and reduced repetition and drop-out ratios, especially for girls. A t-test revealed significant gender differences in grades 5–8 when many girls start to experience their menstrual cycle. Improved water supply in schools, however, did not reveal the same relationship. The findings confirm possible linkages between adequate toilets in schools and educational progression of girls.

The main aim of O&M is to ensure the efficiency, effectiveness and sustainability of a water supply (Castro *et al* 2009). Limited access to groundwater resources in many areas due more to the functionality of the infrastructure than the physical availability of groundwater resources (Cobbing *et al* 2015). Functionality of the infrastructure is also related to infrastructure vandalism (Figure 1-2).

Figure 1-2: Examples of poor O&M and vandalism of groundwater infrastructure (Photo credits: Mark Schapers)

The non-functionality of groundwater supply schemes affects the achievement of 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 modernising 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). It has been shown that one in four handpumps in [SADC] are non-functional at any point in time (Foster *et al* 2019; Figure 1-3). For the provision of drinking water, as set out in SDG 6.1, emphasis can no longer solely be placed on the source of water provision but must be placed on the service level being delivered to the household (Kalin *et al* 2019).

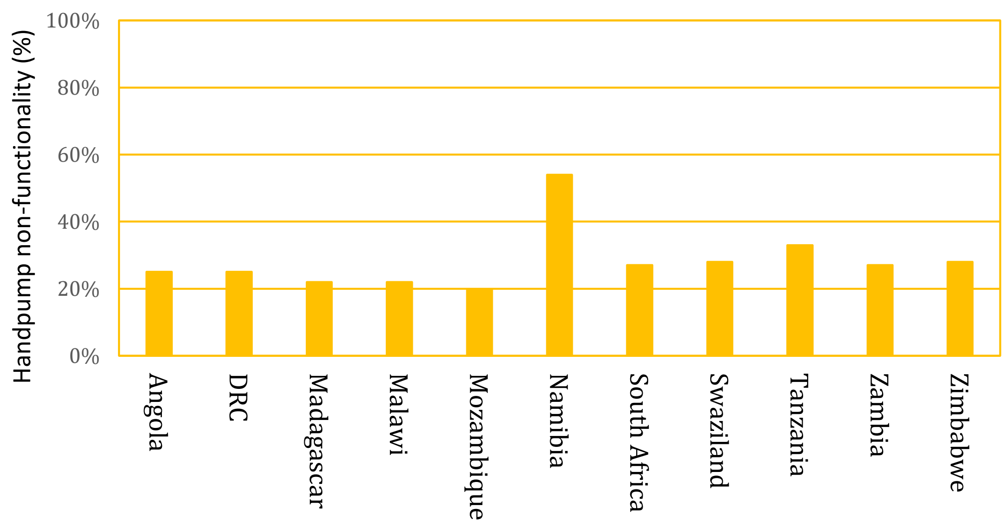


Figure 1-3: Handpump non-functionality statistics for selected SADC countries (Foster et al 2019)

Whilst a significant percentage of hand-pumps are non-functional, there are also a large percentage that are partly or poorly functioning. For example, in a rural water point functionality survey (borehole, gravity fed system, etc.) in Malawi the following statistics were derived. They have been disaggregated into 4 distinct classes, depending on the functionality of the water points (Kalin *et al* 2019):

1. **Functional** (52.9%)—where the water resource asset is functioning as designed and providing improved water service to the community as designed

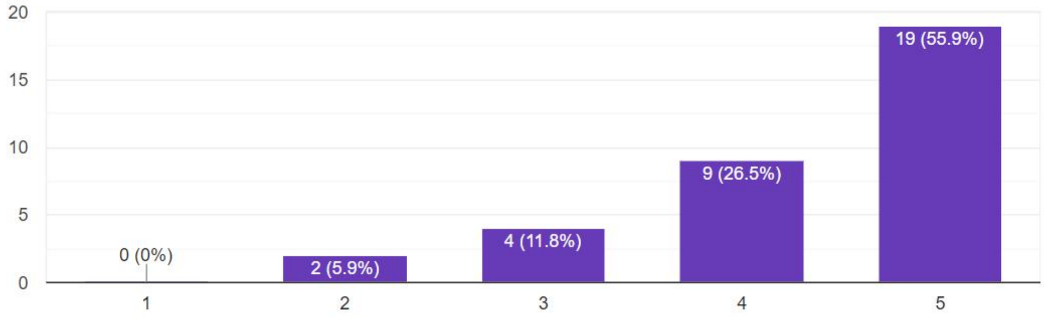
2. **Partially Functional**, i.e., functional but with problems (21.6%)—where the water resource asset provides water intermittently because of a range of issues such as:
   - Poorly installed water point affected by decline in groundwater table resulting in a dry water point during some months
   - Poorly installed water points or low aquifer yield resulting in a water point running dry daily
   - Poorly maintained water points or water system resulting in limited access to water throughout the year
   - Poorly installed water points into a water resource that is contaminated or has been contaminated (e.g., salinity and co-location of pit latrines and waste)
   - Poorly managed water point (issues with tariff setting/collection, non-professional management, mismanagement of resources, lack of capacity)
3. **Non-Functional** (22.3%)—where the water resource asset does not supply water
4. **No Longer Exists or Abandoned** (3.2%)—where the water resource asset has been fully abandoned

This manual encompasses the key technical and institutional aspects of O&M of groundwater infrastructure crucial for groundwater sustainability. Although all care is taken to ensure integrity and the quality of this publication and the information herein, no responsibility is assumed by the SADC-GMI and its Cooperating Partners nor the authors and its organisations for any damage to the property, or persons because of the operation or use of this publication and/or the information contained herein.

1.2. Operation and maintenance challenges

The following operation and maintenance challenges are identified (WEF 2014):

- **Insufficient public funding for infrastructure**: Many SADC countries lack the financial resources to allocate sufficient budgets for water infrastructure, and most peri-urban and rural communities in SADC lack the means to pay for O&M of groundwater infrastructure. Further, groundwater has its own complexities, which can make it less bankable than surface water. In many developing countries that have limited financial resources, groundwater agencies struggle to deliver on the minimum number of critical O&M tasks (Table 1-1).



Range 1 -5 from unimportant to critical

Figure 1-4: The importance of insufficient public funding for infrastructure to O&M challenges as identified by respondents to a survey[2]

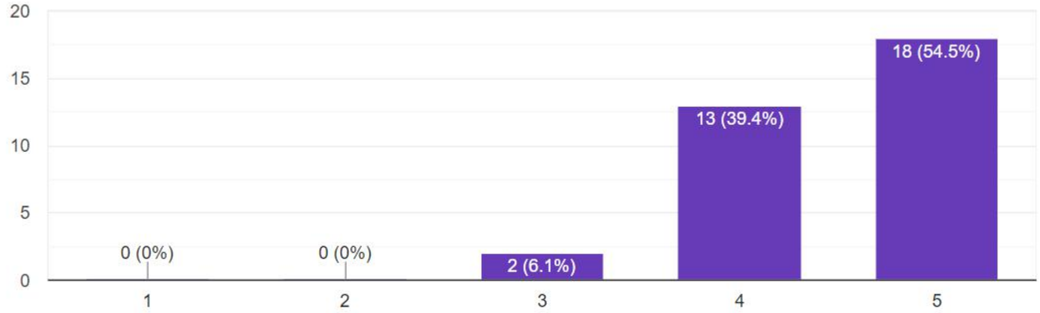
Table 1-1: A typical list of critical O&M tasks (WIN-SA 2015)

Task	Description
Monitoring of water levels	Can be done using a dip meter but may be more efficient and reliable to use automated loggers once initial trends have been established. Water level data needs to be entered into a database or report to provide the "bigger picture" of the groundwater resource. At some sources it is impossible to access the water level.
Monitoring of water quality	Physical, macro, trace and microbiological parameters need to be considered. Sampling protocols and methods of analysis need to be followed. Basic quality monitoring can be done by field personnel by measuring physical parameters such as the electrical conductivity of water.
Monitoring of pumping rates	Can be done using a flow meter fitted to each borehole, or by other methods such as electricity or diesel consumption. Information needs to be recorded in a database or report
Monitoring of electricity consumption	Can be done using electricity meters on each borehole power supply, or even by monitoring electricity charges. Information needs to be recorded in a database or report

[2] A survey was conducted amongst SADC SADC-GMI focal persons and other groundwater experts: (a) To identify the challenges faced by the people responsible for O&M of groundwater schemes; and (b) following on from that, identify the training requirements and support interventions needed to address the challenges.

Task	Description
Monitoring of water demand	Measuring or estimating consumption by various sectors (domestic, industrial, agricultural, etc.). Information needs to be recorded in a database or report
Cleaning and maintaining above-ground infrastructure	Visual checks, partial dismantling, cleaning. As recommended by manufacturers. Protection from flooding also necessary.
Cleaning and maintaining submersible pumps	Involves lifting pump out of borehole using special equipment. Can be difficult and expensive. May only be necessary when pump performance declines. Exact schedule depends on hydro-geochemical conditions.
Servicing of diesel engines	Where surface diesel engines are used for positive displacement pumps, these must be serviced and worn parts replaced.
Cleaning and maintaining boreholes	Can be done by over-pumping, surging, acidification, jetting or other methods. May require pumps to be removed. May only be necessary when borehole performance declines. Exact schedule depends on hydro-geochemical conditions. Prior Inspection of the condition of the boreholes by borehole cameras may be useful in this regard.
Cleaning and maintaining treatment facilities	Infrastructure commonly used to treat groundwater such as sand filters and chlorination systems are robust but not infallible. They need to be maintained and serviced in accordance with the manufacturer's recommendations (e.g. sand needs cleaning or changing in sand filters, chlorine supplies need to be restocked, etc.).
Cleaning and maintaining storage reservoirs	Checking for leaks should be a routine task. Removal of silt via a scour valve or even by draining and manual cleaning may be needed at times.
Electrical systems	Visual checks and testing with specialised equipment
Security of installations	All installations should be secure and off-limits to unauthorised people. Valuable infrastructure should be located underground where possible. Repairs need to be done promptly to prevent further deterioration
Groundwater protection zone security	If a protection zone has been established, encroachment by people or animals needs to be prevented (fences, etc. need maintaining). Negotiation with communities likely to be necessary. Status of the protection zone needs to be monitored, and some policy regarding enforcement needs to be in place.
Reporting	Data from all the tasks listed above needs to be recorded and passed to the relevant management organisation or responsible person. Ordering and budgeting for new parts is important

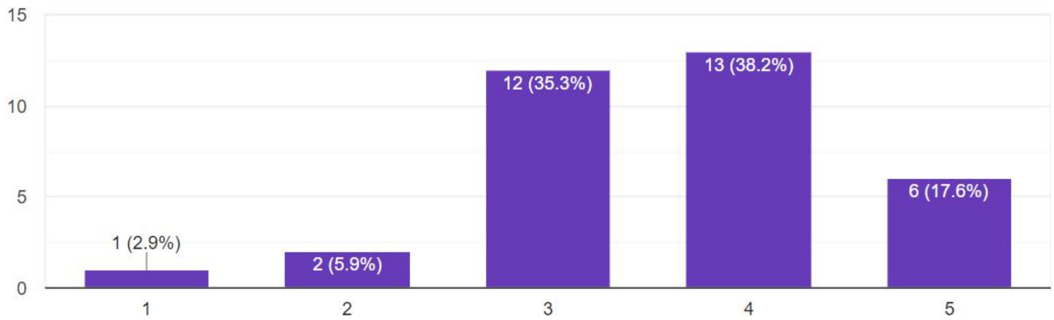
– **Annual budgets not suited to stable multi-year O&M needs:** A typical source of funding for O&M requirements is annual appropriations from the government budget. However, these are vulnerable to political expediency and so are often ill-suited to O&M, which requires a very predictable and sustainable source of funding.



Range 1 -5 from unimportant to critical

Figure 1-5: The importance of annual budgets not suited to stable multi-year O&M needs to O&M challenges as identified by respondents to a survey

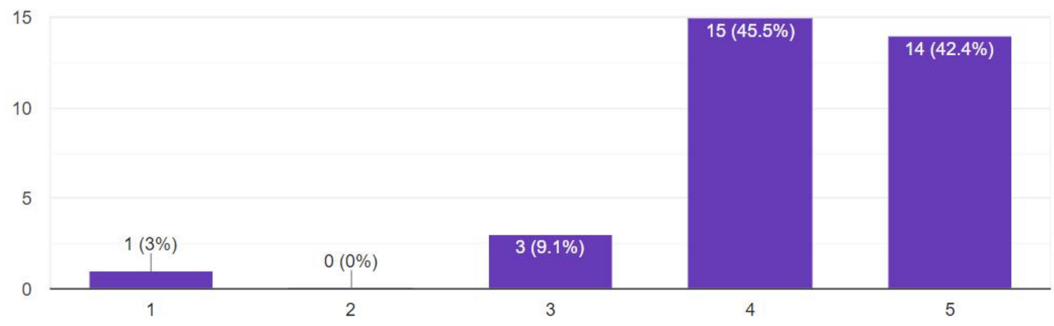
– **Lack of skilled staff:** In many countries, the key constraint to implementing all of O&M best practices is the shortage of skilled staff.



Range 1 -5 from unimportant to critical

Figure 1-6: The importance of lack of skilled staff, as engineers prefer build-projects to O&M challenges as identified by respondents to a survey

– **No life cycle view in design and build; no integrated budget:** The proposed approach does not limit itself to annual cycles but engages in whole life-cycle analysis and decision-making.



Range 1 -5 from unimportant to critical

Figure 1-7: The importance of no life-cycle view in design & build; no integrated budget to O&M challenges as identified by respondents to a survey

– **Inappropriate system design:** No matter how good the management of a water supply facility is, if it is not technically well designed, it will operate inefficiently. It is not uncommon to find water supply schemes that have been badly designed, poorly constructed and using technologies which are inappropriate. When a facility is improperly designed and constructed, even with the best will in the world, it will not perform satisfactorily.

– **Poor borehole drilling technical specifications**: The cost and quality of work depends much on the technical specifications and as such, they need to be clear and of high quality. Failure to develop good borehole drilling and construction technical specifications results in poor workmanship which would in turn impact O&M. Borehole drilling is a specialised field that requires specialised borehole drilling equipment and skilled personnel. Since the bulk of the drilling operations are carried out beneath the ground, it is imperative that reputable, experienced and skilled companies be engaged for such services. The technical specifications for borehole drilling need to be drawn up by qualified and experienced personnel who should plug all the possible loopholes which contractors could use to compromise quality works. Supervision of the drilling works also requires equally qualified and experienced personnel because an untrained eye will find it impossible to detect flaws in the drilling and construction of the boreholes. A larger proportion of costs goes into the drilling and construction of boreholes than into the superstructure (above the ground components) such as handpumps. Poor workmanship can result in the borehole being abandoned or in a drastic reduction of its life expectancy. O&M costs also skyrocket for poorly constructed boreholes (Box 1-3).

Box 1-3: Series of videos demonstrating good practice in borehole drilling (Casey 2016)

WaterAid, together with the Rural Water Supply Network (RWSN), UNICEF and Resource Centre and Consultancies for Development (SKAT) are behind a movement to promote higher standards of water supply implementation. Recently four videos were launched setting out critical steps by which to ensure boreholes have the best chance of success. – Good quantities of groundwater cannot be found everywhere. This video highlights the importance of good borehole siting. – Drilling contractors cannot be left to construct boreholes without full-time qualified supervision; spot-checking is not enough to ensure a good job will be done. This video highlights the importance of enlisting qualified drilling supervision. – Good drilling contract management requires an understanding of the uncertainties and a series of steps that will ensure better drilling. – Find out about casing and screen, gravel pack, and the sanitary seal and see that silting is one reason that boreholes fail. Link to videos: https://washmatters.wateraid.org/blog/a-borehole-that-lasts-a-lifetime

- **Aging infrastructure**: The non-refurbishment and replacement of aging infrastructure leads to frequent breakdowns.
- **Non-availability and high cost of spare parts:** Easy and affordable access to spare **parts** are crucial factors in maintaining a groundwater scheme. As in any operation, parts, through wear and tear, become old and require replacement.
- **Vandalism:** This results in frequent down-time and higher O&M costs with additional burden placed on vulnerable communities.
- **Weak planning, regulation and coordination:** The project was poorly conceived (e.g. a project that only increased the number of water points, or sanitation facilities, as a way of improving accessibility to these services, without considering the wider range of factors needed to sustain the benefits). The performance of the project facilities was either not assessed, or was insufficiently monitored, during the O&M phase of the project cycle.
- **Limited involvement of stakeholders**: There was minimal or no community involvement and participation in the project and hence the communities did not have a sense of project ownership. Demand and community involvement (of both men and women) are key to generating long term community commitment to improved services and in

sustaining the services. Community involvement and participation also makes the community members responsible for the choice of technology and makes community members aware of the financial, managerial and technical implications of their choice, including future O&M tasks associated with the technology

1.3. Target group

The target audience for the O&M Manual includes water supply managers, technical staff, plant operators and water practitioners (Box 1-4). However, the O&M Manual speaks to issues that might be of value to other staff such as personnel in Finance Departments.

Box 1-4: Example of O&M functions

> I am responsible for coordinating all water related developments in the district, starting from construction to operation and maintenance. I coordinate participatory and monitoring of community-based management activities including trainings and O&M of water infrastructure in the district. I am also responsible for ensuring that water supply related data is up to date. I am also responsible for ensuring that only right and appropriate technologies are used in the district.
>
> *Kondwani Andreah, District Water Development Officer, Mangochi, Malawi*

A successful O&M program requires cooperation, dedication, and participation at all levels (including political and technical) and cannot succeed without everyone involved understanding the basic principles and rhythms of O&M and supporting the cause. Table 1-2 lists several key factors that have been identified in the area of groundwater infrastructure maintenance for improved efficiency.

Table 1-2: Key factors for improved efficiency of groundwater infrastructure maintenance (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

Factors	Remarks/Consequences
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

1.4. Strengths, weaknesses, opportunities and threats (SWOT) for groundwater infrastructure operation and maintenance

A SWOT analysis was performed to assess strengths, weaknesses, opportunities and threats for groundwater infrastructure operation and maintenance in SADC-countries.

1.4.1. Strengths

- The region has coordinating mechanisms to leverage best-practices and knowledge amongst SADC Members States
- Blended government support and cost recovery from users

1.4.2. Weaknesses

- Ad-hoc reactive approach to O&M
- Insufficient data on asset condition and use, O&M spend
- Limited bench marking and evidence on O&M impact
- Lack of institutional capacities and skilled staff
- Lack of independent, professional public agencies
- Lack of coordination across functions and agencies
- No life-cycle view in design & build; no integrated budget (limited view of future O&M requirements
- Little private-sector participation & competition
- Level of groundwater infrastructure functionality throughout

SADC

- Basic O&M outsourcing

1.4.3. Opportunities

- Address the needs of vulnerable communities in SADC
- Improve the health profile of communities
- Guaranteed service approach to O&M
- O&M outsourcing

1.4.4. Threats

- Insufficient multi-year funding for O&M of groundwater infrastructure
- Corruption, bureaucracy, lack of accountability
- Groundwater infrastructure at risk of failure
- Public health risks
- Over-reliance on external support agencies
- No full cost recovery from users

1.5. The training manual

Chapter	Chapter descriptions
Introduction	– Explain the purpose of the O&M training manual – Understand the challenges of O&M of groundwater infrastructure in the SADC – Identify the target group for the training manual – Understand the strengths, weakness, opportunities and threats for O&M of groundwater infrastructure in SADC Members States – Set-out the structure for the O&M manual
Infrastructure sustainability and resilience	– Explain the common challenges to implementing resilient infrastructure solutions in SADC – Define infrastructure and resilience including the four dimensions of sustainable infrastructure – Discus the factors undermining groundwater infrastructure sustainability and resilience
Institutional arrangements of O&M	– Develop an understanding of the legislative and regulatory frameworks necessary for O&M – Provide guidance regarding the institutional roles and

Chapter	Chapter descriptions
	responsibilities required for O&M of groundwater schemes as well as the importance of developing institutional capacity to enable effective O&M – Present a typology of maintenance services
Financing of operation of maintenance of groundwater schemes	– Present the typical cost structures of groundwater supply schemes – Understand the primary cost drivers of operation and maintenance – Consider policy considerations for O&M – Being able to undertake basic budgeting for O&M – Understanding the various tariff structures and means to collect revenue
Financial management	– Understand the basic principles of financial management for O&M of groundwater schemes – Consider policy considerations for O&M – Being able to undertake basic budgeting for O&M – Understanding the various tariff structures and means to collect revenue
Non-revenue water	– Develop an understanding of the water balance and its different components – Understand the importance of reducing water losses (physical and commercial) as well as identifying high-level solutions for these losses
O&M of groundwater sources (wells and boreholes)	– Recognise the difference between boreholes and wells (shallow and deep) – Understand what tasks are required for general O&M of the various water supply sources for their effective functioning – Troubleshoot and establish appropriate remedial actions
O&M of positive displacement pumps: piston and cylinder	– Understand how the pump works – Identify the components of the pump – Learn how to specify the correct size pump for the borehole application – Understand the requirements of pump operation – Understand the pump maintenance requirements – Be able to troubleshoot common pump problems
O&M of positive displacement pumps: rotor stator	– Understand how the pump works – Identify the components of the pump – Learn how to specify the correct size pump for the borehole application – Understand the requirements of pump operation – Understand the pump maintenance requirements

Chapter	Chapter descriptions
	– Be able to troubleshoot common pump problems
O&M of centrifugal submersible pumps	– Understand how the pump works – Identify the components of the pump – Learn how to specify the correct size pump for the borehole application – Understand the requirements of pump operation – Understand the pump maintenance requirements – Be able to troubleshoot common pump problems
O&M of spring chambers	– To understand the siting and construction basics of spring boxes – To appreciate the need for pollution and contamination prevention at springs – To understand O&M issues related to springs
O&M of water treatment, transmission and storage systems up to the standpipe	– Understand the components and function of the water supply scheme – Understand the requirements of the scheme operation – Understand the scheme maintenance requirements
O&M of groundwater monitoring infrastructure	– Understand the importance of groundwater monitoring – Describe the of monitoring infrastructure – Understand the groundwater monitoring infrastructure O&M tasks
Monitoring and evaluation	– Describe the importance of monitoring and evaluation – Understand the role of monitoring and evaluation in improving the O&M process – Provide information on sustainability assessment tools
Developing an O&M plan	– Understand the need for an O&M plan – Describe the components of and O&M plan

1.6. Exercises

1.6.1. Exercise: Value proposition of groundwater and factors influencing groundwater bankability

Although groundwater contributes to livelihoods throughout the SADC-region, it is rarely seen as a resource that requires investment by both public and private institutions. Perhaps we should not define groundwater by what it is – representing 98% of freshwater not tied up as ice and snow polar ice sheets, glaciers and snowfields – but by what it does: provides water security or creates new opportunities for agricultural entrepreneurs. In this exercise, the participants are to develop the value proposition of groundwater in SADC (60 min).

For: List target customers or beneficiaries.
Who: Define the need or opportunity i.e. what critical issue for customer or beneficiaries?
The: Name the product or service and place the product or service into a generally understood category.
That: Quantify the benefits of the product or service. Identify the single most compelling benefit.
Unlike: List of competitors and competitive alternatives.
Our: The primary differentiation of the product or service.

Box 1-5: Example to develop value proposition (University of Oxford n.d.)

For: Small scale rural farmers using surface irrigation	**For:** List target customers or beneficiaries
Who: Lose over 50% usable water to surface runoff annually	**Who:** Define the need or opportunity, i.e. what critical issue for customer or beneficiary?
The: IDE-India low-cost drip irrigation system is an advanced irrigation device	**The:** Name the product or service or concept and place the product, service, or concept into a generally understood category
That: Inexpensively and eliminates water loss from surface irrigation	**That:** Quantify the benefits of the product, service, or concept. Identify the single most compelling benefit
Unlike: Currently used, expensive and large-scale drip systems	**Unlike:** List of competitors and competitive alternatives
Our: Product is a customized, modular and scalable system that consistently reduces water loss and increases farmers' yields	**Our:** The primary differentiation of the product, service or concept

You need to prepare an investment opportunity to Banker A to build groundwater infrastructure to supply an urban town. List the factors that may influence the business opportunity (30 min).

1.6.2. Exercise: SWOT analysis

In this chapter a SWOT analysis was conducted for groundwater infrastructure O&M. Please validate the analysis and consolidate your analysis results into a four-box SWOT matrix (30 min).

2. INFRASTRUCTURE SUSTAINABILITY AND RESILIENCE

- Explain the common challenges to implementing resilient infrastructure solutions in SADC
- Define infrastructure and resilience including the four dimensions of sustainable infrastructure
- Discus the factors undermining groundwater infrastructure sustainability and resilience

2.1. Introduction

There are many challenges to implementing infrastructure sustainability and resilience, ranging from inadequate funding to poor governance (Table 2-1). This hinders socio-economic progress in developing countries (Kim and Loayza 2019). Groundwater infrastructure can be considered critical infrastructure as it is socially, economically or operationally essential to the functioning of a society or community, both in routine circumstances and in the extreme circumstances of an emergency (Gallego-Lopez and Essex 2016a). The provision of infrastructure services, such as clean water and sanitation, is essential for human health and the creation of economic welfare (UNEP 2016). However, groundwater infrastructure should not be viewed in isolation but rather viewed as part of a system that comprises a portfolio of interlinked assets that provide essential services for society (Economist 2019).

Table 2-1: Common challenges to implementing resilient infrastructure solutions (Schneider-Roos n.d.)

Challenge/barrier	Implication
Inadequate funding	– Growing gap between existing and the required infrastructure – Increased cost of resilient infrastructure – Difficulty in structuring bankable projects – Difficulty attracting private finance – Basel III Regulatory Framework – further reduced funding

Challenge/barrier	Implication
Weak institutional capacity	– Centralised institutions unable to respond to O&M issues in a timely way – Poorly resourced institutions which are unable to function well – Lack of clarity of roles and responsibilities leading to lack of accountability – Poor planning and coordination (unbudgeted expenditure e.g. decommissioning) – Lack of quality standards or their enforcement – Flawed project analysis, selection & identification of needs – Lack of regional vulnerability assessment & high uncertainty in future conditions – Poor design leading to costly maintenance – Lack of oversight of O&M contractors
Weak legal framework	– Lack of legal instruments for setting operational standards and norms
Lack of security securing the infrastructure leading vandalism of the infrastructure	– Broken infrastructure leading to intermittent water supplies – Increased O&M costs perpetuating the vicious cycle of poverty
Corruption	– Procurement (inflated prices and/poor quality products) – Lack of transparency (breeding more corruption) – Nepotism (unqualified staff who do not add value)
Political interference	– Directing institutional operations (procurement, resource allocation, etc.) – Nepotism
Lack or poor O&M	– Lack of O&M strategies and implementation
Lack of civil society and stakeholder's participation and coordination	– Lack of interest in infrastructure as the communities perceive it as 'theirs' – Lack of women involvement (women are most affected by the unavailability of water resources) – Lack of sectoral coordination leads to players opting for their preferred way of doing things
Inappropriate technology	– Difficult to maintain and repair – Lack of availability of spares – Too complex to be understood by local artisans (disincentive to promotion of village level operation and maintenance or VLOM)
Lack of M&E	– Lack of data and information for proper resource allocation and proper planning

2.2. Defining infrastructure sustainability and resilience

Sustainability is defined through the triple bottom line of environmental, social and economic system considerations. **Resilience** is viewed as the ability of a system to prepare for threats, absorb impacts, recover and adapt following persistent stress or a disruptive event (Marchese *et al* 2018). **Sustainable infrastructure** refers to infrastructure projects that are planned, designed, constructed, operated, and decommissioned in a manner that ensures economic and financial, social, environmental (including climate resilience), and institutional sustainability over the entire life cycle of the project (IDB 2018). The dimensions of infrastructure sustainability are given in Figure 2-1 and described in Table 2-2. Appropriate technology that fits the local context an environment underpins infrastructure sustainability.

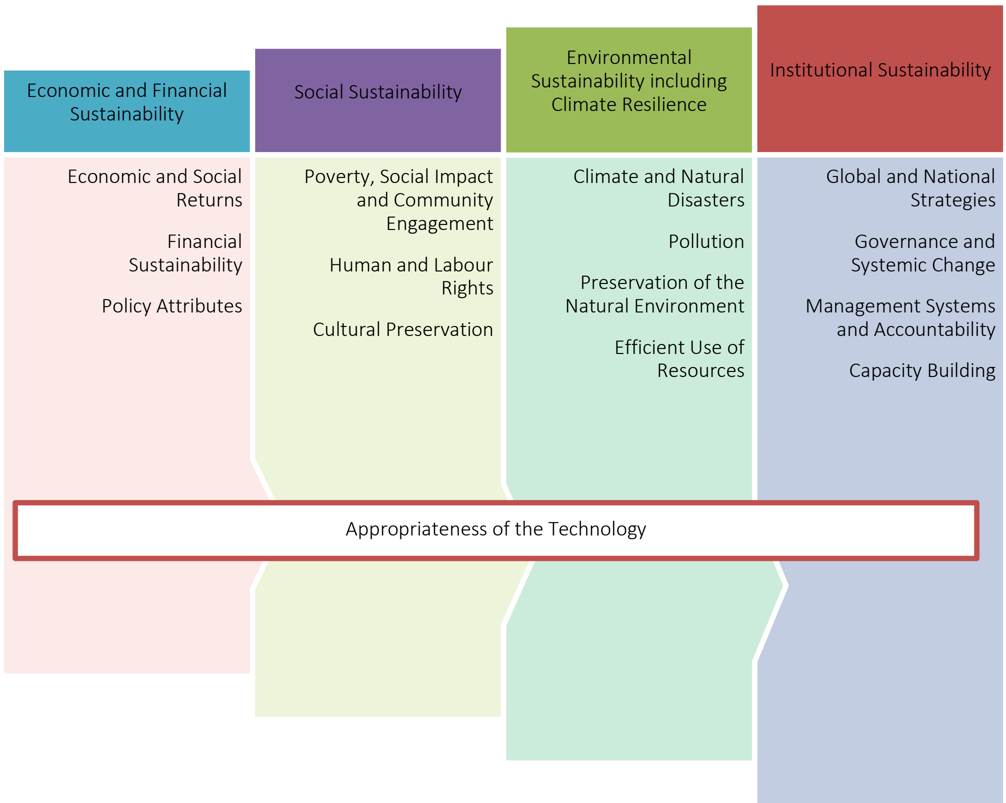


Figure 2-1: The four dimensions of infrastructure sustainability (IDB 2018)

Table 2-2: Description of the four dimensions of infrastructure sustainability (IDB 2018)

Economic and Financial Sustainability
Infrastructure is economically sustainable if it generates a positive net economic return, considering all benefits and costs over the project life cycle, including positive and negative externalities and spill overs. In addition, the infrastructure may need to generate an adequate risk - adjusted rate of return for project investors. Sustainable infrastructure projects must therefore generate a sound revenue stream based on adequate cost recovery and be supported, where necessary, by well - targeted subsidies (to address affordability) or availability payments (when users cannot be identified), or where there are large spill over effects. Sustainable infrastructure must be designed to support inclusive and sustainable growth and boost productivity and to deliver high - quality and affordable services. Risks must be fairly and transparently distributed to the entities most able to control the risk or to absorb its impact on the investment outcomes over the life cycle of the project.
Environmental Sustainability, including Climate Resilience
Sustainable infrastructure preserves, restores, and integrates the natural environment, including biodiversity and ecosystems. It supports the sustainable and efficient use of natural resources, including energy, water, and materials. It also limits all types of pollution over the life cycle of the project and contributes to a low - carbon, resilient, and resource - efficient economy. Sustainable infrastructure projects are (or should be) sited and designed to ensure resilience to climate and natural disaster risks. Sustainable infrastructure often depends on national circumstances, where the overall performance will need to be measured compared to what could have been built or developed instead.
Social Sustainability
Sustainable infrastructure is inclusive and should have the broad support of affected communities — it serves all stakeholders, including the poor — and contributes to enhanced livelihoods and social well - being over the life cycle of the project. Projects must be constructed according to good labour, health, and safety standards. Benefits generated by sustainable infrastructure services should be shared equitably and transparently. Services provided by such projects should promote gender equity, health, safety, and diversity while complying with human and labour rights. Involuntary resettlement should be avoided to the extent possible and when avoidance is not possible, displacement should be minimised by exploring alternative project designs. Where economic displacement and relocation of people is unavoidable, it must be managed in a consultative, fair, and equitable manner and must integrate cultural and heritage preservation.
Institutional Sustainability
Institutionally, sustainable infrastructure is aligned with national and international commitments, including the Paris Agreement, and is based on transparent and consistent governance systems over the project cycle. Robust institutional capacity and clearly defined procedures for project planning, procurement, and operation are enablers for institutional sustainability. The development of local capacity — including mechanisms of knowledge transfer, promotion of innovative thinking, and project management — is critical to enhance sustainability and promote systemic change. Sustainable infrastructure must develop technical

and engineering capacities as well as systems for data collection, monitoring, and evaluation, to generate empirical evidence and quantify impacts or benefits

For groundwater infrastructure to be sustainable and resilient, its designed lifespan must be ensured through proper O&M as this is the main cause of infrastructure breakdown. This leads to community dissatisfaction and continued poor governance of water infrastructure (Sohail *et al* 2005). Figure 2-2 provides an overview of properties that make infrastructure resilient.

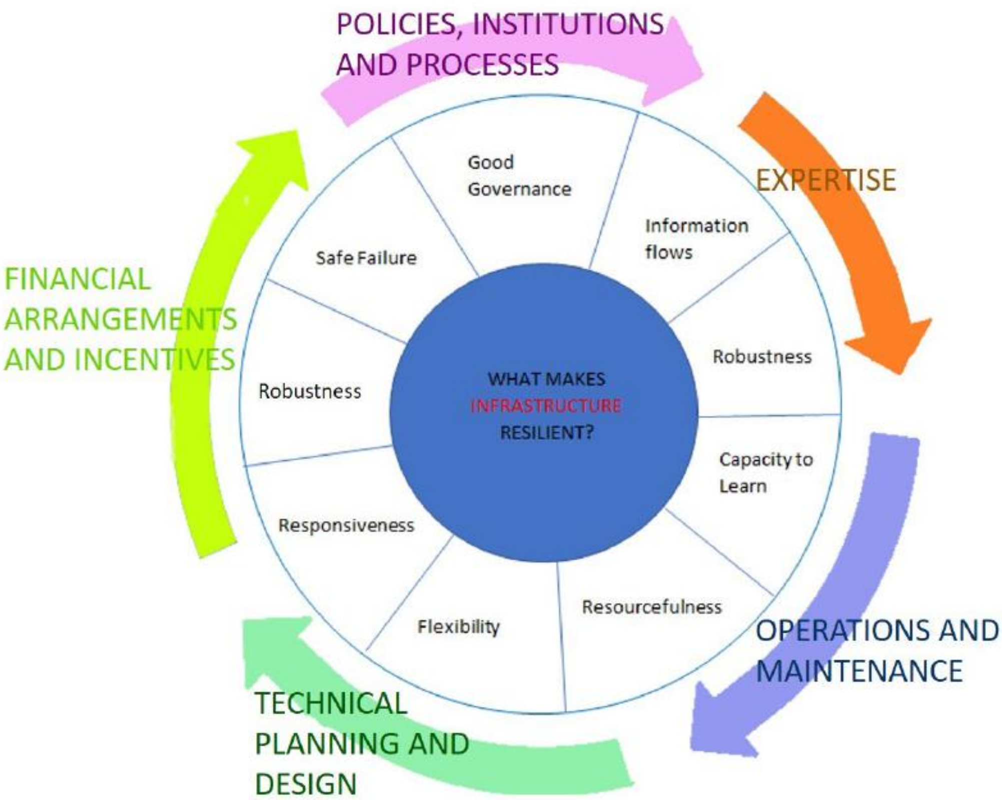


Figure 2-2: Infrastructure resilience properties (Gallego-Lopez and Essex 2016b)

2.3. Factors undermining groundwater infrastructure sustainability and resilience

Sustainability and resilience of services is commonly undermined by the following factors (Brikké and Bredero 2003):

– The project was poorly conceived (e.g. a project that only increased the number of water points, or sanitation facilities, as a way of improving accessibility to these services, without considering the wider range of factors needed to sustain the benefits)

- There was minimal or no community involvement and participation in the project and hence the communities did not have a sense of project ownership. Demand and community involvement (of both men and women) are key to generating long term community commitment to improved services and in sustaining the services. Community involvement and participation also makes the community members responsible for the choice of technology and makes community members aware of the financial, managerial and technical implications of their choice, including future O&M tasks associated with the technology
- The performance of the project facilities was either not assessed, or was insufficiently monitored, during the O&M phase of the project cycle (ineffective or non-existent O&M)

2.3.1. Other factors that undermine sustainability

There are several other factors that could militate against sustainability and these include:

2.3.1.1. Inappropriate system design and quality of infrastructure

No matter how good the management of a water supply facility is, if it is not technically well designed, it will operate inefficiently. It is not uncommon to find water supply schemes that have been badly designed, poorly constructed and using technologies which are inappropriate. When a facility is improperly designed and constructed, even with the best will in the world, it will not perform satisfactorily.

There are many reasons for poor systems design. In some instances, consultants are chosen by external support agencies who are not familiar with suitable technologies for use and end up specifying equipment and/or designs which are inappropriate or poor quality mainly based on what they would have implemented in other project elsewhere or for experimentation. In other cases, there may be political interference to promote one technology or equipment supplier, who often may not provide the appropriate technology for the particular situation.

A lack of communication between the system designer and the operators of the system also provides a further drawback. It is imperative that plant or equipment operators, be they in the rural area receiving a well handpump or in an urban centre receiving complex water supply facilities, need to be familiar with, approve of and be comfortable with the technology. Training should be instituted where required and refresher courses scheduled. In addition, there needs to be a continuous feedback of information from the operators to the designers pinpointing problems or challenges faced with the equipment as this will provide for early remedial measures.

2.3.1.2. Political interference

Political interference has been identified as a serious contributory reason for poor performance of water supply and sanitation agencies/institutions. This is most noticeable in countries where the government is directly involved in owning, operating and maintaining the water supply facilities (Brikké and Bredero 2003). Political interference manifests itself in several ways. In some instances, purely for political reasons, it is directed that water be provided free of charge or that the charges be set low to the extent of not even covering costs of operation and maintenance let alone capital costs. The directive requesting water service institutions not to charge proper tariffs for water makes it difficult to run a self-financing viable system. In rare cases where governments fund O&M costs, when they face fiscal challenges, often it is the water supply facilities which become soft targets for budget cuts.

Political interference is also evident in several other ways such as the choice of technologies. Government officials may, for one reason or another, support the purchase of a technology or system which may not be the best or most appropriate selection for the scheme. Also, equipment suppliers and external support agencies frequently hinder the wise choice of a technology by lobbying politicians or through restrictive policies of tied aid. It has also been established that the award of a contract for provision of services such as drilling of boreholes may be influenced by politics resulting in the selection of a contractor who carries out substandard work which ultimately negatively impacts O&M and thus the sustainability of water supply infrastructure.

A possible and workable alternative for the better management of water supply systems is to devolve the responsibility of managing the systems from government to autonomous agencies/institutions which will manage the facilities under technical, financial and administrative guidelines from the government. This can limit the extent of political interference by governments and allow the facilities to be managed more efficiently.

2.3.1.3. Conflicts, social unrest, theft and vandalism

Conflicts, social unrest, theft and vandalism hinder the sustainability of groundwater infrastructure. In countries that have undergone civil unrest, investment in water infrastructure fell short which was further aggravated by the destruction of infrastructure and consequently regress of water supply (SADC-GMI 2019a). The acts of vandalism are widespread in both urban and rural settings and take a number of forms: they include water theft leading directly to a loss of revenue for the utility, and the vandalism and theft of valuable metal pipes, fittings and manhole covers leading to an increase in the utility's maintenance costs (WSUP 2014). The implications are (WSUP 2014):

- Increased operation and maintenance costs – from the need for repair or replacement of vandalised pipes, fixtures and fittings.
- Increased non-revenue water (NRW) – from water losses due to either water theft or leakage from the

damaged network.

– Reduced customer satisfaction – from more frequent service interruptions and/or rise in tariffs to cover increased costs, which may in turn lead to further dissatisfaction and lost revenue from customers' refusal to pay

2.3.1.4. Borehole/well drilling technical specifications

Technical specifications include the nature and the class of the work, materials to be used in the work, and the workmanship itself. These are important for the execution of the work. A lack of proactive approaches towards major repairs and sub-standard borehole construction alongside aging infrastructure contributes to reduced functionality of decentralised supplies (Truslove *et al* 2019). The cost and quality of the work depends much on the technical specifications and as such, they need to be clear and of high quality. As described in the previous chapter, failure to develop good borehole drilling and construction technical specifications results in poor workmanship which would in turn impact O&M.

The specifications come in two formats, general and detailed. The detailed specifications form a part of the contract document. They specify the qualities, quantities and proportions of materials and the method of preparation and execution for an item of works in a project. When compiling the detailed specifications, the same order sequence as the work to be carried out is to be maintained.

In view of the skills required, legislation may subject the exercise of the profession of commercial well digging or drilling to registration or licensing requirements to ensure that the driller is appropriately qualified, and that borehole drilling and construction standards are adhered to. Unfortunately, in many cases, the drilling industry is not regulated, or regulations are not enforced, and the chances of poor workmanship/construction standards by some companies are high. Box 2-1 provide examples of manuals for good practices of drilling.

Technical specifications are also required for the above the ground components, e.g. pumps (handpumps, motorised pumps) and water storage and conveyance system.

Box 2-1: Examples of good practices manuals for drilling (PRACTICA Foundation 2010, Danert 2015, UNICEF 2016)

Instruction handbook for manual drilling teams on hydrogeology for well drilling, well installation and well development: Available manuals in the series include:

- JETTING - This handbook describes in detail the various jetting techniques that can be used to drill wells in loose and soft soil formations. With this technique, wells are drilled in a number of hours rather than days.
- PERCUSSION - This handbook describes in detail the percussion technique. Although the technique is slower than other drilling techniques, it is the only manual drilling technique that is able to drill through consolidated rock layers
- HAND AUGER - This handbook describes the hand auger technique. This cheap and effective technique is very suitable for sinking shallow wells in soft soils and is excellent for soil surveys. Many drilling teams have this technique in their toolkit to complement other drilling techniques.
- SLUDGING - This handbook describes the sludging technique, and in greater detail the ROTA-sludge technique. It is a combination of sludging and percussion and is particularly useful due to its versatile application for a range of soil formations.

The manual 'Understanding Groundwater & Wells in manual drilling' complements the 4 technical training handbooks and highlights those essential subjects which are relevant to manual drilling, geohydrology, hygiene, well installation and well development in practice, in simple and understandable language.

Manual Drilling Compendium 2015: This compendium draws together experiences of manual drilling from 36 countries. It provides a synthesis of otherwise highly fragmented information, much of which has never been published in academic or even grey literature.

Manual Drilling Toolkit: This is a toolkit to support African countries wishing to embark on the professionalisation of manual drilling. The toolkit includes Technical Notes, Technical Manuals, Advocacy Materials, Mapping of suitable areas for manual drilling, Case Studies, and Implementation and Training Manuals. This initiative aims at builds the capacity of the local private sector to respond to the ever-increasing demand for safe water in rural areas.

2.4. Exercises

2.4.1. Exercise: Dimensions of infrastructure sustainability

Discuss the key-barriers to sustainable groundwater infrastructure development in SADC (30 mins)?

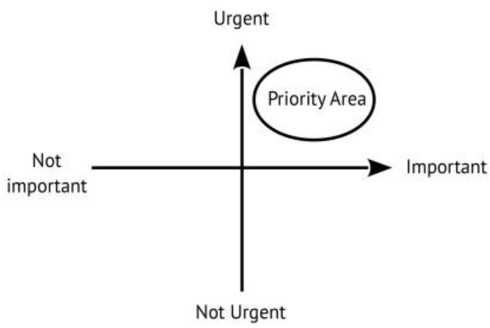
- Structural barriers
- Regulatory barriers
- Cultural/behavioural barriers
- Capacity barriers:
- Technological barriers

For this exercise the World Café Method is used. The participants will form six groups to discuss each type of barrier. At the end of 20 mins, each member (except the table host) of the group moves to the next table (table of their choice). After the small groups, individuals are invited to share insights or other results from their conversations with the rest of the large group.

2.4.2. Exercise: Quality infrastructure

In plenary, discuss the intervention areas necessary to operate and maintain quality infrastructure, efficiently and effectively (30 min)?

- Group the intervention areas according to their urgency and importance.
- Rank the priority area interventions.



3. INSTITUTIONAL ARRANGEMENTS FOR OPERATION AND MAINTENANCE

- Develop an understanding of the legislative and regulatory frameworks necessary for O&M
- Provide guidance regarding the institutional roles and responsibilities required for O&M of groundwater schemes as well as the importance of developing institutional capacity to enable effective O&M
- Present a typology of maintenance services

3.1. Introduction

For the purposes of this manual, Institutions include formal rules, written laws, formal social conventions, informal norms of behaviour and shared beliefs about the world, as well as the means of enforcement. Institutions are “the rules of the game” – i.e. the patterns of interaction that govern and constrain the relationships of individuals. Organisations consist of specific groups of individuals pursuing a mix of common and individual goals through partially coordinated behaviour (North 1990). A formal water law or the custom of sharing a spring protection between community members are institutions, whereas a state Water Department or SADC are organisations (albeit with their own nested internal sets of institutions).

Institutional arrangements refer to the various institutional structures and their positioning relative to each other and can include formal and informal arrangements with varying degrees of authority, accountability and responsibility for coordination, handover and delivery (World Bank 2015). Institutional arrangements play an important role in managing and coordinating groundwater development and management, including O&M. Understanding of the various institutions, their mandate, roles and responsibilities, and capacity requirements are all critical in groundwater management and the O&M of groundwater infrastructure. The overall objective of this chapter is to provide a background to the institutional arrangements for O&M of groundwater infrastructure at a local level as well as establishing linkages wither broader regional and national groundwater-related institutions.

3.2. Laws and regulations

Laws and regulations are a critical part of groundwater governance and create the enabling framework that guides the management of O&M of groundwater infrastructure. This framework comprises of three elements (SADC-GMI 2019b):

- Policy: the statement of intent by which groundwater management and development is framed.
- Legislation: the legal and regulatory instruments that support the implementation of policy.
- Institutions: the various organisations and bodies that undertake actions to implement policy and legislation.

While the legislative framework is an important aspect of groundwater management, national and provincial policy and legislation does not necessarily have a direct influence over O&M. However, there is an increasing trend towards ensuring that borehole drillers are regulated through a process of national registration as well as through various forms of regulation that are underpinned by technical specifications for drilling (Table 3-1). These regulations can specify the requirements for pumping tests and aquifer yield assessments which do ultimately impact upon the O&M regime that is required. Since O&M typically occurs at a local level, it is most often more local operational policy and local regulatory instruments such as local government bylaws that guide the O&M of groundwater infrastructure. It may then be more appropriate to ensure that these more local instruments provide clarity as to effective yield assessments at the drilling stage and the development of an O&M plan, once the groundwater infrastructure is in place.

Table 3-1: Groundwater and borehole regulations Zambia - summary of statutory instruments (Government of Zambia 2018)

Statutory Instrument No. 18 2018 Fees and charges regulation
– Provides for fees involved in the usage for raw water for both surface and groundwater – Categories of sectors subjected to these regulations are those involved in: ▪ Hydropower ▪ Agriculture ▪ Mining ▪ Municipal ▪ Industrial

- Storage dams
- Aquaculture
- Navigation
- Recreation
- De-watering
- Dilution permits
- Drillers licensing
- Weirs
- Diversion canals
- Construction of water works dams
- Draining of swamps, marsh, dambo, wetlands, recharge areas or other land
- Temporary permits charges for water usage

– This implies that any usage of water for commercial purposes is subjected to a fee

Statutory Instrument No. 19 of 2018 Drillers and other constructors' regulations

– Provides for the licensing of drillers and in the construction industry
– The drillers licenses will be renewable annually
– Essentially the players include:
  - Borehole drillers for water use, exploration, monitoring purposes and dewatering
  - Constructors such as installers of borehole pumps
– Drillers licenses have categories attached to them as follows (based on equipment and staff criteria:
  - Category A
  - Category B
  - Category C
  - Category D
– All principal personnel should be fully qualified and registered with Engineering Institute of Zambia
– The SI contain forms relevant for registration and licensing
– During drilling operations, the law requires that standard borehole completions form be filled and availed to relevant authorities

Statutory Instrument No. 20 of 2018 Groundwater and borehole regulations

– Provides for seeking for authority to drill and register boreholes. These are aimed protecting existing users from new developers, pollution and depletions of groundwater
– The SI therefore principally prescribes the following
  - Specification of a standard borehole design
  - Minimum distance from potential sources of pollution
  - Minimum distance between boreholes based on geological formations
  - It also contains a range of forms namely:
    - Notice to drill
    - Application to drill
    - Borehole registration
    - Defective borehole report
    - Register of boreholes
– It is a criminal offense to drill a borehole without authorisation or not to have an existing borehole registered

Overall, national and provincial legislation should promote sustainable groundwater management and development as well as establishing institutions at a national, provincial and local level to effect sustainable groundwater management. O&M plays an important role in ensuring that groundwater resources and infrastructure are sustainably managed. Legislation should clearly formulate and establish institutions that have clear mandates around O&M of groundwater infrastructure.

Local policies, regulations and bylaws should be guided by national legislation and should include specific steps to effectively implement O&M. Noting that O&M occurs at a local level, these bylaws are crucial in determining how and when O&M occurs as well as who is responsible for O&M of groundwater infrastructure. Often these O&M regulations and bylaws form part of the broader maintenance policies or regulations.

