IMPROVING GROUNDWATER KNOWLEDGE IN SELECTED TRANSBOUNDARY AQUIFERS

Monitoring Background Report

May 2018

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The *Support to* ***the Improving Groundwater Knowledge in Selected Transboundary Aquifers*** Study was commissioned by the Secretariat of the Orange-Senqu River Commission (ORASECOM) with technical and financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ), in delegated cooperation with the UK Department for International Development (DFID), implemented through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

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ORASECOM SECRETARIAT

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MONITORING REPORT

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IMPROVING GROUNDWATER KNOWLEDGE IN SELECTED TRANSBOUNDARY AQUIFERS

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Index Number	ORASECOM Report Number	Report Title
1		**Inception report**
2		Draft final report with updated groundwater recharge estimates in the main recharge areas in the Karroo Sedimentary and the Khakhea/Bray Dolomite Aquifers

Index Number	ORASECOM Report Number	Report Title
3		Monitoring Background Report
4		Monitoring Framework Report
5		Report indicating inputs made at the stakeholder's workshop
6		Final Recharge Report
7		User manual of the established groundwater information system.
8		Report on the joint survey

EXECUTIVE SUMMARY

The report summarises the finding of: a literature review of groundwater monitoring studies undertaken in the Basin; visits to the State Parties and their relevant national departments to identify monitoring requirements and existing databases and monitoring systems.

Botswana

Groundwater level monitoring in Botswana suffers from split responsibilities. The Water Utilities Corporation monitor only abstraction holes, while the DWA (Department of Water Affairs) monitors background holes. The Department of Geological Survey (DGS) was monitoring undisturbed areas but it was suggested this has stopped. These departments fall under the Ministry of Mineral Energy and Water Resources. The objectives of DGS were to observe long-term groundwater level behaviour under natural conditions and to accumulate data for future economic development and resources management. The DWA focuses on observation of long-term groundwater level behaviour under pumping conditions to observe changes and to see the aquifers' responses to stress. As such, the DGS monitoring can be considered background (2.3.1) and the DWS network as regulatory (2.3.2), and the WUC networks as compliance (2.3.2).

According to the DWA, there is no national background monitoring framework currently operating and they are only monitoring wellfields with some background boreholes. The strategic or background network was established only on a project basis. None of the networks monitor transboundary flow, nor surface-groundwater interactions.

The network consists of about 800 boreholes. Monitoring activities include groundwater levels observations, estimation of abstraction rates, and specialized (project related) monitoring. Most groundwater levels are measured on a monthly basis. Observation wells equipped with digital loggers are measured daily. Water quality is only monitored as hoc.

DGS records the groundwater data into a national borehole archive (NBA) as paper records and some on the MS-DOS NBA (Nation Borehole Archive) with some on spreadsheets. This contains general borehole information as from construction (borehole Completion certificates). The Department of the Geological Survey (DGS) has not entered much of the data that were collected over the years.

DWA stores their data into WELLMON software. The various databases are currently not properly linked. WELLMON is a software package for groundwater monitoring data, meteorological data and other parameters, which produces groundwater hydrographs. Currently, WELLMON only contains groundwater level and abstraction data. The ad hoc water quality data is stored in the AQUABASE database. The database contains water quality analyses of surface and groundwaters. This database does not contain and detailed positional data.

The following challenges were identified

- Some government departments do not recognize the need to monitor.
- the spatial density of observation wells in Botswana is not yet adequate since it focuses on wellfields
- Additional challenges stem from lack of coordination between departments

- Delay in data processing has resulted in inconsistent data series, which subsequently has generated time series with numerous data gaps.
- Data analysis is not undertaken to add value, such as recharge estimation, and staff only look at trends in water level
- There is no water quality monitoring network
- With no harvest potential available against which to base allocations, no cognisance is taken of existing groundwater use against available resources. The prevention of any further abstraction where a wellfield exists is severely limiting to future development,
- Only large abstractions from mine and industry report on water levels, abstraction and quality annually. The WUC often doesn't report
- Permit holders can pump over permit limits since there is no assessment of compliance.
- The WUC and nonindustrial users often doesn't submit data and there no legislative mechanism for legal enforcement only the land act. If person has an integrated land use permit the DWA cannot control abstraction in control areas.
- A Water Apportionment Board exists, but often there is no recommendation from DWA hydrogeology due to lack of capacity, so the Board cannot regulate water allocations. A Water Regulatory board is being established in future. Validation and verification of water use will fall under this new board

The following tasks are strongly urged to improve groundwater management and monitoring:

- The development of recharge and harvest potential per units so that allocated permits can be compared to available resources without constant referral to a hydrogeologist and subjective evaluations
- An integrated database is required for capturing borehole data and monitoring data, hosted at one department
- A strategic network needs to be established in transboundary aquifers to at least monitor rainfall, abstraction and groundwater gradients towards the border

Lesotho

The DWA has a database contain 8070 records of which about 70% have been geo-referenced. The database is held in spreadsheets and is fully compatible with the Arcinfo based GIS system. This database can be imported into Access and thereby transformed into a series of component Excel spreadsheets.