When developing local regulations, bylaws or policy, the following considerations should be incorporated to ensure that O&M is addressed:

- What is the objective of the O&M-related policy, regulation and/or bylaw?
- Are there specific standards that should be followed when implementing O&M? How often would these technical specifications require review and improvement? Are these technical documents readily available and accessible?
- How will O&M be monitored and tracked? This also includes questions around frequency and schedule/plan for O&M.
- Do these regulations/bylaws/policies incorporate and establish linkages with financial management and budgeting for O&M?
- Do the regulations/bylaws/policies link to broader national and provincial legislation and promote sustainable groundwater development and management?
- How often will the regulations/bylaws/policies be reviewed?
- Do the regulations/bylaws/policies outline the institutions necessary for O&M as well as the roles and responsibilities of the institutions and personnel?
- Are the regulations/bylaws/policies practical and implementable at a local scale?

Box 3-1: Overstrand Municipality, South Africa, maintenance management policy (Overstrand Municipality 2011)

The Overstrand Municipality is a local municipality in South Africa that has a Maintenance Management Policy. While the policy refers to broader maintenance management, the policy provides guidance at a local level for O&M and incorporates both linkages to national legislation as well as on-the-ground conditions. The policy also provides the overarching framework for local regulations and bylaws and helps to support their development.

Bylaws and local regulations will need to be tailor made to match local criteria, considering the rural/urban setting and the institutional capacity.

3.3. Institutions, roles and responsibilities

Institutions play an essential role in managing groundwater infrastructure and have specific mandates that guide their roles and responsibilities in O&M of groundwater infrastructure. In a rural context, O&M of groundwater schemes is often handed over to communities, following a community-based management approach which promotes community ownership and assists with the management of groundwater infrastructure in scattered and isolated areas. In urban settings, groundwater schemes are typically managed by a local authority or a public water utility/ company. In both instances, the roles and responsibilities need to be clearly defined under the various institutions and will require bespoke regimes to cater for the local needs.

Table 3-2 provides a high-level overview of the various groundwater-related institutions and their roles and responsibilities, noting that institutional arrangements do vary between countries (SADC-GMI 2019b).

Table 3-2: Institutions and their roles in groundwater management (Directorate of Water Development 2004, GoI 2013, SADC-GMI 2019b)

Institutions	Roles and responsibilities
Transboundary institutions / river basin organisation	– Guidelines production – Best practice support – Policy harmonisation

Institutions	Roles and responsibilities
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
Community association / water user association	– Plan for & oversee O&M, report problems – Collect and utilise O&M funds
NGOs and others	– O&M financing, tools – Equipment – 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

3.4. Planning for O&M

Planning for O&M requires a systematic approach to ensure that all aspects of O&M are covered and on a routine basis. Part of this includes developing an O&M plan (Chapter 0) that outlines the O&M approach i.e. preventative vs scheduled maintenance as well as reflects the geographic distribution of infrastructure and the frequency of O&M interventions. This plan will have to also incorporate the needs and requirements for emergency maintenance and being able to support rapid response support, whilst still going about the more routine processes.

An O&M plan should have three components (USBR 1990):

1. **Planning**: identify all O&M activities to be performed as well as their frequency and resources required, this would need to include staffing and skillsets, equipment and financial resources to support disbursement costs
2. **Implementing**: Implementation of all the O&M activities listed during the planning phase. This phase also includes establishing monitoring systems to track all O&M activities and expenditures as well as collecting information and record keeping
3. **Evaluating**: After the O&M activities are implemented, the O&M plan is assessed, and the cost and benefits identified. This phase also entails identifying the strengths and weaknesses of the programme to inform the development of the new O&M plan

The O&M plan should be supported by local policies, strategies and bylaws that guide the plan with regards to O&M objectives as well as the overall management method used to achieve the objectives.

Some of the critical sections in an O&M plan include the following:

1. **Introduction**: The section should outline the purpose of the plan and scope of the O&M plan
2. **Organisations** and institutions: The organisations and/or institutions required to implement the plan are described here as well as their roles and responsibilities
3. **Operation and maintenance**: This include detailed descriptions of all the

O&M activities to be conducted as well as which of these activities falls under preventative or scheduled maintenance. Corrective maintenance issues should also be raised here as well as resources required to implement each of the O&M activities

4. **Staffing and equipment**
5. **Monitoring and reporting**: This chapter should indicate the monitoring mechanisms to be put in place to monitor and track the various O&M tasks. This will also include how information will be collected and stored as well as reporting lines that need to be established and followed. A subsection of this should also include compliance monitoring and health and safety standards
6. **Evaluation**: This is the last section and should provide details on how and when the O&M plan will be assessed using the information gathered during the monitoring and reporting phase

It is important to establish what O&M approaches will be undertaken i.e. preventative, scheduled etc. and which will depend on locality. For example, certain rural areas might lack the ability and capacity to implement scheduled maintenance and alternative approaches should be considered that ensure that groundwater infrastructure is adequately and optimally maintained

3.5. Identifying O&M issues

Identifying O&M issues feeds into the O&M planning process described above and will require strong participation from technical and onsite personnel to identify O&M issues. This will require onsite staff to keep a register and log all issues related to O&M. This can be manual or automated and should be reviewed on a regular basis to help management identify which issues are short-, medium- or long-term. Some issues will need to be incorporated in the O&M plan for the next financial year while others, depending on whether it has been planned for or whether it is an unplanned emergency, will need to be addressed in the short-term

The process of identifying O&M issues is an ongoing process at the operational end which requires tracking and reporting to pre-empt and prevent breakdowns or enable rapid repairs. A starting point for this could be the use of operators to identify issues that require some infrastructural changes in order to improve efficiencies and operations. This process would then feed into the broader management system

3.6. O&M management systems

The management system for groundwater infrastructure provides the operational framework for the groundwater scheme and enables more effective and efficient O&M as well as the tracking of issues and challenges as they arise. In effect, the system supports the implementation of the O&M plan and needs to be appropriate to the groundwater infrastructure and the operational context.

Three O&M management systems can be identified: centrally managed, community managed and household managed (Table 3-3). Some evidence suggests that the O&M of even basic (e.g. a handpump) village supply boreholes in Africa may be beyond the means of many impoverished communities, and that such boreholes risk failure without outside assistance (Chowns 2015). However, O&M of groundwater supplies as mainly a local community responsibility retains a degree of support in the SADC region. This is partly because community management avoids the need to engage with complex and often unreliable local government and other "outside" structures. But community-level O&M also remains popular for more ideological reasons, in that it appeals to both left-of-centre (community-led, decentralised, grass-roots) and right-of-center (small government, low taxes, self-sufficiency) development perspectives (Chowns 2015).

Table 3-3: Operation and maintenance management system (Chowns 2015)

Management system	Description
Centrally managed system	Private service connections to individual plots which require external supporting infrastructure. In these instances, it is often public institutions that are responsible for service delivery and O&M
Community-based management system	Non-private facilities which are shared by members of a community that may or may not require external supporting infrastructure. A group of users is delegated responsibility for O&M. However, where there is external supporting infrastructure, other external agencies might be responsible for O&M of the infrastructure (e.g. local water utility, local government etc.) while the community is responsible for onsite O&M of local infrastructure.

Management system	Description
Household managed system	Private on-plot services which do not require external supporting infrastructure (e.g. on-plot handpumps). The responsibility of O&M falls on the owner of the plot.

It will be necessary to identify all the groundwater schemes and what type of O&M system would best suit them. For example, a groundwater scheme in a rural region that is serving a small community might be better suited to a community-based management system while a larger groundwater scheme that supplies an urban population will be better served with a centrally managed system. Box 3-2 presents an example of a community empowered operation and maintenance of water points in Diti Zimbabwe.

Box 3-2: 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.

The type of system will determine how O&M will take place including roles and responsibilities, financing and frequency of O&M activities. It is useful to review the O&M management system for each groundwater scheme on a regular basis as populations and infrastructure might change which can impact the appropriateness of the system. Furthermore, each system should produce action plans that clearly outline the various O&M issues, roles and responsibilities and timelines.

The O&M management system will need to have monitoring and tracking mechanisms in place, be they manual (written entries into a logbook) or automated. This will be critical in tracking the various O&M activities within each scheme and allow for evaluation and assessment of the activities and the overall status of O&M. This also feeds into the O&M planning process.

To provide guidance on the type of O&M management system to use, the following questions should be asked with a focus mainly on centrally managed and community-based management systems:

3.6.1. Centrally managed system

- Will the public institution that is responsible for O&M have sufficient capacity and resources to effectively implement O&M?

    - Critical to a centrally managed system is sufficient capacity and resources to effectively manage groundwater infrastructure. An assessment of institutional capacity is required as well as financial resources and funding to determine whether such institutions are capable of undertaking O&M.

- What is the extent of the service coverage for the centrally managed system?
    - It is important to identify the area that will be covered by the system and whether the system can manage a large area. A community-based system might be better suited if settlements are scattered and relatively isolated from one another.
- What areas (rural, urban, peri-urban) will be covered through the centrally managed system?
    - If rural, consider the location, quality of roads and distance between the rural settlements as a centrally managed system might not be suitable for rural locations.

3.6.2. Community-based management system

- Is the rural population willing to participate in O&M?
    - An assessment of the rural population and their willingness to participate and take ownership of the groundwater infrastructure will be required to determine the suitability of the management system. Capacity building, awareness-raising, follow-up engagements and monitoring are critical in these instances as community members will require the knowledge and expertise to manage the infrastructure.
- Are there sufficient support mechanisms in place to ensure that the community can effectively manage O&M?
    - Government will need to provide various support mechanisms including financing, access to supplies, materials etc. as well as ongoing training and support.

- What is the presence of NGOs in the region and how can they be leveraged to support O&M?
  - Non-governmental organisations (NGOs) play a critical role in rural areas and can assist communities in O&M, especially where government has limited financial and human capacity in the region. Assessment of the NGOs in an area is necessary as well as their services and mandates to better understand how government and NGOs can work together to support the community.
  - It will also be necessary to conduct an on-the-ground analysis, particularly in rural areas, to find out if any other types of management are taking place. It may be that communities are effectively managing the groundwater infrastructure through a different means to that outlined above. Understanding these initiatives are useful in identifying alternative management systems and identifying where the public and private sector can collaborate to improve management of groundwater infrastructure.

3.7. Institutional capacity

Institutional capacity is a core component in effective O&M of groundwater schemes. O&M would not be possible without sufficient capacity of the various institutions involved in O&M, from water utilities to municipalities to communities. From technical expertise to administration, the various roles within an institution need to be filled with appropriately trained and qualified personnel to ensure that an institution is operating efficiently and effectively. Determining the institutional capacity helps institutions to identify critical areas and possible interventions to address them.

In many countries, the key constraint to implementing O&M best practices is the shortage of skilled staff (WEF 2014). Staff tasked with groundwater project O&M should include at least (Table 3-4, DWAF 2004):

- Pump operator
- Pump operator supervisor
- Data capture clerk

- Mechanic
- Electrician
- Technical manager
- Water quality manager

Table 3-4: Job descriptions for staff tasked with groundwater project O&M (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
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

Staff	Functions
	– 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 – coordinating 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).

3.8. Typologies for maintenance services

Typologies for maintenance services were developed and are presented in Table 3-5. At the highest level of the typology there are three broad approaches that characterise the principles upon which maintenance services are provided (Lockwood 2019):

1. **Ad hoc reactive approach**: Under this approach, services are provided on demand (i.e., when something goes wrong and the community actively seeks out maintenance assistance) and are therefore mostly concerned with corrective maintenance when there is a significant problem. Maintenance services tend to be unplanned and normally, but not always, provided by local government or a deconcentrated technical agency of government. Typically, communities would not be expected to pay for such support, but they would contribute to or cover the costs of the spare parts and supplies required to carry out the maintenance task in question; they may also contribute in free labour time. Small private providers sometimes provide one-off services under this model on a fee-for-service basis covering both spare parts and their time.
2. **Structured proactive approach**: Under this approach, maintenance services are provided on a structured basis, with an agreed range of periodicity (i.e., bi-annual or quarterly visits), and typically include both preventive and corrective maintenance tasks. These examples normally also include broader support functions, such as technical guidance and advice on management issues and on linking communities with other external resources. Typically, these services are provided by a higher-level or umbrella provider, which can be organised through the clustering of community-based management systems or private operators into associations, federations, or water boards. In a limited number of cases this type of proactive support can be provided by NGOs or outsourced to external private sector providers. Where there are adequate resources made available, local government may also provide this type of support.
3. **Guaranteed service approach**: This approach is relatively recent to the rural water subsector and typically involves private companies or social enterprises providing both preventive and corrective maintenance for a fixed fee that is paid collectively by the community via the community-based management or a caretaker. Typically, communities pay a flat fee on a monthly or annual basis, which covers all costs for any potential repairs and maintenance. In some instances, the maintenance provider also commits to paying for capital maintenance investments, but this is stipulated by contract. The main difference with this model is that services are guaranteed by contract, with performance targets such as repair response time and functionality rates clearly specified. Risks to the maintenance provider can, in theory, be minimised by having many water schemes to service, thereby applying an insurance principle of

pooling maintenance risk. Financial risks can also be spread by blending different sources of financing under one mechanism, to include tariff revenue, public funding (including aid borrowing), grant funding, and private finance, where possible.

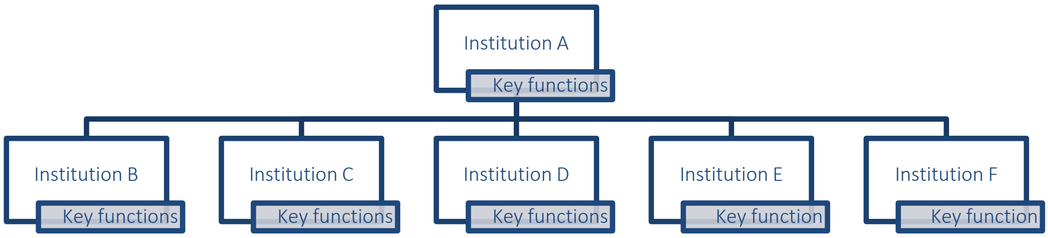
Table 3-5: Maintenance service provision typology (Lockwood 2019)

	Ad hoc-reactive approach		Structural proactive approach		Guaranteed service approach
Principal actors	Local government as provider	Private local service provider	Associations or Federations	Government or NGO circuit rider providers	Private companies or social Enterprises (with stakeholders and NGOS)
Maintenance tasks	Largely corrective with some preventative and broader support	Largely corrective occasionally including preventative	Preventative and corrective with broader advice and support	Preventative and correction with broader advice and support	Both preventative and corrective maintenance to ensure guaranteed service based on KPIs
Triggers for maintenance	Demand driven (normally on failure)		Supply driven (scheduled support) and demand driven		Primarily demand driven, but including some supply driven
Extent of CBM activity	High, still relies on CBM to carry out regular O&M tasks		Moderate to high: some tasks assumed by maintenance service provision but still relies on CBM for basic activities		Low: CBM has more limited role, principality for tariff collection
Financing at point of service	Essentially free highly subsidised users may pay for parts and provide labour	Fee payment for unique repairs on case by case basis	Largely subsidised users may pay for parts and provide labour	Largely subsidised users may pay for part and provide labour	Regular flat fee for service based on monthly or yearly basis, or a percentage of tariff revenue

3.9. Exercises

3.9.1. Exercise: Mapping of Roles and Responsibilities for O&M of groundwater infrastructure

Understanding institutional mandates, roles and responsibilities regarding groundwater management and development can be complex with institutions facing an array of difficulties and having to respond differentially to address these. An important first step is considering how institutions support the O&M of groundwater infrastructure and to map these institutions and their mandates. This can be done graphically as follows:



This can also be undertaken for the relevant policy, legislative and regulatory instruments providing the key purpose of these instruments with regards to the O&M of groundwater infrastructure.

Once that understanding has been developed one can start to develop a more detailed matrix of roles and responsibilities that provides the basis for O&M planning. Multiple institutions can be responsible for a task and the template below highlights the primary institutions responsible for the task with the last column (coordination and/or involvement of other institutions) indicating which other institutions need to be involved. For example, multiple institutions are often involved in policy and programming which will touch on O&M as well as broader aspects of groundwater management. The template also allows for the addition of subtasks to allow for specificity in activities. It is important to note that the template below is a simplified attempt at defining and organising institutions and their roles relevant to O&M which only includes some of the O&M tasks. As such, the template is not exhaustive with regards to O&M activities but can be amended to add more tasks and subtasks.

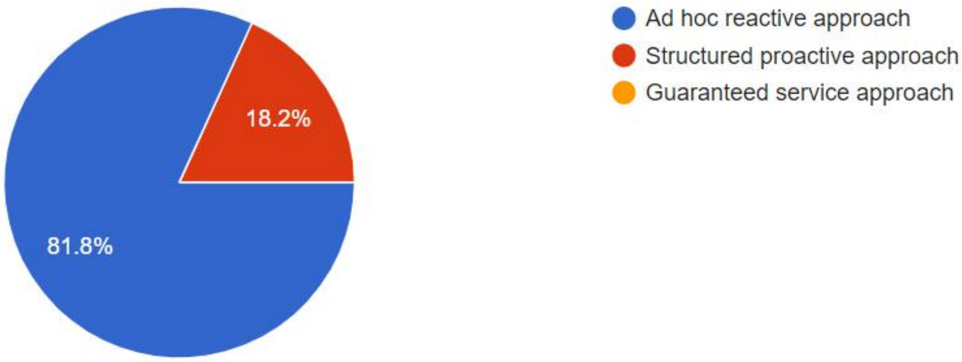
Tasks relevant to O&M	Subtasks	Primary institution responsible	Department/personnel responsible	Coordination and/or involvement of other institutions
Policy and programming				
Development of local regulations / bylaws / policy	1.			
	2.			
	3.			
Review of local regulations / bylaws / policy	1.			
	2.			
	3.			
Planning and design				
Determination of lifecycle costing	1.			
	2.			
	3.			
Preparation of O&M budget and financial planning	1.			
	2.			
	3.			
Monitoring and evaluation	1.			
	2.			
	3.			
Operation and maintenance				
Development of maintenance plan	1.			
	2.			
	3.			
Maintenance and identification of repairs	1.			
	2.			
	3.			
Reliability	1.			
	2.			
	3.			
Maintenance feedback and design improvements	1.			
	2.			
	3.			
Inventory control	1.			
	2.			
	3.			
Financial				
Development of tariffs	1.			
	2.			
	3.			

Tasks relevant to O&M	Subtasks	Primary institution responsible	Department/personnel responsible	Coordination and/or involvement of other institutions
Financial management practices (accounting, record keeping etc.)	1.			
	2.			
	3.			
Training				
Conducting training	1.			
	2.			
	3.			
Monitoring and evaluation	1.			

Using the table above, identify and map the roles and responsibilities of the various institutions in participant countries involved in O&M as well as linkages between them. This also includes identifying personnel and staff responsible for specific subtasks in O&M (60 mins).

3.9.2. Exercise: Typology of maintenance services in Members States

Analyse and review the typologies provided in the manual and assess which approach is suitable, taking into consideration local conditions in participant countries. Identify the barriers to implementation of the barriers service approach taking into account that most SADC Member States (based on survey) has an ad-hoc reactive approach to O&M of groundwater infrastructure.


18.2%
81.8%
Ad hoc reactive approach
Structured proactive approach
Guaranteed service approach

4. FINANCING OF OPERATION OF MAINTENANCE OF GROUNDWATER SCHEMES

- Present the typical cost structures of groundwater supply schemes
- Understand the primary cost drivers of operation and maintenance
- Consider policy considerations for O&M
- Understanding the various tariff models and mechanisms to finance O&M of groundwater schemes

4.1. Introduction

Financing of O&M of groundwater schemes is difficult. Many developing countries lack the financial resources to allocate sufficient budgets and most rural communities in SADC lack the means to pay for O&M. Further, groundwater has its own complexities, making it more difficult to finance than surface water. Some of the challenges around groundwater include (Cap-Net *et al* 2008):

- High costs and complexity of assessing groundwater
- The decentralised nature of groundwater increases management monitoring costs
- Groundwater is an unseen resource with significant time-lag
- Contamination load can vary depending on the vulnerability of the aquifer
- The near irreversibility of most aquifer contaminations

4.2. Typical cost structure of groundwater schemes

The importance of understanding the costs associated with groundwater development (drilling, equipment, O&M) are crucial. However, costing is dependent on a range of factors such as site conditions, labour and capital costs, relative scarcity of water, depth to water table and relative prices of fuel (Custodio and Gurguí 1989). 4-1 summarises the costs associated with groundwater abstraction.

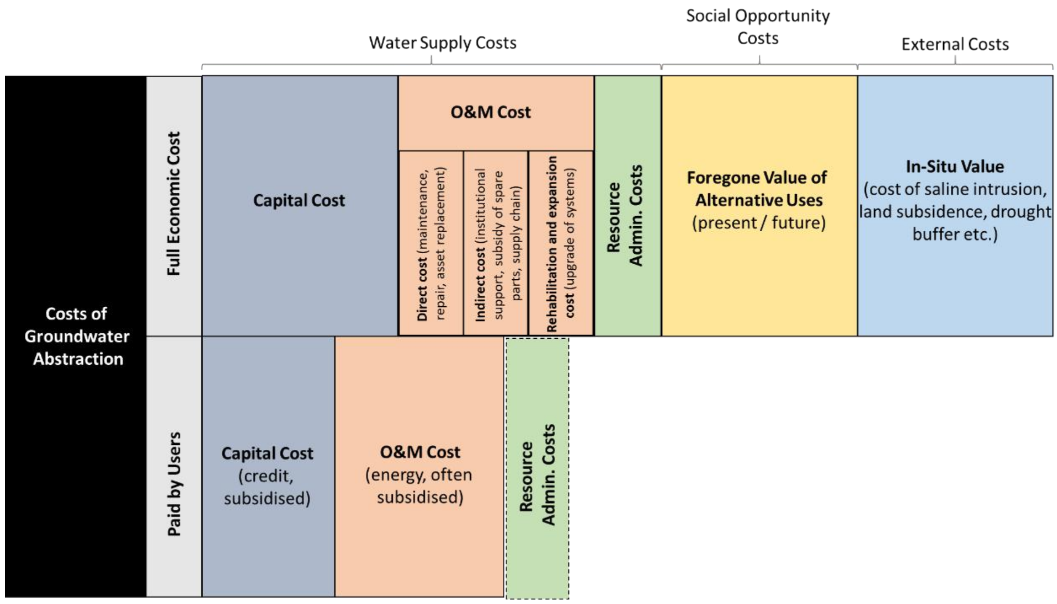


Figure 4-1: Costs associated with groundwater abstraction (Smith et al 2016, Harvey 2007)

To determine the full economic cost, three cost components have to be determined (Smith *et al* 2016):

- Water supply costs (capital costs, O&M costs and resource administration costs)
- Social opportunity cost
- External costs

4-1 breaks O&M costs into (Harvey 2007):

- Direct (maintenance, repair, asset replacement)
- Indirect (institutional support costs, subsidy of spare parts provision and supply chain costs)
- Rehabilitation and expansion costs (upgrade of systems)

However, the above breakdown is more useful for determining tariff setting. Asset replacement, rehabilitation and expansion costs are generally capital costs and not classified as O&M, although they are costs that need to be considered when planning to invest in a groundwater scheme. The same applies to investigation and exploration costs, prior to abstraction. These can vary considerably and need to be factored into the planning.

Users are only responsible for paying a portion of the full economic cost i.e. capital cost, O&M cost and resource administration cost. However, in many cases, the full economic cost is not recovered as many groundwater users have not had to pay the full costs associated with groundwater abstraction. While some developed countries have managed to reduce the gap through the application of a considerable resource administration charge, many developing nations fall short of recovering all monies for total costs of groundwater abstraction (Smith *et al* 2016). Capital costs are not recovered in most African countries and evidence suggests that most community organisations in rural regions fail to generate sufficient revenue to meet direct O&M costs, let alone indirect O&M costs (Harvey and Reed 2004, Harvey 2007). Rehabilitation and expansion costs usually entail large-scale upgrading of the scheme and are generally covered by supporting institutions (government or NGO) as communities are not expected to finance major rehabilitation costs. Further complicating the situation is the difficulty in determining future rehabilitation needs as there is always a level of unpredictability regarding a scheme and future demand (Harvey 2007).

Recovery of full economic costs needs to be explored within SADC with an understanding of the complex and varied aspects of cost recovery. Willingness to pay is a major factor in many of the SADC member states and O&M of groundwater schemes has suffered as a result. Full consideration of all aspects of groundwater abstraction needs to be considered when financing O&M, however determining the real cost of service provision is difficult due to a lack of systematic guidelines to estimate costs (Fonseca and Njiru 2003, Harvey 2007). This makes it difficult to inform water users of the true cost of groundwater supply and to determine the amount of financial support required.

4.3. The primary cost drivers of operation and maintenance

We now take a closer look at the primary drivers of O&M costs for groundwater schemes.

4.3.1. Energy costs

Pumping of groundwater requires energy and potential energy sources include solar, diesel, and grid connected. Energy costs can make up anything from 5% to 50% of the annual costs of running a groundwater scheme, depending on the energy source and extent of pumping required. Solar has minimal running costs, but the capital costs are high, as well as the susceptibility to vandalism and the reliance on sunlight. Diesel, whilst very common for small, rural schemes, is the most expensive to run and maintain, with grid-connected systems generally being 50% to 70% of the running cost of diesel systems. There are other benefits to grid-connected systems, such as the improved ability to automate electric motors, the potential to install a smaller capacity pump (since an electric pump can run continuously whereas a diesel pump generally operates for 8 hours a day), and the ability to install switches that require electricity such as no flow switches, cut off probes and pressure switches.

Solar and diesel pumping systems are preferred in rural regions that lack a grid connection, something that is common in most rural parts of SADC. While diesel and solar-powered pumps are popular for this reason, both have their advantages and disadvantages (Table 4-1).

Table 4-1: Advantages and disadvantages of solar- and diesel-powered pumps (Abu-Aligah 2011).

Type of pump	Advantages	Disadvantages
Solar-powered	Unattended operations Low maintenance costs Long lifetime (low yearly costs)	High investment costs Water storage required Skilled technicians required for repairs
Diesel-powered	Fast and easy installation Low investment costs	Diesel dependent on reliable supply and can be expensive High maintenance costs Short life expectancy Noise and air pollution

Diesel and electricity-powered pumps are observed in other parts of the world with government playing a strong role in subsidising such energy sources. In India, groundwater irrigators in poor states rely on diesel which is subsidised by government while electricity is also provided at subsidised rates. Changes in energy tariffs are borne by the Indian government, particularly in relation to electricity tariffs. In China, smallholder farmers with groundwater pumps pay for the cost of diesel or electricity based on hours of operation or electricity used (Zhu *et al*

2007). In Africa, government also subsidises fossil fuel prices, encouraging groundwater users to opt for diesel-powered pumps (Bertheau *et al* 2015). The relative capital and running costs for different sources of pumping is given in Table 4-2

Table 4-2: Capital and running costs of different power sources for pumping (Bruni and Spuhler 2020b)

		Human	Electricity			Diesel	Wind	Animal	Hydro
			Grid/ Mains	Solar	Diesel Generator				
Capital costs		*	****	*****	***	**	****	**	****
Running costs	Fuel	-	***	-	***	***	*	***	*
	Spares	*	*	*	***	****	*	*	*
	Maintenance	*	*	*	***	****	*	*	*
	Performance	*	***	***	***	****	****	**	***

4.3.2. Spare Parts

Easy and affordable access to spare parts are crucial factors in maintaining a groundwater scheme. As in any operation, parts, through wear and tear, become old and require replacement. With water pumps, this is no exception as both hand- and mechanised-pumps require regular replacements for the water supply system to remain active. Some handpumps, such as the VLOM handpump, require many spare parts on a regular basis to remain in operation (van Beers 2011). The type of parts that require replacement can vary depending on the type of handpump. For example, the Afridev handpump can require replacements of the bearing sets, nuts and bolts, pump platform, well covering, pump rods, pipes, seals, and pistons (University of South Florida n.d.). Mechanised or motorised water pumps also require an assured and sustainable supply of spare parts. Due to their higher performance levels, wear and tear is more common with mechanised pumps and the replacement of parts should occur more frequently. The parts that wear out the most in motorised pumps include pump bearings, pump impellor, pump motor bearings, internal pump check valves and pump control switches (InspectAPedia 2020).

The lack of standardisation of water pumps within a country also creates challenges in relation to provision of spare parts. The variety of different pumps present in a country makes it difficult to create a sustainable supply chain as the market is too small to justify in-country production of spare parts (Skinner 1996). As such, spare parts must be ordered from outside the country, incurring large expense for the user and leading to delays in repairs.

The replacement of parts is also determined by the life expectancy of the pump. Pumps with lower life expectancies will require spare parts more frequently than pumps with longer lifespans. Solar-powered pumps, despite their high investment costs, has a longer life expectancy than diesel-powered pumps and can produce electricity for even longer than 25 years (Bansal 2017).

When looking at spare parts, it is also important to consider vandalism and theft. High occurrences of theft and vandalism can result in the increased purchasing of spare parts on a frequent basis. Theft is a major challenge for solar-powered pumps with solar panels being highly sought after and an easy steal for criminals (Shinde and Wandre 2015). Vandalism is also a recurrent problem for groundwater infrastructure. Depending on site location and community awareness, vandalism can be a significant factor that contributes to increasing costs associated to spare parts.

4.3.3. Personnel costs

The availability of technicians to operate and maintain groundwater schemes also needs to be assessed. While large groundwater schemes would necessitate personnel for O&M, a smaller scheme located in an outlying rural area might not require a permanent technician. This aspect significantly impacts O&M costs and it is important to determine the minimum number of personnel required to maintain a groundwater scheme.

4.3.4. Overheads (indirect costs)

Indirect costs often refer to costs that are not accrued directly to the user but are spread over space and time and are borne by other users or by society at large (Molinero et al 2011). This is an important aspect if groundwater supply systems are centralised or decentralised. Centralised waters systems have high fixed capital costs but relatively low operating costs. However, overhead costs can be relatively high for such systems, including labour which does not depend on the amount of water going through the system. But in a centralised system, economies of scale can be high thereby spreading overhead costs over a large user base. Ideally, a tariff system that contains a fixed element sufficient to cover fixed overhead costs should be implemented, but this is not often the case (OECD 2018).

Decentralised systems, on the other hand, are usually found in rural, urban peripheral and informal areas. These systems are fragmented and often based on individual households or communities. In such situations, economies of scale are less, making unit costs of supply higher than in centralised systems (Bansal 2017). Overhead costs for decentralised systems might be significantly different to centralised systems due to its fragmented nature and predominance in disconnected primarily rural communities.

4.3.5. Other considerations

The scale of operation also has an impact on the cost drivers described above. This includes large- and small-scale groundwater schemes.

Large-scale groundwater schemes entail many wells and extraction sites which require significant amounts of energy to extract groundwater. Development of these schemes usually involves modern technologies (excavation machines, motorised drilling, various types of borehole drilling and motorised pumps of varying size and capacity) that come at a considerable financial cost. However, these technologies allow for rapid development of large-scale infrastructure to enable large water yields and are considered efficient approaches to groundwater extraction (Ali 2011, Xenarios and Pavelic 2013). O&M for such schemes would be more extensive and centralised than small-scale versions, requiring more technical personnel and larger financial resources to maintain and upgrade high-technology equipment.

Small schemes, on the other hand, usually involve a single (sometimes more than one) hand- or mechanised-pump that is used by rural communities and/or small-scale farmers to access groundwater. However, O&M for small-scale groundwater schemes should not be discounted. Small-scale schemes can require relatively onerous O&M particularly in relation to the need to provide institutional support for community-based management systems (Schouten and Moriarty 2003). Institutional support can include encouragement and motivation, monitoring and evaluation, participatory planning and regulation, capacity building, and special technical assistance (including financing support) which must not be underestimated when costing O&M. These costs are ongoing, requiring long-term sustainable funding mechanisms, and will vary from country to country. Institutional support costs, while possible to be levied through a tariff or tax applied to water users, is usually recovered thought government-developed budgets that account for institutional support costs on a long-term basis (Harvey and Reed 2004).

4.4. Funding of operation and maintenance of groundwater schemes

Groundwater financing and funding has always been a challenge for many countries across the world. Funding varies across nations and is dependent on the overall financial situation of the country. In many developing countries that have limited finance, groundwater agencies struggle to deliver on the minimum of critical activities required (UNESCO 2015).

Most national agencies responsible for groundwater management receive most of their funding from government. However, groundwater does not often rank highly enough on political agendas and funding of government groundwater agencies is limited. The overall financing of groundwater management often falls short and groundwater agencies must look for alternative sources of funding. This can take the form of recovery of groundwater costs (cost recovery) through permit fees, tariffs, groundwater use, pollution taxes and fines that are applied to groundwater users and polluters (UNESCO 2015).

Cost recovery refers to “the practice of charging users the full (or nearly full) cost of providing services” (Harvey 2007). Harvey (2007) goes on to explain that full cost recovery refers to the reimbursement to service providers of both recurring and non-recurring costs associated with construction, management, O&M, rehabilitation and expansion of systems. Cost recovery is critical to ensuring effective community mobilisation, planning, design, administration, construction and O&M of groundwater schemes. However, as noted earlier, full cost recovery is rare in SADC due to

1. Costs being unaffordable for most rural communities
2. Reluctance of groundwater agencies to seek full reimbursement due to water being viewed as a right (Harvey 2007)

While many groundwater schemes in SADC entail some form of donor funding, O&M costs are generally expected to be paid for by the users through tariffs (Fonseca and Njiru 2003) with communities contributing a further 5-15% for initial capital costs (Harvey 2007). However, in practice, this is rarely observed and cost recovery practices are viewed as ways to promote community ownership and willingness to pay rather than recovering the full economic cost (Deverill et al 2002).

4.5. Review of tariff models

Ideally water tariffs are the preferred funding mechanism to cover costs associated with system upgrade, rehabilitation, expansion costs and O&M costs (Harvey 2007). Tariffs are "charges for the measured delivery of a valued commodity" (Acharyya 2018). Tariffs usually contain two charges (Acharyya 2018):

- A charge that depends on the volume of water used
- A charge that is not based on water consumption e.g. connection fees, meter charges

Tariffs are either structured as an increasing block rate structure, decreasing block rate structure or uniform rate structure (Figure 4-2). Traditionally, decreasing block rates were preferred but this is changing with a favour for increasing block rates due to the scarcity of the resource and changing economic circumstances. Increasing block rates promote water-use efficiency and are gaining traction in developing nations because basic water uses undertaken by the poor are internally subsidised by this rate structure (Boland and Whittington 2000, Acharyya 2018).

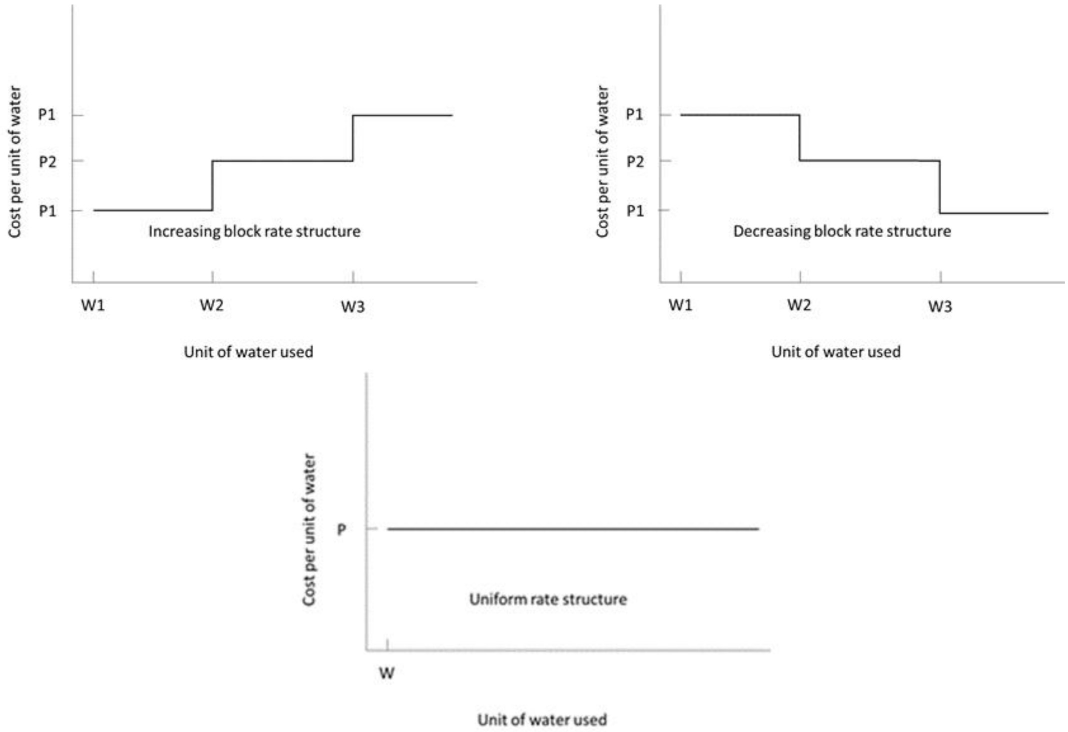


Figure 4-2: Tariff structures (Boland and Whittington 2000)

Tariffs for groundwater schemes should be determined once the full economic cost has been calculated. Complex schemes that rely on consumable energy sources (electricity or diesel) will have higher tariffs than those without.

The effective implementation of tariffs is rare in SADC with many rural communities lacking transparent, secure and sustainable methods for storing and investing money for future use. Furthermore, communities in SADC exhibit either an unwillingness and/or inability to pay and this is supported by the fact that many of these communities have high levels of poverty and unemployment.

4.6. Typical mechanisms for financing operation and maintenance of groundwater schemes

4.6.1. User-based funding

This model sees the costs for O&M being recovered from users, usually through the form of tariffs or voluntary community-based management (Box 4-1; Box 4-2; Box 4-3). Essentially, charges are introduced for the use of water services where these are affordable and where the services are used in a commercial or leisure context, usually on a seasonal, annual, volumetric and/or voluntary basis. Typically, for household water and sanitation, these costs are structured to be affordable to domestic users. Due to the fragmented nature of rural water supply, community-based management is one of the predominant approaches for cost recovery in Africa. These costs can be paid on an ad-hoc basis per repair or visit (payment of technicians and cost of spare parts) or as a regularised fee like a tariff. Tariffs are traditionally developed and implemented by government agencies such as local municipalities or contracted service providers. Appropriately structured tariffs i.e. volumetric tariffs can incentivise water-use efficiency, particularly if the cost of water increases with the volume of water used. Effective tariff implementation often needs complementary policy, regulatory, institutional and social instrument to ensure fairness. A tariff system can also include possible cross-subsidies from other consumer categories or the use of increasing block rate tariffs that help to offset the financial burden on the poor (CapNet *et al* 2010, Lockwood 2019).

Box 4-1: Community Ownership and Management Concept – Ghana (Adomako 1998)

Ghana employed a Community Water and Sanitation Programme in the Eastern Region using the Community Ownership and Management Concept. This demand-driven approach requires communities to co-finance water supply facilities including full financial responsibility for O&M. The aim of the programme is to shift focus away from government dependence towards self-reliance by user communities. The average contribution per person is approximately $4. The funding generation options that are used are:

- Communal levies
- Farmer deduction or kilo-kilo deductions (commercial farmers deduct a certain amount of crops as annual contribution to maintenance)
- Communal farmers or labour association that generate funds for maintenance
- A flat rate applied to all members of the community that must be paid at the end of the month
- A pay-as-you-fetch levy for each bucket of water used.

However, there have been challenges with this approach due to difficulties in collecting levies, non-participation from farming members, seasonal nature of farming, misappropriation of funds and the inequitable nature of flat rates disadvantage the poorer members in the community.

Box 4-2: Community Based Maintenance System – Malawi (Baumann and Danert 2008)

Malawi also employs a model of a Community Based Maintenance System, similar to that observed in Ghana. Government investments in O&M of groundwater schemes are low and focus is more on once-off activities (training and equipping area machines) rather than continuous support. Prior to the drilling of a borehole, communities are expected to collect MWK 15 000 (MWK 3000 for a shallow well) which must be deposited into a bank account as a start-up O&M fund. However, some projects encourage this money to be used to purchase spare parts rather than opening a bank account. A community elected committee is expected to manage the facility and collect money on a regular basis for O&M purposes. Government does provide some form of community-based maintenance training once a borehole has been established, after which communities are expected the maintain the facilities thereafter (approximately 10 years).

However, this approach has proven problematic as users in Malawi still view government as the main driver of O&M. It is perceived by the communities that government is responsible for major repairs, although the definition of major is not specified. The purchase of spare parts is undertaken by the community, government or a combination of both depending on the availability of parts and costs. However, this is not performed in a structured manner and is determined on a case by case basis. Evidence suggests that the collection of monies for O&M prior to borehole drilling as well as after is not always done and funds are only collected when a particular handpump is broken. Furthermore, the training provided to communities is inadequate and/or lacking for some communities.

Box 4-3: Tariff setting - Zambia

Tariff setting is an important part of collecting revenue to compensate for costs of supplying water to the public. How the tariff is structured will depend on the trade-off between cost recovery and affordability, although they are also sometimes used to promote efficient water use.

It is useful to look at examples where groundwater is the primary source of water to better understand tariffs and how they are structured.

Zambia

Zambia is also heavily reliant on groundwater with 60-70 % of water consumed in Zambia coming from groundwater (Kaunda 2018). The water regulator in Zambia (NWASCO) has implemented fees for groundwater use in response to drought and increasing water demand. In 2018, owners of domestic boreholes were required to pay a once-off fee to have their well licensed, with users consuming more than 10 000 litres/day being charged a commercial fee.

4.6.2. Government funding

As water is often viewed as a human right, the option for government to fund all aspects of water supply including O&M of groundwater schemes is present in some cases (Box 4-4). Government takes responsibility for all aspects of financing of O&M of groundwater schemes, noting that water is a public good (Cap-Net *et al* 2008). Users might only pay for the spare parts, but ultimately, no fees are charged for the time of the technician or mechanic during a period of maintenance (Lockwood 2019).

Box 4-4: Kebele Water Technicians – Ethiopia (Lockwood 2019)

The Tigray region is Ethiopia has established water technicians at the lowest administrative level (kebele level). To promote localised management of rural water supply, government has established the kebele water technicians as the main driver of O&M in rural communities in the Tigray region. Although the primary responsibility of day-to-day O&M falls on the village WASH committee, the kebele water technician serves as the first point of contact for communities. If there is no alternative service provider, the kebele technicians carry out O&M. In this model, users only pay for the costs of spare parts while the salaries and operational costs are paid by government.

4.6.3. Donor Funding

Donor funding is a major source of funding for groundwater schemes in SADC and throughout Africa, being one of the primary sources of funding for rural communities (Box 4-5). Although traditionally responsible for only the drilling of a borehole in a region, there are some donors who assume the responsibility of O&M and its associated costs.

Box 4-5: Wahis Mai REST programme – Ethiopia (Lockwood 2019)

The Wahis Mai REST programme is funded completely by Charity: Water, a US-based non-profit organisation that aims to bring clean safe drinking water to people in developing countries. The primary target of the programme is to reduce downtime, increase functionality and inform programme improvements of rural water supply systems. The programmes employ highly trained technicians that provide a rapid response maintenance function. Recently, the programme has been pushed by government to perform the functions of facilitators or trainers to support capacity building rather than performing repairs.

4.6.4. Blended funding

This form of financing is relatively popular in developing nations that lack the budget for O&M and/or have populations that are unwilling or unable to pay for O&M (Box 4-6; Box 4-7). These partnerships between government, NGOs, private service providers, non-profit organisations and community organisations, if structured correctly, can introduce the principle of comparative advantage and allow for appropriate sharing of risks[98]. In most situations, subsidies are used to augment what little revenue is generated from tariffs and community-based financing towards O&M costs.

Donor funding can also provide some form of subsidy for ongoing provision of services alongside a tariff or user fee paid by consumers e.g. the Water for Good Circuit Rider Programme in Central African Republic which subsidised 95% of all costs while users pay per visit (Lockwood 2019). Government-based subsidies usually target the most vulnerable i.e. the poor, women and people with disabilities (Cap-Net *et al* 2008).

Box 4-6: Public Private Partnership - South Sudan (Ministry of Water Cooperatives and Rural Development 2015)

In the Northern Bahr el Ghazel state of South Sudan, the government has initiated a community-based approach to operation and maintenance of rural water supply schemes. Communities are encouraged to take responsibility and to manage their facilities including the collection and payment of fees for regular maintenance and repair. Communities are expected to levy 2-5 SSP (South Sudanese Pound) per month per household to cover O&M costs. The repair works are performed by hand pump mechanics who are either volunteers from the community or employed by government. Communities pay these mechanics irrespective if they are volunteers or employed by the state. Private enterprises provide spare parts which is funded by communities and supported by government and development partners through the establishment of revolving funds and guaranteeing purchase of pump parts. Regular back-up support follow-ups and monitoring of community management is provided by government, NGOs and developmental partners. In addition, government together with developmental partners subsidises the capital costs of new or rehabilitated boreholes fitted with a community handpump. Although communities are expected to contribute cash as an initial deposit to the maintenance fund, external support agencies and government (if funds permit) may cover the full additional costs.

Box 4-7: Case Study 6: FundiFix – Kenya (REACH n.d., Lockwood 2019)

The FundiFix model focuses on the maintenance of existing water infrastructure and is led by local entrepreneurs in Kenya. The model offers a performance-based approach that works with government, communities and investors to maintain infrastructure. This approach uses the idea of "scale reduces risk" whereby economies of scale can be achieved if all rural waterpoints are networked in one system, allowing for improved service delivery at lower costs. The model requires communities to subscribe to a service contract with regular payments. The FundiFix model is also partly funded by the Water Service Maintenance Trust Fund (WSTM) which channels financing from donor organisations, public financiers and other investors. FundiFix applies for O&M gap financing from the WSTM every six months which releases funds based on achievement of pre-identified performance targets. Local companies and entrepreneurs are employed to repair rural water infrastructure with the guarantee of repairs being completed in 3 day (if not, communities are awarded a free month of service). This performance-based approach ensures that ongoing payment of fees by communities and builds trust between the communities and entrepreneurs. The model, through its economies of scale approach, ensures that all water infrastructure is maintained

4.7. Challenges to funding of operation and maintenance

While the importance of O&M and its associated financing has come to the forefront for many countries in SADC, the actual funding of it remains a challenge due to a variety of reasons:

- Construction quality may have been poor, impacting subsequent water supply disincentivising users to pay tariffs or fees
- The financial costs that are expected to be borne by communities in a use-based funding model are either unacceptable, unaffordable or impractical
- Communities are not instilled with a sense of ownership over groundwater infrastructure
- Government is overstretched and under-resourced and are unable to undertake repairs and maintenance on a regular basis
- Communities lose interest in O&M of groundwater schemes with trained community members moving away
- Lack of transparency and mistrust regarding collection and management of revenues collected by community managed schemes
- Change in groundwater recharge or abstraction rates has affected water tables and has resulted in reduced reliability of water supplies
- Misleading statements from NGOs, organisations and government

(especially during political campaigns) that the use of borehole water is free and no revenues need be collected leading communities to believe that there is no need to pay towards any O&M costs (Carter *et al* 2010, Lockwood 2019).

Many models that use some form of external support (donor or government) operate at a loss with regards to operational costs vs revenue generation (Lockwood 2019). It is only due to external funding that these models can continue and maintain operations. Due to the challenges listed above as well as current perceptions amongst communities in Africa that government is responsible for all costs associated with water supply, it appears that many financing models intentionally charge less than the total economic cost of groundwater abstraction.

4.7.1. Challenges to user-based funding

While this model is viewed as the most appropriate for financing of O&M of groundwater schemes, very few groundwater agencies in SADC implement tariff systems that ensure full cost recovery. Carter et al. (2010) reported that tariffs in Africa are often determined either by looking at what is the norm in the country or by looking at the affordability per household. Community based management often runs on an ad-hoc basis, using a "fix on failure" approach that fails to adequately cover the full O&M costs. Typical revenues raised by rural communities served by handpumps are usually around $30-40 per year (Carter *et al* 2010). Lockwood (2010) also reported revenue values raised by communities in different countries (Table 4-3).

Table 4-3: Tariffs or costs to consumers in different countries (Lockwood 2019)

Country / Region and/or name of funding model	Tariff or Cost to Consumer
Central African Republic – Water for Good	$186 per service visit (only paid in full by 25%of consumers)
Kenya – FundiFix	$5-10 per month for hand pump
Uganda – Whave	$70-125 per year based on scheme and discounts
Uganda – Hand Pumps Mechanics Association (HPMA) Volumetric tariff (pay as you fetch)	$2.67 per water point per month

These amounts (Table 4-3) collected from users might be sufficient for minor repairs and preventative maintenance but is woefully inadequate to cover the full economic cost of groundwater abstraction. These tariffs can further be impacted by poverty-related exemptions and regular defaulting by the community significantly reducing revenue generation. Furthermore, willingness to pay is still problematic in many member states either due to communities viewing water as a right that does not require payments or communities being unable to afford costs associated with O&M. The vulnerability of rural communities in SADC to flooding, famine and other external shocks threatens the yearly incomes of households which interrupts the income stream for O&M costs. The use of subsidies is a well-known method to alleviate the financial burden on the poor, however, it has been difficult to implement in SADC with evidence suggesting that individual better-off household "rarely if ever pay on behalf of their poor neighbours" and that communal arrangements for cross-subsidies of those who are exempted are lacking in Africa (Carter *et al* 2010).

4.7.2. Challenges to government and donor funding

A completely government or donor funded model creates overreliance by communities on government and donors to pay for O&M-associated costs. This model also encourages wasteful water use practices as users are not appropriately charged for their water use. This model is not sustainable in the long term and most governments in SADC struggle to adequately budget for O&M of groundwater schemes. Donors are also not a long-term solution as their continued presence is not ensured and the expectation of ongoing donor support undermines efforts to establish more commercially viable O&M programmes (Lockwood 2019).

4.8. Exercises

4.8.1. Costing and tariff exercise

<u>COSTING AND TARIFF EXERCISE (60 min)</u>

The following exercise is adapted from PDG's Setting Tariffs: A guide for local government in South Africa, Namibia and Botswana. For a deeper analysis of tariffs, please refer to the document by Walsh et al. (2012)

<u>The Situation</u>

A municipality is responsible for a relatively small groundwater scheme which provides water services to its population of **10 000 consumers**.

Total consumption of water is **500 000 kilolitres (kl) per month**.

While the municipality is responsible for water supply, the tariff that the municipality wishes to implement should only incorporate 20% of the costs of the municipality. The installation of the groundwater scheme cost $1 000 000, of which 50% was funded by the State and 35% by donors. The remaining 15% (i.e. $150 000) is expected to be recovered from the users through tariffs over a five-year period.

The municipality wishes to develop a tariff that has a surplus revenue of 10% as well as incorporating a subsidy for low income domestic consumers and a 6-kilolitre free basic water provision.

National government, to support the provision of free basic water, provides a subsidy of $50 000 to the municipality each month.

<u>Step 1</u>

Using the above values as well as the assumptions below, calculate:

a) the annual budget required to supply water to the municipality's citizens
b) the effective costs per unit
c) the primary tariff

<u>Step 2</u>

The second part of this exercise looks to see how the calculated tariff can be adjusted to incorporate free basic water as well as subsidies for the poor.

Using the primary tariff calculated in Step 1 of this exercise, calculate a revised tariff if:

a) a free basic water policy of 6 kiloliters is applied
b) a subsidy is introduced to benefit low income domestic consumers in the municipality.

The following information is provided:

Breakdown of consumers			Breakdown of domestic consumers			
Type of consumer	Number	Total consumption (kl/month)			Number	Average use (kl /month)
Domestic consumers (includes indigent, low income, middle income and high income)	8,000.00	250,000.00	Total number of domestic consumers		8,000.00	
Commercial consumers	1,000.00	100,000.00	Indigent	<$500 per average household	1,500.00	
Industrial consumers	500.00	100,000.00	Low income	$501-1500 per average household	4,000.00	20
Institutional consumers	500.00	50,000.00	Middle income	$1501-2000 per average household	2,000.00	24
Total	**10,000.00**	**500,000.00**	High income	>$2000	500.00	28

1 a) Calculate the annual budget required to supply water to the municipality's citizens

The budget needs to be divided into four components: direct costs, overhead costs, installation costs and capital costs.

•Direct costs refer to all costs associated with labour, materials, repairs, maintenance and other expenses directly related to the provision of water.

•Overhead costs refer to the costs associated with the municipality and its operations i.e. municipal staff, planning and utilities.

•Installations refer to the costs associated with the installation of the groundwater scheme.

•Capital costs are fixed once-off costs.

Noting that the tariff the municipality wishes to implement will only incorporate 20% of the costs of the municipality, this 20% needs to be incorporated in the budget. Furthermore, only 15% of the installation costs will be covered by the users through the tariff and this also needs to be incorporated into the budget.

The formula will be as follows:

Annual Budget = [Direct Costs] + 20% [Overhead Costs] + 15% [Installation Costs] + [Other Capital costs (annualised)]

It is important to note that the below calculation is for annual costs. Some of the costs are variable while others are fixed. Variable costs are based on a certain cost per kilolitre and these costs could increase or decrease e.g. amount of diesel required for a pump will vary if pumping for a month is higher or lower.

Direct Costs	
Employee-related costs (salaries, wages and social contributions) ($)	1,800,000.00
Bulk purchases, materials and equipment ($)	800,000.00
Repairs and maintenance ($)	600,000.00
Energy to operate the groundwater scheme (electricity, diesel etc) ($)	300,000.00
Transport ($)	100,000.00
Private contractors / service providers ($)	200,000.00

Other ($)	50,000.00	
Sub-total ($)	**3,850,000.00**	
Allocation of overhead costs		
Municipal Manager ($)	100,000.00	
Municipal Council ($)	90,000.00	
Finance ($)	110,000.00	
HR ($)	90,000.00	
IT ($)	50,000.00	
Planning ($)	75,000.00	
Utilities ($)	10,000.00	
Sub-total ($)	**525,000.00**	
20% of municipal costs ($)	**105,000.00**	The tariff will only incorporate 20% of the municipality's costs.
Installation of groundwater scheme		
Total costs ($)	1,000,000.00	
50% funded and paid for by government ($)	500,000.00	Cost is subtracted from total costs
35% funded and paid for by donor ($)	350,000.00	Cost is subtracted from total costs
15% to be funded by user ($)	150,000.00	
15% to be funded by user over a five-year period ($)	**30,000.00**	While the 15% required from users is $150 000, this amount can be recovered over 5 years. Hence, the amount is divided by 5 as this is an annual budget. This amount will continue to be included in the annual budget for the next five years until the $150 000 is recovered from the users.
Capital costs		
Provision for replacement ($)	200,000.00	
TOTAL ($)	**4,185,000.00**	

The total cost i.e. annual budget required to supply water by the municipality is $4 185 000 per annum

1 b) Calculate the effective cost per unit for the municipality to supply water

The effective cost per unit will be determined by dividing the costs of supplying water per month by the total consumption per month (which was earlier stated to be 500 000 kl/month).
The annual budget of $4 185 000 per annum will need to be divided by 12 months to calculate the monthly costs to the municipality.

The formula will be as follows:
Effective Cost Per Unit = [Annual Budget / 12] / Total Consumption Per Month

	Cost per month ($)	Total consumption (kl/month)	**Effective cost per unit ($/kl)**
Costs of supplying water per month	348,750.00	500,000.00	**0.70**

The effective cost per unit to supply water to the municipality's citizens is $0.70 per kilolitre per month.

1 c) Calculate the primary tariff

While the effective cost per unit provides a good indicator of costs for the municipality to supply water, the tariff will need to reflect other elements. As part of municipal strategic principles relating to cross-subsidisation as well as to counter bad debts, the municipality requires surplus revenue of 10% each month to meet its strategic needs.

To calculate the new tariff that includes the 10% surplus in revenue, the formula will be as follows:
Primary Tariff = 10% [Cost Per Month to Supply Water]+ [Cost Per Month to Supply Water] / [Total Consumption Per Month]

Cost of supplying water per month ($)	Surplus required	Revenue required ($)	Total consumption (kl/month)	**Primary tariff ($/kl)**
348,750.00	0.10	383,625.00	500,000.00	**0.77**

The primary tariff including 10% surplus in revenue is $0.77 per kilolitre per month.

2 a) Provision of free basic water

The municipality is implementing a tariff that incorporates national government's policy to provide 6 kilolitres free water per household per month. To achieve this, national government provides the municipality with a subsidy of $50 000 each month. As such, the required revenue calculated earlier will need to be adjusted to account for this subsidy.

Furthermore, the total consumption of water will also need to be adjusted as 6kl per household will be free and will not be charged for by the municipality. The provision of free water applies to the municipality's 8 000 domestic users

To calculate the new tariff that includes this free water, the formula will be as follows:

*Adjusted Primary Tariff = [Revenue Required - Subsidy] / [Total Consumption Per Month - (6kl/month * 8 000 Domestic Users)]*

Subsidy from national government ($)	Revenue required ($)	Total amount of water provided for free (kl/month)	Volume of water sold (kl/month)	**Adjusted primary tariff ($/kl)**
50,000.00	333,625.00	48,000.00	452,000.00	0.74

The adjusted primary tariff which includes the national subsidy and free water provision is $0.74 per kilolitre per month.

2 b) Subsidy for low income households

The municipality also wishes to implement a subsidy for low income households whereby low-income households only contribute 1% of their household incomes towards water bills.

The municipality has defined low income as households with an income between $500 - $1 500 per month and who consume an average of 20 kilolitres per month. Using this range, the average income per low income household needs to be determined and the formula is as follows:

Average Income Per Month = [(1500-500)/2] + 500

The municipality wishes for these households to only pay 1% of their income towards water:

1% of Household Income = 1% X [Average Income Per Month]

To calculate the new water tariff using the 1% of household income and the average use of 20 kl/month (excluding the 6 kilolitres that is free), the following calculation can be used:

Revised Tariff for Low Income Households = [1% of Household Income] / [20kl - 6kl]

However, while this is useful for application towards low income household, the municipality still needs to evaluate whether this subsidy generates enough revenue. If not, cross-subsidisation will need to be used

Average income per month ($)	1000	*= (1500-500)/2 + 500*
1% of household income ($)	10	*= 0.01*1000 (average income per month)*
Revised tariff for low income households with an average use of 20kl/month ($)	**0.71**	*= % of household income / (20-6)*

As mentioned earlier, the above tariff for low income households will need to be assessed to determine whether the municipality will generate sufficient revenue. This requires looking at the revenue generated from the new tariff for low income households and revenue generated from the adjusted primary tariff.

Noting that the municipality has a total of 4000 low income households, the total revenue generated from low income households can be calculated as followed:
Total revenue from low income households per month = [Tariff] X [Number of Low Income Households] X *[Average Water Use Per Low Income Household - 6 Kilolitres Free Water]*

If a shortfall is identified between the new tariff for low income household and the adjusted primary tariff, cross-subsidisation is needed to ensure that the municipality generates sufficient revenue. To determine if there is a shortfall, the following calculation can be used:
Shortfall = [Total Revenue From Low Income Households Using Adjusted Primary Tariff] - [Total Revenue From Low Income Households Using New Tariff]

Total revenue from low income households per month using new tariff ($)	40,000.00
Total revenue from low income households per month using adjusted primary tariff ($)	41,334.07
Shortfall ($)	**1,334.07**

As can be seen in the above calculation, there will be a shortfall of $1 334.07 per month if the new tariff for low income households is applied.

Noting the shortfall in revenue, the municipality will need to implement cross-subsidisation. A higher tariff will need to be levied against the middle- and high-income households, which have an average consumption of 24 kl/month and 28 kl/month respectively.
This will require determining the revenue generated from the different households using the adjusted primary tariff:
Revenue From Households Based on Adjusted Primary Tariff = [Adjusted Primary Tariff] x [Number of Households] x [Average Water Use - 6 Kilolitres Free Water]

The volume of water sold per household per month will also need to be calculated, as follows:
*Volume of Water Sold = [Number of Households] * [Average Use - 6 Kilolitres Free Water]*

Since both the middle- and high-income households will bear the revenue shortfall equally, the revenue and volume of water sold from both is combined.
It is now possible to develop a cross-subsidised tariff that applies equally to the middle- and high-income households.
*Indigents and other consumers (industrial, institutional, commercial) are excluded from the below equations.

	Revenue based on adjusted primary tariff per month ($)	Volume of water sold (kl/month)
Middle income households	26,571.90	36,000.00
High income households	8,119.19	11,000.00
Combined middle- and high-income households	**34,691.10**	**47,000.00**

It was calculated earlier that the shortfall in revenue for the subsidisation of low-income households would be $1 334 per month. Since the high- and middle-income households will be cross-subsidised to cater for this loss, this shortfall is added to their combined monthly revenue. The new tariff for high- and middle-income households can now be calculated using the following calculation:
Cross-Subsidised Tariff = [Revenue Based on Adjusted Primary Tariff Per Month For Middle- and High-Income Households + Shortfall] / [Volume of Water Sold to Middle- and High-Income Households]

Cross-subsidised tariff for middle- and high-income households	
Shortfall after low income subsidy ($)	1,334.07
Revenue based on adjusted primary tariff per month for middle- and high-income households ($)	34,691.10
Revenue required from middle- and high-income households after subsidising low income households ($)	36,025.17
Volume of water sold to middle- and high-income households (kl/month)	47,000.00
Cross-subsidised tariff ($/kl)	**0.76649**

The cross-subsidised tariff for middle- and high-income households is $0.77 per kilolitre per month.

It is important to note that at all stages, the various tariffs that were calculated were higher than the effective cost per unit ($0.70 per kilolitre per month). This is important as the effective costs per unit provides the baseline below which the municipality will be operating at a loss and not be generating sufficient revenue to recover costs.

5. FINANCIAL MANAGEMENT

- Understand the basic principles of financial management for O&M of groundwater schemes
- Consider policy considerations for O&M
- Being able to undertake basic budgeting for O&M
- Understanding the various tariff structures and means to collect revenue

5.1. Introduction

While it is recognised that water is a public good and a human right, it is still a scarce resource with multiple competitive uses as well as being vulnerable to overuse and pollution. As such, sustainable groundwater management, development and supply is essential to support localised socio-economic development.

Groundwater schemes often have lower initial costs but proportionately higher operational costs (including O&M), compared with surface water schemes (Eales and Cobbing 2013). Whilst a groundwater scheme might be cheaper overall, its operational (or recurrent) costs may be more difficult to secure than an initial capital sum. As mentioned, recurrent costs are also vulnerable to budgetary appropriation for other (often temporarily more important) purposes. Ironically, this is especially true when O&M is successful: it may seem to non-specialists that regular O&M money spent on a well-maintained and functioning groundwater scheme does not yield any marginal improvement for the regular sums of money that are spent. Compounding this problem is the lag or delay between stopping O&M, and scheme failure. Schemes may run for months or even years with inadequate O&M – they will eventually fail, but the causal link between halting O&M and the inevitable failure may be obscured by more proximate events.

Ensuring effective financial management is a crucial element in ensuring the sustainability of a groundwater scheme and its role in supporting local economies. Although its importance has often been emphasised, the aspect of O&M is frequently neglected and clear guidance on financial management to support the O&M of groundwater schemes, particularly in rural areas, is lacking. While guidance for financing of surface water infrastructure O&M is readily available, groundwater, due to its invisible nature, does not receive the same attention. Part of this dilemma is the nature of groundwater infrastructure and its value as an asset, which is distinctly different from the large-scale surface water schemes. This results in the O&M costs of groundwater schemes often being a far more significant investment against asset value and the return on investment[3]. The consequence of this is that O&M for many groundwater schemes in SADC are often underfunded, threatening the sustainability and performance of the groundwater scheme. This is exacerbated by many groundwater schemes supporting the more rural contexts where there are challenges in ensuring a sustainable revenue stream because of communities having a limited ability to pay for water services. Financial resources in SADC member states are limited, prompting the need for careful planning and budgeting when it comes to O&M. This also needs to be supported by exploring better ways to sustainably finance O&M. The objective of this chapter is to provide the basic foundation for the financing of O&M of groundwater schemes. The chapter lays out the building blocks required to ensure sound financial management, but also allows for additions and amendments to suit local contexts. Noting that the on-the-ground conditions can vary across SADC, this chapter aims to guide practitioners and decision-makers by showing the key considerations for financing of O&M of groundwater infrastructure while also highlighting the need for bespoke elements that depend on local conditions.

5.2. General principles of financial management

Financial management entails planning, directing, organising and controlling all financial activities related to O&M of groundwater schemes. Key aspects of financial management are procurement, allocation and control of financial resources available.

The objectives of financial management are to ensure:

- Steady and sufficient supply of funds, i.e. to ensure that funds are available to meet expenditure when required
- Optimum utilisation of funds

[3] Return on investment (ROI) is a financial metric of profitability that is widely used to measure the return from an investment. ROI is a simple ratio of the gain or loss from an investment relative to its cost. It is as useful in evaluating the potential return from a stand-alone investment as it is in comparing returns from several investments. https://www.investopedia.com/articles/basics/10/guide-to-calculating-roi.asp.

- That surplus funds are safely and transparently protected to allow utilisation against future expenses, for example where a tariff makes provision for infrequent outlays such as rehabilitation work or major servicing
- That the financial inflows and outflows can be accurately audited and reported on
- That sufficient information is collected to improve the accuracy of forecasting, budgeting and tariff setting for the next cycle

Through good financial governance, compliance and regulatory reports can be produced while also allowing for more accurate budgets, plans and forecasts. In addition, effective financial governance leads to faster and more efficient financial processes, easy and quick identification of risks and clear ownership and accountability at all levels.

5.3. Policy considerations

An enabling policy environment is a crucial factor towards successful financial management and requires comprehensive policy and regulations that support the various financial aspects of O&M of groundwater infrastructure.

5.3.1. Lifecycle costing

When developing financial policies for O&M of groundwater infrastructure, it is important to emphasise the need for lifecycle costing. Lifecycle costing is the cost to provide and sustain a service over the lifetime of the asset. This includes not just considering the upfront purchasing and installation of the groundwater system, but also the ongoing costs of maintaining the asset. Part of this is the consideration of future replacement costs to ensure the sustainability of the system. Lifecycle costing includes acquisition and use or disposal of assets, in order to achieve optimum use of all assets at the lowest cost. There is often a lack of financial data on the realistic costs of maintaining water services over time (Burr and Fonseca 2013).

A breakdown of the typical components of a lifecycle costs approach is detailed below in Table 5-1 adapted from Fonseca *et al* (2011). Table 5-1 primarily focuses on pro-poor approaches to water supply in rural areas and can be adapted for groundwater schemes in SADC, noting that many rural communities rely on groundwater as their main source of water.

Table 5-1: Typical components of a lifecycle costs approach (Fonseca et al 2011)

Cost component		Description
Capital expenditure The costs of providing a service where there was none before; or of substantially increasing the scale or level of services.	Capital expenditure construction	Capital invested in constructing and/or purchasing fixed assets e.g. concrete structures, pumps etc. to develop or extend a service. This includes initial construction, system extension as well as system enhancement, augmentation and ancillary equipment (vehicles or offices to support operation of the water supply system).
	Capital expenditure establishment	The costs of one-off work with stakeholders prior to construction or implementation, extension, enhancement and augmentation (including costs of one-off capacity building).
Recurrent expenditure (post-construction costs) Service maintenance expenditure associated with sustaining an existing service at its intended level.	Operational expenditure	Regular expenditure on labour, fuel, chemicals, materials, and purchases related to operation and maintenance of groundwater scheme.
	Capital maintenance expenditure	Expenditure on asset renewal, replacement and rehabilitation which goes beyond routine maintenance to repair and replace equipment, in order to keep scheme running. Potential revenue streams to pay these costs are critical to avoid the failures resulting from ad-hoc and late rehabilitation.
	Cost of capital	The cost of financing a programme or project. This is the cost of accessing funds to construct a system and consists of interest on any loans and the return required on the Capex investment by government as owner. If capital has been provided in the form of a grant, this can be viewed as an "Indirect Cost of Capital"
	Expenditure on direct support	Expenditure on both pre- and post-construction support activities directed to local-level stakeholders, users or user groups. This includes the costs of capacitating local government and ensuring there are adequate resources to plan for and manage emergencies and monitoring of private or public service providers' performances
	Expenditure on indirect support	Includes macro-level support, capacity-building, policy, planning, and monitoring that contribute to

Cost component		Description
		capacity and regulation but are not part of any programme or project.

5.3.2. Funding sources of O&M

Another essential element that needs to be included in policy is funding sources for O&M. While water is considered a human right, there is still the need to sustainably manage and maintain the infrastructure required to supply water to users. This comes at a significant financial cost which needs to be recovered from somewhere. Policy needs to take this into account as well as exploring alternative funding sources for O&M of groundwater infrastructure in SADC as traditional funding sources such as tariffs or user fees are not always practical or affordable to the user. Donor and government funding are popular funding sources in many SADC nations, but these options are not sustainable in the long-term and create an overreliance on government and donors, while also encouraging wasteful water use practices. The introduction of a user pays principle is generally recommended to recover monies related to the cost of O&M of groundwater infrastructure but needs to be directed to those that can afford it as well as being implementable at a local level. Community-based management and strong collaboration between local government and private sector can help to reduce the administrative burden on government in implementing a user pays principle while also encouraging water-use efficiency as tariffs are often based on volume of water used.

On-the-ground conditions also need to be understood when developing policy as rural and urban areas will have different contexts i.e. rural communities might lack the financial resources to pay for O&M-related costs and alternative measures need to be considered to ensure that funds are recovered. Noting that a large portion of SADC's population lack the financial resources to pay for full cost recovery tariffs, the application of a tariff system is not necessarily practical or affordable in many instances. Alternative funding sources can include increased grants and donor contributions being directed to rural areas or areas consisting of vulnerable groups (women, children, elderly and people with disabilities). Another alternative can include cross-subsidisation whereby higher prices are charged to one type of user (i.e. those that can afford tariffs, such as industrial and commercial users) to allow for lower prices for rural and vulnerable populations. Tariff concessions are also an option to reduce the financial burden on vulnerable groups.

5.4. Budgeting for O&M

Budgeting is essentially the process of developing a plan that details how money will be spent. This allows financial managers to determine in advance if sufficient money is available to implement the various activities related to O&M. The development of an O&M budget will help to determine line-item costs that need to be included in the annual budget for O&M. The O&M budget should be prepared four to six months before the start of the financial year and will allow the financial manager to review where the funds for the various activities will come from. This level of planning can be used to determine if there is sufficient capital for the O&M budget and whether alternative funding sources are required e.g. grants. It also allows for tariffs to be adjusted accordingly to ensure that sufficient revenue is collected for the O&M budget. It is generally useful to look at past spend from previous years to provide some guidance on developing the O&M budget. This also helps to anticipate future spending and identify past practices that could be considered wasteful and/or unnecessary.

Questions that should be asked when preparing an O&M budget are:

- What is the cost of undertaking O&M for the upcoming financial year?
- Are the available funds sufficient to cover these costs or is alternative funding required (e.g. grants, donor funding etc.) (Jordan and Wyat 1989). Separate plans will need to be developed if alternative funding is required. This will include the total amount needed from alternative funds as well as potential sources that can provide these funds. In addition, listing the advantages and disadvantages of the different sources can help to determine which options are most viable.

Budgeting can be complicated and time consuming but it is necessary to allow for the efficient and optimal allocation of funds for O&M of groundwater infrastructure.

The primary costs that need to be considered in the budget are Figure 5-1:

- Staff
- Materials / equipment
- Transport
- Utilities
- Private contractors / service providers
- Other

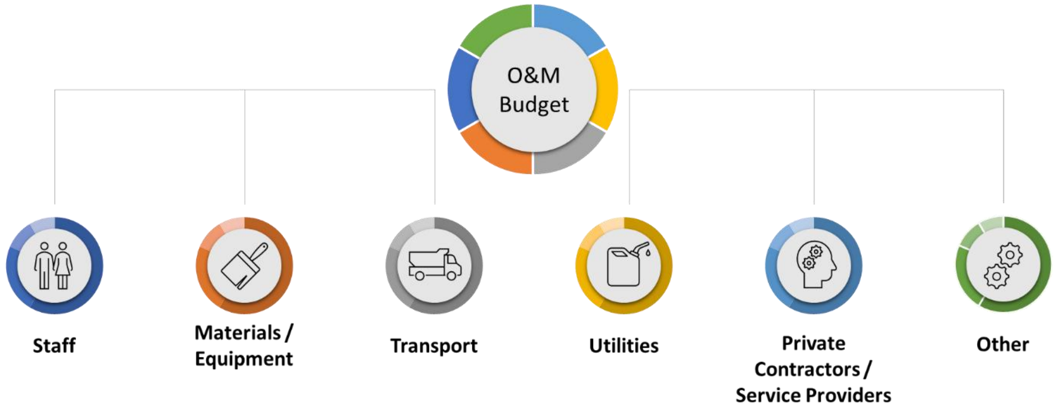


Figure 5-1: Primary costs for O&M budget.

5.4.1. Staff

This will vary depending on the type of groundwater scheme (large- vs small-scale, rural vs urban areas). Larger schemes will require a greater number of trained personnel while a small rural scheme may require only a few technicians. However, staffing costs must be determined using the minimum number of staff required to effectively operate and maintain a groundwater scheme and should also include administrative personnel if deemed necessary to perform O&M of the scheme. Otherwise, the cost for administrative personnel that is not critical to O&M is included under other costs. Job classifications (defining duties, tasks, responsibilities, authority level of job), amount of overtime required, staff wages (including taxes and benefits) must be determined to calculate labour costs. Schemes in rural areas may require personnel who can perform other non-technical tasks such as community development, health education and project administration.

5.4.2. Materials / equipment

This includes supplies and spare parts. Supplies refer to consumable items that can be purchased in bulk e.g. paint, lubricating oil etc. Spare parts refer to specific components and/or subcomponents of equipment and machinery that require replacement. While it might be easy to determine the unit cost of individual items for supplies and spare parts, the frequency of their purchase will depend on the functions of each. Furthermore, common tools also need to be considered in budgeting as these items are often lost, stolen or misplaced. The determination of costs for materials and equipment can be time-consuming and will require extensive investigation. Relying on technical expertise to identify vulnerable parts and components can aid financial managers in planning and budgeting for breakdowns. Replacement costs, while an important factor, should not necessarily be included in every annual O&M budget. Depending on the wear, tear, age and lifespan of the equipment, replacement times can vary and use of technical expertise will be required to estimate when parts will be requiring replacement and when financial managers should budget for it.

5.4.3. Transport

Transport costs refer to the use of vehicles and other transportation mediums to perform O&M of groundwater infrastructure. Identifying the tasks in O&M that require transport including transportation of staff to site for various O&M tasks as well as transport of diesel/fuel, materials and supplies will provide an overview of the transportation-related activities and the estimation of its associated cost. Each task will also need to be classified according to the type of vehicle required for transportation, distance of travel required, and frequency of visits. When calculating transport, fuel costs, tyres, lubricants, the amortised cost of the vehicle, insurance and mileage of the vehicle, maintenance and repair as well as driver-related costs will need to be incorporated into the calculation.

The transport aspect of O&M budgeting will be greatly impacted by the scale of the groundwater scheme, noting that small-scale groundwater schemes that are scattered in the region will necessitate a bigger transport budget owing to its isolated nature. The state of the roads will also influence transport and can increase the wear and tear on vehicles and increase travel times. In such cases, it might be suitable to perform circuit routes to minimise the number of trips and reduce overall transport costs.

5.4.4. Utilities

Utilities refer to the support required to conduct O&M of groundwater infrastructure and can include electricity, fuel, and communication-related costs. This will require identifying all equipment that requires electricity and fuel to operate. This will be of particular importance for electric- and diesel-powered pumps and the hours of use per day will need to be determined as well as pump capacity and daily water production to calculate the amount of electricity or fuel required to operate the pump.

An estimate of electrical power consumed by electric-powered pump will need to also be determined to calculate the power consumption. This then feeds into the rates for electricity that are charged by the electric utility or organisation that provides electricity in the area. The same applies to diesel and the costs of fuel supply. The cost of transport of fuel is also often a significant cost factor.

Communication-related costs may not be significant in the broader scheme but do need to be considered in the O&M budget and includes telephonic costs and mobile internet data.

5.4.5. Private contractors / service providers

This refers to contractors or service providers that are outside of the organisation who are required for certain O&M functions that staff are unable to perform. This also includes local technicians from rural communities who perform repairs on a community pump which often forms part of community-based management.

While not always necessary, it is important to budget for this as there will be instances where internal staff will not be able to conduct certain

O&M-related tasks. While difficult, it is advisable to identify such tasks during the budgeting process as well as their frequency of occurrence.

5.4.6. Other

This is to cover general overheads not referred to in the above categories as well as unforeseen or unexpected costs that could arise during the financial year. This is a common practice in most budgeting processes and is usually allocated 5- 10% of total O&M costs. it is important to set aside budget for emergencies. Reactive maintenance is sometimes unavoidable, and it is always wise to set aside a portion of the budget to address these emergencies. The amount allocated for emergencies will depend on the age of the infrastructure, location, and whether long-term plans are in place to upgrade or replace certain assets (Jordan and Wyat 1989).

The cost of administrative personnel who are not essential for O&M can be included under costs.

Hidden costs, while not always present every year, can have a significant impact on the budget and need to be incorporated, particularly around procurement costs.

5.5. Tariff setting and revenue collection

Tariffs are an important source of revenue for O&M of groundwater infrastructure and is required to fund many of the O&M-related activities. The use of tariffs is not popular in developing nations where most of the communities in rural regions are unable to pay tariffs. Furthermore, there is also an unwillingness to pay in many parts of SADC as water is often viewed as a public good that does not require any form of payment. As such, groundwater infrastructure in the region is prone to failure and the lack of a sustainable and ongoing source of revenue makes it difficult for groundwater authorities to adequately operate and maintain groundwater infrastructure.

While unpopular, tariffs are a useful means to obtain funding and are generally necessary for ongoing O&M. Ultimately, tariffs contribute to the recovery of the full financial cost of groundwater abstraction. As such, tariffs need to be structured in such a way as to reflect this. Tariffs usually contain two charges (Acharyya 2018):

- A charge that depends on the volume of water used
- A charge that is not based on water consumption e.g. connection fees, meter charges

Tariffs are either structured as an increasing block rate structure, decreasing block rate structure or uniform rate structure. Increasing block tariffs (IBTs) are the preferred tariff structure and typically provides two or more prices for water use where each price applies to a customer's use within a defined block. The price increases with each successive block and each block has a different price (Boland and Whittington 2000). The price is usually determined based on water usage in the region with the first block often being priced relatively low in line with the minimum amount of water deemed necessary to survive, thus affording all users the ability to access the minimum amount of water for basic needs. An increase in the volume of water used will see prices moving to the next block which will have a higher rate thus incentivising users to conserve water and be water-use efficient. Typically, the higher blocks are applicable to industry and commercial users who pay more due to their larger water consumption and in this manner, the IBT subsidises the cost of water for the poor (Boland and Whittington 2000, Acharyya 2018).

5.5.1. Tariff setting

A good tariff ensures revenue sufficiency, economic efficiency, equity and fairness (Walsh 2012). Tariffs for groundwater schemes should be determined once the full economic cost has been calculated. Determining what it really costs to provide water to the community provides guidance on how the tariff should be structured. Complex schemes that rely on consumable energy sources (electricity or diesel) will have higher tariffs than those without. Other factors that must be considered when setting a tariff are the direct day-to-day costs incurred in running the service, overhead costs from running the municipality / local government (the organisation that will be administering the tariff) as a whole and capital financing costs to expand and manage infrastructure. The budgeting process feeds into this process and serves as the starting point for setting the tariff. Determining a primary tariff baseline (the minimum tariff required to recover the full economic cost of groundwater extraction) can help to understand the impact of setting a tariff below or above the baseline (Walsh 2012).

Some key questions to ask when developing tariffs are:

1. Will there be a tariff revenue deficit for the provision of groundwater and are you willing to accept this?
   - This question asks whether full economic cost is to be recovered in the provision of groundwater. If not, cross-subsidisation plays an important role and will need to balance out with other profitable trading services
2. Will you be making a tariff revenue surplus?
   - This question will be useful to ask once a tariff system has been implemented for a while and the region has a successful history of tariff implementation and payment
3. Do you wish to provide groundwater to some for free? If yes, will you subsidise this to compensate for the revenue lost? (also consider cross-subsidising and which consumers will be targeted in this approach)
   - This is an important question within the context of SADC as most of the population cannot afford high tariffs. Subsidising groundwater O&M costs and cross-subsidisation are useful measures to ensure that water is provided to all at a price which they can afford
4. Do you wish to limit the tariff levied on certain consumers? If yes, how will you define these consumers, what limit will you apply and how will lost revenue be recouped (Walsh 2012)?
   - Definition of these types of consumers will be necessary and strict controls and monitoring will be required to ensure that the system is not abused.
5. Is the tariff practical, affordable and implementable at a local level?
   - While there is evidence of tariff implementation in rural regions in SADC, their success has been limited. Challenges around the isolated nature of many of the rural settlements as well as the lack of a regulatory authority at a local level means that tariff implementation is not practical in all cases and innovative ways

will need to be developed to implement tariffs in an equal and fair manner

6. How will monies be collected from consumers, with special attention to those from rural and outlying regions?

- Community-based management is the primary form of collecting tariffs in rural communities but there have been many difficulties with this including mismanagement of funds, lack of transparency around collection and general disinterest. Furthermore, physical cash is not readily available, and many households' incomes are negatively impacted by flooding, famine and other external shocks, resulting in regular defaulting and interruption of income streams
- It will also be important to determine how the tariffs will be communicated to the community, how users will be billed and in what form payments can be paid
- The tariff will also need to be reviewed on a regular basis and adjustments incorporated. Tariff adjustments will need to consider and incorporate gradual increases to account for emergency or ad-hoc maintenance, which, while difficult to predict, can be expected to occur every few years. A gradual increase in tariffs can provide the necessary funds for such a case and will only be minimally felt by the user. There are various sources available to help determine tariffs and a guideline for tariffs by Walsh (2012) is listed below in the footnotes[4].

5.5.2. How to structure a tariff?

Tariff setting is an important part of collecting revenue to compensate for costs of supplying water to the public. Typical tariff structures include (Trémolet and Binder 2009):

1. Flat-rate tariff (a flat-rate that is applied to all consumers regardless of volume consumed)
2. Volumetric tariff (a tariff based on metered consumption of water)

[4] https://www.westerncape.gov.za/text/2012/10/transparent-tariffs-setting-tariffs.pdf

3. Multi-part tariffs (a tariff consisting of multiple elements including a monthly fee for access and a usage fee for consumption)

How the tariff is structured will depend on the groundwater network's characteristics as well as the objectives of the tariffs and overall policies in groundwater management. The operator such as a water utility has overall control over the tariff structure with some regulatory oversight from other national or provincial agencies. Often, the operator and government are aligned in their objectives i.e. to charge fair and equitable tariffs that adequately cover the costs of water supply.

Key factors that are considered when determining a tariff are (Trémolet and Binder 2009):

- Financial viability (maximum revenue is recovered)
- Cost-reflectiveness (customers are charged an appropriate amount that reflects the costs plus a reasonable return on investment)
- Efficiency (setting tariffs at marginal costs)
- Social acceptability (charges are fair and reasonable for all types of consumers)

It is not always possible to incorporate all the factors listed above and sometimes trade-offs are required depending on the overall objective of government and the operator.

Box 5-1 Denmark full cost recovery tariffs (OECD 2017)

Full cost recovery for wastewater collection and treatment has been a legal requirement in Denmark since 1992 with full cost recovery also recently applying to water supply. As such, water prices are relatively high in Denmark with 50% of the monies paid by consumers for water going to wastewater companies, 30% as taxes accrued to government and 20% going to drinking water utilities. The tariff in Denmark promotes water-use efficiency and protection of the groundwater by incentivising reduced pollution as well as ensuring full cost recovery water supply and wastewater treatment.

Some basic steps to tariff setting can be seen below in Figure 5-2.

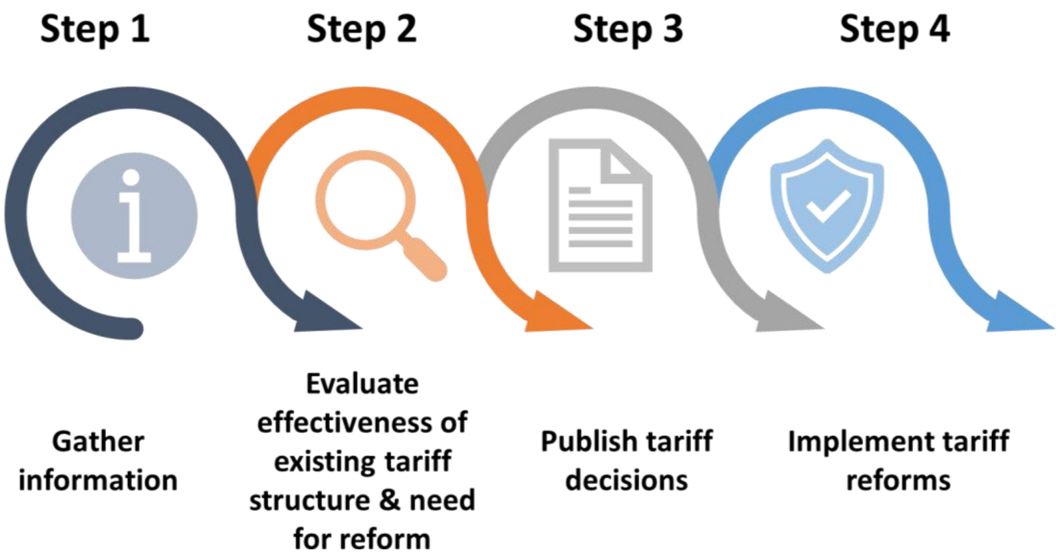


Figure 5-2: Steps for developing tariff (Trémolet and Binder 2009)

1. Gather information
   - Gather information about the current activity of the utility (current and projected operating costs, assets, and investment plans), the demand forecasts (trend analysis, statistical analysis) and feedback from consumers on the actual service and price (consultations, public hearings, focus groups, a consumer representative to the regulatory agency board, or consumers' associations).
2. Evaluate the effectiveness of the existing tariff structure and the need for reform
   - Assess whether an excessive level of operating costs and investments are predicted and estimate the corrected cost of service
   - Evaluate economic efficiency
   - Calculate the revenue requirements: proposed tariff covers operating and maintenance costs, depreciation, and a return on capital
   - Evaluate whether current tariffs are sufficient to cover costs or whether there needs to be an overall tariff increase/decrease to move towards cost-covering

tariffs

- If revenues from tariffs do not cover the full cost of service, then subsidies must cover the difference. Existing subsidies should be identified, their targeting performance evaluated and adjusted accordingly

3. Publish tariff decisions
   - Present and publish the results of this evaluation to all relevant stakeholders to build support and participation mechanisms.
   - Provide opportunities for stakeholders to appeal, especially if the operator or water utility disagrees
4. Implement tariff reforms
   - Identify the winners and losers from the proposed reforms and develop compensation or transitional measures.
   - Monitor the impact of tariff reform over time to allow for potential adjustments over time

Tariff structures will require careful consideration when considering poor water users who will be disadvantaged if the tariff unfairly targets the poor and disadvantaged.

5.5.3. Revenue collection

The primary challenge with regards to revenue collection in SADC is affordability for users and unwillingness to pay. Noting that a large portion of SADC's rural population rely on groundwater, the ability of these rural communities to pay for the water supply and services is difficult due to deeply entrenched poverty. The perception that water is human need that does not require payment also embeds an attitude of unwillingness to pay. In addition, many communities throughout SADC have not paid for their groundwater and will be hesitant to begin paying for a service that was previously free. All of this impacts revenue collection. Designing and implementing a perfect tariff system is null and void if the ability to collect revenue is compromised.

Revenue collection requires strong and reliable systems to ensure that it occurs in an efficient, effective and transparent manner, however, this can come at a significant cost to the municipality or water utility.

One option that can be implemented for revenue collection in rural areas is the installation of prepaid water meters. The meters allows users to pay in small increments that align with the user's income flows while also ensuring that revenue collection is improved (Kojima and Trimble 2016).

Box 5-2: Improved revenue collection in the West Rand District Municipality, South Africa (Honeywell 2017)

The West Rand District Municipality in South Africa was facing significant challenges with regards to revenue collection due to faulty and non-operational meters in residential areas. To address this problem, the municipality installed prepaid water meters in all residences under their jurisdiction which significantly improved the municipality's revenue collection that was previously lost as a result of faulty meters. The meter incorporated a multi-tier tariff system that monitored monthly consumption of the user and charged them according to the appropriate tariff. The system that the meter is linked to also allowed for the easy generation of reports to be used by the municipality as well as including tamper-proof switches to prevent tampering.

Table 5-2 is adapted from the African Development Bank's Guidelines for User Fees and Cost Recovery for Rural, Non-Networked, Water and Sanitation Delivery and provides further guidance on revenue collection.

Table 5-2: Option for billing and revenue collection (AfDB 2010)

Billing and revenue collection	Possible options
How to collect monies?	Billing and charging groups of users
	Collection at water points
	Home visits
	In meetings
	Users go to a public office
When to collect monies?	Each time a service is provided
	Monthly
	After harvest
	Beginning of the financial year
	Every 6 months
Who collects the monies?	Caretaker
	Operator
	User group

Billing and revenue collection	Possible options
	Village / Community Water Committee
	Community leaders
	Staff from an institution e.g. water utility, municipality etc.
	Treasurer
Where will the monies be kept?	In a safe
	In a village / community account
	In a bank account
	In a development fund
	In the house of the treasurer
	In an official account e.g. the water utility's or municipality's account

5.6. Concessions

Concessions refer to preferential allowances granted by an authority to certain individuals or groups of individuals. Tariff concessions are often applied to indigents, pensioners and people with disabilities. This also includes free basic water which refers to a minimum amount of water that is required for basic needs below which users will not be charged for the service. Where tariff concessions target a group of individuals, these individuals can pay a lower rate for water services and in some instances, this can be free as well. This pro-poor approach can help to reduce the financial strain on the poor but the broader implications on revenue need to be considered. Cross-subsidisation could possibly address this, particularly if commercial and industrial water users are targeted. Alternative sources of funding can also be considered such as increasing government and grant contributions to offset the loss in revenue.

However, water that is essentially free for certain users can create its own set of challenges as these users are not incentivised to conserve water which can lead to over-abstraction and abuse e.g. a person falsely putting themselves forward as a vulnerable person to be excused from paying for their water. A limit on the volume of water that can be used for basic needs will need to be defined to prevent users from over-abstracting, especially if this use is for domestic purposes. Monitoring and compliance will need to be implemented and enforced to prevent abuse of the system and will require strict control and verification measures.

5.7. Implementing financial management

When looking at financial management, it is important to understand the role of financial governance and how financial policies and procedures can be used to effectively manage the organisation and ensure data accuracy. Part of the procedures for financial governance includes audits (internal and external), internal controls, financial controls, data security and data tracking and validation. All of this serves the purpose of ensuring that the correct data is used by the finance staff to complete reports, plans and budgets.

Some measures that can be put in place to improve financial governance are (CFI 2020):

1. Centralised management software
2. Automated processes (where possible)
3. Regular risk assessments and audits
4. single data repository
5. Up-to-date processes for compliance and regulation purposes

While the ability to automate processes and employ digital processes might be limited in rural and resource constrained settings, the need for good governance through manual processes should not be discarded. Manual checks and measures can still achieve similar goals to automated processes.

There are a range of financial management practices that can be implemented to ensure operational efficiency of a groundwater scheme. Some examples are provided below (CFI 2020):

- Financial management and implementation
  - Employing only suitably qualified individuals when it comes to financial management. While it is understood that O&M and the overall functionality of a groundwater scheme relies heavily on groundwater-related expertise, the need for an appropriately qualified financial manager is critical when developing and implementing financial management policies and practices
  - Clear and efficient chains of communications within the finance department is a useful way to allow for management to obtain information about the situation. Mapping this out beforehand

together with roles and responsibilities can provide a useful base to establish communication chains that can eventually be expanded to the rest of the organisation
    - Regular training of accounting staff ensures that personnel are kept abreast of latest developments in financial management as well as legislation and policy
    - Conducting regular and comprehensive financial analysis of all statements when any anomalies and fluctuations have been identified
    - Delegation of financial roles and responsibility in a hierarchical manner will reduce bottlenecks and establish a clear chain of operation
- Cash inflows
    - Strict policy relating to credit reporting
    - Regular reconciliation of bank statements to the general ledger as well as regular reporting (monthly, quarterly and annually)
    - Conducting periodic reviews of financial policies and regulations to ensure that the policy and regulatory framework is relevant and suited to the changing conditions
    - Backups and strict rules regarding storage and record keeping will allow for efficient and timely retrieval of information when needed and also allows for analysis of the performance of the organisation. This data would also require strict controls around access with only certain senior individuals having access to help prevent fraud and financial mismanagement.
- Cash outflows
    - All outgoing payments must be monitored and require the proper authorisations to prevent excessive expenditure
    - A vendor database should be developed and maintained which will provide details on purchases to monitor cash outflow
    - Regular reconciliation of bank statements to the general ledger should be conducted
    - A reimbursement policy should be developed that provides clear guidance around reimbursements to employees. This policy should include details around expense reports and receipt verification to ensure that there is no employee fraud

5.8. Exercises

5.8.1. Exercise: Tariff setting and implementation

Tariff implementation requires careful planning and consultation with various stakeholders to understand the willingness of users to pay for services. Part of this process entails asking questions around affordability, revenue, subsidisations, and types of consumers. The following exercise provides some questions for this in which a basic understanding of tariff implementation and its various dimensions can be achieved (30 mins for each question).

The questions are listed below:

1. **What is volume of water that you are expecting to sell per month (including overall amount and per user) and what is the desired collection percentage when implementing the tariff? Also, list the factors that could prevent the collection percentage being achieved and how this can be mitigated.**
   This is essential in determining if tariff implementation will be successful as well as managing expectations. While a high collection percentage is desired, this needs to be balanced with affordability and willingness to pay.
2. **What are the different subdivisions of consumers that will be used when implementing the tariff (e.g. commercial, residential etc.) and how will the tariff be applied to each?**
   Understanding the different types of consumers will help in determining how a tariff will be implemented. In addition, different rates can be applied to different users which requires an understanding of the local population and the groundwater use. This could vary for different locations depending on the proportion of commercial users in a region as well as the volumes of groundwater used.
3. **Are deficits in tariff revenue expected and if yes, how will this be compensated for?**
   In most cases in SADC, it can be expected that there will be a shortfall in revenue from tariffs. It is important to develop alternative plans that compensate for this loss. Brainstorm ideas

such as cross-subsidisation, increased grant funding etc. that can help to recoup the revenue deficit.

4. **How will the proposed tariff accommodate the poor and vulnerable in society that are unable to pay for water use?**
   List the various approaches that can be used e.g. subsidisation, cross-subsidisation, a minimum amount of water that is free for all non-commercial users, etc.

5. **Describe the type of users that will be subsidized with regards to tariffs?**
   This is critical and requires some rigour regarding the type of consumers to be subsidised as well as if this will vary across the country. Also consider how to prevent the system from being abused and ensuring that these subsidies are used by the intended beneficiaries.

6. NON-REVENUE WATER

–	Develop an understanding of the water balance and its different components
–	Understand the importance of reducing water losses (physical and commercial) as well as identifying high-level solutions for these losses with regards to large urban groundwater schemes

6.1. Introduction

Non-revenue water (NRW) refers to water that is lost after production before reaching the consumer. It is equal to the total amount of water flowing into the water supply network from a water treatment plant, borehole system or imported bulk water supply, minus the total amount of water that consumers are authorised to use and are billed for (DAI 2010).

NRW can be divided into three components (Frauendorfer and Liemberger 2010):

1. **Physical or real losses**: leakages from all parts of the system and overflows at the utility's reservoir.
2. **Commercial or apparent losses**: losses caused by customer meter under-registration, data handling errors and theft of water.
3. **Unbilled authorised consumption**: Water used by the utility for operational purposes as well as for firefighting. This includes water provided for free to certain consumer group.

Typically, NRW has been analysed from a surface water context, specifically large municipal water supply systems that have large distribution networks. While physical losses might not be an issue for individual borehole pumps within a rural context, commercial or apparent losses are a key concern for groundwater schemes. The common lack of metering for groundwater use in SADC and the frequent free use of groundwater means that groundwater use only rarely generates significant revenue to help operate and sustain groundwater infrastructure. As such, O&M plays a critical role in managing and reducing NRW in a groundwater scheme. The objective of this chapter is to provide an understanding of NRW within groundwater schemes. This also includes understanding the broader impact NRW has on revenue collection and the importance of O&M to minimise NRW in a system.

6.2. Water balance

Determining NRW in a groundwater scheme will require understanding the water balance or a water audit (the overall state of the water system) and can be better understood in Figure 6-1.

System input volume	Authorised consumption	Billed authorised consumption	Billed metered consumption	Revenue water
			Billed unmetered consumption	
		Unbilled authorised consumption	Unbilled metre consumption	NON-REVENUE WATER
			Unbilled unmetered consumption	
	Water losses	Commercial losses	Unauthorised consumption	
			Customer metering inaccuracies & data handling errors	
		Physical losses	Leakage on transmission and/or distribution mains	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer use	
NRW = System input volume – Billed authorised consumption				

Figure 6-1: Water balance (DAI 2010)

By determining the water balance, it will be possible to calculate NRW by subtracting billed authorised consumption from the system input volume. As such, it is important to have reliable and accurate data relating to water volumes in the system. Based on the result of the water balance, it will be possible to identify the components that have the biggest contribution towards NRW and thus be prioritised accordingly. This can then guide policy changes and operational practices.

DAI (2010) provides some basic steps to calculate the water balance:

1. Determine system input volume

2. Determine authorised consumption
    a) Billed: total volume of water billed by the water utility
    b) Unbilled: total volume of water provided at no charge
3. Estimate commercial losses
    a) Theft of water and fraud
    b) Meter under-registration
    c) Data handling errors
4. Calculate physical losses
    d) Leakage on transmission mains
    e) Leakage on distribution mains
    f) Leakage from reservoirs and overflows
    g) Leakage on customer service connections

DAI (2010) suggests using a confidence limit of 95% which will require collection of reliable data. However, there will be data gaps that can make it difficult to calculate commercial losses and this will need to be flagged and addressed in future water balances through improved meter accuracy and customer billing cycles.

It should be noted that not all the elements in Figure 6-1 will apply to a groundwater scheme and this will depend on scale and on-the-ground conditions e.g. a single handpump supplying water to a rural village will not have leakage and overflows at the utility's storage tanks. However, unaccounted for and/or unbilled water in a groundwater scheme can contribute significantly to NRW.

6.3. Reducing water losses

Reducing water losses involves looking at both physical and commercial losses. The former can occur across the entire distribution system (primary network to individual pumps) while the latter is concerned more with the unauthorised water consumption as well as meter and data handling errors (Frauendorfer and Liemberger 2010).

6.3.1. Physical losses

Leaks are the primary cause of physical water losses and are not always easy to detect making this problem difficult to identify and correct. While large leaks are often easily identified and repaired, smaller leaks can lead to a greater volume of water loss over time.

It is important to understand the different types of leaks that can occur in the scheme and the effect that the leak run time can have on the total volume of physical losses.

Dealing with leaks involves having an efficient and intensive active leakage control system (Frauendorfer and Liemberger 2010). This includes developing a leakage management strategy that outlines how leaks in the system will be managed and addressed. DAI (2010) provides a leak management strategy that has four basic pillars:

1. Pressure management
2. Repairs
3. Active leakage control
4. Asset management

These factors have the most influence on how leakage is managed and can reduce overall leakage in the system (DAI 2010):

6.3.1.1. Pressure management

Pressure management looks at the pressure applied by pumps, or due to gravity, which influences the rate of leakage. Effective pressure management can have a great impact on reducing non-revenue water and can include variable speed pump controllers, break pressure tanks and automatic pressure reducing valves.