The DRWS provides data from boreholes drilled for rural water supply in the National Database (NDB). The NDB is an administrative database listing information such as village name, borehole depth, handpump type and installation information. Although it is the largest database of borehole and spring data, the NDB lacks technical data such as georeferenced co-ordinates, geological logs, borehole yield, test pumping data and hydrochemistry.

To drill a borehole requires a construction permit. No limits exist on distance from a river where boreholes allowed. Boreholes can be drilled anywhere, which creates a potential for baseflow reduction.

Only non-domestic use needs an additional water use permit. Only safe yield from test pumping is registered, not use, in the permitting system. The only use calculation is based on based on 30 l/c/d

There have been signs of groundwater stress in the Caledon basin. During a recent drought, production boreholes dried up and some monitoring holes were converted to production holes, further reducing the network.

Yield is recommended by pump testing, hence considers borehole yield, not aquifer yield. Interference is not considered, nor Harvest or Exploitation Potential, which may explain wellfield failure.

The Department of Water Affairs (DWA) in the Ministry of Energy, Meteorology and Water Affairs (MEMWA) is the executing agency for the national groundwater monitoring network. Groundwater monitoring started in the early 1990's with only a few springs across the country. Currently the network consists of 162 monitoring springs and 72 observation wells. The network has since been reduced to 60 boreholes and 130 springs.

Monitoring is of abstraction boreholes and monitoring boreholes near the wellfield. Hence is a compliance type of network, not a true background network. Seven wellfields are monitored. DWA doesn't analyse water level data for recharge; just evaluate data qualitatively for signs of stress.

Water quality monitoring is ad hoc and random and based on wellfields. Quality issues include iron, Mn, F No3 biological contaminants.

The NDB Data base is not active. Data is now stored in excel spreadsheet. This data is available on request. The spreadsheet is uploaded to aGeographical Information System. Data is not publicly available online but can be given out publicly on demand. The groundwater division performs annual groundwater resources assessments. These assessments include determination of the seasonal fluctuations of the water table, determination of groundwater flow direction and sustainability of groundwater abstraction.

The following challenges can be identified:

- Due to financial and human resource constraints monitoring points and frequency of monitoring is limited.
- Lesotho needs public awareness on the importance of groundwater. There is a poor understanding of the importance of observation wells among local communities.
- Although a good density of boreholes and detailed geological maps (may) exist, data crucial for hydrogeological assessments are rarely recorded.
- With decentralisation of rural water supply and greater involvement of NGOs, there has been a tendency to use minimum standards of construction to reduce the borehole installation costs. The use of minimum diameter borehole components results in access of water level measuring equipment being sacrificed.

- With no harvest potential available against which to base allocations, no cognisance is taken of existing groundwater use against available resources. The prevention of any further abstraction where a wellfield exists is severely limiting to future development,
- The groundwater monitoring network is also hindered by a poor streamflow and rainfall network. Many gauge rating curves need to be recalibrated to obtain baseflow figures for recharge estimation. The rainfall network has been reduced from 120 gauges to 35, but this was not confirmed by the Meteorological services.
- Since most abstraction occurs in the Lowlands, in catchments shared with South Africa, transboundary aquifers are important. To manage allocations, allocations on both sides of the border need to be known
- Software for monitoring is a priority since the current spreadsheet system is not suitable as a national data base
- Since most abstraction takes place near perennial rivers, the impact on baseflow needs to be quantified
- The current Monitoring holes are sited as production boreholes, nor for not monitoring
- Private sector use is not monitored. Only mines and utilities have records of use. Industrial water use is the biggest problem
- After issuing of a water use permit, only spot check of big users takes place. There is no set way of checking compliance
- No data on GW contribution to Baseflow exists, (But the South African GRAII does include Lesotho, albeit, it is uncalibrated)
- There is a challenge protecting wetlands, which have a high impact on low flows. They are now monitored with piezometers and for discharge. This is a sperate network. However, monitoring does not ensure protection.
- Some data is collected but not captured as it is not trusted. They are sensitive to bad data. They also have a problem of capturing data due to staffing
- Priority is how to incorporate private contractors for capturing data. Have standard forms but not used.

The following tasks are strongly urged to improve groundwater management and monitoring:

- The development of recharge and harvest potential per units so that allocated permits can be compared to available resources without constant referral to a hydrogeologist and subjective evaluations
- The development of a monitoring strategy (Where to monitor, how, which aquifers etc) is seen as a priority by the DWA
- The DWA expressed a need for drought recharge figures, however, this can be mitigated if harvest potential figures were available.

Namibia

There are some 40 000 records of Borehole Completion Forms of WW-numbered boreholes. The captured data records farm name and number, borehole depth, water strikes and associated yields, lithology and casing and more recently drilled boreholes include GPS data. The Department of Water Affairs owns the data sets. Some 90 000 water chemical analyses of mainly major ions plus some bacteriological data is also available. Many operational analyses from distribution networks and chemical data from numerous groundwater schemes are also available from the DWA.