6.3.1.2. Repairs

Repairs form a critical component in leakage management and can determine how long a leak persists. Repairs should be conducted as soon as possible to minimise the volume of water leaving the system and the quality of repairs must be of the highest standard to ensure sustained repairs and minimise the potential for future leaks in the same place.

6.3.1.3. Active leakage control

Active leakage control refers to monitoring flows into zones, or district meter areas where bursts and leaks are unreported. This approach helps to determine where leak location activities should be conducted and allows for quick location of bursts or leaks. Modern flow metering can, together with data capture technologies, also aid in the quick identification of leaks and bursts. Monitoring of flows in a water distribution system between 2am and 4am, when few users are using water, is an accessible strategy for identifying leaks in a system.

6.3.1.4. Asset management

Asset management has close linkages to management of NRW and enables sustainable economic leakage management. As repairs involve a large amount of materials and equipment, effective asset management allows for cost-effective measures to tackle leaks.

6.3.2. Commercial losses

Commercial losses refer to losses incurred due to customer meter under-registration, illegal water use (theft) and errors in metering, data handling and billing. Commercial losses are a major source of revenue loss in groundwater schemes in SADC and are worsened by lack of payment for water supply services. Various measures are available to reduce commercial losses (DAI 2010, Frauendorfer and Liemberger 2010).

6.3.2.1. Metering

Inaccurate meters can provide incorrect meter readings which can lead to underbilling of customers for their actual water use. Initially, focus should be on large-scale and commercial users as corrections amongst these users will have the biggest impact. Ideally, the practice of using assumptions and estimates to bill customers should be discouraged, relying rather on metered readings. Procurement of meters should focus on the purchase of meters that meet the specific needs within the local context

6.3.2.2. Billing system issues

A billing system can be complex and difficult to maintain, especially systems that rely on manual inputs and processes. However, having an effective billing system ensures that customers are billed correctly for the volume of water used thereby ensuring generation of revenue. Incorrect meter reading practices and over-estimations can lead to incorrect billing and reduced revenue. Active checking of the billing system and conducting regular customer surveys to establish where all water users are registered on the billing system help to ensure the billing system is accurate. The survey should capture information relating to physical address, name of owner / water user (including some form of identification) and status of the meter on the property.

6.3.2.3. Water theft

Water theft, while illegal, is a difficult issue to address as there are social and political considerations. Communities entrenched in poverty and unable to afford water services might resort to illegal water use. However, it has also been observed that water theft occurs amongst high-income earners and commercial users. In this regard, these users should be targeted, and the lost revenue should be recuperated. There are also ways to reduce illegal connections such as lockable valves. In addition, meter tampering also contributes to water theft and should be addressed through the installation of tamper-resistant meters.

6.4. Exercises

6.4.1. Exercise: Water losses

Water losses are often significant and can have impacts upon the sustainability of the supply and effect the viability of the institution that is providing the service. These losses can be as high as 50% of water supplied and effectively addressing non-revenue water can enable improved revenue generation, ensure improved reliability of supply to customers, and provide water than can be made available to underserved areas or new areas of supply. In parts of the SADC region water resources are constrained and as such the need to ensure improved levels of water conservation is increasingly important.

The objective of this exercise is to gain an understanding of the nature of water losses in your area, the root causes of these losses, the magnitude of these losses and to develop a suite of interventions that are needed to address these losses. Therefore, we will work through the following core questions (60 min):

1. What are the different types of losses being experienced?
   - Develop a mind map of what you consider to be the major elements of non-revenue water. Against each issue note down the institution that needs to play a role in addressing this. This provides a first snapshot of what the issues are and who needs to be engaged
2. How much water is being lost?
   - The first step in reducing NRW is to develop an understanding of the big picture of the water supply system, which involves establishing a water balance. There are two ways to determine this:
     - Non-revenue water = System input volume - Billed authorised consumption
     - Non-revenue water = Unbilled authorised water consumption + commercial losses + physical losses
3. Where are losses occurring?
   - The calculation above will indicate broadly where these

losses are occurring and the severity of these. It will also be useful to note the physical losses geographically when looking at a specific scheme

4. Why are losses occurring?
   - For each of these losses that have been described above determine why these losses are occurring. It is useful to develop a results or causal chain for these reasons. Simply ask yourself why there is a specific outcome and ask that question 5 times. For example:
     - We have high levels of leakage in transmission pipelines
       - Why? Because the infrastructure is in a poor condition
       - Why? Because there is not enough regular maintenance
       - Why? Because we do not have skilled staff and the necessary equipment
       - Why? Because there are insufficient funds to appoint and purchase
       - Why? Because our revenue collection is only collecting 50% of what is invoiced
     - Such a technique can provide us with a sense of the priority causes that we need to address.
5. What actions can be taken to reduce losses and improve supply?
   - Using the information that you have determined above develop a simple matrix of actions noting who needs to lead these and the broad timeframes that would be needed. Prioritise and focus on causality i.e. what do we need to address first, before we can address something else? Add in “outcome” into the matrix to show what the result of the action would be.

7. OPERATION AND MAINTENANCE OF GROUNDWATER SOURCES (WELLS AND BOREHOLES)

- Recognise the difference between boreholes and wells (deep and shallow)
- Understand what tasks are required for general O&M of the various water supply sources for their effective functioning
- Troubleshoot and establish appropriate remedial actions

7.1. Introduction

Groundwater forms an essential natural resource, particularly in rural southern Africa where close to 70% of the population lives and relies on it for their livelihoods. Groundwater has of late been a key source of water for some urban centres such as Harare (Zimbabwe) and Lusaka (Zambia) due to failure by the local authorities to provide adequate potable water resources as a result of, inter alia, poor O&M of water supply infrastructure, inadequate investment in water infrastructure and ballooning population. The sources of groundwater include wells, springs and boreholes and these need to be properly constructed and regularly maintained to ensure sustainability of the groundwater supply. Inasmuch as these sources of groundwater are vital to communities, they can also pose serious health risks if not properly constructed and maintained. Poorly constructed water sources are highly susceptible to pollution which can affect humans who rely on them. It therefore calls for the establishment or development of water source construction standards and regulations, such as borehole drilling standards, and the registration of contractors to safeguard against poor or substandard services. Pollution of groundwater presents a bigger challenge in that it is very difficult and costly to remedy and would result in abandonment of the groundwater as a source of water thereby exacerbating water insecurity. Communities without any alternative source of water will end up using the polluted water, which is a serious health risk. Professional construction of groundwater sources (according to the appropriate standards or regulations) and periodic maintenance of the sources will ensure long term sustainability of the groundwater supply.

7.2. Shallow wells

Shallow wells are most suitable where the groundwater levels are shallow (usually less than 5m below groundwater level). These are hand dug to a diameter less than 1m and can either can be lined with brick or stone masonry, reinforced concrete rings, etc., or left unlined. A simple lid, from a metal sheet or moulded from concrete is used to cover the well. A simple windlass system is usually used to lift the water although some families resort to using a bucket and rope. A lift pump, jet pump or a small fuel powered submersible pump can also be used in drawing the water. The wells are susceptible to pollution and due precautions need to be exercised such as construction of an apron around the well. Contamination could result from lack of hygienic procedures in handling the bucket and the rope. Cattle dip tanks, pesticides and waste dump sites easily pollute shallow groundwater and should be considered when locating shallow wells. A distance of 30 m is usually recommended between the water source and any potential pollution source. A technically competent person such as a hydrogeologist can provide advice on the most appropriate distance. Shallow wells are relatively cheap to construct and maintain and should thus be considered as an option where groundwater levels are shallow, and in sparsely populated areas. Shallow wells are usually family owned. Figure 7-1 shows a well under construction and a completed well.

Figure 7-1: a) Well under construction (Uvinjo n.d.) b) Completed well fitted with a windlass (Aquamor n.d.)

7.3. Deep wells

Deep wells are also generally hand dug in soft rock. Construction of deep wells in relatively hard rock is usually by way of blasting using explosives and hence requires personnel with the requisite experience and in possession of a blasting licence. Deep wells are usually less than 20 m deep and 1-2 m in diameter but can be wider and much deeper. Wells dug in soft rocks often need to be lined with brick or stone masonry, reinforced concrete rings, etc. to prevent them from collapsing. Wells dug in relatively competent/not highly collapsible rock by way of rock blasting using explosives may be left unlined. A concrete apron and spillway channel can be constructed to prevent pollution of the well. In open wells, a metal lid or concrete lid are used to cover the well. Water is drawn by way of a rope and bucket, windlass or handpump. In the case of a handpump, a piece of steel casing for clamping the handpump on needs to be cast into a concrete ring that will form the lid to the well. Grid electrified or fuel powered submersible pumps can also be used in lifting the water.

Wells have large storage which helps make them less vulnerable to drought, but because they typically tap only shallow groundwater, they can dry up in dry seasons or longer droughts. Figure 7-2 shows the lining options of deep wells.

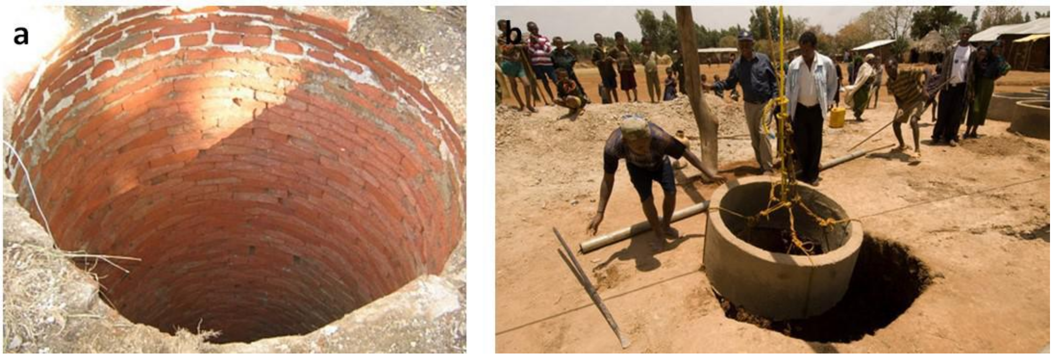


Figure 7-2: Deep well a) lined with bricks (DIY Chatroom 2009), and b) lined with concrete rings (Global Living as cited by Bruni and Spuhler 2020a)

7.4. Boreholes

Boreholes are sometimes referred to as tube wells or simply wells and should be properly constructed (lined with proper casing material, screens, gravel packed and well developed). Some are meant to yield large volumes of water. They can be drilled through hard rocks and can be more easily protected from contamination than hand dug wells. There are many different techniques for drilling boreholes, some of which are more suited to certain geological environments. Usually, a motorised drilling rig is used, operated by specialist drillers. Since groundwater tapped by boreholes is often deep seated, it requires the services of appropriately trained and qualified personnel who use specialised equipment to carry out geophysical investigations to establish localities where the boreholes can be drilled. There are various borehole drilling techniques such as down the hole hammer/air percussion, mud rotary and cable tool. In certain instances, drilling additives/agents such as foam and mud are used to assist in bringing out the drilling cuttings from the hole. Drilling mud is mostly used during mud rotary drilling in unconsolidated formations such as alluvium. The use of biodegradable agents is highly recommended. The use of bentonite mud as a drilling agent is NOT recommended because it is a clay that is difficult to disperse and remove from the borehole/well because it is relatively sticky and tends to cling to the borehole walls, casing and screens, thereby reducing the yield of the borehole.

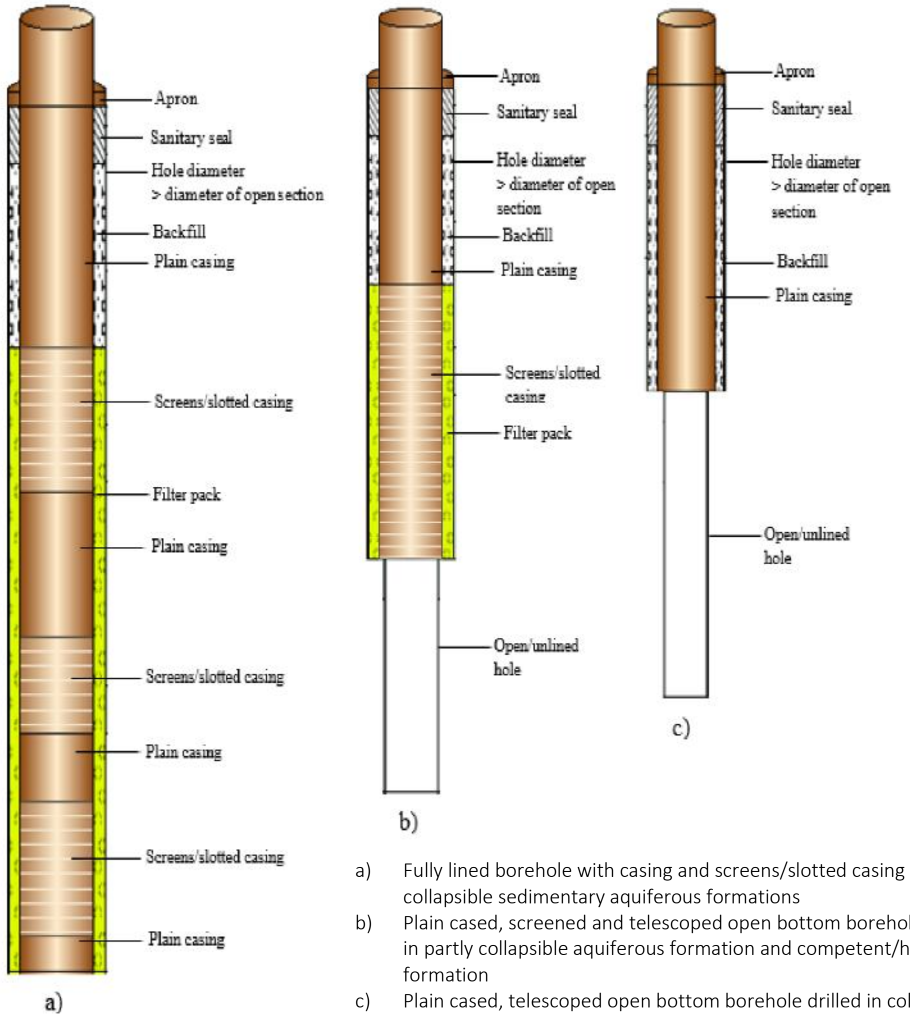
The prevailing geological conditions will dictate the type of borehole to be drilled. Borehole drilling should be carried out according to the applicable national drilling standards. Workmanship during borehole drilling and quality of construction material are important because they determine the quality of the borehole and its lifespan. Poorly drilled and constructed boreholes will not last long and will significantly increase O&M costs. Utilisation of poor-quality material also has the same effect on O&M costs. In certain instances, the boreholes cannot be salvaged, and replacement boreholes will have to be drilled instead.

There are different borehole designs, and the common ones are given in Figure 7-3.

7.5. Operation and maintenance tasks

7.5.1. Boreholes

There are different borehole designs for the various geological formations e.g. crystalline and sedimentary consolidated formations (Figure 7-3). Poor borehole drilling and construction will make O&M more difficult and more expensive.



a) Fully lined borehole with casing and screens/slotted casing drilled in collapsible sedimentary aquiferous formations

b) Plain cased, screened and telescoped open bottom borehole, drilled in partly collapsible aquiferous formation and competent/hard formation

c) Plain cased, telescoped open bottom borehole drilled in collapsible formation (no water) and aquiferous competent/hard formation

Figure 7-3: Different borehole designs for various geological formations

O&M tasks for boreholes include:

Monthly

- Water level measurements to establish if there is a decline
- Abstraction volumes to establish if there is a decline
- Checking the water turbidity

Yearly

- Check the specific yield (Box 7-1 and Figure 7-4)
- Monitor the water quality
- Use borehole camera to check for borehole integrity including incrustation and biofouling

Box 7-1: Specific yield

Specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the water table and is denoted Sy. It is sometimes referred to as effective porosity (Kruseman and de Ridder 1994). Clay has high porosity values due to the high number of voids or spaces between the clay particles, but the spaces are not connected to each other (effective porosity) to allow for gravity drainage of the water hence its specific yield is very low (Figure 7-4). The clay retention forces are greater than the weight of the water to allow for its release by gravity. The values of specific yields for alluvial aquifers are in the range of 10 to 20% and for uniform sands about 30%. Specific yield can be determined through laboratory (e.g. column tests) or field (e.g. pumping tests) methods

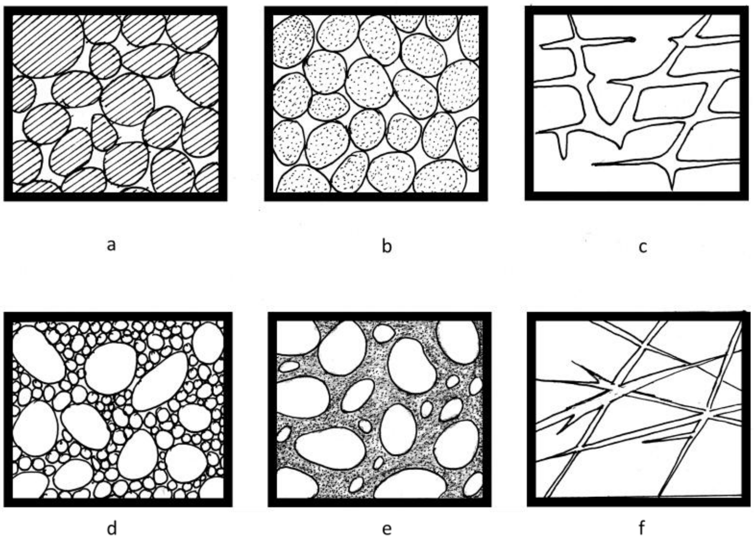


Figure 7-4: Illustration of effective porosity (a)well sorted sedimentary deposit having high porosity; (b) well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; (c) rock rendered porous by solution; (d) poorly sorted sedimentary deposit having low porosity; (e) well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; and (f) rock rendered porous by fracturing (after Meinzer, 1923 as cited by Freeze and Cherry 1979)

7.5.2. Wells

Routine maintenance of wells does not only prolong their life spans but also ensures sustainability of supply (Figure 7-5).

Figure 7-5: Maintenance of a well (inter aide 2012)

7.5.2.1. Preventive maintenance: wells and surroundings

The pump mechanic/caretaker through the Water Point Committee should:

- Carry out necessary repairs on cracked headworks (apron, spillway and soak-away)
- Keep away livestock from the well by fencing it off and ensuring the fence is always intact
- Repair any holes developing around the well
- Ensure that there is no stagnant water near the well by filling the depressions/holes
- Always keep the surroundings tidy

7.5.2.2. Shallow wells

Broadly, the maintenance of shallow wells includes:

- Carrying out necessary repairs on cracked headworks (apron, spillway and soak-away)
- Ensuring that livestock should always be kept away from the well by fencing off the well and ensuring the fence is always intact

- Repairing any holes developing around the well
- Ensuring that there is no stagnant water near the well by filling the dents/holes
- Keeping the surroundings tidy always
- Advising users on the best way of handling the well pump or windlass
- Dewatering the well and cleaning the bottom (at least once a year)
- Checking the support posts for the pulley and repairing it as needed

7.5.2.3. Deep wells

The maintenance of deep wells is similar to that of shallow wells, and the broad maintenance activities are:

- Checking for any debris in the well and removing it
- Inspecting the wall lining and repairing it when needed
- Cleaning and repairing the concrete apron and spillway channel
- Checking the condition of the rope, pulley, bucket, handpump and fence and replacing these when needed.
- Greasing the pulley or handpump as needed
- Monitoring the water level with a rope scale or similar device
- Dewatering the well and cleaning the bottom (at least once a year)

7.6. Borehole remediation

There are several reasons for borehole failure, and these include equipment failure, depletion of the aquifer, corrosive qualities of the water, and improper well-design and construction. Fully understanding and correctly identifying the cause of the failure is critical in selecting the appropriate remedial action. Assistance from technically competent persons is needed to accurately identify and fix the problem. Figure 7-6 shows a borehole being rehabilitated by airlifting.

Figure 7-6: Borehole rehabilitation by airlifting[5]

7.6.1. Causes of borehole problems

Borehole problems could arise from:

- Improper borehole/well-design and construction
- Incomplete borehole/well development
- Borehole stability problems
- Incrustation build-up
- Biofouling
- Corrosion
- Over-pumping
- Aquifer problems

These are discussed in detail below.

[5] Photo credit: Hans Beekman

7.6.1.1. *Improper Borehole design and construction*

The borehole should be designed in a way that matches the type of borehole construction to the characteristics of the aquifer. Technical considerations include:

1. **Borehole screens**: The selection of the well screens is done after conducting a sieve analysis of the aquifer material obtained during drilling or from prior knowledge of the aquifer. Generally, the screens should allow for a low entrance flow velocity (should be <3 cm/s) (Mabillot, 1979 cited in Driscoll 1986), have a large open area (>2.5%), have the correct design of slots to minimise blockages, have a slot size that matches aquifer material and gravel/filter pack, the screen material should be corrosion resistant, have enough strength to resist collapse, and the screens should allow for periodic maintenance through flushing. Types of screens include (Figure 7-7 and Box 7-2): Johnson wire wound screens, bridge, slotted polyvinyl chloride (PVC) casing or plastic casing, and mild steel casing. Johnson screens are very expensive and ordinary screens (perforated mild steel or PVC casing or plastic casing can be used instead. Hack saw cut slots tend to clog more easily thus reducing the borehole yield and are not recommended for well fields (a number of boreholes are drilled into an aquifer and connected to supply a large amount of water). They may be sufficient for hand pumped equipped boreholes.

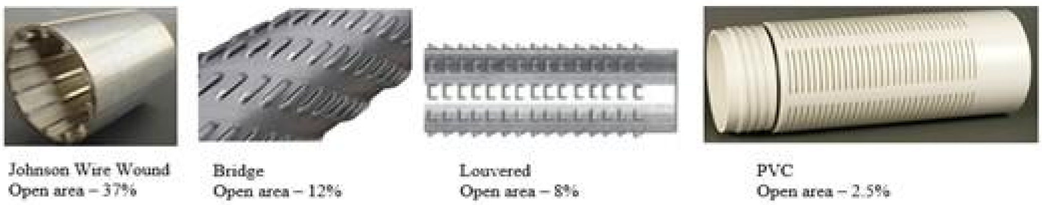


Figure 7-7: Types of borehole screens (Driscoll 1986)

Box 7-2: Description of the various screens (Driscoll 1986)

Johnson wire wound screens: are typical example of continuous slot screens and are made from winding cold-rolled wire which is roughly triangular in cross section around a circular array of longitudinal rods producing a cage-shaped cylindrical configuration (Figure 7-7). The wire is welded to the rods producing a rigid one-piece unit having high strength characteristics at minimum weight. Slot openings are created by spacing successive turns of the outer wire to produce the desired slot size. The slot openings take a V-shape and is narrowest at the out face and widen inwardly. The V-shape minimise clogging of the screen openings. The continuous slot screens have the highest open area (close to 40%).

Bridge screens: are manufactured on a press from flat sheets or plates. The slot opening is usually vertical and provides two orifices, longitudinally aligned to the axis. The perforated steel sheets or plates are then rolled into cylinders and the seam welded (Figure 7-7). They have a fairly high open area (around 12%) but have a disadvantage of low collapsing strength due to the large number of vertically oriented slots. The screens cannot be used directly without gravel/filter pack because the openings become easily blocked in the absence of gravel/filter pack.

Louvered screens: are also known as shutter screens. They were originally manufactured by punch-forming downward facing louver apertures into short lengths of pipe, then welding them together forming sections up to 6m long. A more modern method has been developed which permits manufacture from tubes up to 15m in length. This process incorporates the use of an internal mandrel which perforates the shutter against external die blocks. One of the main advantages of louvered screens is that they have higher collapsing strength (up to 60%) than blank casing of the same wall thickness. This is due to the corrugating effect of the louver-shaped openings. The screen open area can be around 10%.

Slotted PVC casing: Slots are created by machine cutting, milling or by hand sawing. Slotted PVC casing have very low open area and increasing the open area will result in the screens easily breaking during installation. They cannot be installed in very deep boreholes because they can easily strip during installation. PVC casing have an advantage in that they are non-corrosive but are prone to clogging.

Slotted metal pipe: Plain metal casing can be machine milled to produce slots. The slots can also be created by hand sawing or with a blow torch. The slotted open area is generally very low and the openings easily clog. The metal pipe is also susceptible to corrosion.

2. **Placement of borehole screens**: screens need to be properly placed against the aquifers (water yielding formations). In confined aquifers (aquifers in which the water level rises above the level of the aquifer), 80-90% of the thickness of the aquifer should be screened and

best results are obtained by centering the screen section in the aquifer (Driscoll 1986). For unconfined aquifers (aquifers in which the water level may be roughly the same level as the water strike), maximum yield is obtained by using the longest screen possible. Screen design is a critical factor for the efficiency of a successful borehole. The screen design must accommodate the varying physical and chemical characteristics of groundwater. Screens that have the wrong slot size, low open area, slots not matching aquifer material and gravel/filter pack, or screen placed in the wrong locations can result in reduced borehole yields though clogging of the screens (Figure 7-8).

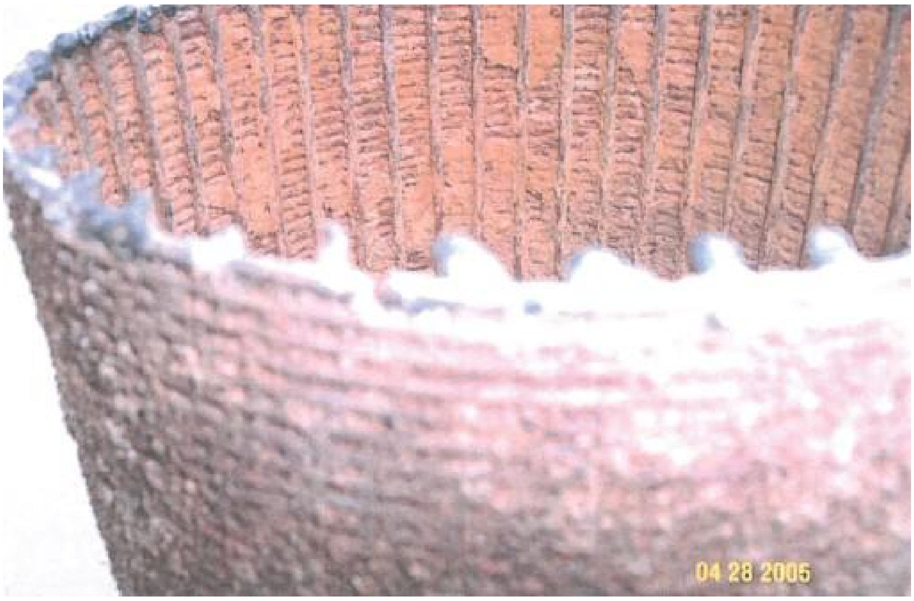


Figure 7-8: Encrusted minerals on a totally plugged well screen (Plumley 2017)

3. **Gravel/Filter Pack**: gravel pack helps in filtration, stabilising of the aquifer, preventing collapse of the formation which would lead to low abstraction volumes (low yields), minimising sand pumping which would damage the pump, reducing the groundwater flow velocity to levels that will not cause screen encrustation or wear, and reduction in head losses. The width of the annular space (gap between the outside of

the screen and the walls of the drilled hole) and the type of material are also important considerations.

4. **Location of the pump in the borehole**: The pump should ideally not be placed within the borehole screens. It should rather be placed within a section of plain or unperforated casing which is commonly referred to as a pumping chamber. Ideally, in confined aquifers, pumping should be carried out at levels above the top of the aquifer to avoid agitating the filter pack and aquifer material.

7.6.1.2. Incomplete Borehole development

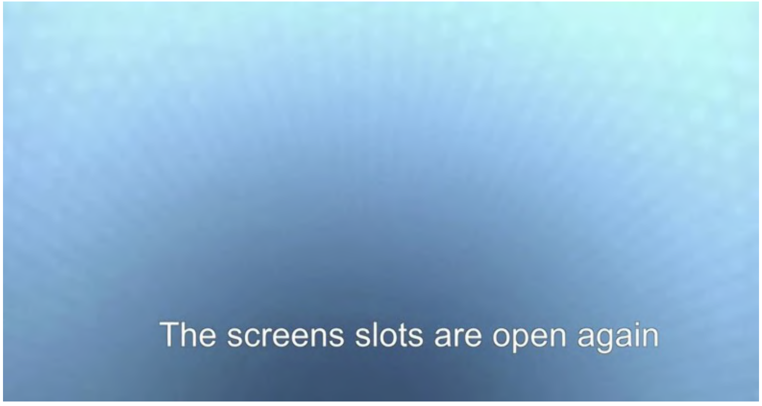
During drilling, mud and borehole cuttings can partially plug the aquifer (Box 7-3). This material must be fully removed through a borehole development process. This process has a number of methods which include over-pumping, backwashing, surging, use of compressed air, bailing and surge blocking. These methods can be carried out by an experienced drilling contractor. Development should continue until the discharged water is clear and all fine material from the borehole and adjacent aquifer have been removed. The time required for development depends on the nature of the water bearing layer, the thickness of screen slots relative to aquifer particle size, the amount of material cleaned from the borehole prior to placing the filter pack, and the type of equipment and degree of development desired. Large amounts of development energy are required to remove drilling fluid containing clay additives (Plumley 2017) and hence such drilling fluids should be avoided.

Box 7-3: Borehole development[6]

Borehole development helps improve borehole yield and minimises damage to pumps since the water will have little to no sediment, thus enhancing sustainability of the borehole and the project benefiting from the borehole.

Clogged screens

Cleaned screens



Clogged screens significantly reduce the borehole yield, and clean screens after borehole development greatly improve borehole yield

7.6.1.3. Borehole stability problems

Borehole stability problems could result from damaged casing and screens, borehole wall collapse, corrosion or excessive water entry velocities into the borehole. High water velocity can cause formation particles, like sand, to flow into the borehole, causing eventual collapse of the borehole wall.

[6] https://www.etbs.de/home.html

Box 7-4: Borehole casing damage due to poor quality casing[7]

Poor workmanship and/or poor-quality casing and screen material results in failed boreholes which often require re-drilling resulting in unanticipated high development costs or abandonment of projects due to lack of financial resources. Good workmanship and use of quality material help to ensure high quality and sustainable boreholes. Down the hole camera showing collapsed casing due to poor quality material	

It is essential that the proper materials be selected and installed to avoid such problems. A combination of poor materials, improperly placed screens and a poor borehole seal make it uneconomical to maintain and restore such a borehole. In such cases, often, the most cost-effective solution is to drill a new borehole that is professionally designed and constructed.

7.6.1.4. Mineral Incrustation

Mineral incrustation is a common problem in some shallow water table type aquifers where there is an abundance of dissolved minerals including calcium, magnesium and iron, as well as iron bacteria (Figure 7-9). When water is pumped from boreholes in such aquifers, changes in pressure and temperature occur resulting in minerals precipitating around the casing or screens. This process is known as incrustation and it reduces borehole yields. A combination of good preventive maintenance and good management practices can minimise the effect of incrustation. Management practices that reduce water pumping rates can reduce the effects of mineral incrustation. A strategy of reduced pumping rate with longer pumping intervals helps prevent incrustation of screens and perforated liners (Ministry of Agriculture and Forestry n.d.).

[7] Photo credit: DHVI – www.DHVI.NET

Figure 7-9: Mineral incrustation (Driscoll 1986)

7.6.1.5. Biofouling

Pumping a borehole increases the level of oxygen and nutrients in the borehole and in the surrounding aquifer. Bacteria, such as iron bacteria, may thrive under these conditions. They can form a gel-like slime or biofilm that captures chemicals, minerals and other particles such as sand, clays and silts (Figure 7-10). Minerals, such as iron, oxidise and get trapped in the biofilm. "Biofouling" occurs where biofilm accumulations are enough to reduce water flow. The implication is reduced borehole yield and water quality.

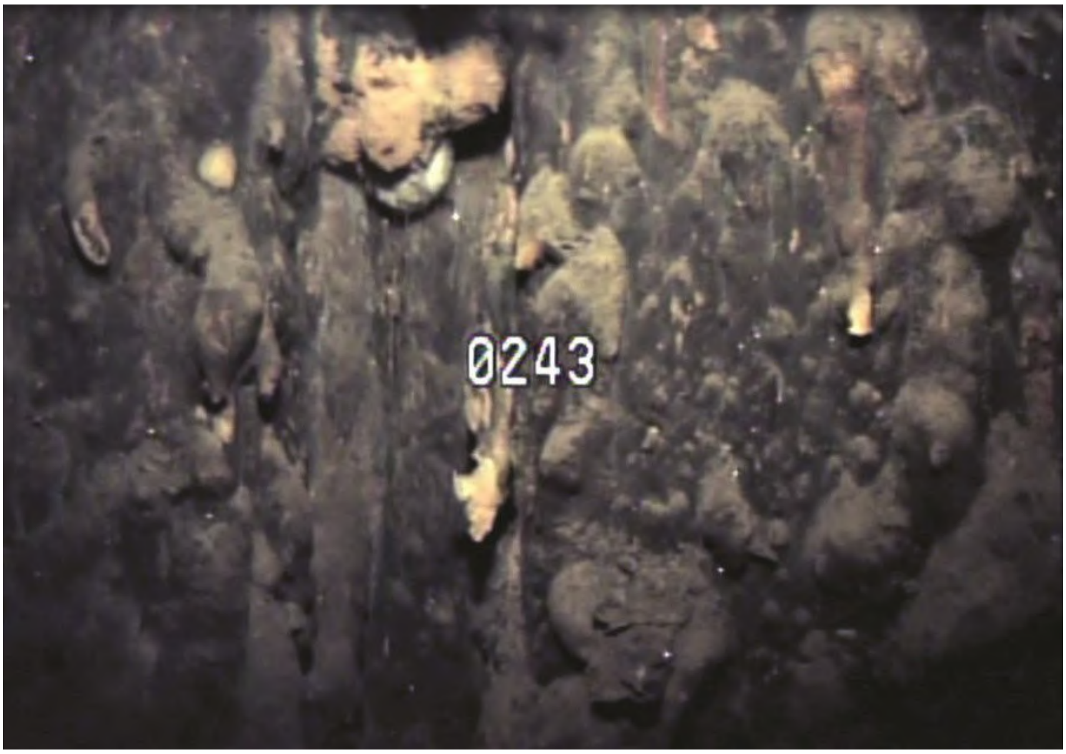


Figure 7-10: Borehole video image showing heavy biological and scale fouling, completely covering the screened section of the borehole (Swistock and Rizzo 2014)

7.6.1.6. Corrosion

Chemical substances found in water can corrode metallic borehole casings and screens (Figure 7-11). The use of corrosion resistance material such as PVC or plastic casing and stainless steel will abate this problem. Sulphate-reducing bacteria can also cause corrosion. Chlorinating the borehole can kill the bacteria.

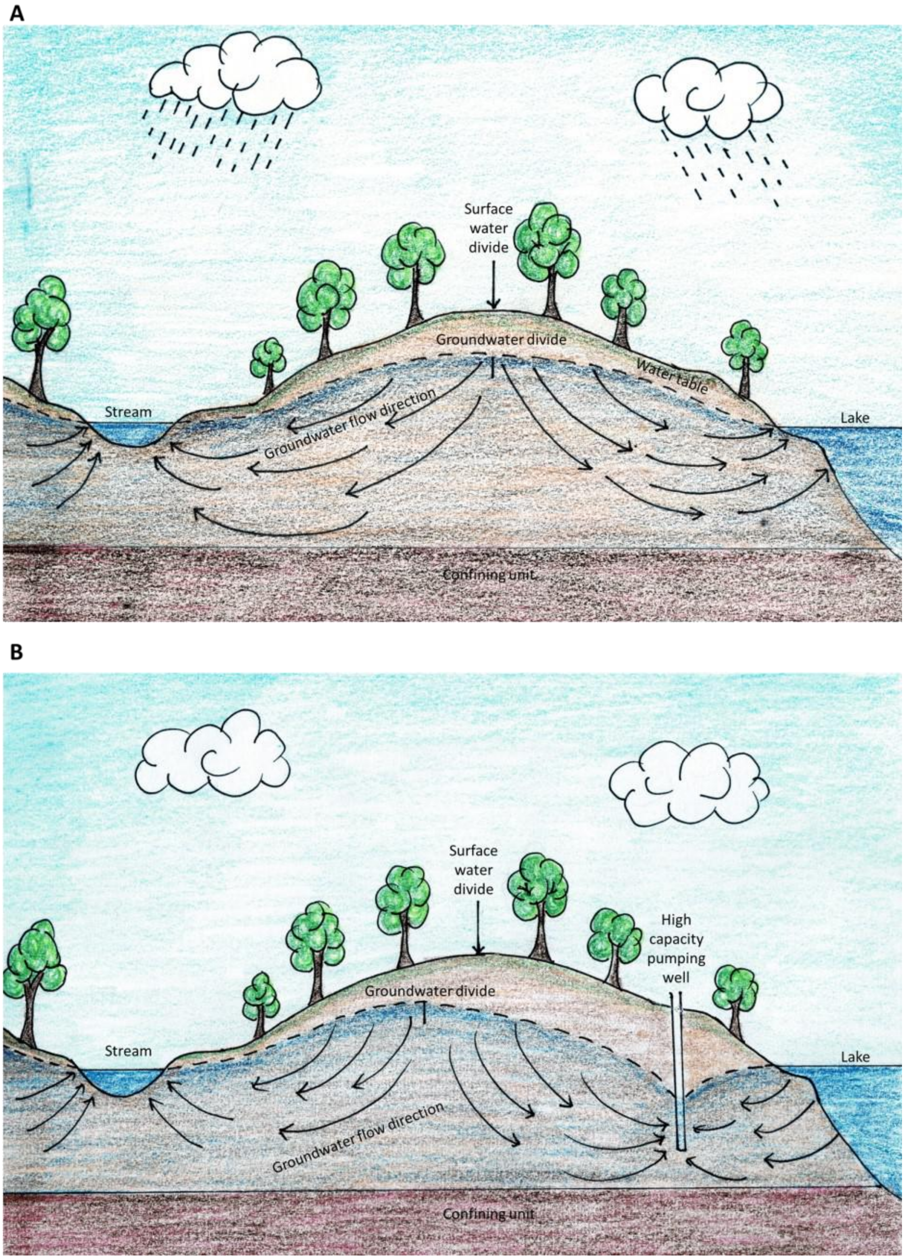
Figure 7-11: Impact of corrosion on pipes used for pumping water (Alhameid and Naeem 2014)

7.6.1.7. Over-pumping

A borehole is over-pumped if water is withdrawn at a faster rate than the borehole was designed for or the aquifer can produce (Box 7-5). Over-pumping is the most common problem that leads to premature borehole failure. Over-pumping not only depletes the groundwater aquifer (or source), but it rapidly increases the rate of corrosion, incrustation and biofouling related problems. Over-pumping also increases the rate of sediment particles moving toward the borehole, causing plugging of the screens or slotted casing. It can also cause the aquifer to settle and compact which further restricts water flow to the borehole. In areas where there is saline water nearby, over-pumping may cause saline water intrusion into the borehole which results its abandonment.

Box 7-5: Over-pumping problems (USGS 2007)

Borehole over-pumping depletes the aquifer, increases rate of casing corrosion, resulting in sediment pumping which damage pumps or water quality deterioration.



Schematic cross-section showing the effects of over-pumping: Image A is under natural conditions showing an equal groundwater flow direction to the stream and the lake split at the groundwater divide while image B shows the effect of over-pumping causing a cone of depression. Water flows from the groundwater divide to the stream as before but also to the well. Water is also pumped from the lake to the well instead of flowing out to the lake. The groundwater divide also shifts to the left as the water table drops. The lake water could be polluted hence posing a health risk to consumers.

7.6.1.8. Aquifer Problems

While most borehole problems are related to the construction, development or operation of the borehole, the formation can also be a source of problems. Reduced aquifer yield can be caused by lack of aquifer recharge due to droughts or low rainfall. Monitoring the groundwater level in the borehole is an important maintenance procedure (Figure 7-12). Groundwater level monitoring assists in establishing water level trends which in turn help with identifying borehole problems or aquifer depletion before the problem becomes serious. Figure 7-13 shows a declining groundwater level trend over time.

Figure 7-12: Groundwater level monitoring[8]

[8] Photos credit: Hans Beekman

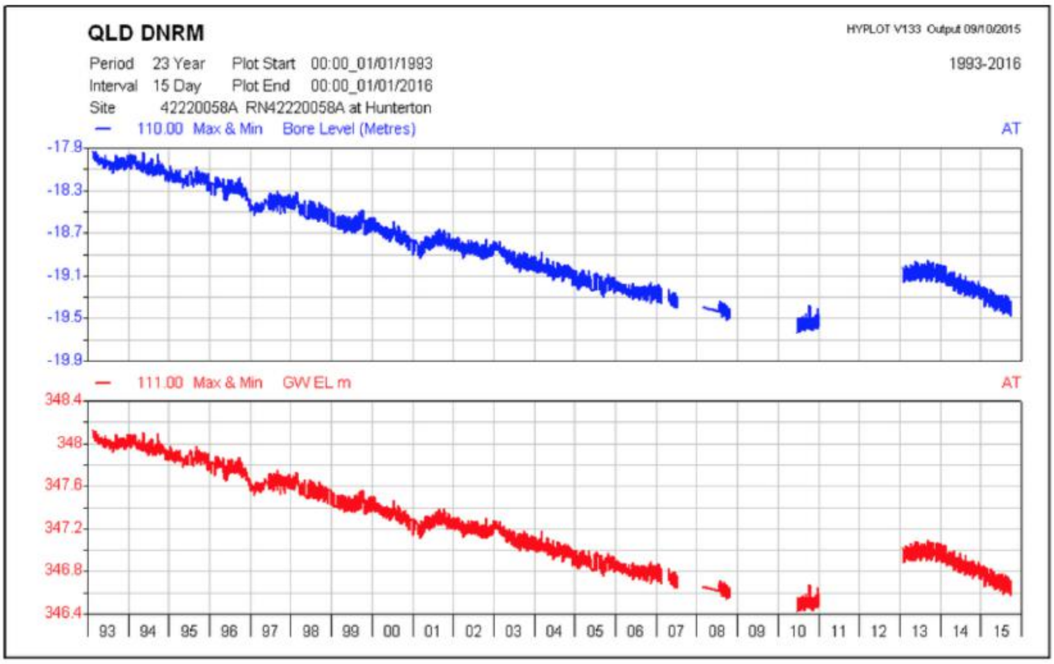


Figure 7-13: Declining Groundwater level (Mallants et al 2016)

7.7. Trouble shooting

7.7.1. Problem 1: Reduced Borehole Yield

Possible causes	What to check for	Remedy
Pump and/or water system	Low pump production despite normal water level in borehole. Leak in system; worn pump impeller	Competent person to check the pump and water system
Biofilm build-up in borehole casing, well screen or pump intake	Slime build-up in distribution pipes. Inspect pump and use down-hole camera to check for slime build-up	Chlorinate the borehole and water system as required. Normally once or twice a year
Incrustation build-up on perforated borehole casing and/or screens, or on pump screen	Scale formation in distribution pipes Inspect pump. Use down - hole video camera (if available) to check for mineral build- up. Calculate the Ryznar Stability Index[9] to determine the water's incrusting potential	Once the type of mineral scale has been identified, the borehole should be cleaned by a specialist. Treatment could include both physical agitation and chemical/acid treatment

[9] The Ryznar Stability Index is a tool that is used to predict the likelihood of calcium carbonate scale to form in a given sample of water. The 'neutral' value of the Ryznar index is roughly around

Possible causes	What to check for	Remedy
Sediment plugging on outside of perforated casing or screen	Sediment in water, followed by a sudden decline in yield	Experienced contractor to redevelop borehole/well
Collapse of borehole casing due to age of borehole	Sediment in water. Compare current depth of borehole with original depth from records. A collapsed well will show a shallower depth than the original well	Recondition the well. If repair is not economical, plug the borehole and drill a new borehole. Plugging to be carried out by an experienced contractor and according to laid out guidelines
Interference with neighbouring boreholes	Check for significant drop in water levels in nearby boreholes	Identify other nearby boreholes located in the same aquifer. Reduce pumping rates as required
Aquifer depletion: - rate of withdrawal exceeds rate of recharge - periods of drought can temporarily deplete shallow aquifers	Compare current non-pumping static water level with the level at the time of borehole construction. A lower level confirms aquifer depletion	Reduce the water use. Install additional storage to meet peak water requirements. Drill a deeper borehole or one that taps into another aquifer

7.7.2. Problem 2: Sediment in water

Possible causes	What to check for	Remedy
Improper borehole design or construction	Sediment appears in water shortly after borehole completion. Well production does not improve with pumping	Contractor should return to assess and repair the construction problem
Insufficient borehole development after construction	Sediment appears shortly after borehole completion. Well production may improve with pumping	Contractor should return and redevelop the borehole
Continuous over-pumping of well	Sediment may appear in water. Compare current discharge rate of well with the recommended rate at the time of construction	If the current flow rate is higher than the recommended rate, install a flow restrictor on pump. If required, install additional storage to meet peak water requirements

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the numerical value 6. Generally, any value above 6 indicates that the water is likely to form a calcium carbonate scale. A value below 6 indicates that the water will dissolve calcium carbonate formations. Calculation: Ryznar Stability Index = 2 x pHs – pH; where: pHs = the saturation pH

Possible causes	What to check for	Remedy
Corrosion of well casings and/or screens	Sudden appearance of sediment in water when there was no previous problem. May be coupled with a change in water quality and water colour (rust might show in the water). Use down the hole camera if available	Depending on the well construction, repair or replace well using alternate construction materials
Failure of the annular	Sudden appearance of sediment coupled with a change in water quality and/or reduced yield. Test water quality regularly and investigate when quality changes occur. Use down the hole camera if available	Consult an experienced borehole contractor to repair the borehole. If repair is not economical, plug the borehole and drill a new borehole. Plugging to be carried out by an experienced contractor and according to laid out guidelines

7.7.3. Problem 3: Change in water quality

Possible cause	What to check for	Remedy
Corrosion of borehole casing and/or screen, causing holes. Holes can allow water of undesirable quality to enter the well	Change in water quality, may be coupled with sudden appearance of sediment in water. Calculate the Ryznar Stability Index to determine the water's corrosion potential	Consult an experienced borehole contractor. Depending on the borehole construction, repair or replace borehole using alternate construction materials
Failure of the annulus	Sudden appearance of sediment coupled with a change in water quality. Test water quality regularly and investigate when quality changes occur	Consult an experienced borehole contractor. If repair is not economical, plug the borehole and a new borehole. Plugging to be carried out by an experienced contractor and according to laid out guidelines
Iron-related bacteria or sulphate-reducing bacteria (biofouling)	Change in water quality such as colour, odour (e.g., rotten egg) or taste. Check slime build-up in tanks and inspect pump	Chlorinate the borehole
Contamination sources.	Changes in water quality such as colour, odour or taste. Compare results from regular water analyses for changes*	Identify and remove contamination source. Continue to monitor water quality through regular water testing.

***** In many cases, variations in water quality will not result in observable changes in odour, taste or colour. For instance, in situations where nitrate levels are increasing, there may be no apparent change in the odour, taste or colour of the water.

7.8. Exercises

The purpose of the exercises is to understand the various groundwater sources, sources of contamination and pollution and how to prevent them, and general O&M activities of the water sources. Participants to work in groups and report back in plenary (60 mins). Each group to raise questions/clarifications/additions to the other group' presentation. Groups to be split into two: one for deep and shallow wells (sections 7.2; 7.3) and the other for boreholes (section 7.4).

7.8.1. Exercise: Wells (Deep and Shallow)

1. If you were to plan and develop groundwater for particular communities in your country, how would you decide on the groundwater sources to use as water supply sources? Motivate your decisions.
2. What are the most common sources of contamination and pollution of shallow wells and deep wells?
3. How would you prevent contamination and pollution of the various water sources?
4. What is the general O&M activities for wells and what is their significance?

7.8.2. Exercise: Boreholes

1. What are the main causes of borehole failure?
2. How would you prevent them?
3. What are the 3 main problems encountered with boreholes?
4. List at least 3 probable causes, how you would check for them, and the remedial action to be taken.
5. Do boreholes provide the best option for groundwater sources? Give reasons.
6. Why is it critical to maintain O&M records of boreholes?

8. OPERATION AND MAINTENANCE OF POSITIVE DISPLACEMENT PUMPS: PISTON AND CYLINDER

- Understand basics of pump operation and maintenance of positive displace pumps: piston and cylinder
- Able to troubleshoot and establish appropriate remedial action
- Appreciate the link between O&M and sustainability of water supply

8.1. Introduction

There are a variety of positive displacement pumps (PDP), Figure 8-1. A PDP makes water move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe. The principle is similar to the operation of a bicycle pump or a syringe. Some PDPs use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Water flows into the pump as the cavity on the suction side expands (similar to pulling out the syringe piston) and the water flows out of the discharge as the cavity decreases (similar to pushing down the syringe piston). If there are no seal leakages, the volume is expected to be constant through each cycle of operation.

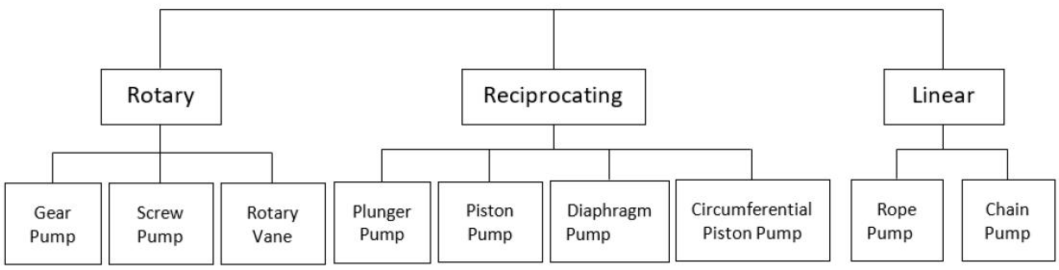


Figure 8-1: Types of positive displacement pumps

The most commonly used piston and cylinder pumps in SADC countries are shown in Table 8-1. The Afridev is the most commonly used across the SADC. Other types are either used alongside the Afridev pump or constitute the main pump type for the particular country. The Afridev pump lifts water from depths ranging from 15–45 m whereas the Zimbabwe Bush Pump can lift water from depth of up to 80 m. Wind pumps, though now rarely used for supply of potable water to communities, are mostly used for livestock watering (Fraenkel 1986) and in Namibia, where they form an important water lifting device.

Table 8-1: Types of handpumps used in SADC countries

Country	Type of handpump					
	Afridev	India Mark II	Vergnet	Nira	Volanta	Other
Angola						
Botswana						
Comoros						
DRC						Duba
Eswatini						
Lesotho						
Madagascar						Tany Rope
Malawi						Maida Life Pump (being piloted)
Mauritius						
Mozambique						Rope
Namibia						
Seychelles						
South Africa						
Tanzania						Walami
Zambia						
Zimbabwe						Bush pump

Lesotho, with the aid of UNICEF, introduced India Mark III and Mark IV hand pumps in 1995-96, but the majority of them failed due to mechanical breakdown which could be attributed lack of a clear O&M strategy (Davies 2003). Malawi is currently testing a new type of pump capable of pumping water from depths greater than 45 m called the Life pump (Design Outreach 2019). This pump is reported to be capable of pumping water from depths of up to 150 m[10]. Issues of standardisation and development of a clear O&M strategy are paramount. Local production of standardised pumps also improves access to the pumps and the spare parts.

Box 8-1: Pump selection

Be cognisant of the country's standardisation policy because they could be a restriction on the types of pumps to be used. Select a pump which can be operated at the village level, with easy accessibility to spare parts, corrosion resistant, and cheap but robust. The community should be involved in the selection of the pump.

[10] Manangi, A., 2020. personal communication

Table 8-2 provides links to O&M manuals and specifications for various handpumps.

Table 8-2: Links to handpumps O&M manuals and specifications

Hand Pump Type	Link
Afridev	https://www.ircwash.org/sites/default/files/Erpf-2003-Installation.pdf https://waterwellsforafrica.org/wp-content/uploads/2012/01/AFRIDEV_MANUAL.pdf
India Mark II	https://www.ircwash.org/sites/default/files/232.2-11889.pdf
Vergnet	Note: pump not in the public domain and O&M manuals only available from manufacturer available from Vergnet S.A. 6, rue Henry Dunant, F- 45140 INGRE, France. Tel: + 33 1 38 43 36 52 / Fax: + 33 1 38 88 30 50
Nira	https://www.rural-water-supply.net/en/implementation/proprietary-handpumps/nira-af-85-pump (note: pump not in the public domain and O&M manuals only available from manufacturer)
Volanta	https://www.rural-water-supply.net/en/implementation/proprietary-handpumps/volanta (note: pump not in the public domain and O&M manuals only available from manufacturer)
Duba	https://akvopedia.org/wiki/Duba_pump
Tany	https://www.rural-water-supply.net/en/implementation/public-domain-handpumps/no-6-pump
Rope	http://www.rural-water-supply.net/_ressources/documents/default/ROPE-Pump_Mozambique_Installation_English_Ed-2007.pdf www.rural-water-supply.net/en/implementation/public-domain-handpumps/rope-pump
Maida	http://www.rural-water-supply.net/_ressources/documents/default/MALDA_Handpump-Specification_Rev-2-2005.pdf
Walami	http://www.rural-water-supply.net/_ressources/documents/default/WALIMI_Hand-Book-for-Water-Users_Ed-2002.pdf
Bush pump	http://www.clean-water-for-laymen.com/support-files/bushpumpmanual.pdf
General information	https://ifrcwatsanmissionassistant.files.wordpress.com/2018/10/water-lifting-skat-1.pdf. https://sswm.info/sites/default/files/reference_attachments/ BAUMANN%202000.%20Water%20Lifting.pdf https://www.rural-water-supply.net/en/resources/sort/title-desc/filter/2_33

8.2. System components

The basic components for most of the handpumps are similar and comprise of down the hole components and above the hole or ground components. Down the hole components consist of a foot valve, cylinder, rods and rising main. Examples will be provided in the form of the Afridev and the Bush pump handpumps since they respectively represent a commonly used pump in the region and a country specific pump. The components are generally similar in their function. The wind pumps will also be discussed. Links to O&M manuals of some of the handpumps are provided at the end of this chapter.

8.2.1. Afridev handpump

The Afridev pump comprises:

Above the ground components, Figure 8-2

- head and T-bar handle
- pump stand
- water discharge unit/spout

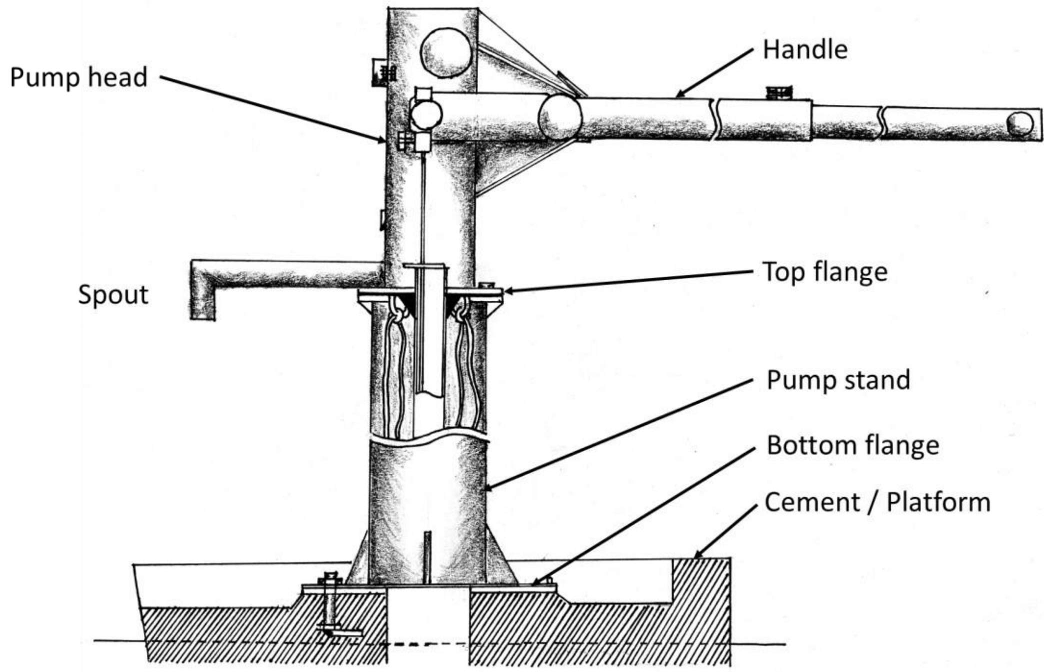


Figure 8-2: Afridev pump -above the ground components (SKAT 2007)

Down the hole components, Figure 8-3

- pump rods
- rising main of galvanised steel or PVC casing-U pipe (Ø 63 mm)
- cylinder (Ø 50 mm), plunger and foot valve

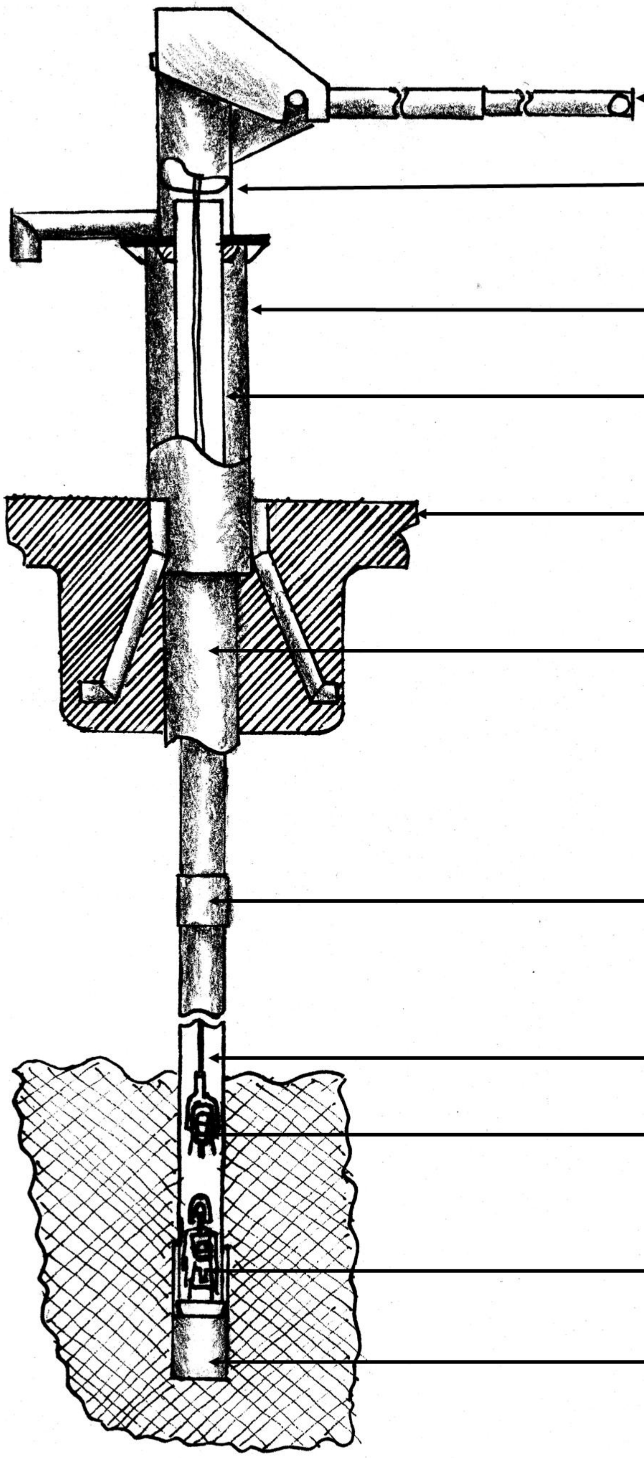


Figure 8-3: Typical Afridev pump (Baumann et al 2010)

8.2.2. Zimbabwe bush pump

Above the ground components (pump head), Figure 8-4

- wooden block and Ø 50 mm pipe handle
- pump stand
- U-brackets
- U-bolts (Ø 16 mm)
- pivot pins
- rubber buffer
- water discharge unit

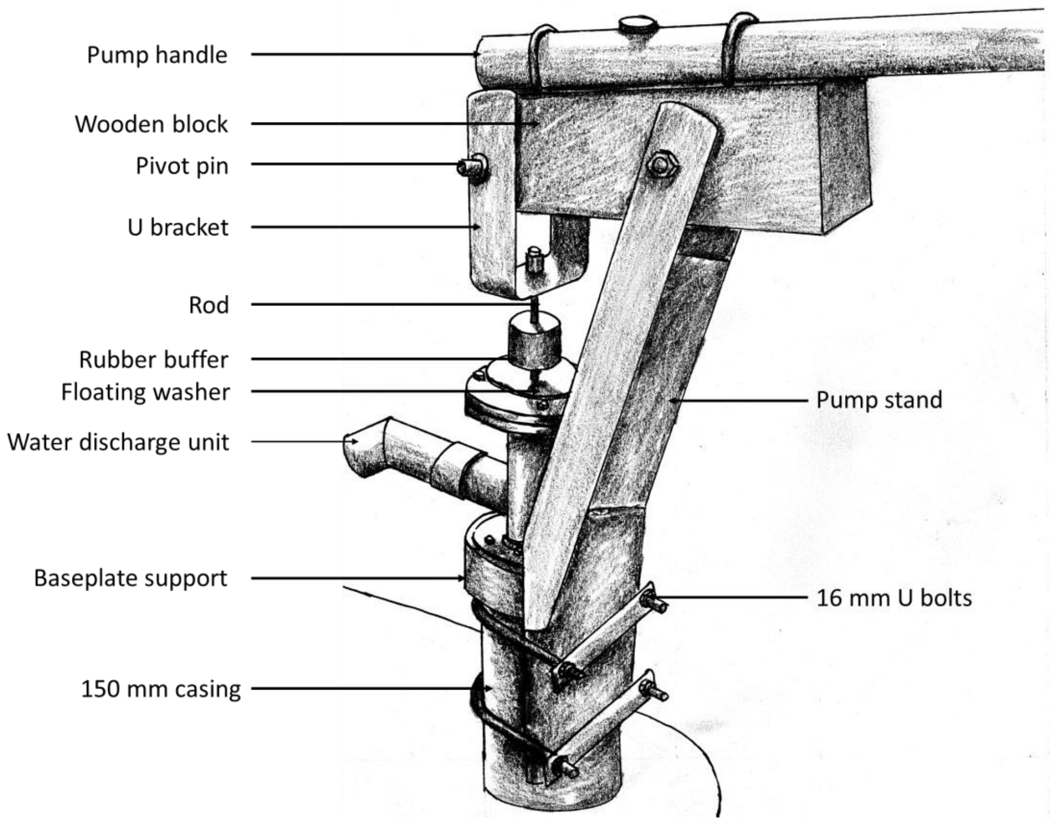


Figure 8-4: Zimbabwe bush pump- above the ground components (Morgan 2012)

Down the hole components, Figure 8-5

- pump rods (Ø 13 or 16 mm)
- rising main of galvanized steel pipe (Ø 50 mm)
- brass cylinder (Ø 75 mm) and 600mm long
- heavy duty brass foot valve with poppet
- piston fitted with two leather seals

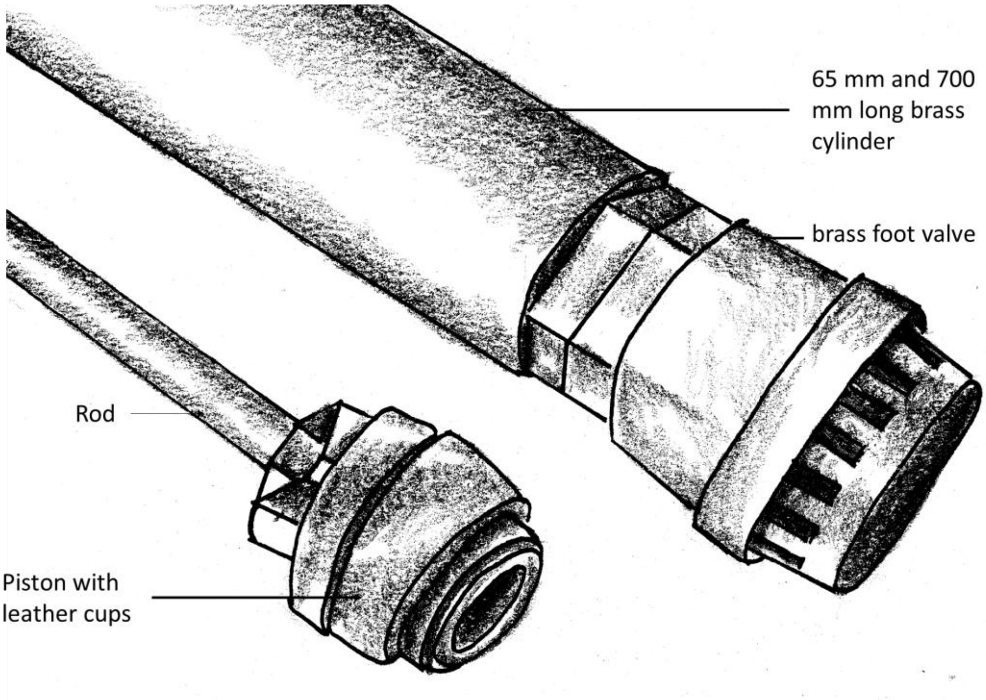


Figure 8-5: Zimbabwe bush pump – down the hole components (Morgan 2012)

8.2.3. Wind pump

Above the ground components, Figure 8-6.

- guide wheel
- guide wheel shafts
- pitman arm
- bull/driven gear
- pinion/driving gear
- pump rod guide
- wind wheel shaft
- wind vane and blades
- tripod mast (9-15 m high)
- water discharge unit

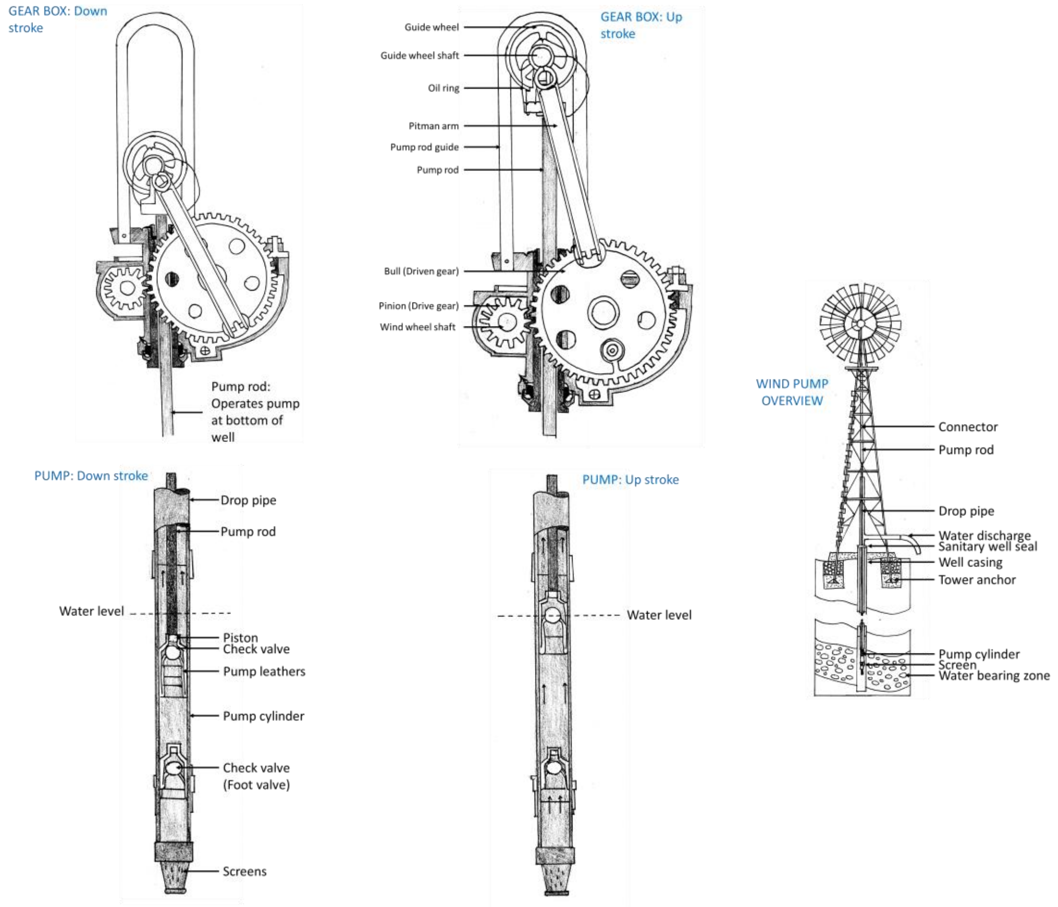


Figure 8-6: Wind pump – components[11]

Down the hole components, Figure 8-6

- pump rods
- drop/rising pipes
- cylinder
- check/foot valves
- pump leathers

[11] homepower.com

8.3. Operation

8.3.1. Handpumps

The pumping motion by the user at the pump stand is transferred to the piston by a series of connected pumping rods inside the rising main/pipes. On the upstroke, the plunger lifts water into the rising main, and replacement water is drawn into the cylinder through a foot valve. On the downstroke, the foot valve closes due to the weight of the water in the rising main, and the water passes the plunger and is lifted on the next upstroke. The repeated upstroke and downstroke actions will result in the water being discharged at the surface. Closed systems require that all the pipes and rods be removed to access the cylinder and foot valve. Nowadays, most pump cylinders have an open top (Brikké and Bredero 2003) and this largely relates to the Afridev handpump. This allows the piston and foot valve to be removed through the rising main for servicing and repairs, while the rising main and cylinder stay in place. The pump rods have special connectors that allow them to be assembled or dismantled without tools, or with only very simple ones. The connecting joints incorporate pump rod centralisers that prevent wear of the rising main. To a large extent, improved models can be maintained at village level. Cost of the pump and spares and ease of access to the spares is vital for the sustainability of the handpump and hence water supply.

8.3.2. Wind pump

Wind pumps are rarely used for supplying water to communities. Nevertheless, the most common models of wind pumps have a rotor fixed to a horizontal axis that is mounted on a steel tower or tripod mast usually 9–15 m high. Operation is usually automatic. Wind energy drives the rotor whose movement is transmitted to drive a pump (usually a piston type), either directly or via a gear box (Brikké and Bredero 2003). A vane keeps the rotor facing the wind during normal wind speeds, but there is also a mechanism to position the rotor parallel to the wind to avoid damage to it from excessive wind speeds. Some wind pumps are permanently installed facing the wind whilst others must be manually manoeuvred to face the wind. When no pumping is required, the wind pump may be temporarily furled out of the wind by hand. The right combination of pump, wind blades and wind characteristic is important for the success of this technology (Brikké and Bredero 2003).

8.4. Maintenance

8.4.1. Preventative maintenance

8.4.1.1. Afridev pump

Table 8-3 list detailed O&M activities for the Afridev pump. Always record servicing and maintenance information in a logbook. *Please note: Always refer to the manufacturers' manuals for detailed information* (Erpf and SKAT 2007).

Weekly

- Check that all bolts and nuts are tight
- Check that the Fulcrum pin-nuts and Hanger pin-nuts are tight
- Check that the handle moves smoothly, moves for its full arc, and water comes out when the handle is operated
- Lubricate moving parts

Monthly

- Check if any fasteners or parts in the pump head are missing. If so, replace the parts
- If any unusual noise is noticed, check reason for the same and take corrective actions (see Table 8-3 for Troubleshooting and Remediation)
- Check if the pump stand is shaky during operation. If yes, the stand is loose in the foundation and continued use will worsen the situation. Moreover, contamination of the well could occur through the gap between the pump stand and foundation. Immediately take

corrective measures to repair the foundation. The pump should not be operated when the foundation has been repaired. Wait until the cement has set

- Check if there is leakage in the pump. If more than 5 strokes are required before water comes out from the spout, it means the pump is leaking beyond the acceptable limit. It may be necessary to replace bobbin / foot valve, O-ring or attend to a leaking joint in the rising main. For attending to a defect in the rising main, a skilled mechanic may be required
- Carry out a "Leakage- and Discharge Test"

Annually

- Replace fulcrum/hanger bearings
- Replace plunger seal and plunger bobbin
- Replace foot valve bobbin and foot valve "O" ring
- Remove the pump and rising main from the well and inspect
- Check pipe threads and re-cut corroded or damaged threads
- Replace badly corroded pipes

Leakage Test

1. Operate the pump handle until water is flowing from the spout
2. Stop operating the pump handle for approximately 30 minutes
3. Then operate the handle and count exactly how many strokes it takes before the water starts flowing again
4. If more than 5 full handle strokes are required to make the water flow again, there must be a leakage in the rising main or the foot valve
5. Leakage mostly occurs because of a worn bobbin or O-ring of the foot valve, disconnected rising main joints or perforated or cracked riser pipes. Report problem to pump mechanic immediately

Discharge Test

1. Operate the pump handle until a continuous water flow has been achieved (pump ratio approximately 40 full strokes per minute)
2. Place a bucket in the continuous water flow for exactly one minute
3. Take the bucket off the water flow and check the amount of water drawn
4. The water collected should be generally not less than 15 litres
5. If the discharge is less than 10 litres for 40 full strokes, there might be a problem with the bobbins or the cup seal. Report problem to pump mechanic immediately

List of spares and tools

The following tools/items and spares are needed for the repair and maintenance of the Afridev handpump. *Please note: Always refer to the manufacturers' manuals for detailed information* (Erpf and SKAT 2007).

- Rod Resting Tool (used when the cylinder installation depth between 30 m to 45 m, since the total weight of pump rods will be heavy).
- 19mm spanner (India Mark 2)
- Fulcrum pin
- Bobbin
- O-ring
- Pump Washer
- Cup seals
- Bearing bushes
- Spanner for M16 hexagonal bolts and nuts,
- Fishing tool for retrieving the foot valve
- Grease and grease gun
- Fencing staples (if well is fenced)

Table 8-3: Main O&M Activities of Afridev Handpump

Actor	Responsibility	Frequency	Skills needed
Water Users/Pump caretaker/Minder/Water Point Committee	Report malfunctions, keep the water source site clean, assist in major repairs through provision of bricks, sand, etc.	Weekly or sooner	Nil
	Ensure that the gate of the fence is always closed	Daily	
	Laundry is carried out at least 30m away	Daily	
	Animals are watered from troughs at least 30m away	Daily	
Caretaker	Keep the site clean, check for damage, repair fence and keep apron, spillway channel and soak-away clean, perform small repairs, repair cracks	Weekly or sooner	Artisanal
	Clean the well	Annually	
	Check for turbidity	After each flood	
	Grease necessary joints	Monthly	
	Tighten nuts and bolts	Monthly	
	Report and record major breakdown	When necessary	
	Check for leakage in foot valve O-ring/valve bobbins/riser pipes	Yearly	
	Monitor discharge volume	Monthly	
	Monitor groundwater level	Monthly	
Water Point Committee	Supervise the pump caretaker/minder	Daily	Basic
	Organise/mobilise users for bigger repairs	When necessary	
	Collect user fees/levies	Monthly	
Mason/ Specialised builder	Repair apron, spillway channel and soak-away (headworks)	When necessary	Technical
	Deepening of well	When required	
	Inspect well walls	Annually	
Responsible institution	Check and record water quality	Quarterly	Highly technical
	Supervise mason/builder, guide and motivate local communities	Quarterly	
	Supervise washing and disinfection open wells e.g. with chlorine	Annually	

Actor	Responsibility	Frequency	Skills needed
	Attend to major pump breakdown beyond pump minder/caretaker's capability	When required	
	Supervise specialised builder in deepening wells	When required	

8.4.1.2. Zimbabwe bush pump

Table 8-4 provides detailed O&M activities for the Zimbabwe Bush Pump. Always record servicing and maintenance information in a logbook. *Please note: Always refer to the manufacturers' manuals for detailed information* (Morgan 2009, 2012).

Weekly

- Keep all pump head bolts greased and tightened
- Keep lock nut tightened
- Keep pump stand U-bolts tightened

Monthly

- If any unusual noise is noticed, check reason for the same and take corrective actions (see Table 8-4 for Troubleshooting)
- Check if the pump stand is shaky during operation. If yes, the stand is loose in the concrete apron/well slab and contamination of the well can take place. Take corrective measures to repair the apron
- Check if there is leakage in the pump. If more than 5 strokes are required before water comes out from the spout, it means the pump is leaking beyond the acceptable limit
- This needs to be attended to. It may be necessary to replace foot valve or attend to a leaking joint in the rising main or the rising main has perforations. For attending to a defect in the rising main, a skilled

mechanic may be required.
- Carry out a “Leakage- and Discharge Test”.

Annually

- Remove the pump and rising main from the well and inspect
- Check pipe threads and re-cut corroded or damaged threads
- Replace badly corroded pipes

Leakage Test

1. Operate the pump handle until water is flowing from the spout
2. Stop operating the pump handle for approximately 30 minutes
3. Then operate the handle and count exactly how many strokes it takes before the water starts flowing again
4. If more than 5 full handle strokes are required to make the water flow again, there must be a leakage in the rising main, leather cup or the foot valve
5. Leakage mostly occurs because of a worn foot valve, malfunctioning poppet valve, disconnected rising main joints or perforated or cracked riser pipes. Report problem to pump mechanic immediately

Discharge Test

1. Operate the pump handle until a continuous water flow has been achieved (pump ratio approximately 40 full strokes per minute)
2. Place a bucket in the continuous water flow for exactly one minute
3. Take the bucket off the water flow and check the amount of water drawn
4. The water collected should be generally not less than 15 litres

5. If the discharge is less than 10 litres for 40 full strokes, there might be a problem with the down the hole components particularly the foot valve. Report problem to pump mechanic immediately.

List of tools

The following tools are required. Please note that a detail list is provided in the Manufacturer's Manual. The tools are supplied as a mechanic's toolbox. *Please note: Always refer to the manufacturers' manuals for detailed information* (Morgan 2009, 2012).

– Special clamping too for 16mm rods. If 13mm rods are being used, a tool for the rods is required
– Pipe clamps
– Wrench spanners
– Files
– Die for threading
– Pump spanners
– Hacksaw
– Pipe joining compound
– 50mm swivel nipple
– Pulleys
– Rope

Table 8-4: Main O&M Activities for the Zimbabwe Bush Pump

Actor	Role	Frequency	Skills needed
Water Users/Pump caretaker/Minder/Water Point Committee	Report malfunctions, keep the water source site clean, assist in major repairs through provision of bricks, sand, etc.	Weekly or sooner	Nil
	Ensure that the gate of the fence is always closed	Daily	
	Laundry is carried out at least 30m away	Daily	

Actor	Role	Frequency	Skills needed
	Animals are watered from troughs at least 30m away	Daily	
Caretaker	Keep the site clean, check for damage, repair fence and keep apron, spillway channel and soak-away clean, perform small repairs, repair cracks	Weekly or sooner	Artisanal
	Clean the well	Annually	
	Check for turbidity	After each flood	
	Grease necessary joints	Monthly	
	Tighten nuts and bolts	Monthly	
	Report record major breakdown	When necessary	
	Check for leakage in foot valve/leather cup/poppet valve/riser pipes	Yearly	
	Monitor discharge volume	Monthly	
	Monitor groundwater level	Monthly	
	Fishing of fallen rising main components	When necessary	
Water Point Committee	Organise for general hygiene education around the well point by the Village Health Worker	Quarterly	Basic
	Supervise the pump caretaker/minder	Daily	
	Organise/mobilise users for bigger repairs	When necessary	
	Collect user fees/levies	Monthly	
Mason/ Specialised builder	Repair apron, spillway channel and soak-away (headworks)	When necessary	Technical
	Deepening of well	When required	
	Inspect well walls	Annually	
Responsible institution	Check and record water quality	Quarterly	Highly technical
	Supervise mason/builder, guide and motivate local communities	Quarterly	
	Supervise washing and disinfection open wells e.g. with chlorine	Annually	
	Attend to major pump breakdown beyond pump minder/caretaker's capability	When required	

Actor	Role	Frequency	Skills needed
	Supervise specialised builder in deepening wells	When required	

8.4.1.3. Wind pump

Weekly

- lubricate moving parts
- tighten bolts and nuts

Monthly

- visually check the pump and wind blades
- tighten nuts and bolts

Annually

- repaint the wind pump mast/tower
- replace worn out bearings (or when necessary)
- repair the furling mechanism (or when necessary)

8.5. Trouble shooting

8.5.1. Troubleshooting Afridev Handpump

Table 8-5: Trouble Shooting of Afridev Handpump

Problem	Operation	Possible cause	Possible remedy
Water is turbid	Drawing dirty water	Flood/surface water entered the well	Seal areas around well head Raise protective structure above ground level
		Walls could be collapsing	Rebuild the walls and disinfect e.g. with chlorine thereafter
Deterioration in water quality	Drawing contaminated water	Contamination through seepage of water through sides or cracks of apron	Scour the well and disinfect e.g. with chlorine Water Point Committee to conscientize users on need to

Problem	Operation	Possible cause	Possible remedy
			cover the well after use/Recast the lid
		Well lid not being used/broken (in open wells)	Conscientize users on importance of closing well/builder to recast lid
Reduced discharge	Handle operation is normal	Low water levels due to drought	Deepen well and disinfect e.g. with chlorine thereafter (where possible)
		Walls could be collapsing	Rebuild well and disinfect e.g. with chlorine thereafter
		Full stroke is not possible	Adjust length of top rod
		Cup seal is worn	Replace seal
		Leaking of vale Bobbins	Replace Bobbins (Plunger and Foot valves)
		Leaking cylinder	Pull out rising main and replace cylinder (solvent cement joints)
	Handle operation is hard	Cup seal too tight	Replace with correct size of seal
No water	Handle operation too easy or like loose	Pump rods are disconnected	Pull out all pump rods and replace broken/corroded rods
	Hand operation is hard	Riser pipe is disconnected	Pull out complete rising main, repair/replace pipes (solvent cement joints)
	Handle operation is normal	Cup seal is defective	Replace the seal
		Borehole is clogged with silt or sand	Rehabilitate borehole through flushing with compressed air or by bailing
		Water level dropped below cylinder	Add riser pipes and pump rods if there is room
Delayed discharge of water	Handle operation is normal	Leaking of vale Bobbins	Replace Bobbins (Plunger and Foot valves)
		Leaking foot valve O-ring	Replace O-ring
		Leaking through pipe joints or holes in rising main	Pull out rising main and replace cylinder (solvent cement joints)
Abnormal noise during operation	Handle operation is normal	Pump rods rubbing against riser pipes	Replace bent pump rods and worn out riser pipes
		Pump rods centralisers worn out	Replace worn out centralisers. Also replace bent pump rods
		Pump rods are touching riser pipes	Replace bent pump rods/worn out riser pipes/centralisers

Problem	Operation	Possible cause	Possible remedy
	Handle operation is abnormal	Bearings are worn out/fork touching the sides of the pump head	Check and replace bearing sets
Pump handle shacky	Shaky handle during operation	Bearings are worn out	Check and replace bearing sets
		Fulcrum pin is loose	Check Fulcrum pin and bearing sets and fully tighten both nuts
		Hanger pin is loose	Check Hanger pin and bearing sets and fully tighten both nuts
	Pump head is shaking	Flanges are loose	Tighten all bolts and nuts of the flanges
	Pump stand is shaking	Pump platform is cracked	Repair Pump Platform or well cover for dug wells

8.5.2. Troubleshooting Zimbabwe Bush Pump

Table 8-6: Trouble Shooting of Zimbabwe Bush Pump

Problem	Operation	Possible cause	Possible remedy
Water is turbid	Drawing dirty water	Flood/surface water entered the well	Seal areas around well head Raise protective structure above ground level
		Walls could be collapsing	Rebuild the walls and disinfect e.g. with chlorine thereafter
Deterioration in water quality	Water has iron content	Riser main could be corroding	Pull out rising main and replace corroding components. Preferably use stainless steel
	Drawing contaminated water	Contamination through seepage of water through sides or cracks of apron	Scour the well and disinfect e.g. with chlorine Water Point Committee to conscientise users on need to cover the well after use/Recast the lid
		Well lid not being used/broken (in open wells)	Conscientise users on importance of closing well/builder to recast lid
Reduced discharge	Handle operation is normal	Low water levels due to drought	Deepen well and disinfect e.g. with chlorine thereafter (where possible)
		Walls could be collapsing	Rebuild well and disinfect e.g. with chlorine thereafter
		Full stroke is not possible	Adjust length of top rod

Problem	Operation	Possible cause	Possible remedy
		Leather cup is worn	Replace leather cup
		Leaking of vale Bobbins	Replace Bobbins (Plunger and Foot valves)
		Leaking cylinder	Pull out rising main and replace cylinder (solvent cement joints)
	Handle operation is hard	Cup seal too tight	Replace with correct size of seal
No water	Handle operation too easy or like loose	Pump rods are disconnected	Pull out all pump rods and replace broken/corroded rods
	Hand operation is hard	Riser pipe is disconnected/Footvalve is leaking	Pull out complete rising main, repair/replace pipes (solvent cement joints)
	Handle operation is normal	Cup seal is defective	Replace the seal
		Borehole is clogged with silt or sand	Rehabilitate borehole through flushing with compressed air or by bailing
		Water level dropped below cylinder	Add riser pipes and pump rods if there is room
Delayed discharge of water	Handle operation is normal	Leaking of vale Bobbins	Replace Bobbins (Plunger and Foot valves)
		Leaking foot valve O-ring	Replace O-ring
		Leaking through pipe joints or holes in rising main	Pull out rising main and replace cylinder (solvent cement joints)
Abnormal noise during operation	Handle operation is normal	Pump rods rubbing against riser pipes	Replace bent pump rods and worn out riser pipes
		Pump rods centralisers worn out	Replace worn out centralisers. Also replace bent pump rods
	Handle operation is abnormal	Pump rods are touching riser pipes	Replace bent pump rods/worn out riser pipes/centralisers
		Bearings are worn out/fork touching the sides of the pump head	Check and replace bearing sets
Pump handle shaky	Shaky handle during operation	Block U-bolts are loose	Tighten U-bolts or rethread using appropriate die if threads are worn out
		Bearings are worn out	Check and replace bearing sets

Problem	Operation	Possible cause	Possible remedy
		Fulcrum pin is loose	Check Fulcrum pin and bearing sets and fully tighten both nuts
		Hanger pin is loose	Check Hanger pin and bearing sets and fully tighten both nuts
	Pump head is shaking	Flanges are loose	Tighten all bolts and nuts of the flanges
	Pump stand is shaking	Pump platform is cracked	Repair Pump Platform or well cover for dug wells

8.6. Importance of maintenance and repairs record keeping

Maintenance and repairs record keeping provides an insight into how the equipment is functioning. There are several benefits, some of which are:

- **Prevents expensive repair works:** Equipment wears and tears due to constant use. Routine inspections allow for repairs of minor damage before it becomes a big problem. Documenting these inspections and small repairs assists in keeping track of all the maintenance work and the frequency of the repairs, which could be indicative of a simmering larger problem which can then be investigated and rectified before it occurs.
- **Assists in the development of specialised maintenance programs or strategies:** Each piece of equipment or component undergoes different working conditions and has different limitations. Routine check-ups help in determining and recording the changes in each piece of equipment or component with regards to maintenance works required. In turn, this information assists in the development of maintenance programs or strategies specifically catering to each individual piece of equipment or component.
- **Prevent problems regarding warranty claims:** Documenting every repair or maintenance conducted on the equipment will assist in processing warranty claims. The record should include the type of maintenance performed, date and time.
- **Safety of operators or users:** Well-maintained plant reduces risks of accidents that would otherwise occur due to malfunctioning equipment. Records will help to provide any safety concerns and allow for timely intervention.

- **Improves accountability:** Record keeping improves accountability since each and every piece of equipment or spare part will be on record and can easily be tracked.
- **Management of stock items or spares:** Record keeping provides a dashboard of fast-moving items or spares and allows for timely ordering of the items or spares thereby minimising downtimes.

8.7. Exercises

8.7.1. Exercise: Hand pump selection criteria

To understand handpump selection criteria, general problems encountered with handpumps, general handpump O&M activities, and the importance of O&M record keeping (60 min). Participants to work in groups and report back in plenary. Each group to raise questions/clarifications/additions to the other groups' presentations. The groups will work on the following:

1. When is it most appropriate to select handpumps as water lifting devices?
2. What would be your selection criteria for the most appropriate type of handpump to use?
3. What are the general O&M activities for handpumps and why are they necessary?
4. List at least four problems that could be encountered with handpumps, how you would identify these problems, and the possible remedies to the problems.
5. Is handpump standardization necessary? Give reasons.
6. Why is it important to record maintenance, breakdowns and repairs in a logbook, and where and who should keep the logbook?

9. OPERATION AND MAINTENANCE OF POSITIVE DISPLACEMENT PUMPS: ROTOR STATOR

- Understand how the pump works
- Identify the components of the pump
- Learn how to specify the correct size pump for the borehole application
- Understand the requirements of pump operation
- Understand the pump maintenance requirements
- Be able to troubleshoot common pump problems

9.1. Introduction

Positive displacement rotor stator type pumps are also called progressive cavity pumps. The pump consists of a single helix rotor inside of a double helix stator (Figure 9-1). This shape leaves several separate voids between the helix and the stator and, as the helix rotates, the voids are forced to move up the pump. Water enters the lowest void and then is forced up the pump.

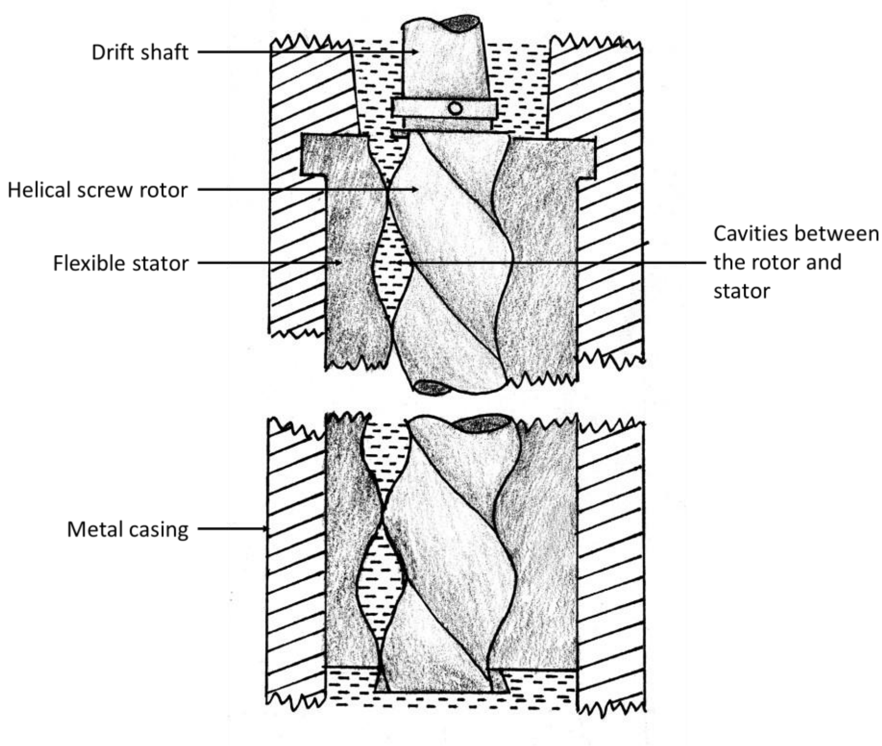


Figure 9-1: Progressive cavity pump showing the single helix rotor and double helix stator (Castle Pumps 2020)

The pump technology has been in use since the 1930s but is not used as much as submersible centrifugal borehole pumps today. The main reason for this is cost. Submersible centrifugal borehole pumps are mass produced and are less expensive, both for a new installation and to operate and maintain.

The progressive cavity pump needs to turn at a relatively high speed and while there are handpumps that have a geared drive head that can be used with this type of pump, these are not widely used, and most progressive cavity pumps are driven by diesel or electric motors.

Mono and Orbit pumps are the makes of progressive cavity pump most used in the SADC region and since 2004 have been part of the same company. While most of the pumps used are motorised, both companies also supply handpumps, a direct drive that operates in the range of up to 60 m deep and a geared drive that pumps up to 120 m deep. Because of the geared drive head on these handpumps, operation and maintenance are more complicated than the more commonly used piston and cylinder type of handpumps.

9.2. System components

The positive displacement rotor stator type pumps consist of a drive motor that is located at the wellhead connected by a driveshaft to the pump that is located below the water level in the borehole (Figure 9-2).

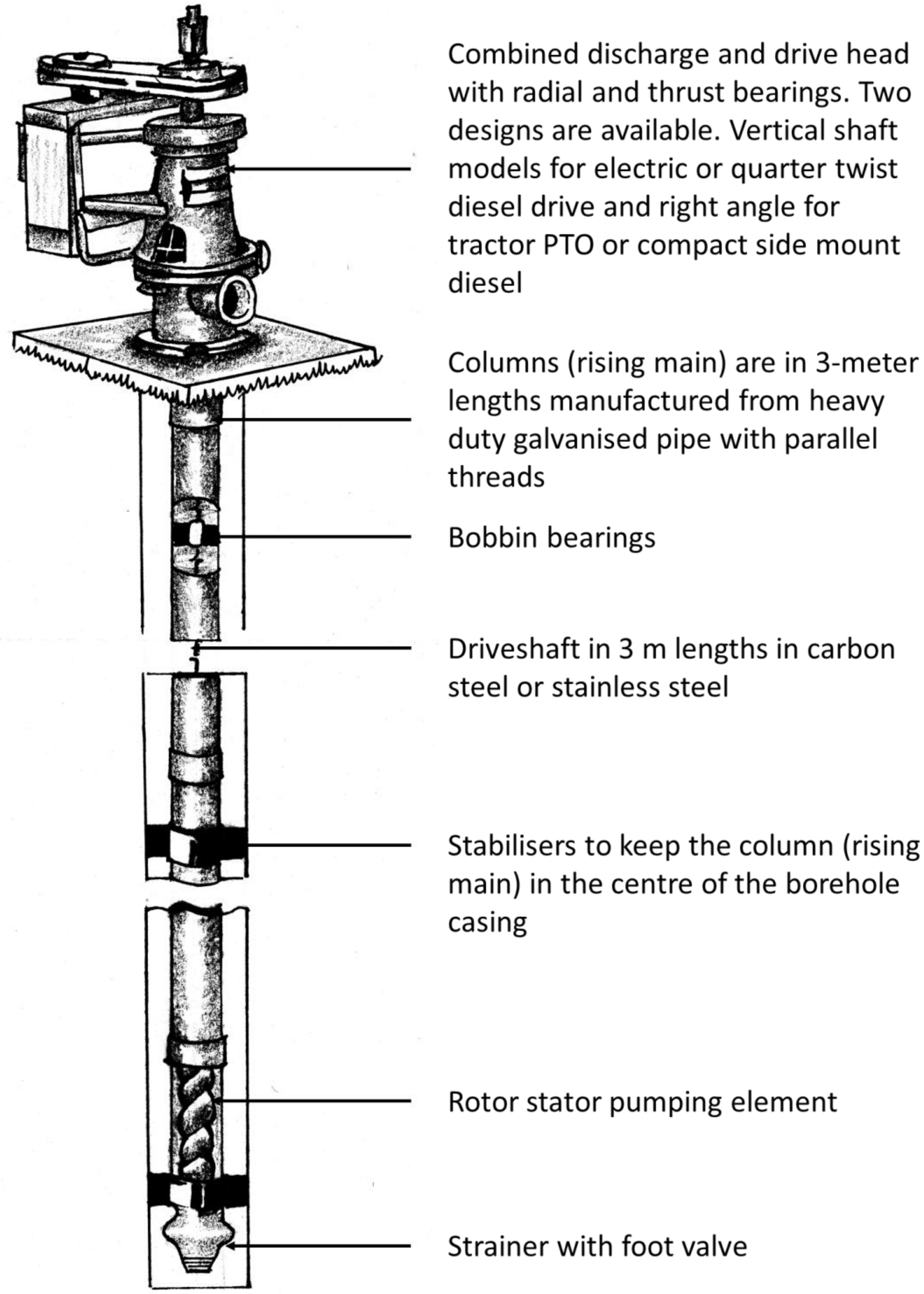


Figure 9-2: Components of an electrical driven progressive cavity pump[12]

The following characteristics are typical of positive displacement pump installations:

[12] Mono Agricultural Products Catalogue May 2002

- The flow rate from a positive displacement pump is relatively constant at a given speed (RPM – revolutions per minute) and does not change when the water level in the borehole drops or with different pump delivery heads
- The pump is lubricated and kept cool by the water it is pumping. The intake must be installed below the minimum operating water level in the borehole and must not be operated without water covering the inlet to avoid the pump being damaged
- The pump is connected to the above ground drive head with rods located inside the rising main, kept in position in the middle of the pipe by bobbin bearings
- The rising main is made of rigid galvanized pipes with parallel threads. Both the pipes and the rods are supplied in 3m lengths
- The motor connects to the drive head with belts that are like a car fan belt. The moving parts and belts must be enclosed with a safety guard for the operator's protection
- One must never close a valve on the delivery pipeline or block the flow in any way. If the pump operates against a closed valve it will continue to deliver water and pressure into the rising main until the pipeline bursts or the pump is severely damaged or both
- There is a small tolerance between the polished chrome rotor and the rubber stator and the pump can be damaged by pumping abrasive fluids. The borehole must be well constructed to ensure that excessive sediment is not drawn from the aquifer into the borehole.
- Knowing the quality of the water to be pumped is important. For corrosive water, the pump must be constructed of materials that can resist corrosion. The pumps are not prone to clogging and can pump water containing iron oxides.

Figure 9-3: Positive displacement pumps equipped with electric motor at left and diesel motor

9.3. Choosing the correct positive displacement pump

It is extremely important to match a borehole or well with a positive displacement pump that is designed for the anticipated duty. The range of different Mono pumps and the heads they can pump are shown in Figure 9-4.

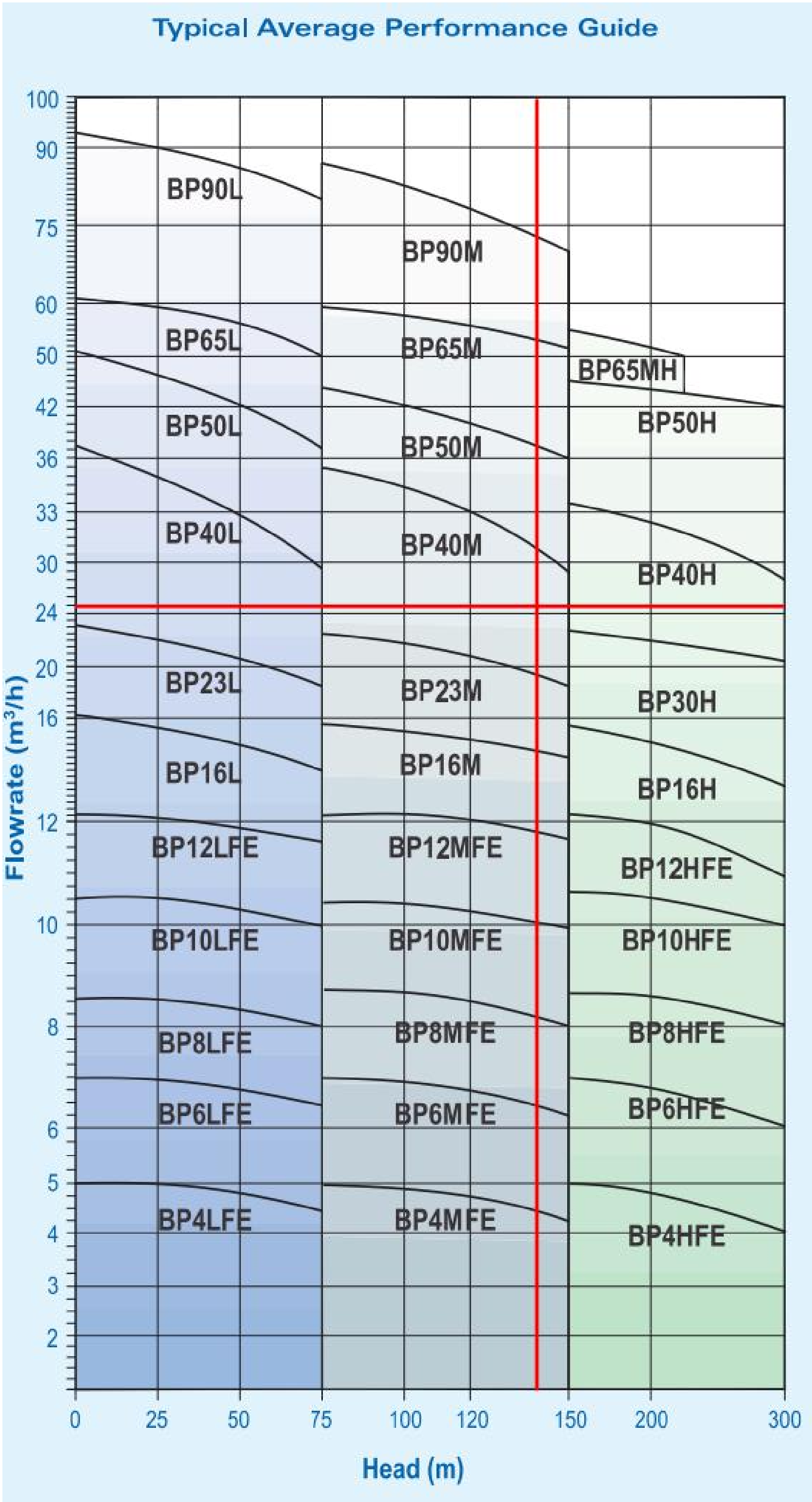


Figure 9-4: Pump selection chart for Mono pumps BP borehole pumps (Franklin Electric n.d.)

To demonstrate how to select the correct pump the following example will be used.

- Borehole depth: 85 m
- Borehole elevation: 510 masl (meters above sea level)

Hydrogeologists recommendation from the pumping test

- Sustainable borehole yield: 7 ℓ/s pumping 24hr a day
- Pump intake depth: 70 mbgl (meters below ground level)
- Probable drawdown at 7 ℓ/s: 58 mbgl
- Maximum permissible drawdown: 65mbgl
- Main water strike: 75 mbgl

Scheme details

- Reservoir elevation: 560 m
- Pipeline and fittings friction: 20m when pumping at 7 ℓ/s

Therefore, the total pumping head when pumping at 7 ℓ/s = 560-510+70+20 = 140m

Looking up in Figure 9-4 for a pump that can deliver 7 ℓ/s (or 25.2 kilolitres per hour - kℓ/hour) to a head of 140 m, you would choose to look at the detailed pump curves of model BP40M (Figure 9-5).

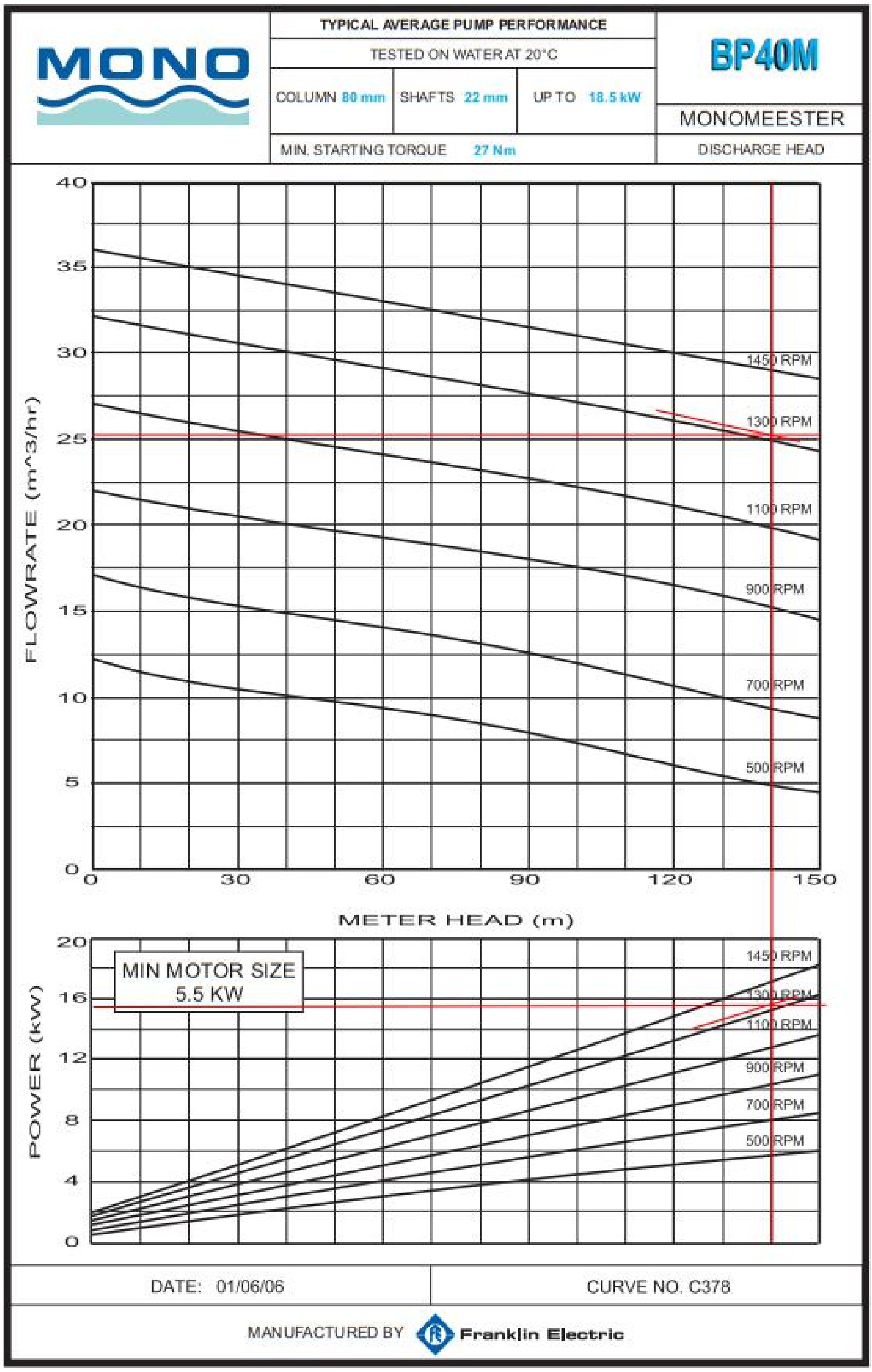


Figure 9-5: Pump selection chart for Mono pump BP40 (Franklin Electric n.d.)

Reading off the duty point on the BP40M pump curve, the pump must run at approximately 1320 revolutions per minute (RPM) and would require an 18.5-kilowatt (kW) motor. The size of the pulleys and the best are selected to ensure the pump will run at 1320 RPM.

9.4. Energy sources

Most progressive cavity pumps are driven by diesel or electric motors although you do get progressive cavity handpumps.

9.4.1. Hand powered pumps

Both Mono and Orbit manufacture 2 handpumps, a direct drive for heads up to 60 m and a geared drive for heads up to 120 m. The volume of water produced in proportional to the speed that the pump is operated.

Figure 9-6: Pump selection chart for Mono HP Handpumps (Franklin Electric n.d.)

9.4.2. Diesel motors

Progressive cavity pumps powered by diesel motors have been installed in many areas where there is no electricity supply. The motor and discharge head are installed on a baseplate and connected with belts. Diesel motors must be manually started and stopped by an operator and require regular servicing and maintenance. In some areas, diesel engines are targeted by thieves.

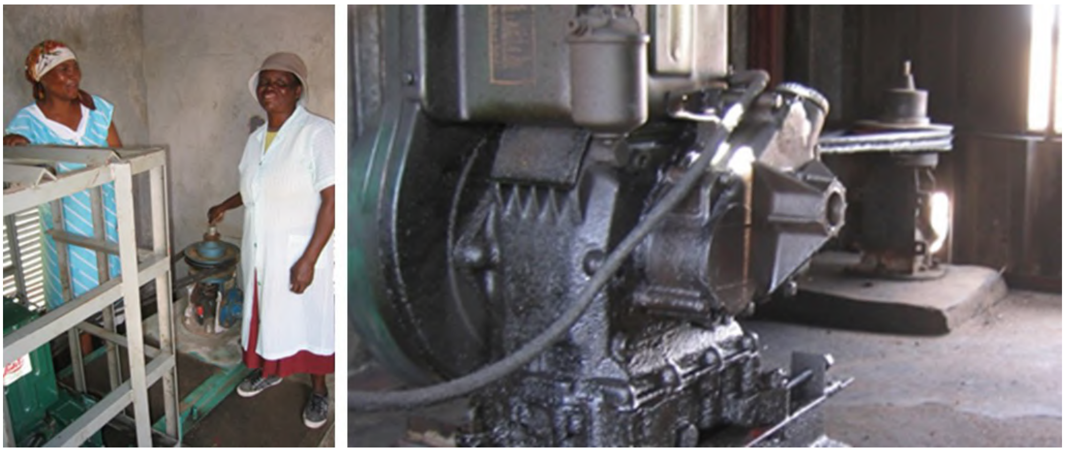


Figure 9-7: Examples of diesel-powered pumps both lacking belt guards. A homemade anti-theft cage has been installed over the motor on the left.

Diesel motors commonly used for powering progressive cavity borehole pumps include Lister Petter and Yanmar engines.

9.4.3. Electric motors

Three phase and single phase alternating current (AC) motors are used to power progressive cavity pumps where the pump installation can be connected to the electricity supply network. The advantage of electricity over diesel is that the pump can be set up to run automatically and can have electrical controls and protection instruments such as pressure and flow sensors. Figure 9-8 is an example of electric powered pumps. The belt guard has been removed from the pump on the right for maintenance.

Figure 9-8: Examples of electric powered pumps

Rotor stator pumps that use direct current (DC) output from solar panels have been developed for high head solar pumping installations although most solar pumping installations use submersible centrifugal DC pumps.

9.5. Operation[13]

The pump must never pump against a closed valve and the operator must always check that the flow is not obstructed. The operator’s level of skill and responsibility will govern how many of the following tasks are done by the operator, and which tasks are the responsibility of more specialist regional teams.

9.5.1. Operational tasks for a diesel-powered pump

9.5.1.1. Daily (when the pump is being operated)

1. Check condition and level of oil - top up oil if required
   - check fuel level - top up if required
   - visual check for oil or fuel leaks
   - check tension in vee belts (tighten if necessary)
   - check nuts, bolts, and screws (tighten if necessary)
2. Check isolation valve is open and waste valve is open

[13] Mono Pumps Limited (2010)

- check water level in borehole
- start engine
- record in logbook (hours run, flow meter, oil pressure, water pressure, water level)
- check that water is flowing through waste valve, if not stop engine.
- slowly close waste valve
- check that water is flowing through the water meter, if not stop engine.

3. Check that pump is running and water is being delivered during the day.
    - check the gland packing for excessive leaks
4. Open waste valve slowly
    - stop engine
    - close waste valve
    - check water level in borehole
    - record in logbook (hours run, flow meter, water level)

9.5.1.2. Weekly

1 Remove and clean air filter

2 Clean engines

3 Clean inside and outside of pump station

9.5.1.3. Monthly (or every 250 hours of service)

- Drain and replace oil
- Clean sump strainer
- Renew oil filter
- Check exhaust system and repair if necessary
- Record service in logbook

9.5.1.4. Every 4 month (or every 1000 hours of service)

- Renew fuel filter element
- Remove injectors and test spray (reinstall or service as

necessary)

- Check valve clearance and adjust as necessary
- Record service in logbook

9.5.1.5. Yearly (or every 3000 hours of service on the pump)

- Check that the pump flow and pressure are to specification
- Remove pump and rising main from well and inspect
- Check pipe threads and recut corroded or damaged threads
- Replace corroded pipes
- Decarbonise piston inlet and exhaust valves
- Regrind valves in valve seating and check wear.
- Record service in logbook

9.5.1.6. When required

- Periodically clean fuel tank
- Drain water from fuel filter
- Check that pressure cut out is operating
- Check engine bearings for signs of wear
- Repair leaks and service/repair/replace faulty valves on the rising main
- Scour the rising main
- Open and close all valves (approximately every two months)

9.5.2. Operational tasks for an electrical-powered pump manually operated

9.5.2.1. Daily

1. Before pump is operated
   - check condition all electrical connections and wires
   - check that all three phases of power supply

have power
- visual check for dangerous electrical connections or wires
- check tension in vee belts (tighten if necessary)
- check nuts, bolts, and screws (tighten if necessary)

2. Starting
   - check isolation valve is open and waste valve is open
   - check water level in borehole
   - start motor
   - record in logbook (hours run, flow meter, water pressure, water level)
   - check that water is flowing through waste valve, if not stop motor and investigate and repair the problem.
   - slowly close waste valve
   - check that water is flowing through the water meter, if not stop motor and investigate and repair the problem
3. During operation
   - check that pump is running and water is being delivered during the day
   - check the gland packing for excessive leaks
4. Stopping the engine
   - open waste valve slowly
   - stop motor
   - close waste valve
   - check water level in borehole
   - record in logbook (hours run, flow meter, water level)

9.5.2.2. Weekly

- Clean inside and outside of pump station

9.5.2.3. *Every 4 month or every 1000 hours of service)*

- Check that pressure cut out is operating
- Check that no-flow switch is working
- Inspect electrical connections and wiring
- Check bearings and lubricate

9.5.2.4. *Yearly (or every 3000 hours of service on the pump)*

- Check that the pump flow and pressure are to specification
- Remove pump and rising main from well and inspect
- Check pipe threads and recut corroded or damaged threads
- Replace corroded pipes
- Record service in logbook

9.5.2.5. *When required*

- Check that pressure cut out is operating
- Check engine bearings for signs of wear
- Repair leaks and service/repair/replace faulty valves on the rising main
- Scour the rising main
- Open and close all valves (approximately every two months)

> With an automatic electrical driven pump, the operator must check the settings and correct operation of the pump control and pump protection systems. This would typically include operation timer, no-flow switch, pressure cut of switch and can include electrical components like variable speed drives, soft starters, phase failure protection relays, overload and underload protection relays.

9.6. Maintenance

If the pump is correctly specified for pumping the sustainable yield of the borehole and has been correctly installed, the downhole components should require little maintenance.

9.6.1. Preventative maintenance

Regular maintenance of the wellhead infrastructure is required and typically includes:

- Checking the baseplate mounting bolts
- Checking the downhole vibration and reporting if excessive
- Checking the and adjusting the belt tension and checking the condition of the belts. When a belt needs replacing the complete set of belts should be replaced
- Checking gland packing – it should be replaced after 5000 hours of operation
- Checking the bearings and lubrication – they are rated to operate for 10000 hours
- Checking the pipes and valves for leaks and verifying that they are still operating correctly. Malfunctioning pressure relief valves, air valves, non-return valves and isolation valves could result in damage to the pumping system

9.6.2. Breakdown maintenance

The pumping element is water-lubricated and will only experience excessive wear if pumping abrasive or corrosive water or if the water level drops below the pump inlet. If the pump element does need to be removed, a tripod with a winch or block and tackle is needed to remove the column, driveshaft, and bobbin bearings. Removing a positive displacement pump, especially a large pump, is a major undertaking and the maintenance team should use the opportunity to inspect all the downhole parts ensuring that any suspect or warn parts are replaced.

9.7. Troubleshooting

Regular recording of the following parameters allows the operator to identify when the pump performance is deteriorating, giving an early warning of potential pump problems.

- Motor hour meter
- Power drawn for an electric motor
- Flow meter – volume of water pumped
- Flow rate measurement
- Water pressure
- Oil pressure for diesel engines
- Groundwater levels

If the pump stops working the records of these parameters are especially useful for identifying the trends and what the problem with the pump could be. The following procedure can be followed for site investigation of a non-functioning pump (Table 9-1).

Table 9-1: Procedures for site investigation of non-functioning pump

Symptom	Verify	Action
Electrical pump will not switch on	Check the incoming power and verify that voltage is correct on all 3 phases	If no power, first verify that the account is not in arrears and then report the fault to electricity supply authority
	Check that the starter is receiving power and delivering power to the motor	Replace/repair starter
	Disconnect the motor and check that the resistance on each phase is to specification	If motor is faulty remove and get assessed by suitably qualified electrician
	Check for a lost phase	Diagnose cause of lost phase and address
Motor vibration excessive	Check for a lost phase	Diagnose cause of lost phase and address
Excessive vibration of the pump	Down hole problem	Pump must be removed from the borehole and sent to specialist workshop
Pump will not turn	Pump seized	Pump must be removed from the borehole and sent to specialist workshop

Table 9-2: Troubleshooting diagnostic table (Saveth n.d.)

Perceived problems	Possible causes
No production	2, 3, 4, 5, 7, 16, 18, 24m 26, 27, 32
Production drops off	3, 4, 5, 7, 8, 9, 10, 11, 14, 16, 17, 25, 26, 27
Intermittent production	4, 5, 8, 14, 15, 17, 25, 26, 27, 31
Pump will not start	6, 7, 8, 12, 17, 20, 22, 24, 27, 29, 32
Motor stalls at pump-up	8, 11, 12, 20, 22, 23, 26, 27, 29, 30, 31, 35
Motor overheats	6, 8, 11, 12, 15, 18, 20, 22, 24, 26, 29
Pump consuming excessive power	8, 11, 12, 15, 18, 20, 26, 30, 31
Excessive noise and vibration	2, 3, 4, 6, 8, 9, 11, 14, 15, 17, 18, 19, 20, 24, 26, 30, 31
Wear on pump elements (rotor or stator)	1, 11, 15, 1825, 26, 31
Excessive packing gland wear	1, 12, 15, 23, 25, 28
Packing gland leakage	13, 22, 25, 28
Pumps lock up	9, 11, 12, 20, 24, 25, 26, 27, 30, 31, 32
List of causes	**Plan of action**
% abrasion above max recommended	Select correct rotor fit, decrease pump speed
Sucker rods parted	Fish parted rod and replace
Tubing parted	Fish parted tubing and replace. Tighten adequately
Inadequate fluid (reservoir or completion related)	Reduce pump speed or put on a timer
Hole in tubing or collar	Replace tubing or collar
Motor supply or wiring	Check electrical supply and wiring
Pump intake blocked	Pull up rotor. Circulate well
Fluid viscosity above design point	Decrease pump speed
Fluid temperature above/below design point	Select correct rotor fit
Fluid viscosity below design point	Increase pump speed
Discharge pressure above design point	Check flowline for blockages or partially closed valves
Packing gland to tight	Adjust packing gland
Packing gland not tight enough	Adjust packing gland
Excessive free gas at pump intake	Install gas anchor, reduce speed or lower pump
Pump speed above design point	Decrease pump speed
Pump speed to low	Increase pump speed
Drive belts slipping	Check belt tension and adjust as necessary
Incorrect roto setting	Check and adjust rotor spacing
Drive mounting insecure	Check and tighten all mounting hardware
Drivehead bearing wear/failure	Remove drivehead. Replace or overhaul.
Worn pump (rotor/stator)	Replace worn components
Low voltage	Check voltage, wiring sizes
Abrasives in the packing gland area	Check packing type and condition

Failure of drive arrangement	Check and replace failed drive components
Incompatible treating chemicals	Re-check materials of compatibility with chemicals
Pump discharge blocked or valve closed	Remove pressure, clear blockages
Stator worn/damaged	Replace worn parts
Packing gland destroys packing	Check polished rod for excessive wear and replace
Motor is too small	Check and recalculate motor size
Incorrect rotor spacing	Re-space rotor
Stator elastomer swollen	Re-evaluate well characteristics and elastomer selection
Pump sanded in	Pull rotor up, circulate and re-set rotor

9.8. Exercises

9.8.1. Exercise: Pump selection

Sizing a replacement pump for an existing installation. The participants will be given the results of the hydrogeologist's report and details of the scheme and pumping main, as well as copies of a pump catalogue with pump curves. The participant will use the information to select a pump (60 mins).

9.8.2. Exercise: Schedule of O&M tasks

Develop a schedule of O&M tasks for the operator of a diesel-powered rotor stator borehole pump. Participants to work in groups and report back in plenary. Each group to raise questions/clarifications/additions to the other groups' presentations (30 mins).

10. OPERATION AND MAINTENANCE OF CENTRIFUGAL SUBMERSIBLE PUMPS

- Understand how the pump works
- Identify the components of the pump
- Learn how to specify the correct size pump for the borehole application
- Understand the requirements of pump operation
- Understand the pump maintenance requirements
- Be able to troubleshoot common pump problems

10.1. Introduction

Centrifugal submersible pumps are by far the most commonly used motorised borehole pumps (Figure 10-1). There are many different manufacturers and suppliers and the pumps are made in almost any size that will meet the needs of any borehole installation, from small 3-inch diameter pumps for small boreholes to 12-inch diameter borehole pumps. The pump is close coupled with the pump motor with both having the same outside diameter such that both can be inserted into the borehole to the optimal pumping depth.

It is extremely important to match a borehole or well with a submersible pump that is designed for the anticipated duty. This includes the flow rate, the pumping head and the water quality. In some cases, pump selection is an afterthought, and the main pump selection criteria may be whether the pump fits the borehole, and whether it falls inside the budget. Incorrect pump specification can dramatically reduce the life of the pump and other infrastructure, and greatly reduce system reliability. In some cases, a poorly specified pump can also impact on water quality (e.g. by drawing the water level down too far and encouraging oxidising conditions in the aquifer). Funds allocated to pump specification and design will likely repay themselves many times over.

Figure 10-1: Submersible borehole pump and cutaway showing the motor and pump stages[14]

[14] Grundfos

10.2. System components

The submersible borehole pump is made up of several centrifugal pump chambers, each with its own impeller, stacked on top of each other. These are called stages and the more stages a pump has, the greater the height it can pump to. The size of the stages and the impellers governs the volume of water that can be pumped.

There are several key considerations for the correct specification of a submersible borehole pump:

- The pump motor is water cooled and must be installed such that the flow of water from the aquifer into the pump passes over the motor. The motor is attached to the bottom of the pump and the motor sits in the water below the pump inlet. It is important that the pump motor is installed above the main water strike of the borehole such that the water is drawn into the pump inlet over the motor. If this is not possible the pump should be provided with a shroud to induce the flow over the motor (
- Figure 10-2). The shroud has a larger diameter than the pump and the need for a shroud can restrict the size of pump that can fit inside the borehole. If the pump motor is placed below the water strike without a shroud, the motor will sit in water that is not flowing and will overheat.

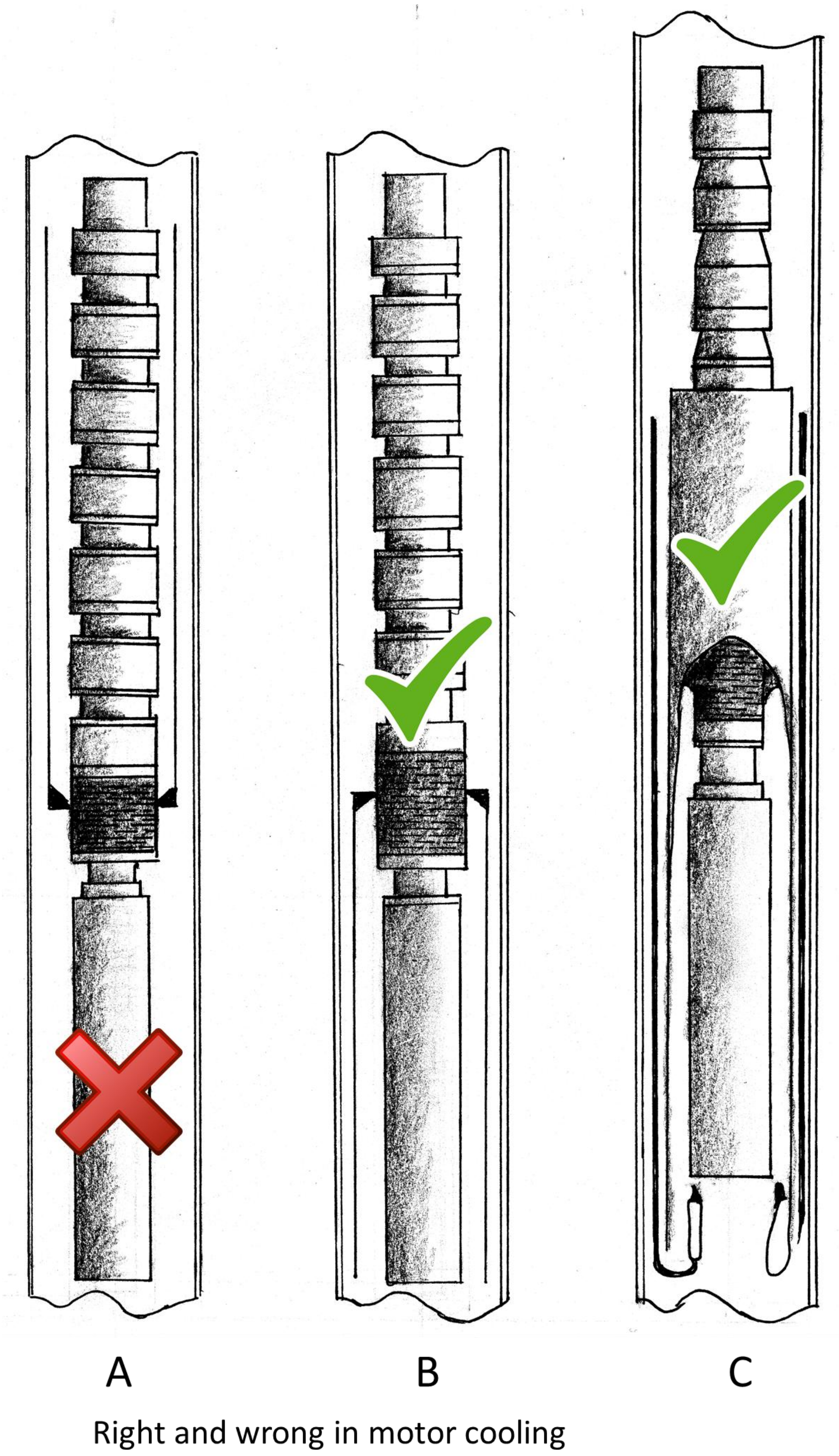


Figure 10-2: Use of a pump shroud to induce flow over the motor shown in diagram C (BWA 2020)

– The diameter of the pump and the internal diameter of the borehole casing need to be matched. If a piezometer pipe is required for monitoring groundwater levels, you need to ensure that the rising main, together with the piezometer pipe can fit into the borehole.

- For smaller pumps, the rising main for a submersible pump can be HDPe pipe. For larger pump installations borehole riser pipe made from threaded uPVC or flexible hose is normally used.
- The residual head of water inside the borehole is transferred through the submersible centrifugal pump. In other words, the pump only needs to lift the water from the water level in the borehole to where it is required, typically in a reservoir. As the water level drops in the borehole the work to be done by the pump will increase.
- It is important that the pump is sized to operate as close as possible to the best efficiency point (BEP) for the pump. This is the point where water enters and leaves the pump with the minimum amount of flow separation, turbulence and other losses.

Figure 10-3: Borehole pump installation on a sugar estate in Tanzania (BWA 2020)

10.3. Choosing the correct submersible borehole pump

The range of different Grundfos SP range pumps and the heads they can pump are shown in Figure 10-4.

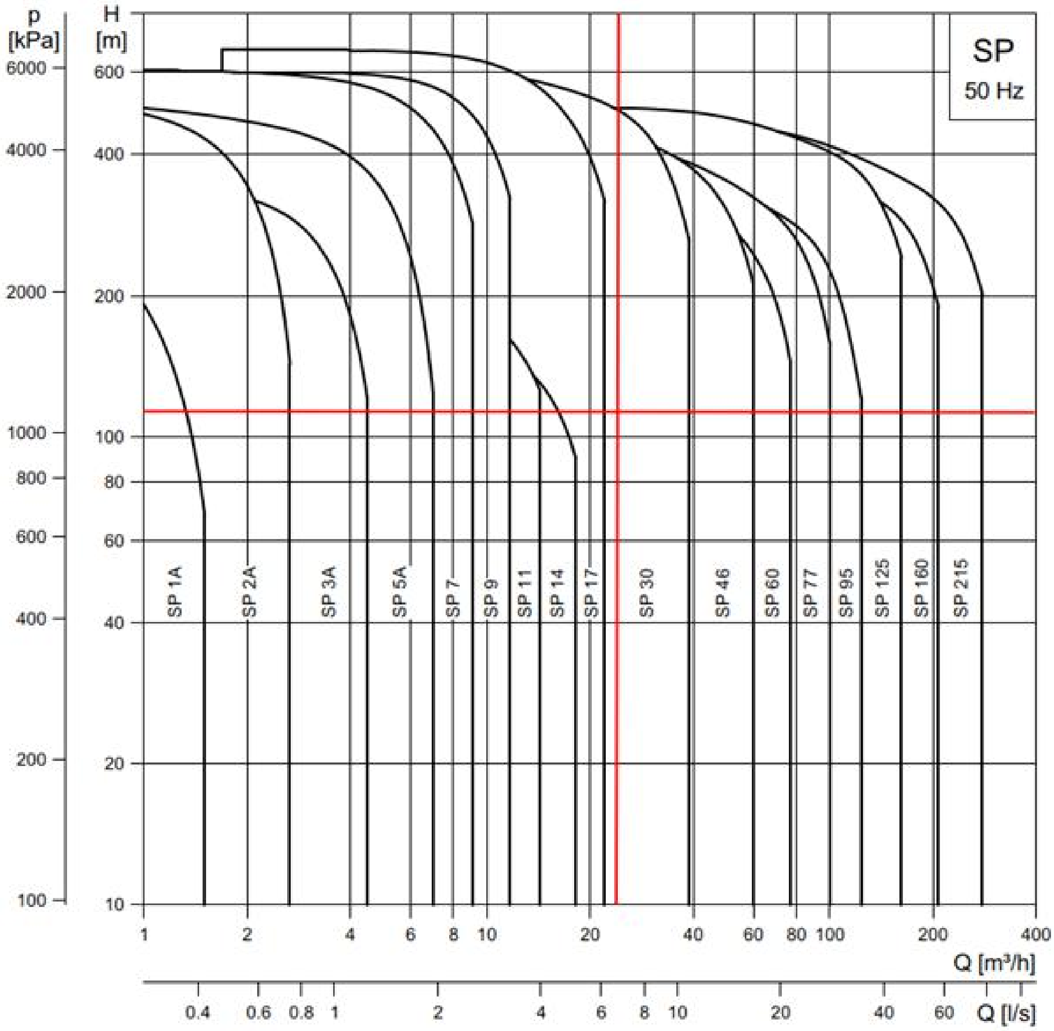


Figure 10-4: Grundfos SP range of pumps and selection of Grundfos SP30 pump (Grundfos-Lenntech n.d.)

To demonstrate how to select the correct pump the same example will be used.

- Borehole depth: 85m
- Borehole elevation: 510 masl (meters above sea level)

Hydrogeologists recommendation from the pump test:

- Sustainable borehole yield: 7 ℓ/s pumping 24hr a day
- Pump intake depth: 70 mbgl (meters below ground level)
- Maximum permissible drawdown: 65 mbgl
- Probable drawdown at 7 ℓ/s: 58 mbgl
- Main water strike: 75 mbgl

Scheme details

– Reservoir elevation: 560m

A submersible borehole pump is a centrifugal pump. The impellors allow water to flow through the pump unlike the rotor stator pump. As a result, the pump only needs to overcome the difference in the water level between the borehole water level and the reservoir height as opposed to the rotor stator pump that must overcome the difference between the pump inlet and the reservoir level.

Probable Pump head at 7 ℓ/s = 560-510+54+20 = 124 m

Choosing to use the Grundfos SP pump range, one first identifies that a pump in the SP30 range of pumps would be required and then looks at the pump curve to identify the correct model of pump (Figure 10-5). In the example it is a SP30-14 with the 14 designating the number of stages that the pump has. The lower graph shows the efficiency and one can see that the pump will be operating close to its BEP at the specified duty.

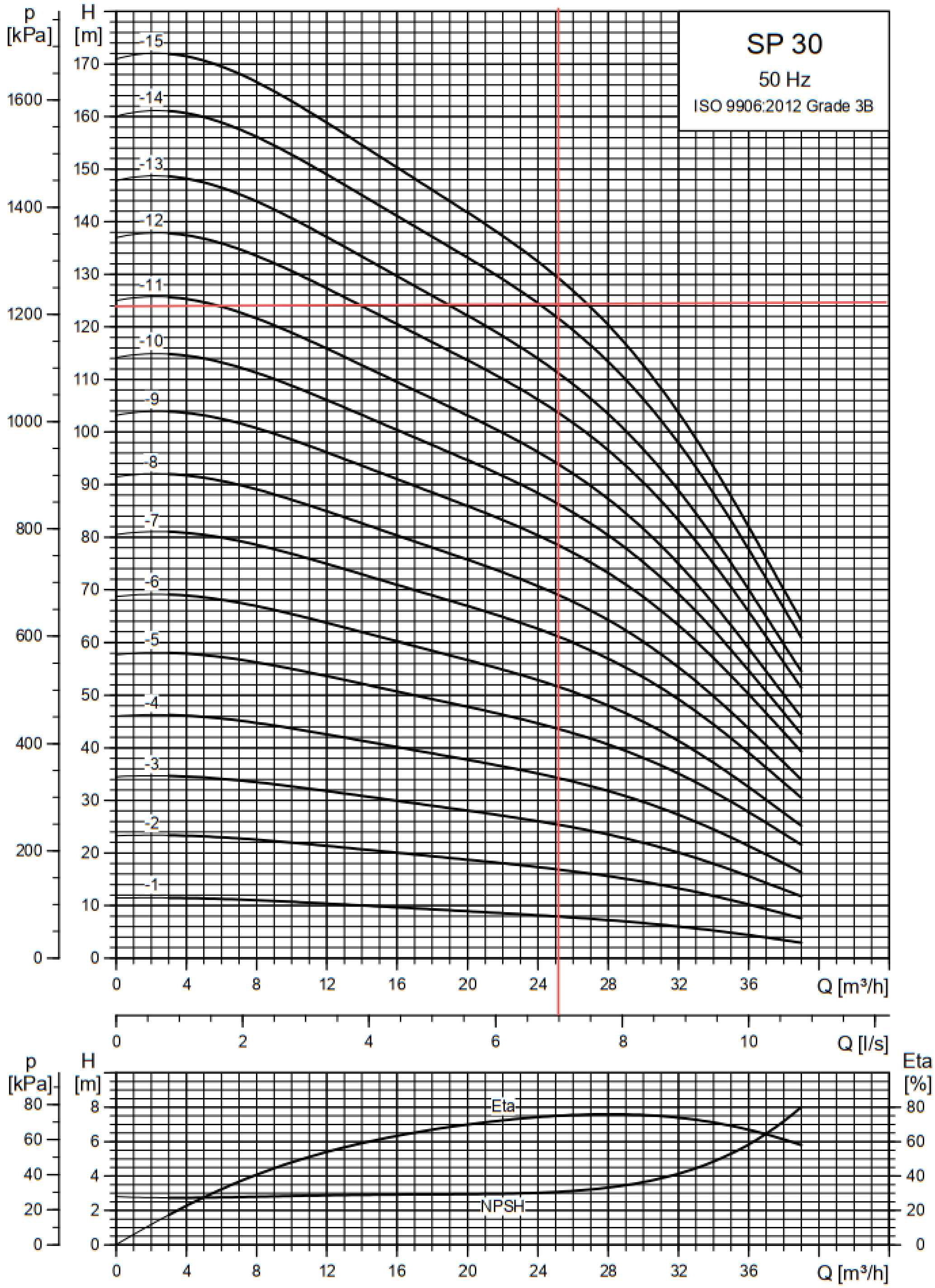


Figure 10-5: Grundfos SP30 pumps and selection of Grundfos SP30-1 or SP30-15 pump (Grundfos-Lenntech n.d.)

For a submersible borehole pump the selection of the pump based upon a single duty point in not enough. The pump duty will change as the water level is drawn down in the borehole and the flow rate that the pump delivers will change accordingly (Table 10-1). By developing a system curve for each anticipated pumping condition one can check that the pump will operate at a reasonable efficiency for all conditions and not run off to the left or right of the pump curve where it would be damaged.

Table 10-1: Table of flow rates, pipeline friction and drawdown water levels

Flow (ℓ/s)	Flow (kℓ/h)	Friction	Static Head (m)	Total pumping head for rest water level of 38m	Total pumping head for probable drawdown of 54m	Total Pumping head for maximum drawdown of 65m
4	14.4	6.1	50	94.1	110.14	121.14
6	21.6	13.3	50	101.3	117.33	128.33
8	28.8	23.2	50	111.2	127.22	138.22
10	36	35.8	50	123.8	139.82	150.82

In Figure 10-6 the flow rate that the pump will supply will range from 29.5 kℓ/hour when the borehole water level is at its highest down to 22 kℓ/hour when the water level is drawn down to the maximum allowable. The selected SP30-15 pump is coupled with a 13kW motor and would operate between 75% and 80% efficiency for this range of duties which is acceptable.

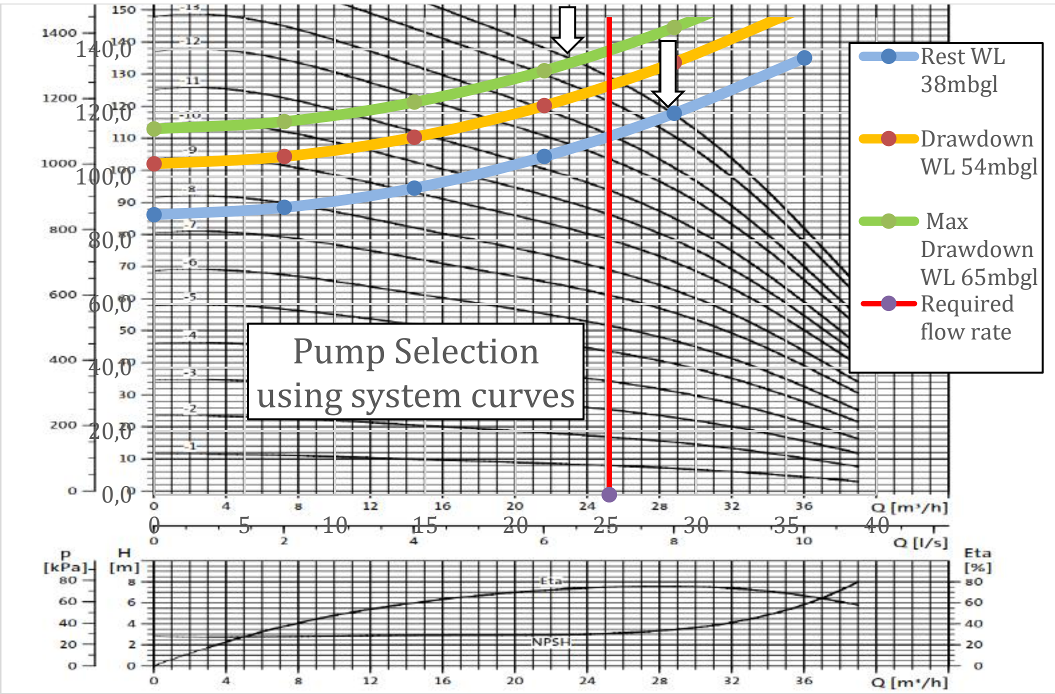


Figure 10-6: Grundfos SP range of pumps and selection of Grundfos SP30 pump (Grundfos-Lenntech n.d.)

10.4. Energy sources

Submersible centrifugal pumps come in two main types, alternating (AC) and direct current (DC). Pumps with DC motors are used for solar pump installations where the pump is supplied power directly from the solar panel and those using alternating current (AC) that are normally connected to an electrical grid but can also be powered from a generator.

10.4.1. Direct current (DC) pumps

The solar borehole pump installation consists of three main components, the borehole pump, the solar panel array to power the pump, and a controller. While most solar pump motors operate on direct current (DC), some can be supplied with alternating current (AC) but then an alternator is also required to convert the DC from the solar panels to AC. Storing power in a battery and using it at a later stage has a low efficiency. For that reason, rather than store the power, it is more efficient to pump water when the sun is shining and store the pumped water in a reservoir. Figure 10-7 shows the basic components of a solar powered borehole pump installation. More complex systems can include integration with a generator or mains electricity, battery power storage and inverter.

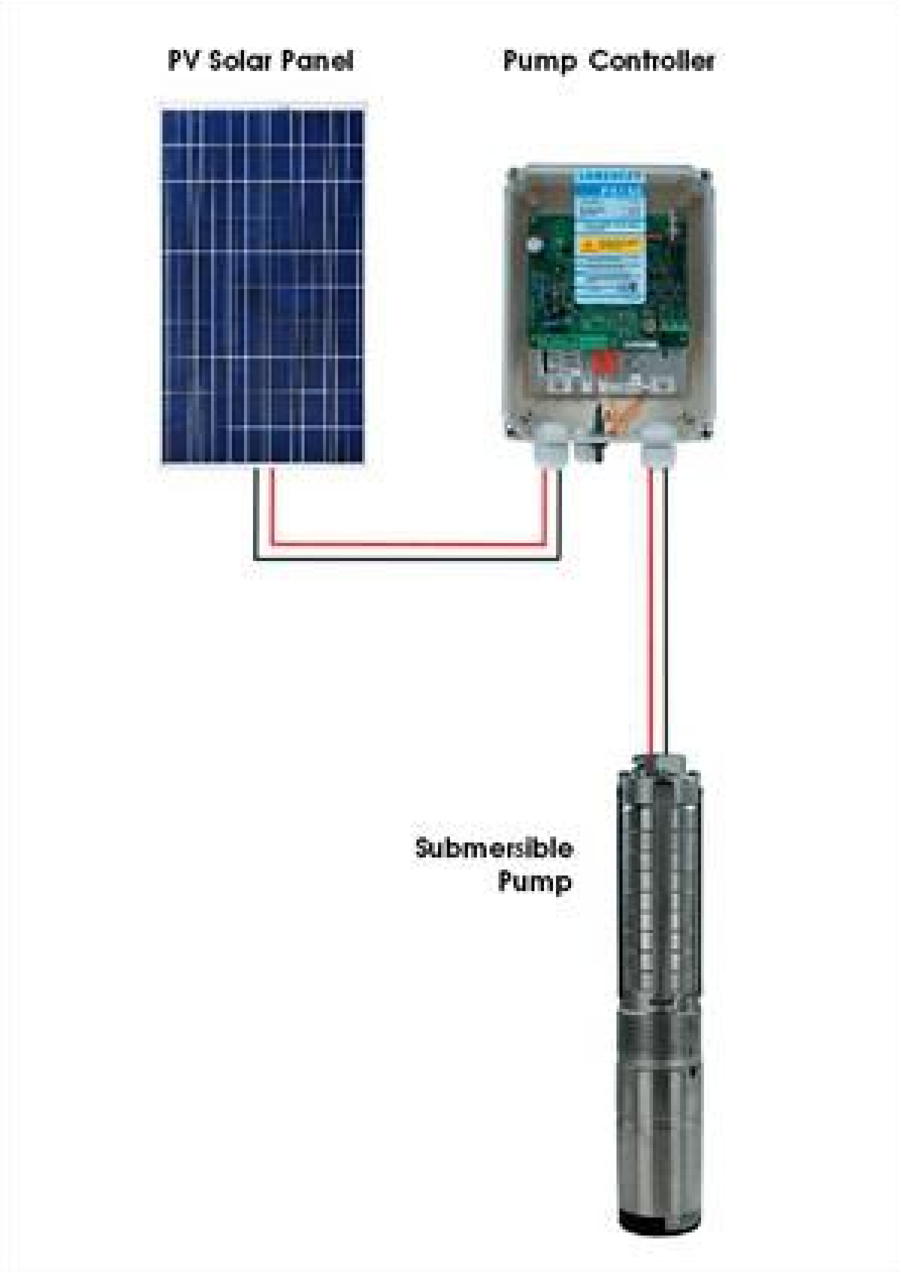


Figure 10-7: Solar borehole submersible pump components (Wind & Sun Ltd n.d.)

10.4.2. Alternating current (AC) pumps

Most submersible pumps are supplied with AC motors. For small pumps these can be single phase 220V motors and for larger pumps they are normally 3 phase 400 volt motors. AC submersible borehole pumps with a reliable electricity supply are well suited to automatic operation with little input required from an operator. The electrical control panel would typically include operation timer, no-flow switch, and pressure cut off switch, and can include electrical components like variable speed drives, soft starters, phase failure protection relays, overload and underload protection relays.

10.5. Operation

With an automatic electrical submersible pump, the operator must check the settings and correct operation of the pump control and pump protection systems. This would typically include the operation timer, no-flow switch, and pressure cut off switch, and can include electrical components like variable speed drives, soft starters, phase failure protection relays, overload and underload protection relays.

10.6. Maintenance

10.6.1. Preventative maintenance

10.6.1.1.1. On each visit to the pumphouse

- Check condition all electrical connections and wires
- Check that all three phases of power supply have power
- Visual check for dangerous electrical connections or wires
- Check nuts, bolts and screws (tighten if necessary)
- Check water level in borehole
- Record in logbook (hours run, flow meter, water pressure, water level)
- Start pump

- Check pipework for leaks
- Check that the water meter is turning, if not stop pump, investigate and repair the problem.
- Measure and record flow rate

10.6.1.1.2. Weekly

- Clean inside and outside of pump station

10.6.1.1.3. Every 4 months (or every 1000 hours of service)

- Check that the pressure cut out is operating
- Check that the no flow switch is working
- Inspect electrical connections, instrumentation, and pump protection relays and wiring
- Check the pump by measuring pressure, groundwater level and flow, and compare with the pump curve

10.6.1.1.4. Yearly (or every 3000 hours of service on the pump)

- Remove pump and rising main from well and inspect

10.6.2. Breakdown maintenance

Small centrifugal pumps are normally installed with high density polyethylene (HDPe) riser pipe and are relatively easily removed from the borehole by hand. Large submersible pumps are too heavy to lift by hand and are often installed on rigid PVC pipes and need mechanical lifting to remove from the borehole. It is always prudent to make sure it is not a problem with the above-ground electrical panel before deciding to pull out the pump.

Common causes of centrifugal pump failure include:

- Pump motor failure from pumping air or pumping against a closed valve
- Pump impellor damage from pumping abrasive water. This is

normally a result of sediment in the water from a poorly constructed borehole

- Corrosion
- Thrust bearing failure – caused by the pump operation to the "right side" of the pump curve when the pump is moving more water than it is designed to do
- Voltage surges and spikes
- Shaft damage due to non-functioning non-return valves

As with the positive displacement pump, the operator must check the settings and correct operation of the pump control and pump protection systems. This would typically include the operation timer, no-flow switch, and pressure cut of switch, and can include electrical components like variable speed drives, soft starters, overload and underload protection relays

The operator must regularly check the pipes and valves for leaks and verify that they are still operating correctly. Malfunctioning pressure relief valves, air valves, non-return valves and isolation valves could result in damage to the pumping system.

10.7. Trouble shooting

Regular recording of the following parameters allows the operator to identify when the pump performance is deteriorating and is an early warning of potential pump problems.

- Motor hour meter
- Power drawn for an electric motor
- Flow meter – volume of water pumped
- Flow rate measurement
- Water pressure
- Groundwater levels

If the pump stops working the records of these parameters are especially useful for identifying the trends and specifying the problem with the pump. The following procedure can be followed for site investigation of a non-functioning pump. If there is a pump controller installed and it has power, check the error message that is displayed with the controller manual and address (Table 10-2).

Table 10-2: Procedures for site investigation of non-functioning pump

Symptom	Verify	Action
Electrical pump will not switch on	Check the incoming power and verify that voltage is correct on all 3 phases	If no power, first verify that the account is not in arrears and then report the fault to electricity supply authority
	Check that the starter is receiving power and delivering power to the motor	Replace/repair starter
	Disconnect the motor and check that the resistance on each phase is to specification	If motor is faulty remove and get assessed by suitably qualified electrician
	Check for a lost phase	Diagnose cause of lost phase and address
Not above ground electrical problem	Remove pump from the borehole	Bench test the pump to verify if it is still able to pump the flow and head as per the pump curve

10.8. Exercises

10.8.1. Exercise: Pump selection

Sizing a replacement pump for an existing installation. The participants will be given the results of the hydrogeologist's report and details of the scheme and pumping main, as well as copies of a pump catalogue with pump curves. The participants will use the information to select a pump (60 mins).

10.8.2. Exercise: Schedule of O&M tasks

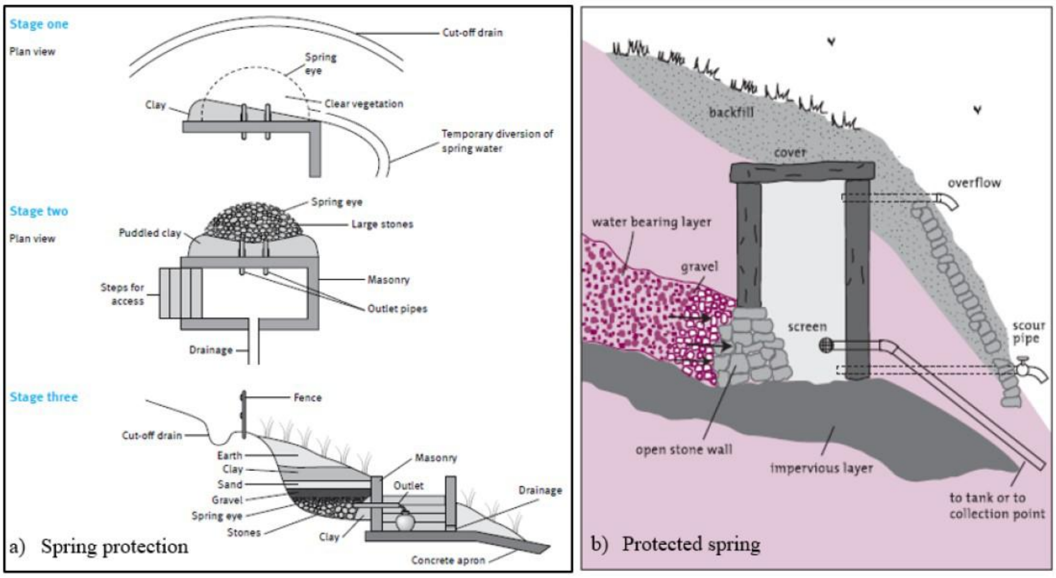
Develop a schedule of O&M tasks for the operator of a diesel-powered rotor stator borehole pump. Participants to work in groups and report back in plenary. Each group to raise questions/clarifications/additions to the other groups' presentations (30 mins).

11. OPERATION AND MAINTENANCE OF SPRING CHAMBERS

- To understand the siting and construction basics of spring boxes
- To appreciate the need for pollution and contamination prevention at springs
- To understand O&M issues related to springs

11.1. Introduction

Springs occur when groundwater naturally flows out of an aquifer (underground layer of water-bearing permeable rocks such gravel and sand). The water may emerge either in open as a spring, or invisibly as an outflow into a river, stream, lake or the sea (WHO 2000). Springs need to be protected if they are to be used as sources of water for human consumption. Figure 11-1 shows steps involved in spring protection, a protected spring, and a spring in use. Springs are usually managed at the local level, though the initial construction (spring box) could involve the organisation charged with the development and management of water resources.



a) Spring protection
b) Protected spring

Figure 11-1: a) Spring protection, b) protected spring, c) spring in use (WHO 2000, WaterAid n.d.)

Springs on elevated ground, like in mountains, can be tapped to supply water by gravity. However, the sustainability of supply is generally limited. Hydrogeological investigations can provide an estimate of the duration of supply. This information can also be readily available from the local communities.

Box 11-1: Costs for spring protection

Springs provide the cheapest sources of potable water, both in terms of construction and maintenance, if pumping is not involved.

11.2. System components

The main parts of a spring box system are:

- Spring box constructed from mortar and brick, stonework or concrete
- Water outlet usually of galvanised iron/steel (sometimes with wire gauze/screen)

– Overflow pipes to drain excess water (sometimes with wire gauze/screen)
– Scour pipe with a protected valve
– Heavy concrete cover

11.3. Operation

Springs come from aquifers (bodies of permeable rock that can contain and transmit groundwater). They are simply a place where the water from aquifers flows out of the ground naturally. Some springs are seasonal. To prevent contamination by infiltration from the surface, a ditch (known as the interceptor or cut-off drain) diverts surface water away from the spring box, and a fence keeps animals out of the spring area. Gravel and a large stone open wall are placed at the spring eye to prevent sediment flow, filter the water and reduce the flow velocity into the spring box, which acts as a storage unit. Water accumulates in the box with excess water flowing out through the overflow pipe. Water is collected through an outlet pipe. A scour pipe is used to clear the spring box of debris and sediments.

11.4. Preventive Maintenance

Preventive maintenance for springs is usually the responsibility of the caretaker and/or water point committee. The following preventive maintenance needs to be carried out.

11.4.1. Protection zone

– Condition of the fence should be good
– The diversion drainage above the spring should be intact
– No farming activities in the spring catchment

11.4.2. At the spring chamber

– Leakage at the chamber to be avoided
– Intactness of manhole cover to be maintained
– Blockage at the supply line - water comes through the reserve (overflow) pipe should avoided

- Ventilation should always be ensured
- The water quality and quantity should good (tasteless, not muddy or murky)

11.4.3. List of stock items

There are not too much sophisticated tools/items required for O&M of springs. Simple items are needed, and these include:

- Axe
- Shovel
- Pick
- Slasher

11.5. O&M activities for springs

Table 11-1: Main O&M Activities for springs

Actor	Role	Frequency	Skills Needed
Users	Report malfunctions, keep the spring site and catchment area clean, assist in major repairs through provision of bricks, sand, etc. Ensure that the gate of the fence is always closed	Weekly or sooner Daily	Nil
Caretaker	Keep the site clean, check for damage, repair fence and keep drains clean, perform small repairs, repair pipes and valves if installed Scour the spring Check for turbidity/water murkiness Check and record discharge volume Record major breakdowns and quality of water (taste wise)	Weekly or sooner Annually After each flood Weekly When occurred	Technical
Water committee	Organise bigger repairs, control the caretaker's work Collect fees/levies	When necessary Monthly	Basic
Mason	Repair masonry or concrete Rebuild structure (spring box)	When necessary When necessary	Technical

Actor	Role	Frequency	Skills Needed
Government agency	Check and record water quality Supervise mason, guide and motivate local organisation Wash and disinfect the spring e.g. with chlorine Attend to reported water quality issues	Quarterly When needed Annually When required	Highly technical

11.6. Trouble shooting and Remediation

Table 11-2: Troubleshooting of Springs

Problem	Possible cause	Possible remedy
Water is turbid	Flood water entered the spring, or walls could be collapsing	Seal areas around protective structure (spring box) Raise protective structure above ground level Repair walls if collapsing
Deterioration in water quality	Contamination through seepage of water into spring Foreign material could have been inserted into the spring	Scour the spring and disinfect e.g. with chlorine Seal seepage passages Replace wire mesh in exposed pipes
Reduced discharge	Drought/Low rainfall Walls could be collapsing Leaking valves where installed	 Rebuild spring box and disinfect after Replace valves
Foreign matter coming out	Wire gauze damage and children pushing foreign matter through spouts	Clean spring and replace wire gauze on spouts

11.7. Exercises

11.7.1. Exercise: Spring development

To understand what a spring is, how it can be developed and protected, the general O&M activities for springs, and the importance of O&M record keeping. Participants to work in breakaway groups and report in plenary. Each group to raise questions / clarifications / additions to the other groups' presentations. The groups will work on the following:

1. Draw a hypothetical village plan with a spring as a source of water
2. Outline how you would develop the spring
3. Indicate why it is important to protect the spring and from what should it be protected?
4. Outline measures you would put in place to protect spring
5. What are the O&M activities that are needed for the spring sustainability?
6. Should there be any record keeping about the spring and if so, what type of records should be maintained and what is the importance of the records?

12. OPERATION AND MAINTENANCE OF WATER TREATMENT, TRANSMISSION AND STORAGE SYSTEMS UP TO THE STANDPIPE

- Understand the components and function of the water supply scheme
- Understand the requirements of the scheme operation
- Understand the scheme maintenance requirements

12.1. Introduction

Apart from boreholes and wells equipped with handpumps, almost all groundwater supply schemes include infrastructure for the transmission (pipelines), storage (reservoirs), and distribution of the abstracted water to the users (through reticulation pipelines to standpipes). Schemes may also include facilities for water treatment and disinfection. Maintaining a piped water supply scheme so that it provides a continuous service is key for ensuring the support of the users and to minimise the potential for vandalism (WSUP 2014). When water schemes provide an intermittent supply the users end up removing valves and opening pipes to gain access to water.

12.2. Pipelines

Corrosion resistance is a key consideration for underground pipelines and pipeline materials should be chosen to reduce the amount of O&M required. Corrosion on the inside of the pipeline can be caused by corrosive water and corrosion to the outside of the pipe can result from corrosive soils. High density polyethylene (HDPe) and polyvinyl chloride (uPVC) are both corrosion resistant pipeline materials and are commonly used. The figure below describes the types of pipes and their use. Where it is not possible to bury the pipeline, galvanised mild steel (GMS) pipelines mounted on concrete pedestals should be used. Where GMS pipelines are used in contact with soil, they should be protected with a non-hardening flexible petrolatum tape wrapping like Denso tape.

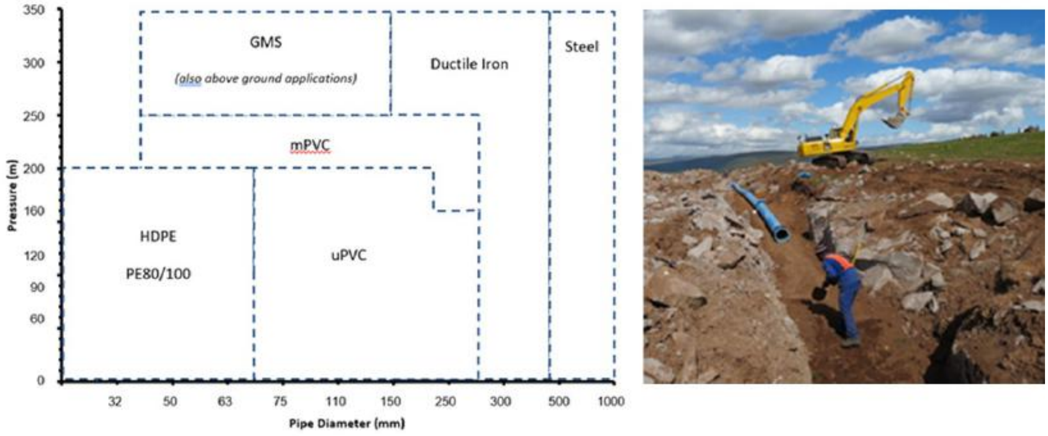


Figure 12-1: Pipe materials and applicable use and laying a 350mm diameter Ductile Iron Pipeline

The valves that are normally found on pipelines include:

- **Isolation valves**. Types of isolation valves commonly used include gate valves, resilient seal gate valves (RSVs), ball valves, butterfly valves, and globe valves. Their function is to close and shut off the flow in a pipeline
- **Non-return valves** (NRVs). Also referred to as check valves, the purpose of the NRV is to allow flow in one direction only. They are used on pumping mains so that the pumped water does not flow back down the pipe when the pump is switched off.
- **Pressure relief valves** (PRVs) allow water to be "blown off" or spilt when the pressure in the pipeline gets higher than the maximum allowable pressure. PRVs are normally installed at the wellhead of mechanically driven rotor stator pumps
- **Air valves** are used to allow air to be removed from the pipeline when it is filling and to allow air into the pipeline when it is draining. Air valves are located at high points on a pipeline and after isolation valves and other places where a vacuum could form when the pipeline is draining.
- **Float control valves** are used at reservoirs to stop the inflow when the reservoir is full.
- **Scour valves** (also called a washout or drains) are tees on a pipeline with a gate valve and are used to drain water out of the pipeline for cleaning or maintenance. Reservoirs are also equipped with a scour to draining the reservoir during cleaning.

Water meters are used for recording the volume of flow. Water meters are used to measure the flow from a source or reservoir or to a water supply zone (referred to as bulk water meters), and are also used to record the flow to the water utility's customers for the purpose of billing. Water meters are needed at key points within a water supply system to do a water balance and to calculate the unaccounted-for water or water losses in the system.

12.3. Reservoirs

The most common material used for reservoirs is reinforced concrete and a properly constructed reservoir will require little O&M besides cleaning from time to time. Plastic tanks are more easily damaged and not commonly used for community or municipal supplies but are routinely used for private schemes. Pressed steel tanks are most used where a small volume, elevated reservoir is required. Large elevated municipal reservoirs are normally constructed from reinforced concrete.

Figure 12-2: Concrete reservoirs

A properly constructed and installed reservoir requires little maintenance. The most common problem experienced at reservoirs is the failure of float control valves on the inlet that results in the reservoir overflowing and wasting water.

12.4. Standpipes

The standpipe is the main point of contact between the water supply scheme and the users and as a result is often the component of the scheme that requires the most O&M. Drainage of water away from standpipes is a common problem that needs to be addressed when designing schemes and during O&M.

Figure 12-3: Standpipes with inadequate drainage

12.5. Water Treatment

Sampling and testing of chemical groundwater quality must be done during the groundwater exploration phase for two purposes. The water quality must be assessed to verify that it is suitable for potable water consumption and if any treatment is required. Testing is also needed to check if the water is corrosive which will inform what materials should be used for the pump and pipework for the raw water pumping infrastructure. The Langelier Stability Index (LSI) is calculated from the pH, the total dissolved solids (TDS), and the Calcium and Alkalinity concentrations as $CaCO_3$. Acidic waters with low Calcium Carbonate tend to be corrosive. If the water has an LSI of above 0.5, the water will tend to form scale and if the LSI is less than negative (-0.5) the water will be corrosive.

Sampling and testing of both the chemical quality and microbiological indicators are needed to determine if the groundwater needs to be treated prior to being used as a potable water source or if the untreated water would be a health risk if supplied untreated. While groundwater is less susceptible than surface water to contamination from human activities and the natural environment, the water chemistry is influenced by the geology of the aquifer and this can result in some chemical constituents exceeding the safe drinking limits.

The conventional water treatment process used to treat surface water in most municipal water treatment works describes the treatment train of flocculation, sedimentation, filtration, and disinfection. Groundwater mostly does not have the suspended and colloidal matter that requires removal by flocculation, sedimentation, and filtration, and only needs to be disinfected to kill micro-organisms like bacteria and viruses. Chlorination, ultraviolet light and ozone are the methods that can be used for disinfection, with chlorination being the most commonly used method. Chlorination has the added advantage of providing a residual that ensures that the water remains disinfected in the distribution system.

There are three types of chlorine used for disinfection:

- Sodium hypochlorite (NaOCl) also known as household bleach
- Calcium hypochlorite ($Ca(OCl)_2$)
- Chlorine gas (Cl_2)

The effectiveness of chlorination is governed by 2 key aspects, the concentration and the contact time. Sufficient chlorine must be added to give a free chlorine residual of not less than 0,2 mg/ℓ after 20 minutes contact time. To achieve the contact time and adequate mixing it is advisable to chlorinate before the water is supplied into the main storage reservoir.

Turbidity reduces the effectiveness of chlorination and if the water has a turbidity of more than 1NTU it should be filtered before chlorination.

Another factor that effects chlorination is sunlight. Sunlight breaks down chlorine, reducing its disinfection power, and chlorine tanks should always be covered.

The ion concentrations that are typically found in groundwater are not all treatable with the conventional treatment train and many require additional processes as tabulated in Table 12-1.

Table 12-1: Commonly used municipal treatment processes and associated relative cost and complexity (Brikké and Bredero 2003)

Determinand	Units	Most Common Municipal Treatment Processes	Treatment type	Treatment Cost
Electrical Conductivity	mS/m	Reverse Osmosis or ion exchange or electrodialysis	Advanced	High cost
Fluoride as F	mg/l	Activated Alumina	Additional to Conventional	Medium cost

Determinand	Units	Most Common Municipal Treatment Processes	Treatment type	Treatment Cost
Nitrate and nitrite as N	mg/l	Reverse Osmosis or ion exchange or electrodialysis	Advanced	High cost
Sodium as Na	mg/l	Reverse Osmosis or ion exchange or electrodialysis	Advanced	High cost
Sulphate as SO_4	mg/l	Precipitation with salts of Calcium, settlement and filtration or Reverse Osmosis or ion exchange or electrodialysis	Additional to Conventional or Advanced	Medium cost OR high cost
Arsenic as As	mg/l	Flocculation, settlement and filtration	Conventional	Medium cost
Calcium as Ca	mg/l	Chemical precipitation and sedimentation	Additional to Conventional	Medium cost
Iron as Fe	mg/l	Oxidation, precipitation and filtration	Additional to Conventional	Medium cost
Magnesium as Mg	mg/l	Lime softening & re-carbonisation	Additional to Conventional	Medium cost

Advanced treatment describes the processes used to desalinate water, normally reverse osmosis but it could be ion exchange or electrodialysis. Water treatment is both complex and specific and the design of appropriate treatment processes should always be done with specialist knowledge.

Conventional and advanced treatment processes require skilled operators, but a greater level of operator expertise is required for additional processes involving chemical dosing and for advanced treatment.

Always consider blending groundwater with water of different qualities to reduce concentration of chemical constituents before considering treatment. When one has multiple sources, it is almost always beneficial to blend the different waters and dilute the concentrations of substances that would normally require advanced treatment. This is especially true when one has a combination of ground and surface water sources but is also true for multiple groundwater sources. One may be able to reduce the concentration of substances and avoid costly treatment.

Aerate groundwater where you can. Groundwater of poor quality has normally been underground for some time in an environment that is starved of oxygen. Spraying groundwater when pumping from boreholes into primary storage allows for aeration of the water which can precipitate some substances like iron and manganese and makes the water chemistry more stable.

12.6. O&M requirements for rural piped water systems

Piped rural water systems will typically have a locally based operator reporting to either the water supply authority or a community structure or both. Local operators are the key to keeping the water flowing but often lack the resources and support needed to do their jobs effectively (Danert and Flowers 2012).

Operational tasks for pipelines, reservoirs, and standpipes includes:

- Fortnightly
    - at the reservoir check that:
        - there are no leaks
        - the overflow is working
        - valves are open or closed (as required)
        - the inlet float control valve is working correctly
        - the flow meter is working
        - the flow into the reservoir is adequate (if not check and clean strainer or flow meter)
        - the roof of the reservoir is not damaged, and that the manhole cover is in place.
        - If chlorinated, is the chlorine content of the water within the specified limits
    - pipelines:
        - walk the pipeline routes and check for leaks
        - take meter readings at taps (if metered)
        - check that taps are working (unblock strainers and meters as required)
        - attend to dripping or leaking taps
        - attend to minor damage on taps
        - clean around tap attend to drainage
        - check that all valves are correctly set
        - attend to any leaking valves

- Yearly
  - drain reservoir, clean and inspect
  - repair any damage to reservoir
  - check and repair all valves
  - check and reinstate all markings on reservoirs
  - check air release valves
  - open wash out valves and scour pipelines
- When required
  - open and close all valves and check working correctly every 2 months
  - repair pipeline leaks
  - repair erosion on pipelines, at reservoirs and standpipes

Figure 12-4: A robust standpipe with drainage soakaway

12.7. O&M requirements for storage tanks

A properly constructed and installed reservoir requires little maintenance. The most common problem experienced at reservoirs is the failure of float control valves on the inlet that results in the reservoir overflowing and wasting water. The responsibility of the operator must include:

- Checking the reservoir for overflow regularly and checking and servicing the float control valve
- Checking for leaks
- Checking the correct operation of a water level indicator (if installed)
- Valves need to be regularly checked and exercised. Valves need to be opened and closed once every couple of months to prevent them from seizing. Faulty valves must be serviced, repaired or replaced.
- Recording bulk water meter readings (if equipped with a meter)
- Once a year the reservoir must be drained and cleaned.
- For elevated steel reservoirs the structure and the reservoir body must be checked for corrosion and loose bolts. If the reservoir has cathodic protection installed, maintenance of the cathodic protection system must be performed by a suitable qualified technician.

12.8. O&M requirements for water treatment

Water treatment processes are made up of physical and chemical processes that must be operated by trained operators according to the design specifications of the plant. Detailed O&M manuals are required for a treatment plant that are specific to the water quality and processes for that plant.

- The operators work must be guided by the detailed O&M manual describing in detail the following:
- The procedure for correct operation
- Calibration for chemical dosing based on water quality and volumes
- The schedule of regular maintenance that is required, when filters must be backwashed, valves exercised, pump flow rates tested, etc.
- The requirements of monitoring and recording of water quality tests of both the raw and the treated water, flow readings, hours of operation, chemical supplies and rate of consumption
- Major servicing intervals and requirements
- The procedure for ordering chemicals and spares
- Safety procedures including chemical handling procedures and protective equipment requirements

Processes like disinfection with chlorine require a high level of monitoring, control, and supervision to ensure that the water is adequately disinfected before being supplied to consumers and adjusted when the quality of source water varies.

12.9. Exercises

12.9.1. Exercise: List scheme operational tasks

Develop a schedule of O&M tasks for a groundwater scheme with which the participant is familiar. List the components of the scheme and for each component, identify the person responsible, and the frequency and the resources needed. Make a list of the information to be recorded and the frequency of when it must be recorded and reported on.

13. OPERATION AND MAINTENANCE OF GROUNDWATER MONITORING INFRASTRUCTURE

- Understand the importance of groundwater monitoring
- Describe the of monitoring infrastructure
- Understand the groundwater monitoring infrastructure O&M tasks

13.1. Introduction

Groundwater monitoring and groundwater data acquisition are pre-requisites for any effective management of groundwater resources, in terms of both the groundwater quality and the availability of the groundwater resource itself (AGW-Net *et al* 2015). Data such as groundwater levels (Figure 13-1) and water quality must be collected to detect potential changes or trends in groundwater flow and water quality. Monitoring of groundwater abstraction volumes is necessary. Constant groundwater monitoring provides the necessary data input for the decision-making process concerning spatial planning, development and management of groundwater resources. The monitoring data will also provide an input into climate change adaptation. Groundwater monitoring is achieved through the establishment of a groundwater monitoring network and these are expensive for most developing countries to set up. However, a groundwater monitoring network system could initially be developed from existing boreholes, which eliminates the costs of constructing new boreholes. The monitoring network essentially comprises a series of observation wells coupled with a selection of abstraction wells, with the aim of:

- Detecting changes in groundwater storage, flow and quality
- Assessing specific risks to the aquifer
- Assessing aquifer recharge and discharge
- Assessing the interaction between groundwater and surface water (e.g. in rivers and dams)
- Assessing the potability of groundwater
- Assessing salty water intrusion for coastal aquifers and salty water upconing in deep aquifers
- Determining groundwater dynamics (including flow direction)

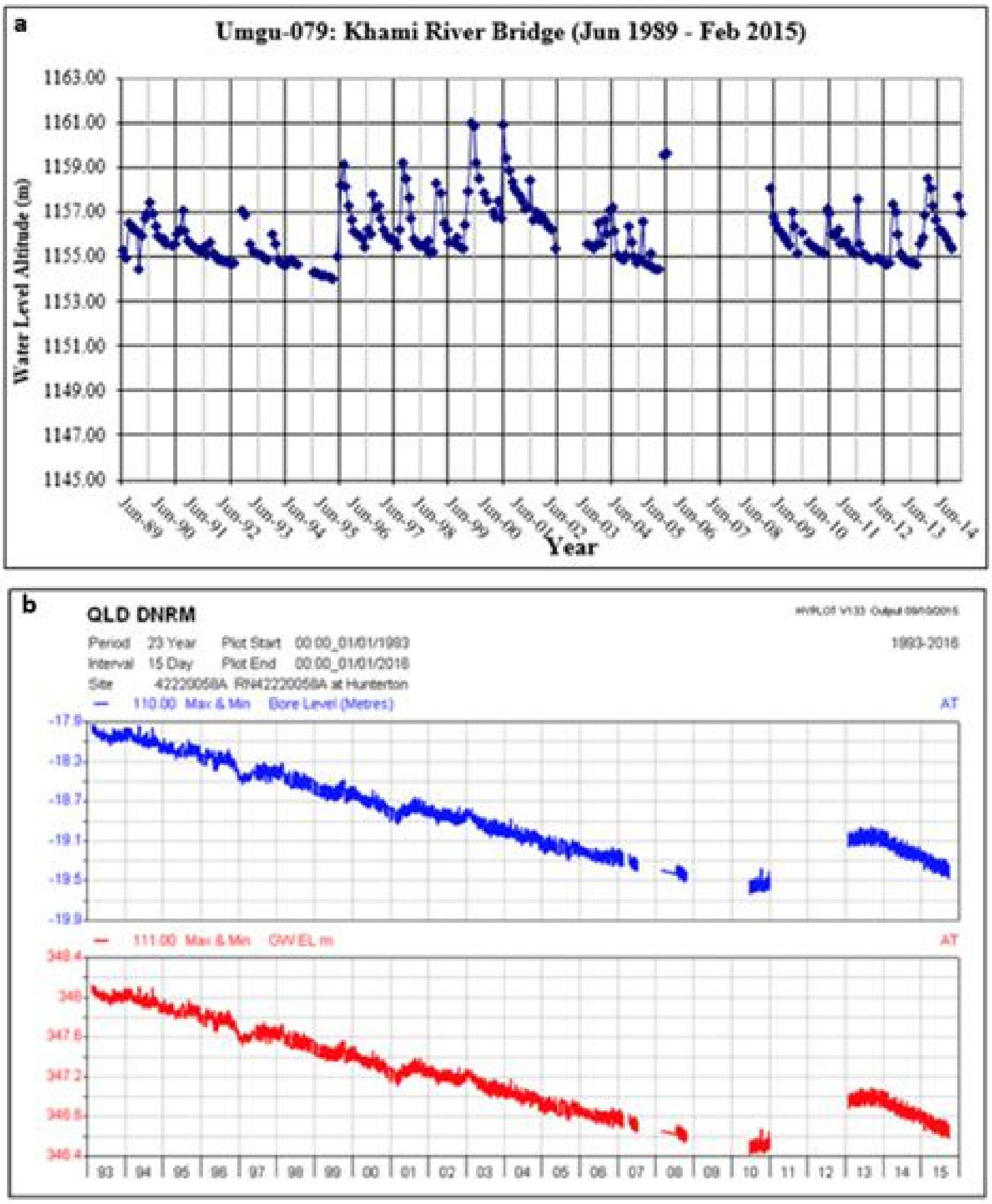


Figure 13-1: a) Groundwater level fluctuation hydrograph[15]; and b) groundwater level decline (Mallants et al 2016)

Monitoring is therefore a fundamental component of aquifer management and provides the necessary information for management decisions to protect the groundwater resource from excessive abstraction and from pollution. Permanent negative impacts associated with over-pumping and pollution can be avoided by a

[15] Courtesy: Sam Sunguro

well-designed and managed monitoring system that provides timely information on aquifer responses to pumping or contaminant loading (CapNet *et al* 2010).

Equipment for groundwater monitoring comprises monitoring boreholes, groundwater level monitoring, groundwater quality, and volume measuring equipment.

13.2. Groundwater monitoring

Groundwater monitoring is the scientifically designed, continuous measurement of the groundwater situation with regards to groundwater levels, groundwater abstraction volumes and groundwater quality. IGRAC (2006) define groundwater monitoring 'as the scientifically-designed, continuing measurement and observation of the groundwater situation'. Groundwater systems are dynamic and adjust continually to short-term and long-term changes in climate, groundwater withdrawal, and land use. Monitoring should also include the analysis, interpretation and reporting of the data and the reporting procedures. Figure 13-2 represents the monitoring cycle. Groundwater monitoring might be constrained by legal and institutional frameworks and funding.

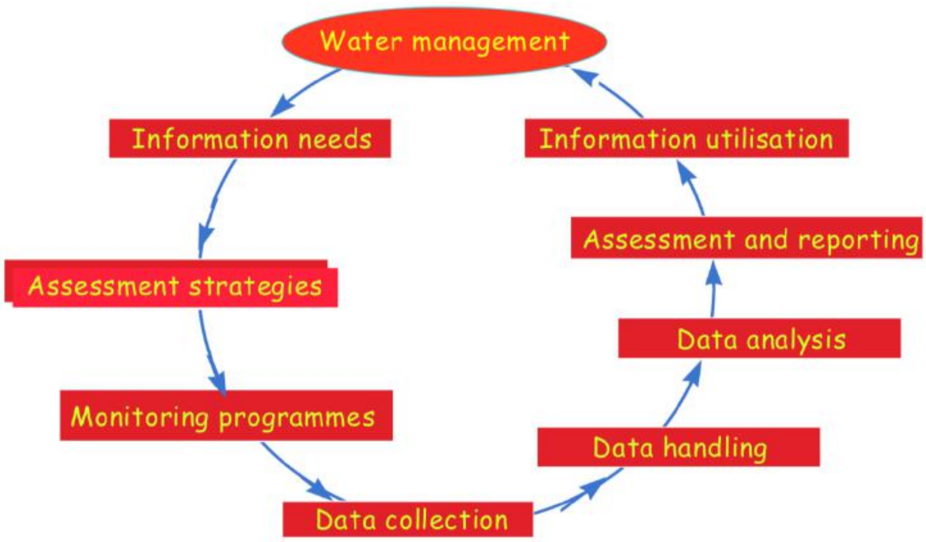


Figure 13-2: The monitoring cycle (UN/ECE 2000)

13.2.1. Defining groundwater monitoring objectives

Groundwater data are required in the investigation/assessment of the actual groundwater situation, planning groundwater development and in observing the effects of management measures. In order to be effective, the groundwater monitoring programme needs to be adjusted to the data needs of data-users. Users may be governmental institutions, universities or private companies with tasks in the groundwater sector or related areas (UN/ECE 2000). Groundwater monitoring objectives vary widely, but as described above have the general aim of:

- Detecting changes in groundwater storage, flow and quality
- Assessing specific risks to the aquifer
- Assessing aquifer recharge and discharge
- Assessing the interaction between groundwater and surface water (e.g. in rivers and dams)
- Assessing the potability of groundwater
- Assessing salty water intrusion for coastal aquifers and salty water upconing in deep aquifers
- Determining groundwater dynamics (including flow direction)

Table 13-1 gives examples of groundwater monitoring objectives in relation to the need.

Table 13-1: Examples of groundwater monitoring objectives (UN/ECE 2000)

Related to groundwater status and development: – Provide groundwater data for (sustainable) development of the groundwater resources – Provide data for determining the best locations for groundwater abstraction – Provide periodical information on the actual status of groundwater for management or for publication Related to protection of groundwater systems and the environment: – Provide data for protection of groundwater systems from over-exploitation – Provide data for protection of nature conservation areas from unacceptably declining groundwater tables – Provide data for control of saline water intrusion or up-coning in aquifers – Provide data for control of land subsidence caused by groundwater abstraction – Provide data for protection of aquifers from contamination by diffuse sources of pollution

13.2.2. Monitoring objectives and type of data requirements

In order to meet the management objectives shown in Table 13-2, various types of sources of groundwater data are needed. Table 13-2 shows examples of the relative importance of the data sources for the different management objectives. The importance is depicted in the figure below by (x) for desirable data and (xx) for necessary data (IGRAC 2006).

Table 13-2: Example of data needs from different data sources for specified objectives (IGRAC 2006)

		Groundwater Observation Wells			Groundwater Pumping wells			Springs			Surface water Observation points		
	Monitoring objectives	*Levels*	*Discharge*	*quality*	*Level*	*Discharge*	*quality*	Level	Discharge	Quality	Level	Base flow	quality
	Groundwater development												
1	GW system characterisation	xx	n.a		x			x			x		
2	GW potential for development (quantity and quality)	xx	n.a	xx		xx	xx		xx	xx		xx	xx
3	Best location for well fields	xx		xx			xx			x			(x)
	Control and protection												
4	Trends over exploitation	xx	n.a		x	xx			xx			xx	
5	Nature conservation	xx	n.a			xx		x	xx			xx	
6	Saline water intrusion	x	n.a	Xx *							x	x	(x)
7	Land subsidence	x	n.a			xx							
8	Contamination of aquifers		n.a	xx			xx			xx			xx

x desirable data, xx necessary data, xx* mainly chloride, n.a not applicable

13.2.3. Design of monitoring programme components (set-up, parameters, frequency)

The different components of a groundwater monitoring programme follow from the data needs related to groundwater development, management and protection in the aquifer of interest. Several objectives may have to be served at the same time. The frequency of measurements/monitoring is one of the most important design considerations and as with network density, it must consider the objectives of the monitoring program and the budgetary constraints.

Groundwater level monitoring can either be periodic or continuous. Periodic measurements could be on a weekly, monthly, seasonal, semi-annual, or annual frequency basis, and monthly monitoring is the most commonly used frequency. This level of monitoring is often adequate for deep aquifers with slow recharge rates and fewer withdrawals and is useful for potentiometric surface mapping. Continuous groundwater level monitoring, on the other hand, is beneficial in shallow unconfined aquifers with rapid recharge rates and significant withdrawals. The frequency of water quality monitoring is dependent on the purpose. Higher monitoring frequencies are associated with hazardous groundwater contamination whereas low frequencies (biannually, annually, etc.) provide information on the evolution of groundwater chemistry. Water quality is often monitored at stations where water quantity is also measured. Groundwater abstraction volumes should be measured continuously. Table 13-3 shows examples of monitoring duration as a function of the monitoring objective.

Table 13-3: Monitoring duration as a function of the intended monitoring objective (Cunningham and Schalk 2011)

Intended use of water level data	Typical length of data collection effort or hydrologic record required			
	Days/ Week	Months	Years	Decade
To determine the hydraulic properties of aquifers (aquifer tests)	x			
Mapping the water table or potentiometric surface	x			
Monitoring short-term changes in groundwater recharge and storage	x	x	x	
Monitoring long-term changes in groundwater recharge and storage			x	x
Monitoring the effects of climate variability			x	x
Monitoring regional effects of groundwater development			x	x
Statistical analysis of water level trends			x	x
Monitoring objects in groundwater flow directions	x	x	x	x
Monitoring groundwater and surface water interaction	x	x	x	x
Groundwater resource assessment			x	x

Intended use of water level data	Typical length of data collection effort or hydrologic record required			
Numerical (computer) modelling of groundwater flow or contaminant transport	x	x	x	x

13.2.4. Network Design

An effective groundwater monitoring programme must be based on having clear monitoring objectives and a good conceptual model of the hydrogeology. A suite of observation wells coupled with a selection of abstraction wells normally comprises a monitoring network, which should be designed to provide the required access to the groundwater resource. The density of monitoring sites and instruments, observation wells and piezometers chosen for an observation well network will provide data representative of various topographic, geologic, climatic and land-use environments. Decisions about the areal distribution and depth of completion of piezometers should also include considerations about the physical boundaries and geologic complexity of aquifers under study. Water level monitoring programs for complex, multilayer aquifer systems may require measurements in nested piezometers (water level measuring devices) completed at multiple depths in different geologic units (Figure 13-3). Piezometer nests are more cost effective than observation well clusters but should only be used if proper sealing can be achieved to prevent vertical flow between their screens (Tuinhof *et al* 2006). If one of the purposes of a network is to monitor ambient groundwater conditions or the effects of natural, climate-induced hydrologic stresses, the observation network will require dedicated piezometers that are unaffected by pumping, irrigation and land uses that affect groundwater recharge.

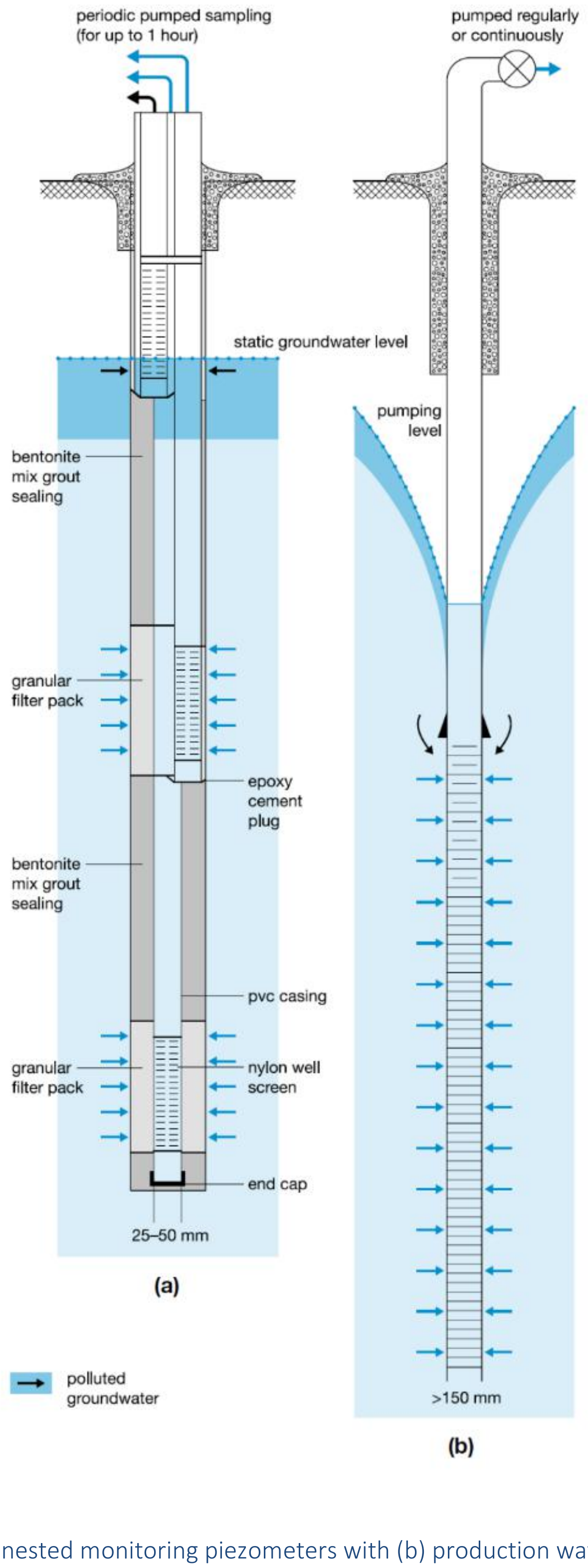


Figure 13-3: (a) nested monitoring piezometers with (b) production water well for comparison (Tuinhof *et al* 2006)

The spatial density of groundwater monitoring networks can be classified into baseline, management and project types(Borden and Roy 2015). Baseline networks extend over entire aquifers with observation sites representing typical hydrogeological characteristics in order to estimate the groundwater resource availability. The groundwater monitoring exercise is long term. Management networks supplement the baseline networks, and the monitoring well density is greater to represent diverse hydrogeological units. The monitoring in this network should be continued for longer periods with a high frequency of monitoring. Project networks are for studying localised issues. The monitoring stations need to be operated for a more limited period, ideally occurring before, during and after the project or study. Typical problem areas requiring project networks are for mining activities, industrial / commercial contamination, monitoring the freshwater/saltwater interface in coastal areas and evaluation of proposed abstraction schemes. The GW Mate literature (Tuinhof *et al* 2006) has a slightly different approach to classifying monitoring networks. They classify monitoring networks into three main (but not mutually exclusive) systems (Table 13-4). **Primary Systems** are specifically designed and operated to detect general changes in groundwater flow and trends in groundwater quality, and bridge gaps in scientific understanding of the groundwater resource base (reference monitoring), **Secondary Systems** for protection against potential impacts (protection monitoring) and **Tertiary Systems** for early warning of possible negative impacts on groundwater (pollution containment).

Table 13-4: Classification of groundwater monitoring systems by function (Tuinhof et al 2006)

System	Basic function	Well locations
Primary (Reference Monitoring)	Evaluation of general behaviour: Trends resulting from land -use change and climatic variation Processes such as recharges, flow and diffuse contamination	In uniform areas with respect to hydrogeology and land use
Secondary (Protection Monitoring)	Protection against potential impacts of following: Strategic groundwater resource Wellfields/springheads for public water supply Urban infrastructure from land subsidence Archaeological sites against rising water table Groundwater dependant ecosystems	Around areas/facilities/features requiring protection

System	Basic function	Well locations
Tertiary (Pollution Containment)	Early warning of groundwater impacts from: Intensive agricultural land use Industrial sites Solid waste landfills	Immediately down-and up-hydraulic gradient from hazard

13.3. Monitoring wells/stations/points

Groundwater characterisation is observed as water level in wells, discharge from springs and abstraction/recharge from pumping wells. Monitoring wells are dedicated monitoring stations, sited and designed to detect potential changes in groundwater flow and quality. Their design parameters include selection of depth for the intake screen, frequency of measurement and selection of quality parameters. To overcome the widespread presence of depth variation in hydraulic head and/or groundwater quality, nested piezometers or well clusters can be used (Figure 13-3). Monitoring can also be can also be conducted in shallow wells, abandoned deeper tube wells and pumping wells if they are not continuously used or when they have been made to 'idle' for sufficiently long periods to allow for attainment of quasi natural conditions. In most cases, it is difficult to 'idle' pumping wells for prolonged periods without upsetting the designed supply of water to the intended beneficiaries.

13.4. Groundwater level monitoring infrastructure

Improper monitoring well-design and construction techniques during monitoring well installation may lead to collection of erroneous data. Sosebee *et al* (1983) determined that the solvent used to weld PVC casing together could leach significant amounts of tetrahydrofuran, methylethyl ketone, methylbutyl ketone, and other synthetic organic chemicals into water that comes in contact with the solvent-welded casing joint, resulting in false determinations of the presence of certain chemical constituents in water samples taken from PVC wells. Monitoring well installation procedures could also have a significant impact on the integrity of groundwater samples. Brobst and Buszka (1986) found that organic drilling fluids and bentonite drilling muds used in mud rotary drilling could influence the chemical oxygen demand of ground water adjacent to the wellbore in a rotary drilled well, thereby affecting the quality of a water sample taken from such a well. Vertical seepage of leachate along well casing can also produce non-representative samples. Monitoring wells are frequently sealed with neat cement grout, bentonite, or a cement-bentonite mixture. The correct choice of a grout and the proper emplacement method to ensure a seal are critical to assure groundwater sample integrity and prevent cross contamination of aquifers.

Equipment for groundwater monitoring comprises of monitoring boreholes, groundwater level monitoring, groundwater quality and volume measuring equipment.

13.4.1. Groundwater level fluctuation monitoring instrumentation

There are several instruments that can be used to monitor groundwater levels. The groundwater levels can be monitored/recorded by using different types of equipment.

13.4.2. Graduated steel surveyor's tape

A graduated steel surveyor's tape with a weight on the end to ensure it hangs vertically in the well has been used to measure groundwater levels in boreholes for over a century (Hopkins and Anderson 2016). A steel tape does not stretch like some of the other instruments and hence does not introduce significant variability in the measurements. They are intuitive to use and inexpensive but require manual operation and thus are only acceptable for periodic monitoring. Maintain the tape in good working condition by periodically checking the tape for rust, breaks, kinks, and possible stretch due to the suspended weight of the tape and the tape weight (Cunningham and Schalk 2011). The tape should be recalibrated annually and recorded in the calibration logbook (Cunningham and Schalk 2011).

13.4.3. Electronic tapes and sounders

Electronic measuring tapes or tape sounders (dipmeters) are made up of a pair of insulated wires which are separated and when the electrode gets in contact with water, the powered circuit is completed causing a light to show and/or a beeping sound, indicating contact with water and hence the depth to the water (Figure 13-4). These water level measuring instruments are widely used. Just like the graduated steel surveyor's tapes, they are intuitive to use and inexpensive but require field visits to carry out the monitoring exercise. Manual operation means that they are usually only acceptable for periodic monitoring. Confirmation of water level using water level tapes is usually performed during pressure transducer installation, to ensure the transducer is correctly monitoring water level elevations.

Figure 13-4: Electric dipper used to measure groundwater level[16]

The electronic tape calibration and maintenance includes (Cunningham and Schalk 2011):

– Before using an electric tape in the field, calibrate it against a steel reference tape. A reference tape is one that is maintained in the office only to calibrate other tapes.
  - Calibration of electric tape:
  - Check the distance from the probe's sensor to the nearest meter marker on the tape to ensure that this distance puts the sensor at the zero-meter point for

[16] Photo credit: Hans Beekman

the tape. If it does not, a correction must be applied to all depth-to water measurements.

  - Compare length marks on the electric tape with those on the steel reference tape while the tapes are laid out straight on level ground, or compare the electric tape with a known distance between fixed points on level ground
  - Compare water-level measurements made with the electric tape with those made with a calibrated steel tape in several wells that span the range of depths to water that is anticipated. measurements should agree to within +/– 0.6 cm. If measurements are not repeatable to this standard, then a correction factor based on a regression analysis should be developed and applied to measurements made with the electric tape

– Using a repaired/spliced tape: If the tape has been repaired by cutting off a section of tape that was defective and splicing the sensor to the remaining section of the tape, then the depth to water reading at the measuring point will not be correct. To obtain the correct depth to water, apply the following steps, which is similar to the procedure for using a steel tape and chalk. Using the water-level measurement field form to record these modifications:
  - Ensure that the splice is completely insulated from any moisture and that the electrical connection is complete
  - Subtract the length of the removed section of defective tape from the final depth reading, to obtain the true reading.

– Maintain the tape in good working condition by periodically checking the tape for breaks, kinks, and possible stretch

– Carry extra batteries, and check battery strength regularly

– The electric tape should be recalibrated annually or more frequently if it is used often or if the tape has been subjected to abnormal stress that may have caused it to stretch.

13.4.4. Air line

This air line (Cunningham and Schalk 2011) method is used when there is no provision to lower electronic tapes or sounders or when the cap cannot be easily removed. The method entails inserting a small diameter pipe or tube from the top of the well to a point say about 3 m below the expected water level. The tube is then connected to a pressure gauge and an air pump is used to pump air into the line until the water inside the line is displaced. The gauge reading indicates the length of submerged airline which can be converted into the water level by subtracting the submerged length from the total length of the air line.

13.4.5. Pressure transducers and automatic dataloggers

Pressure transducers and automatic dataloggers are ideal for long term or continuous monitoring of groundwater levels. Pressure transducers are submersible sensors that use some sort of silicon, stainless steel, or ceramic membrane, as a strain gauge to generate an electrical current. The electric current is calibrated to a pressure rating which can then be converted into a water level reading. Some pressure transducers use a vented cable to prevent atmospheric pressure changes from affecting the reading. If the pressure transducer does not have a vented cable, then their pressure reading must be compensated for by using external barometric pressure readings. Transducers can also be connected to remote telemetry systems which allow for the groundwater level readings to be transmitted to a remote station such the desktop at the main office. Telemetry systems can be expensive for developing countries, but they have a huge advantage in that they reduce field trips and thus associated expenses as well as the likelihood of non-field visits due to lack of logistical support. Pressure transducers are subject to drift, offset, and slippage of the suspension system. For this reason, the transducer readings should be checked against the water level in the borehole on every visit, and the transducer should be recalibrated periodically and at the completion of monitoring (Cunningham and Schalk 2011).

Activities after installation include (Cunningham and Schalk 2011):

- If the water-level measurement and transducer reading differ, raise the transducer in the borehole slightly and take a reading to confirm that the sensor is working. Check for possible cable kinks or slippage. Return transducer exactly to its original position
- Recalibrate the transducer if necessary
- If the water-level measurement differs from the instrumentation reading by an amount specified in the groundwater quality assurance procedures of the local office, record it on the inspection sheet and reset the instrumentation to reflect the proper depth
- to water.
- Use a multi-meter to check the charge on the battery, and the charging current supply to the battery
- Check connections to the data logger and tighten as necessary. Burnish contacts if corrosion is occurring. Check dessicant and replace if necessary
- Verify the logger channel and scan intervals, document any changes to the data logger program, and reactivate the data logger. Make sure the data logger is operating prior to departure

13.5. Groundwater quality monitoring

Groundwater can be contaminated or polluted by a variety of sources such as septic tanks (in urban areas), pesticides, spillage of hazardous chemicals, dissolution from the rocks of toxic chemical elements such as arsenic, etc. It is important to know the water quality so that the health of humans and animals is not put on risk, and this knowledge assists in planning and instituting remedial actions. Groundwater quality comprises the physical, chemical, and biological qualities of ground water. Temperature, turbidity, colour, taste, and odour make up the list of physical water quality parameters.

13.5.1. Field measurements

A representative sample of the groundwater from the aquifer is required for sampling. In order to achieve this, purging of the borehole before sampling is required to ensure that aquifer water is drawn instead of standing water in the borehole. An effective way of ensuring that the water is flowing from the aquifer is to monitor the temperature, electric conductivity (EC), pH and oxidation-reduction potential (ORP) of the emerging water as it is run to waste. Once the readings are constant for some minutes and the amount of water purged approaches the estimated volume of the well, the sample can be taken.

Sampling protocols need to be adhered to, to avoid contamination of the samples. Due care is needed during:

- Sample handling
- Sample preservation
- Sample transportation
- Sample storage
- Labelling and coding of samples

Field observations must be recorded.

13.5.2. Water quality sampling equipment

13.5.2.1. Water Quality Samplers

The objective of water quality sample collection is to obtain a small portion of water from the well that accurately represents the water in the aquifer. This is referred to as taking a 'representative sample' and is vitally important if the analysis that follows sampling and the conclusions, which are ultimately drawn from the data, are to have any validity. A suitable sampling device meets the following requirements:

- allows removal of stagnant water from the well (well purging) so that the sampled water represents the water in the aquifer
- avoids degassing of the sample and volatilisation of components in it
- prevents oxidation caused by contact with the atmosphere

– avoids contamination of the sample and the well

Sampling devices include bailers or depth samplers, gas driven devices that apply positive gas (air) pressure directly on the water which drives it from the borehole, back flow being prevented by check valves, and submersible pumps.

13.5.2.2. Field Kits

It is often necessary to measure a number of water quality parameters in situ (at the monitoring point) because these values can change before they can be analysed in a laboratory. Parameters that must be measured in situ include temperature, dissolved oxygen (DO), EC, pH, ORP potential, alkalinity and turbidity. Field kits are used in carrying out in situ measurements. Several commercially available field kits are available, and these include the Hach. Data such as pH, DO, conductivity, temperature, turbidity, and ORP can also be transmitted telemetrically using more sophisticated equipment.

Water samples may be collected in glass and PVC bottles of varying but appropriate sizes. Bottles that are to be used for collecting microbiological samples must be sterilised and thoroughly washed before use. After sampling, some water quality parameters undergo chemical or biochemical reactions in the sample bottle, causing the concentration to change from their original values. To prevent this alteration of parameter values, samples should be kept at a temperature below 4°C in transportation cooler boxes until they are analysed, and acidification of samples for cations as well as filtering may be recommended. The laboratory that will analyse the samples will advise on these procedures.

13.5.2.3. Sampling procedures and precautions for specific groups of groundwater quality parameters

As pointed out earlier, the process of well pumping and sample handling causes major sample modification through such processes as air entry, degassing and volatile losses (potentially introducing more significant errors than actual sample analysis), which need to be addressed through appropriate sampling procedures (Table 13-5).

Table 13-5: Summary of sampling procedures and precautions for specific groups of groundwater quality parameters (Tuinhof et al 2006)

Determinand group	Sampling procedure	Preferred materials	Storage time/temperature	Operational difficulty/cost
Major Ions Cl, SO_4, F, Na, K	0.45 pm filter only No acidification	any	7 days/4°C	minimal
Trace Metals Fe, Mn, As, Cu Zn, Pb, Cr, Cd, etc	Sealed 0.45 pm filter Acidify (pH<2) Avoid aeration through splashing/head space	plastic	150 days	moderate
N species NO_3, NH_4 (NO_2)	Sealed 0.45 pm filter	any	1 day/4 °C	moderate/low
Microbiological TC, FC, FS	sterile conditions unfiltered sample on-site analysis preferred	dark glass	6 hours/4 °C	moderate/low
Carbonate Equilibria PH, HCO_3, Ca, Mg	unfiltered well-sealed sample on-site analysis (pH, HCO_3) (Ca/Mg as base laboratory on acidified sample)	any	1 hour	moderate
Oxygen status pE(EH), DO, T	On site in measuring cell Avoid aeration Unfiltered	any	0.1 hour	high/moderate
Organics TOC, VOC, HC, CIHC, etc	Unfiltered sample Avoid volatilisation (direct absorption in cartridges preferred)	dark glass or teflon	1-7 days (indefinite for cartridges)	high

13.6. O&M tasks

Please note that equipment for monitoring groundwater levels, groundwater quality and abstraction volumes is specialised and will thus require the manufacturer's assistance for maintenance and repairs.

Monthly

- Check intactness of boreholes where monthly manual monitoring is carried out
- Remove batteries from equipment such as electric or sound dippers after taking measurements because some batteries may leak and damage the equipment.
- Ensure that electric/sound water level monitoring dippers do not rub directly against the casing as this may damage them. A plywood donut can prevent the damage. *Note: Always have a reference point for the measurements*

Yearly

- Check intactness of monitoring boreholes
- Re-calibrate monitoring equipment

Figure 13-5: Plywood donut[17]

13.7. Dealing with vandalism

Vandalism of groundwater infrastructure is a huge challenge.

13.7.1. Vandalism of boreholes

Monitoring boreholes often fall prey to vandalism, Figure 13-6.

[17] Courtesy: Steve Maxwell

Figure 13-6: Vandalised monitoring borehole[18]

13.7.1.1. Casing and special padlocks

A possible solution would be to fit a thick steel casing (8mm or 10mm) firmly grouted and installed around the borehole casing. The thick steel casing will have lid that can be locked in place with a unique 360-degree lock ring which has a very small clearance between the lid and housing to prevent vandalism through the insertion of prying tools. The housing is secured with concrete around the borehole casing. A high security lock barrel is used to protect the lid from unauthorised entry[19], Figure 13-7.

[18] Courtesy: Kevin Pietersen
[19] www.interlock.co.za

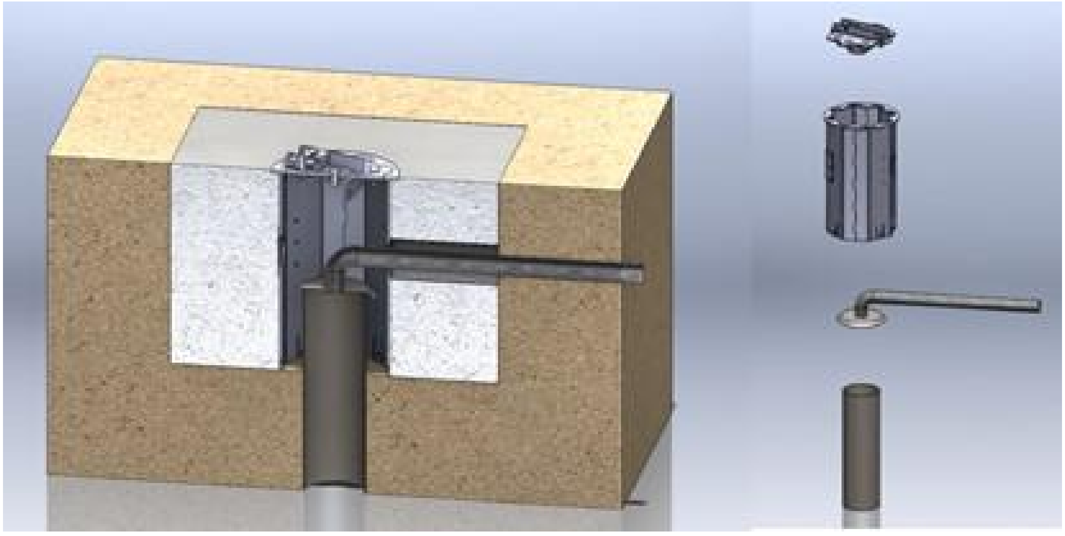


Figure 13-7: Vandal proof monitoring borehole locking system[20]

13.7.1.2. *Purpose made borehole lids*

Alternatively, a purpose made monitoring borehole lid can be used. The lid is secured around the borehole casing with a concrete plinth that is cast in situ. The method is used in Tanzania and they call the lid the BHX extreme protection monitoring borehole lid, Figure 13-8 and has an alternative pre-cast ballast version[21].

The BHX features a tamper proof lock mechanism and is manufactured from stainless steel.

[20] ibid
[21] ibid

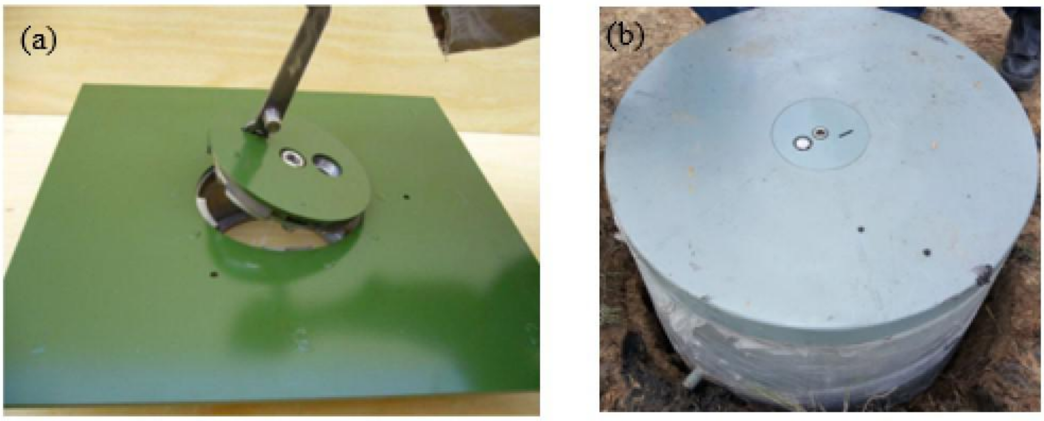


Figure 13-8: Vandal proof monitoring borehole lid (a) BHX cast-in, (b) BHX Concrete version[22]

Equipment for automatically recording of groundwater level fluctuations (pressure transducers and automatic dataloggers - ideal for long term or continuous monitoring of groundwater levels) and water quality can be mounted within the protected borehole. The data can be transferred to the office telemetrically.

13.7.1.3. Community engagement

It is vital to engage the community on the importance of such infrastructure because its vandalism is rarely by outsiders. Some elements of the community are generally responsible for infrastructure vandalism. Communities would want to know of the direct benefits accruing to them from the infrastructure and this must be eloquently communicated to them. Community leaders have respect within the communities and have to be enlisted so that they can advise their communities about the need to safeguard the monitoring infrastructure. School platforms can also be used to disseminate the information and knowledge.

[22] ibid

13.8. Exercises

13.8.1. Exercise: Groundwater monitoring and vandalism

1. What are the effects of not having groundwater monitoring data?
2. What are the main reasons for groundwater monitoring infrastructure vandalism and who are the chief culprits and how would you prevent the vandalism?
3. How would you engage communities to be involved in the protection of groundwater monitoring infrastructure?

14. MONITORING AND EVALUATION

- Describe the importance of monitoring and evaluation
- Understand the role of monitoring and evaluation in improving the O&M process
- Provide information on sustainability assessment tools

14.1. Introduction

Monitoring is a planned, systematic process of observation that closely follows a course of activities and compares what is happening with what is expected to happen (UNEP n.d.).

Evaluations can have a variety of purposes, and follow distinct methodologies (process, outcome, performance, etc) (UNEP n.d.).

Monitoring and evaluation (M&E) are important project management tools to assess the sustainability of groundwater infrastructure.

Box 14-1: Key Definitions (Bergeron, et. al. 2006 as cited by TANGO International Inc 2007)

Inputs: The range of resources (staff, financial resources, space, equipment, etc.) utilised to accomplish the project's objectives.
Processes: The specific activities (training, program design, planning, etc.) to which resources are allocated in pursuit of project objectives.
Outputs: Quantifiable products that result from the combination of inputs and processes.
Outcomes: Identifiable beneficiary and population-level changes resulting from the intervention.
Impacts: Long-term results observed at the beneficiary and population level and achieved due to better
practices, improved knowledge, changing attitudes, etc.
Performance: General indication of project productivity in relation to its stated objectives. Performance monitoring differs from impact evaluation in that it focuses on the degree to which activities are implemented efficiently rather than the extent to which they have led to expected change.
Beneficiaries: The portion of the population within the target area that receive direct benefits from the population

The six main components of a project M&E system (SOAS n.d.):

– Clear statements of measurable objectives for the project and its components
– A structured set of indicators covering inputs, process, outputs, outcomes, impact, and exogenous factors
– Data collection mechanisms capable of monitoring progress over time, including baselines and a means to compare progress and achievements against targets
– Where applicable building on baselines and data collection with an evaluation framework and methodology capable of establishing causation (i.e. capable of attributing observed change to given interventions or other factors)
– Clear mechanisms for reporting and use of M&E results in decision-making
– Sustainable organisational arrangements for data collection, management, analysis, and reporting

Indicators are measures of inputs, processes, outputs, outcomes and impacts (Table 14-1).

Table 14-1: Structured indicators for project M&E[23]

Impact indicators: measures of medium- or long-term physical, financial, institutional, social, environmental or other developmental change that the project is expected to contribute to.	**Leading (early outcome) indicators**: Advance measures of whether an expected change will occur for outcomes and impacts.	**Cross-cutting indicators**: measures of crosscutting concerns at all levels. For example: gender-disaggregated differences; regulatory compliance; legislative provision; capacity building.	**Exogenous or external indicators**: measures of necessary external conditions that support achievement at each level
Outcome indicators: measures of short-term change in performance, behaviour or status of			

[23] World Bank., n.d. Toolkit for Monitoring and Evaluation of Agricultural Water Management Projects. Washington DC, p. 305. http://documents.worldbank.org/curated/en/137921468140948443/pdf/447990WP0Box321BLIC10m1etoolkit1web.pdf.

resources for target beneficiaries and other affected groups.			
Output indicators: measures of the goods and services produced and delivered by the project.			
Process indicators: measures of the progress and completion of project activities within planned work schedules.			
Input indicators: measures of the resources used by the project.			

14.2. Importance of monitoring and evaluation

Below are the key reasons for carrying out monitoring and evaluation (Red Cross and Red Crescent Societies 2007):

- Water supply managers, technical staff, plant operators, and water practitioners including external support agencies need to know the extent to which installed groundwater infrastructure is functioning and meeting the objectives of installation, and leading to their desired outcomes
- M&E builds transparency and accountability in terms of use of project/programme resources
- Information generated through monitoring and evaluation provides management with a clear basis for decision making
- Future planning and programme development are improved when guided by lessons learned from experience

Box 14-2: Common pitfalls in developing an M&E system (GWP n.d.)

Not having a system: Defining a loose collection of disparate indicators with little or no relationship to each other, instead of a system in which indicators relate to each other and to the strategy goals, objectives and targets in a meaningful way

Bad fit between targets and indicators: Defining indicators with a weak relationship to the targets set for strategy activities, objectives and goals. In most cases, the problem is with the indicator; in others, the root of the problem is a poorly formulated target.

Building a system based on bad baseline data and/or unreliable indicators: Indicators need to provide a consistent measure of progress. This means that the starting point (the baseline data) is accurate and that the indicator provides an objectively verifiable result, i.e. two people applying the same indicator should get the same result

Not taking into account that impacts may differ according to location and to the gender and socio-economic status of intended beneficiaries

Poor feedback mechanisms: Developing a system in which indicator results do not feed back into the strategy process and into decision-making and planning processes. M&E systems are worthless if the information they provide is not acted upon

14.3. Role of monitoring and evaluation in improving the O&M process

14.3.1. Sustainability checks

The sustainability framework covers the following areas (ONEWASH Plus 2015):

- Institutional sustainability: policies, strategies and management arrangements
- Technical sustainability: mechanisms to ensure sustainable service provision including spare part supply, technical support etc.
- Financial sustainability: to ensure WASH services are financially viable over time
- Environmental sustainability: to ensure that WASH services do not have a negative impact on the environment
- Social sustainability: measures to ensure that everyone can benefit

Each factor is considered at three levels (ONEWASH Plus 2015):

- Service provision: day-to-day management, including operation and maintenance
- Service authority: local and regional level that sets the enabling environment
- National: the overall enabling environment

Table 14-2: Example of technical indicators, sub indicators and scores: Urban water at service provision level (ONEWASH Plus 2015)

<table>
<tr><th>Indicator</th><th colspan="2">Score 0</th><th>Score 25</th><th>Score 50 (BM)</th><th colspan="2">Score 75</th><th>Score 100</th></tr>
<tr><td>Availability of information on quality of infrastructure</td><td>No information available</td><td>Some information available</td><td>All system information available</td><td colspan="2">All system information available, inspected, but in poor condition</td><td colspan="2">All system information available, inspected, but in good condition</td></tr>
<tr><td>Non-revenue water (NRW)</td><td>NRW is not known</td><td>NRW>20%</td><td>NRW 10%<20%</td><td colspan="2">NRW 10%<20%, action developed for reducing on NRW</td><td colspan="2"><10%</td></tr>
<tr><td>Adequate supply of spare parts for minor maintenance (pipes, fittings etc.)</td><td>No spare parts available</td><td>Spare parts available, but takes more than 3 days</td><td>Spare parts available within 3 days</td><td colspan="2">Spare parts available within day</td><td colspan="2">Store available with adequate pipe and fittings for a month or there is PS which delivers within 24 hours</td></tr>
<tr><td>Effective maintenance system in place</td><td>Utility has no capacity to execute simple repairs</td><td>Utility has capacity to execute simple repairs, but does not do so within 24 hours</td><td>Utility can execute all repairs within 24 hours</td><td colspan="2">Utility executes all repairs within 24 hours and executes periodic maintenance</td><td colspan="2">Utility executes all repairs within 24 hours and executes monthly periodic maintenance</td></tr>
<tr><td>Water quality management and disinfection</td><td>No disinfection of reservoir(s)</td><td>Disinfection of reservoir(s) but less</td><td>Monthly disinfection of reservoir(s)</td><td colspan="2">Disinfection of reservoir(s) by qualified operator and intermittent</td><td colspan="2">Disinfection unit in place with qualified operator and periodic (at</td></tr>
</table>

Indicator	Score 0		Score 25	Score 50 (BM)	Score 75	Score 100
		other than monthly	by qualified operator	quality check (chemical, bacteriological, physical) on network	least monthly) check (chemical, bacteriological, physical) on network	

14.3.2. Response strategies

The sections below set out response strategies to improve M&E of groundwater infrastructure (OECD 2016):

1. **Develop a strategic vision for infrastructure:** Establish a national long-term strategic vision that addresses infrastructure service needs. Ideally the strategy should provide guidance on how the needs should be met, although there must be room for adjustment as more information is gathered. The strategy should be politically sanctioned, coordinated across levels of government, take stakeholder views into account and be based on clear assumptions.
2. **Manage threats to integrity**: Corruption entry points should be mapped at each stage of the public infrastructure project, and integrity and anticorruption mechanisms should be enhanced. A whole of government approach is essential to effectively address related integrity risks
3. **Choose how to deliver the infrastructure**: When choosing how to deliver an infrastructure service, i.e. delivery modality, government should balance the political, sectoral, economic, and strategic aspects. Legitimacy, affordability and value for money should guide this balancing.
4. **Ensure good regulatory design**: Good regulatory design and delivery are necessary to ensure sustainable and affordable infrastructure over the life of the asset.
5. **Integrate a consultation process**: The consultation process should be proportionate to the size of the project and take account of the overall public interest and the views of the relevant stakeholders. The process should be broad-based,

inspire dialogue and draw on public access to information and users' needs.

6. **Co-ordinate infrastructure policy across levels of government**: There should be robust co-ordination mechanisms for infrastructure policy within and across levels of government. The co-ordination mechanisms should encourage a balance between a whole of government perspective and sectoral and regional views.
7. **Guard affordability and value for money**: Governments must ensure that infrastructure projects are affordable and the overall investment envelope is sustainable. The asset should represent value for money. This requires the use of dedicated processes, a capable organisation and relevant skills.
8. **Generate, analyse and disclose useful data**: Infrastructure policy should be based on data. Governments should put in place systems that ensure a systematic collection of relevant data and institutional responsibility for analysis, dissemination, and learning from this data. Relevant data should be disclosed to the public in an accessible format and in a timely fashion.
9. **Make sure the asset performs throughout its life**: Ensure a focus on the performance of the asset throughout its lifespan by putting in place monitoring systems and institutions.
10. **Public infrastructure needs to be resilient**: Infrastructure systems should be resilient, adaptable to new circumstances and future proof. Critical risks materialise and technological change can fundamentally disrupt sectors and economies.

The key policy questions to ensure groundwater infrastructure performs throughout its life includes:(OECD 2016)

- Is there a strategy for how performance of the asset throughout the life of the asset is to be ensured?
- Are the line departments, sector regulators or audit institution responsible for monitoring asset performance?
- Are there programs in place for training and capacitating relevant institutions?
- Do PPP/concession contracts state the required output and performance?

Benchmark indicators:

- Policy document for ensuring performance from assets regulated by agency (sector regulator) or by contract with line department or similar
- Strategy for re-negotiations
- Ex-post evaluation of value for money

14.3.3. Institutions

M&E can be performed by the primary beneficiaries themselves, evaluations by the program teams, and evaluations by a central evaluation team. They can also be undertaken by an independent evaluation office or commissioned from consultants, though less than half of respondents reported that they always or very frequently do so. Nevertheless, the more frequently used evaluation approaches include commissioned consultancy evaluations and program team evaluations. Fully independent evaluations and self-evaluation by grantees are less often used (KPMG 2014).

14.4. Monitoring and evaluation tools

Table 14-3 sets out a number of M&E tools in use by a number of different agencies, especially in the WASH area.

Table 14-3: Monitoring and evaluation tools (Schweitzer et al 2014)

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
Sustainability Assessment Tool (SAT)[24]	Implementing organisations	To determine the sustainability of the programme interventions	Economic, environmental, institutional, knowledge, social and technological.	Each of 22 indicators has between 2 and 8 sub-indicator questions (total of 110 questions) to derive indicator scores. Indicators are adapted to meet the unique assessment requirements and ensure appropriateness for the local context	Primary and secondary data is collected through the review of policy and program documents, semi-structured interviews with key informants, and field observations. This data is used to determine the responses for sub-indicator questions which are used to determine indicator scores from 0 to 100. Factor scores are the average of the indicator scores	Area scores are graphically represented by a radar graph, and the indicator scores are shown in a traffic light system. The SAT output report contains recommendations at the sector level which are useful for future planning and assessment	Excel file; English.
Gender Analysis Snapshot	Project staff	To understand the level of gender equity in sample communities	Water sanitation and hygiene, Household decision making Access to public spaces and services Woman	24 indicator questions	Focus groups were conducted in each community. Two focus groups (one male, one female) were used due to the sensitive nature	Indicator and composite scores and bar chart showing scores by community and area.	Downloadable Word document; English

[24] http://www.aguasan.ch/

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
			empowerment.		of the topics. Participants were asked to score each of 24 questions. Individual scores were averaged to come up with a final score for each indicator for the community. All the indicator scores were aggregated for an overall score (range of 21-90) with higher scores indicating higher levels of gender equity in the community. Comparison of scores between the focus groups can be utilised to highlight the perceptions of each gender.		
Governance into Functionality Tool	Project or programme staff, commune/district authorities	To assess efforts to improve governance, environmental protection and risk management	Governance is defined with the following: accountability, inclusiveness, participation, and transparency. Functionality is assessed through a technical audit (using various indicators)	For the governance framework, each of the four areas has five indicator questions, for a total of 20 questions.	The 20 indicator questions are asked to stakeholders at the community level through key informant interviews or focus group discussions with community management committees. Each	Indicator and area score	Word document; English

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
					indicator is scored from 1-3 based upon a system developed by project staff and government stakeholders. The indicator scores are aggregated for an area score and can further be presented as an overall score (percent). The quantitative data can be presented alongside qualitative information that is collected through the focus groups with the community management committees		
Local Government Integrated Water Resources Management (IWRM) Support Assessment	Local governments of districts reached by Global Water Initiative (GWI)	To assess GWI efforts towards their strategic objectives on enhancing local government capacity in IWRM interventions and on addressing gender equity and diversity issues in IWRM	Policy, planning and implementation; personnel and finance; learning, harmonised information systems and monitoring & evaluation; coordination of relationships of District government downwards and upwards (with communities and	There are 20 indicators in total, distributed across the different areas as follows: policy, planning and implementation (5); personnel and finance (5); learning, harmonised information systems and monitoring & evaluation (6); coordination of relationships	One guiding question per indicator to aid local government to a) self-assess each indicator, scoring on a scale of 1-3 according to scoring labels provided in framework b) provide a score (1=worse, 2=same, 3=better) on level of improvement	Numerical score per district synthesised to the regional level demonstrating overall perception of support provided to local government and a score	Downloadable Word document; English.

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
			regional/national government)	of district government downwards and upwards (4).	from the previous year c) assess support provided by GWI partners (No=0, Minimal=1, Some=2, Significant=3) and general quality of support provided to local government (1=getting worse, 2=same, 3=getting better). Overall scores subtotalled per area and overall total produced.		
WASH Life-Cycle Assessment[25]	Project managers (implementing organisation) or knowledgeable stakeholders	To assess the effectiveness and viability of completed water and sanitation projects, either as a self-assessment or a third-party assessment	Socio-cultural respect, community participation, political cohesion, economic sustainability, environmental sustainability	Checklist of 100 sustainability recommendations guiding questions (4 per matrix element	rating (0-4) for each matrix element, depending on the number of sustainability recommendations (check boxes) that are completed.	Provides an overall sustainability score on a scale of 0-100 and a score for each project life stage and each sustainability factor (out of possible 20 points) presented on a radar diagram	PDF; English
Sustainability Monitoring Framework (SMF)	Donors and implementing organisations	Assess the presence or absence of factors with a proven impact on	Financial, Institutional, Environmental,	Specifically developed for each country and intervention	Primary data collected through surveys and focus group discussions	A series of Excel-based graphs presenting the results for each FIETS	Excel and Word document; English

[25] McConville, J., Mihelcic, J., 2007. Adapting Life Cycle Thinking Tools to Evaluate Project Sustainability in International Water and Sanitation Development Work,' Environmental Engineering Science, 24(7), 937-948. (related M.Sc. thesis can be obtained at: http://cee.eng.usf.edu/peacecorps/5%20-%20Resources/Theses/Assessment/2006Mcconville.pdf),

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
		sustainability (positive or negative).	Technical and Social (FIETS).		are used along with a literature review to determine a score (positive effect, negative effective, or no effect) for each indicator. No weighting factors are used in the framework and the questions and sampling methodology are adapted to each context	dimension. In addition, a 'reliability' score describes the number of questions that are answered and an overall sustainability score represents the aggregate of the five-dimension scores	
WASHCost tool[26]	WASH sector stakeholders (e.g. donors, implementers, governments, WASH planners, managers, analysts).	To aid users to effectively plan, budget, manage and evaluate the delivery of water and sanitation services using a lifecycle costs approach. The tool helps stakeholders consider what the expected capital and recurrent expenditures will be for different technologies and service levels	Context, cost, and service level	There are 9 indicators for water and 10 indicators for sanitation. These include context (country, population, and technology), cost (capital and recurrent), and those for service levels. For sanitation, the service level indicators include latrine technology, permeability, environmental impact, usage, and reliability. For water, the service level indicators are access, quantity, quality, and reliability	The user inputs data describing context and expenditures currently made on water and sanitation interventions. The inputs are compared with WASHCost benchmarks for a stated technology. Finally, the user inputs information that is used to determine the service levels	Summary reports are produced that can also be saved to a user dashboard or shared via a web-link. These reports contain information on the capital and recurrent expenditures (total and per person) that are presented against a service level categorisation determined using WASHCost benchmarks: high, standard, sub-	Web-based; English and French

[26] http://www.ircwash.org/washcost.

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
						standard, and no service for water, and improved, basic, limited, and no service for sanitation	
Planning-Orientated Sustainability Assessment (POSAF)[27]	WASH planners	To make stakeholder participation in sustainability assessments more consequential in order to facilitate sustainable technological choices	Environment, cost and benefits, user issues, institutional issues	Environment, cost and benefits, user issues, institutional issues; the number of indicators is variable, depending on the context	Participatory processes are used to analyse different planning scenarios. Following a technical feasibility study further participatory assessment is used to analyse trade-offs of the different scenarios and create quantitative criteria and weighting used for assessing future plans	Weighted criteria are produced through the process. In addition, a visualisation of the relationships between each stakeholder is created through a complex statistical process. In the graphic shown, the nodes represent respondents, the colours represent their responses grouped through a qualitative process. The node shapes and lines reflect statistical relationships between the individual responses for each user	PDF; English
Sustainability check	UNICEF project and programme planners	To assess the sustainability WASH infrastructure.	5 weighted factors: institutional (10%), social (40%), financial (10%),	Defined for each factor and allocated a score based on responses to sub-indicator	Random sampling is carried out on 10% of programme	Scores and recommendations conveyed through a	PDF; English

[27] Starkl, M., Brunner, N. Lopez, E., Martinez-Ruiz, J., 2013. “A planning-oriented sustainability assessment framework for peri-urban water management in developing countries.” Water Research 47(1).

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
			technical (30%) and sanitation (10%) (these have evolved over time to include sanitation as independent factor).	questions at the community and district levels.	interventions (water points and open defecation free (ODF) villages). Data is collected through semi-structured focus groups with the district authorities, facility audits of water points, audits of ODF villages and semi-structured household surveys in ODF villages. Indicator scores are averaged to obtain a factor score and then an overall score aggregated to the provincial and programmatic level using averages.	management memo and audit statement to inform decision makers' corrective action	
Sustainable Index Tool (SIT)	USAID, implementing partners, local stakeholders	Assess the sustainability of the services provided by WASH project interventions	Institutional, management, financial, technical and environmental	Designed for each factor with sub-questions, but no weighting is introduced into the scoring	A statistically significant number of households per intervention type is determined and selected at random within each community assessed. Data collection includes site inspections, household and key informant interviews, focus group	Presented as aggregate scores and graphically for the programme and district level for each of the different WASH interventions; can also be expressed by intervention type.	PDF and Excel files; English

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
					discussions at various levels (service provision, district, national), review of policy documents and technical standards and norms. The analysis is carried out separately for each intervention type and responses are aggregated for each indicator and subsequently averaged for each of the five areas		
Tool for Planning, Predicting & Evaluating Sustainability (TOPPES)	Project managers	To predict service delivery sustainability for WSA projects	Socio-economic context, service delivery, water resources/quality/and environmental needs, technical, financial, O&M and institutional	Each factor has a number of indicators, totalling 23, which are scored by answering 92 yes/no sub-indicator questions. Scores are then weighted according to perceptions of importance that resulted from the field test.	TOPPES uses a case study approach with judgement sampling; a comprehensive list of communities with interventions is used to identify communities where data will be collected. Data is collected through focus group meetings with water committees, physical inspections, and in some cases information from district level is	Numeric output indicating the likelihood of sustainability (i.e., scores of sustainable, moderately sustainable, or not sustainable) for the water supply system in question and for each sustainability factor	Word document; English

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
					incorporated. Data collection is done by third party contractors or project staff and the responses are field coded. The user interface is designed for real-time analysis		
Methodology for Participatory Assessment (MPA)[28]	Communities, project staff, project managers, sector policy formulators, and project designers and donors	To understand the links between demand responsiveness, gender sensitive approaches and sustainability and how the actions of different stakeholders contribute to the sustainability of services	Four areas or 'variables' for sanitation and seven for water. The areas include sustained services, effective use, demand responsiveness projects, equity for women and poor, community management, institutional support, and policy support. These variables are arranged into two phases: service establishment and management/use.	The framework includes a total of 19 indicators each with 1-5 sub-indicators (total of 47 sub-indicators)	Physical inspections, focus group discussions, stakeholder meetings, and key informant interviews	There are many potential outputs of an assessment with MPA. One example is the sustainability component scores shown at right (i.e. the 4 indicators of 'sustained services' area	PDF; English
Wash Sustainability Sector Assessment Tool	Development partner staff with responsibility for the design and	To provide a better understanding of programme design, priorities and decision-	Policy, legislation and institutions, financing, planning, transparency and accountability,	Each area has a number of indicators: policy, legislation and institutions (5), financing (2), planning (3),	Three or four guiding questions help the respondent determine a single score, from 0 to	Relative strengths or weaknesses of the WASH sector in a given country are summarised	Excel file; English

[28] https://www.ircwash.org/news/quantified-qualitative-monitoring.

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
	programming of WASH sector investments and implementation	making within the context of the sector level as opposed to individual project level, as well as identifying key weaknesses or bottlenecks	capacity, sector learning and knowledge management, harmonisation and alignment, and environment	transparency and accountability (3), capacity (2), sector learning and knowledge management (1), harmonisation and alignment (2), and environment (1)	100, for each indicator. Indicator scores are averaged for an area score	graphically through a bar chart for indicator scores and a radar diagram for the area scores	
Water, Sanitation and Hygiene Bottleneck Analysis Tool (WASH-BAT)[29]	Principally line ministries responsible for WASH, as well as Ministries of Finance, external partners and the sub-national level, including service providers	To remove barriers at different service levels to sustainable and efficient WASH service delivery, and increase in sector resources	Environment and equity, supply, demand and quality	32 enabling factors: national (18); sub-national (17)—same factors as 'national' omitting legal framework; service provider (10) community (4); each enabling factor assessed by six criteria	Each criteria scored between 0 and 1 by increments determined by user. Scores totalled and categorised by a traffic light system: 0 to 3.0 (red), 3.1 to 5.3 (orange) and 5.4 to 6.0 (green). A low score equates to the presence of a bottleneck. Bottlenecks, their causes and remedial activities identified. Costs of activities estimated, activity funding determined (fully-partially-not funded) and activities prioritised (high-medium-low-not a priority). Bounded and	Overall summary report containing Score Report, Funding Report, Activities Report determining how, when and the means by which these bottlenecks will be removed	Excel spreadsheet; English, French, Spanish, Vietnamese

[29] https://www.slideshare.net/ircuser/6-hutton-wash-bat.

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
					unbounded impact analyses can be generated		
Sub-Sector Scorecard[30]	National/state decision makers and planners, donors, implementing organisations	To identify bottlenecks and build consensus on high-level priority actions for reform and to ensure that finance is effectively turned into accelerated and sustainable water supply and sanitation service delivery	Enabling, developing, and sustaining services	Policy, planning, budget, expenditure, equity, output, O&M (water sub-sector only), markets (sanitation and hygiene sub-sectors only), uptake, and use	Indicator scores (0, 0.5, or 1) are assigned based on relevant resource documents (e.g. strategies, policies, reports) or WASH expert knowledge. Indicator scores are converted into a score (0-3) for each of the nine building blocks, which are subsequently colour coded (<1 = red, which means barrier to service delivery and requires immediate attention; 1-2 = yellow, hindering service delivery and requires attention; >2 = green, building block is in place and contributing positively)	Score (0-3) and coloured graphic indicating the status of each service delivery building block	Excel files: English and Spanish. The score cards results are presented with the financial processes in a country Report, available in PDF.

[30] https://www.wsp.org/content/pathways-progress-status-water-and-sanitation-africa.

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
Enabling Environment Assessment[31]	National and regional stakeholders (e.g. programme planners, donors, government).	Monitor, assess, and improve the enabling environment for sanitation and hygiene programmes	Policy, strategy and direction; institutional arrangements; programme methodology; implementation capacity; availability of products and services; financing and incentives; cost-effective implementation; monitoring and evaluation	Each dimension has 6 indicators which form a checklist.	Indicator scoring is binary (0 or 1) and scores aggregate to a dimension score of 0 to 6, for each of the 8 enabling environment dimensions	A score of high, medium and low and a stop light graphic is used	PDF report; English
Sector Wide Investment and Financing Tool (SWIFT)	National and sub-national governments	To support government understanding of financial balances in the water sector and allow strategic analysis of options available to close those gaps	The tool takes the form of five modules: sector definition and target setting; public finance (can show financial flows between institutions and specify regional allocations of funds for capital and O&M expenditure); sector development; service delivery; and policy scenarios, under which separate analyses are conducted.		Data from country level inputted into the spreadsheet, a hypothetical scenario presented, policy analysis performed, and financial balances in the baseline presented, after which, indicative policy options are explored.	Appropriate expenditure generated using costing methodology designed by PEM Consult to reach specified targets	Spreadsheet-based programme; English

[31] http://documents.worldbank.org/curated/en/567221468325172546/Synthesis-of-four-country-enabling-environment-assessments-for-scaling-up-handwashing-programs.

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
Sistema de Información de Agua y Saneamiento Rural or SIASAR	Water policy makers, planners, service providers, and implementing organisations	To improve the operational value of existing rural water and sanitation information systems; system classification provides a metrics for comparison (e.g. same system over time or between systems).	For the system classification: technical; for the other entities: community organisation, environment, service level, financial, and general coverage	Each entity has a different number of indicators: community (8), system (8), service provider (7), and technical assistance provider (5). For the system classification indicators include water supply, intake structure, conduction line, storage condition, distribution network, storage capacity, micro-shed status, chlorine residual	An operations and maintenance technician or 'circuit rider' collects general community information, conducts an interview with the service provider, and conducts a technical assessment of the system. Information for the technical service provider is collected separately. A ranking is given for each indicator on a scale of 1-4. From this ranking a classification of A-D is given for each 'entity': community, system, service provider and technical service provider.	Tables, charts, and map with stoplight	Online; Spanish (a multi-lingual platform is being planned).
Check Up Program for Small Systems (CUPSS)[32]	Operators of small-scale water and wastewater systems	To help small drinking water or wastewater systems manage their physical assets, track maintenance and replacement, plan annual budgets, and	Inventory, O&M, finances, check-up	11 indicators across all areas: inventory (3 with 8 sub-indicators); O&M (4 with 180 sub-indicators); finances (2 with 6 sub-indicators); checkup (2 with 6 sub-indicators).	Primary data is collected by the user and inputted into the computer program, which can be downloaded from the EPA's website.	Record of assets; a schedule of required tasks; a tailored asset management plan focussing on response time, planning, and coordination; as well as	Desktop software with supporting documentation; English

[32] https://www.epa.gov/dwcapacity/background-information-check-program-small-systems-cupss-asset-management-tool.

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
		provide an overall plan for the management of the water system.				an asset risk matrix, which projects the probability of failure and the consequences of failure	
Financing For Environmental, Affordable and Strategic Investments that bring on Large-Scale Expenditure (FEASIBLE)	Local and national government staff with responsibility for creating financing policy for water and sanitation investments	To support constructive dialogue and effective programme implementation through the creation of affordable and realistic financing strategies and cost-effective use of resources for the WASH sector	Solid waste, water supply, wastewater, supply of finance	16 indicators across all areas: solid waste (7), water supply (2, with nine sub-indicators), wastewater (2, with 10 sub-indicators), supply of finances (5).	Data collected using questionnaires, key stakeholder discussions, document reviews. A baseline scenario is developed and the user enters technical and financial data on infrastructure covered by present finance strategies	Technical results, expenditure needs, financing and financing gap, with the option to view aggregated values for water supply and wastewater areas	CD Software with accompanying user guide; results can be exported to Excel; English
Technology Applicability Framework (TAF) and Technology Introduction Process (TIP)[33]	District and national government, R&D institutions in developing countries, donors/development partners, local and INGOs, small and medium enterprises, training and academic institutions	Project the applicability, scalability and sustainability of individual WASH technologies.	Social, economic, environmental, institutional, technological, and knowledge	Each of the 6 areas has one indicator related to each of three different perspectives of key actors involved: 1) user/buyer, 2) producer/provider, or 3) regulator/investor/facilitator. Each of the 18 indicators has between two and six sub-indicator questions for a total of 57 questions.	Data collection methods include a desk study of secondary data and focus group meetings with key stakeholders, as well as limited household surveys using joint field visits. Scoring of the indicators is done by the focus groups involving all key actors. They answer the guiding questions on a	In the form of a traffic light per indicator. The output graphic can be interpreted by looking at each row or 'dimension' (e.g. score for environment), each column or 'perspective' (e.g. score for user), and the overall profile (e.g. score for technology) or specific issues (e.g. O&M).	Available in hard copy, PDF and Word formats; English & French (Spanish to come).

[33] https://technologyapplicability.wordpress.com/.

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
					scale of 3 levels (negative, neutral, positive). Answers are aggregated qualitatively and the 18 indicator scores are presented in a traffic light system (green = positive, yellow = neutral or partial impact, red = critical/alert). If there is disagreement in the group or the basis for the scoring is unclear a black icon and a question mark are used.		
Sustainability Snapshot	Local government, project planners and managers involved with community managed water supply interventions	To determine the financial and technical capacity of the community-managed water system as well as the availability of spare parts and equipment	Financial, technical, spare parts/equipment		Stakeholders select one statement from a choice of three statements for each of the three sustainability ‘themes. The statements are analogous to a Likert scale (e.g. none=1, some=2, all=3). Points are awarded for each theme, and an overall sustainability score is obtained by aggregating	A score for each theme (1-3) and an overall sustainability score (3-9)	PDF; English

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
Water for Life Sustainability Rating	Donors that need to identify organisations to fund	Assess organisational capacity for implementing sustainable projects	Organisational structure, water services, sanitation, hygiene education, project design and construction, water system long-term O&M, water source protection, community commitment & management	There are 22 indicators: each with a series of 2-11 sub-indicator questions. A total of 101 questions were used in the pilot assessment in Honduras	Judgement sampling is used to collect anecdotal evidence in a case study approach. For the pilot assessment 4 communities were randomly selected out of a total of 159 water projects and between 2-16 households were visited in each community (35 households total). Information provided by the implementing organisation that is the focus of the evaluation is triangulated with data obtained through interviews with water boards, random household visits, community focus groups, and infrastructure inspections. Each yes/no question has a designation of 'basic' or 'high' and based upon the responses for each	A numerical score is given for each organisation evaluated and a four-colour scheme graphic is provided for each indicator as well as for the overall score	PDF and Excel; English and Spanish

Name	Target	Objectives	Areas	Indicators	Methodology	Outputs	Tool format and language
					an overall score is determined qualitatively. A quantitative score can be determined by assigning numerical values to the Likert categories and calculating a percentage		

14.5. Exercises

14.5.1. Exercise: Point out areas of the O&M process where organisations could have constraints that could limit M&E

Brainstorm areas of the O&M process where organisations could derive value from M&E (30 mins).

1. How is M&E currently done?
2. Devise a set of outputs and outcomes that would contribute to proper O&M of groundwater infrastructure
3. Develop indicators for both the identified outputs and outcome.

15. DEVELOPING AN OPERATION AND MAINTENANCE PLAN

– Understand the need for an O&M plan – Describe the components of an O&M plan

15.1. Introduction

The O&M plan is an endorsed document by all stakeholders that describes groundwater system safe functioning and adhering to legal prescriptions from which communities can derive social and economic benefits including safeguarding public health. The O&M plan provides a written source of material that can be referred to for guidance in operating the groundwater supply system. This includes standard operating and maintenance procedures. The O&M plan also sets out procedures to deal with emergency situations. The O&M Plan will also provide a ready reference for all equipment data which is necessary for performing normal maintenance and for ordering replacement parts and supplies. It will be an organised system for keeping records of the operation of the system. The components of an operation and maintenance plan includes (Georgia Environmental Protection Division 2000):

15.2. Description of groundwater supply system

- **Service area**: The service area needs to be defined both legally and physically
- **Legal and regulatory permissions**: Water suppliers must be aware of the permits (including any standard and/or special conditions), laws and regulations under which their system was built and operates. The O&M Plan for the facility allows the water supplier to integrate these documents into the record keeping system for easy retrieval.
- **System description:** Provide general descriptions of sources of supply:
    - **Boreholes**
        1. Describe its location, diameter, depth, length of casing, depth of grout, static water level, pumping water level, pumping rate, date of installation, and any expansions or modifications
        2. Describe drainage area around borehole site, nearest

source of pollution, borehole seal, and borehole enclosure

3. Include borehole log and borehole construction details. Include borehole driller and supervising hydrogeologist details, if available, and well driller's name
4. Describe land ownership access and control
5. Measurement of groundwater levels and pumping rates should be taken daily, if these are not automated (Table 15-1)

Table 15-1: Groundwater level and pumping sheet

Date	Borehole number	Borehole type	Water level before start of pump (mbgl)	Flow meter reading before pump is switched on	Time pumping starts	Water level before pump switched off	Time pump is switched off	Hours pumped	Volume pumped (m^3)

- Springs
  1. Describe location, capacity, enclosure, land ownership, access, and control
  2. Include date acquired and dates of any modifications
- Treatment Process
  1. General
     - Describe in general terms the treatment processes used at each facility. Include a flow diagram of the treatment facilities as part of this description
  2. Discuss each part of the treatment process separately with details of the component and its operation
     - Intake or Raw Water Source
       - Describe the control gates or valves including size and type of operation
       - Include dates facilities were installed and/or modified
     - Chemical Additions

- It is probably best to describe each chemical addition as a separate process. Provide the name of the chemical applied, chemical formula and strength, name of chemical supplier, and type and size of containers
- Indicate the type of chemical feeder, manufacturer's name, model number, maximum capacity, and normal range of feed rates. Describe where the chemical is applied to the water, what controls the dosage of chemical, and what tests are made to determine dosage
- What are the safety precautions applicable to this chemical? What safety equipment is available?
- When were chemical feeders installed?

- Disinfection
  - Describe the chlorine chemical, chlorine feed equipment, point of application, and maximum capacity of chlorinators

- Major Pumping Systems
  1. Describe the purpose of each pump, size, capacity, rpm, manufacturer, model number, motor manufacturer, horsepower, motor frame size, location, suction and discharge piping size, and pressure controls
  2. A copy of the pump performance curve showing the impeller diameter, the designed capacity, and head should be included with each pump description
- Transmission and Distribution Systems
  1. Total system size (miles of pipe)
  2. Number of service connections (or customers)
  3. Highlights of transmission line characteristics (main size, dates of original installation and expansions)

- Storage
    1. Effective capacity
    2. Maximum withdrawal rate
    3. Materials of construction, coatings
    4. Altitude valves (i.e., how does the tank operate)
    5. Geographic location of reservoirs and elevated storage tanks
- Other
    1. Alternative or emergency sources of water
    2. Shared utilities (e.g., power generating capabilities employed by others)
    3. Unusual aspects of the system

– Distribution Map
    - If not already detailed in the definition of Service Areas, the supplier should have a detailed map of the system's transmission and distribution facilities. On a typical water distribution system map, each type of pipe can be identified with a number. This number may reference the plan number (since most systems require multiple plans). Additionally, valves and hydrants are identified and assigned identification numbers. Pipe sizes, year installed, and materials are identified alongside the pipe. Other pertinent information may be included to aid in the maintenance of the system. While it is not necessary to show all of this information, it is a valuable planning tool for development or rehabilitation

– Flow Charts for Treatment Plants
    - Each treatment plant should be represented by a line diagram depicting flow of water through the facility. Major equipment and systems should be labeled on the chart. Although a proper scale is not required, some attempt should be made to depict the plant in its actual layout

– Pressure Gradients
    - A tabulation of the annual pressure surveys and hydraulic gradients for major transmission mains should be included

– Other Maintenance Requirements
    - Suppliers need to be aware of and document long-term maintenance needs such as five-year equipment inspections, tank painting, facility (such as roof) requirements, and routine

items such as sludge disposal

15.3. Start-up and normal operating procedures

- Controls
  - Flow Rates - Describe control for each source or pump
  - Chemical Dosages - Describe control for each chemical
  - Tank or Reservoir Levels - Describe control limits high and low
- Start-up
  - On start-up of any piece of equipment, certain procedures must be followed to assure that the equipment will not be damaged, that other pieces of equipment are interlocked so they start or stop in tandem with another facility, and that the water produced is of acceptable quality
  - The O&M plan should have a checklist for each piece of equipment showing step-by-step the items that should be checked at and during start-up
- Normal Operating Conditions
  - A description of the water quantity and quality including any anticipated variations should be provided for each part of the treatment process. The description should include maximum and minimum conditions
  - A pressure survey of the distribution system must be conducted annually. The information should be recorded in the O&M Plan

15.4. Planned maintenance program

- Equipment data base
  - Equipment List - Individual pieces of equipment are numbered according to the facility they are associated with and their position in the process flow. The number becomes the equipment's identifier whenever maintenance is involved
- Maintenance Procedures
  - Routine Procedures - All routine procedures should be grouped together on a checklist according to their scheduled frequency. The procedures normally are scheduled for specific time periods so there is a uniform workload over the calendar year. All work

should be done by persons who are qualified and knowledgeable in the operation and maintenance of the equipment

- All maintenance procedures should conform to the manufacturer's recommendations to avoid cancellation of any warranties. Unusual use or environmental factors should be considered when establishing procedures (e.g., wet or dusty conditions would require more frequent maintenance)

15.5. Spare parts inventory control

- List of equipment and spare parts on hand for emergency repairs
- List of sources of needed equipment and spare parts, not on hand
- List of distributors and suppliers of replacement parts

15.6. Sampling and analysis program and compliance monitoring

- The primary responsibilities of the public water supply operator include routine sampling and testing of the water quality
- Bacteriological contamination of drinking water can have serious consequences for consumers. It is recommended that water samples be taken and analysed for their chemical composition and bacteriological contents according to the protocol listed in Table 15-2.

Table 15-2: Analytical requirements

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

- The O&M Plan should emphasise the importance of and outline procedures for properly scheduling, locating, and collecting samples, as well as obtaining reliable laboratory services and qualified personnel
- Raw water samples may be collected from a sample tap installed on the borehole discharge line at a point prior to any chemical additions or treatment processes

- Entry point samples or finished water needs to be collected before entering the water system's distribution
- Proper sample collection, handling, preservation, transportation, and storage techniques are essential to a meaningful and useful monitoring programme
- All monitoring equipment used to determine water quality parameters must be used, maintained and calibrated in accordance with the manufacturer's instructions. This includes in-line monitoring equipment such as turbidimeters, particle counters, and chlorine analysers, and portable equipment used to measure pH, disinfectant concentration, and turbidity.

15.7. Public notification

- The water supplier must notify its customers when the system is in violation of the regulations
  - Who - The name of the water system
  - What - The purpose of the notice (i.e., the violation, variance, or exemption)
  - When - The date the violation was observed or the variance or exemption was granted
  - Authority - The name of the government agency that established the regulation or granted the variance or exemption
  - Regulation involved - A description of the standard
  - Health significance - Mandatory WHO health effects language for the contaminants are to be used
  - Precautions to be taken - (i.e., boiling water, etc.)
  - Steps being taken to correct the problem - A description of what actions are being taken by the water supplier to correct the problem (i.e., searching for an alternate source of supply)
  - Alternatives - Where the customers can obtain an alternate supply of water if necessary
  - Contact for Information - List a name and telephone number for a water system staff person who can answer questions
  - Where appropriate, bilingual or multilingual notices must be issued

15.8. O&M Safety plan and emergency procedures

- The safety hazards associated with water supply systems are numerous and varied. Water system personnel should be made aware of all hazards, where these hazards are present in the water system, and how they may affect the employees
- This includes:
  - Electrical safety
  - Chemical handling and storage
  - The O&M plan also need to contain emergency procedures to the following situations:
  - Distribution system problems
  - Equipment failure
  - Disinfection failure
  - Power outages
  - Loss of supply
  - Contamination of supply
  - Strikes
  - Vandalism and Sabotage

15.9. Check list[34]

The following is a checklist for an O&M plan:

- Does the O&M Plan answer all the questions of who, what, where, and when concerning O&M?
- Does the Plan identify the personnel responsible for O&M? The preparation of an organisational chart clearly will define the responsibilities of each position and will provide guidance as to whom to contact for help in emergencies
- Does the Plan identify the human resources and facilities, including tools, needed for O&M?
- Does the Plan identify funding sources for on-going O&M?
- Does the Plan describe the O&M activities to be performed?
- Does the Plan describe the checks to be made, and the data to be

[34] https://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_12.cfm.

collected, for health and performance monitoring?

- Does the Plan cover periodic reporting of system health and performance to provide feedback to management on the effectiveness of O&M?
- Does the Plan address the training of operators and maintenance personnel?
- Does the Plan address safety and security?
- Does the Plan identify other documents used in O&M, such as relevant policy directives, system configuration documentation, and O&M manuals?
- Does the Plan address system testing and configuration documentation updates, following configuration changes, repairs, and upgrades?
- Does the Plan address preventive maintenance as well as reactive maintenance?
- Does the Plan address expected life and end-of-life replacement or upgrade?

15.10. Exercises

15.10.1. Exercise: O&M Plan

Review the components of the O&M plan discussed above. How would you improve the plan (30 mins)?

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