Any abstraction for more than 1 ha of irrigation requires a licence. For domestic consumption, an abstraction of > 200 000 m3/a needs licence. Every licence must have a water meter in theory and must submit quarterly. There are some spot checks but no set schedule.

Allocations are then based on a historic volume per compartment, equivalent to a basin. This is a coarse form of Harvest Potential on a large scale. This is a problem if abstraction occurs all in one place. They divide a basin into high and low productivity and have different allocations.

The Department of Water Affairs and Forestry is responsible for national groundwater management. Groundwater level monitoring started in Namibia in the 1960s. The Monitoring Network consists of over 2000 stations. They are currently monitoring 630 of which 196 are digital. The rest are inactive.

The network consists of a master station network for representative sites in each major aquifer, and a Selective network for GWC areas where use and water level are monitored. Monitoring covers all high and moderate potential aquifers

In Namibia the groundwater database is hosted in the Ministry of Agriculture, Water and Forestry (MAWF). The National Groundwater database called GROWAS, which has been superseded by GROWAS II, which is linked to a GIS. The database is used for storing groundwater data such as groundwater levels, groundwater quality, permits for abstraction and all the hydrogeological data in the country. The data is checked and verified before being entered in the database. The database is not publicly available, but data can be supplied on request as csv files or shp files.

The database also contains a documents archive. The GROWAS front end is implemented in MICROSOFT Visual Basic 6.0, the database itself is running on MICROSOFT SQL Server 2000. The data model was designed by the Division Hydrogeology who is also the custodian of the database.

Each major aquifer is operated according to an aquifer management plan. However, the knowledge about the water balance, or recharge versus abstraction, is often insufficient due to short historical records of these aquifers. Regional groundwater reporting has not yet been done in the country, but plans are there to start with this.

Data can share data if an application to Permanent Secretary is made with a stated purpose.

The following challenges can be identified:

- Human capacity is lacking to carry out the groundwater monitoring in all basins. Challenges are financial and rehab of network and staff. Only 22 of 48 posts are filled in geohydrology department
- There is a problem with the ability to undertake data analysis. They have some thresholds which function as an operating rule to limit abstraction in groundwater control areas, but no rigorous approach.
- Groundwater quality monitoring is inadequate as well as data processing.
- Four of the monitored aquifers in Namibia are of transboundary nature. For transboundary monitoring it is often politically difficult, and time consuming to amend legal provisions and make organizational arrangements.
- The harvest potential or natural recharge of the country has not yet been fully determined. For some schemes and projects, the safe yield has been determined but since recharge is rainfall dependent and as rainfall is highly variable, such values must be viewed with caution. Harvest potential information for certain areas does exist in certain reports but is on a very coarse basin level. A qualitive overview is presented in the Hydrogeological Map of Namibia, however, this map is not quantitative, so of very limited value. A process to upgrade the map with quantitative data has been initiated.

The following tasks are strongly urged to improve groundwater management and monitoring:

- The staffing needs to be upgraded as the extent of the existing network is already large for the small existing staff
- The resource assessment needs to be upgraded to derive a harvest potential per sub-basin, or per km^2 so that allocations can be made on a quantitative basis, rather than on basins as a whole on historic information. The existing network can be utilised to derive such estimates and recharge values.

South Africa

Groundwater level monitoring started in the 1950s and the number of active stations increased to almost 3 000 across the country in 2005. About 3800 stations have existed in total. However, since then this has decreased so that less than 2000 are still open.

This network includes a background monitoring network. The number of stations has been in rapid decline since 2010. The declining number of stations is of concern as only 30% of the stations extend to present, or near present that include 2014 data in their records and over 3 000 stations have records that end before 2010.

There are 422 chemical monitoring points, which are sampled twice a year (end of dry - and end of wet season. The number of water quality stations has gradually increased.

The rainfall monitoring networks has been in a state of decline since 1945, with a rapid decline since the 1980s. The present number of stations is less than there were in 1920.

The National Groundwater Information Systems (NGIS) portfolio includes the National Groundwater Archive (NGA). The latter is a relational database management system of boreholes and springs. The NGA contains in excess of 260 000 geosites, of which 242 000 are boreholes.

The NGA is a centralized web enabled database. People with a direct interest in groundwater can register to search, capture and store data. The database is an ArcGIS geodatabase storing all verified spatial hydrogeological data. Spatial data is available in GIS format.

Data sources from which groundwater related information can be obtained include:

- National Groundwater Archive – NGA, which includes a searchable archive of downloadable reports. This is a Borehole information database which is internet based but without a spatial GIS interface. Data is downloadable in CSV format. The database includes borehole information and historic water levels http://www.dwa.gov.za/Groundwater/NGA.aspx
- Water Management System - WMS [Water quality database including ZQM groundwater monitoring] https://www.dwa.gov.za/iwqs/wms/default.aspx
- Water monitoring database - HYDSTRA [borehole time-series data]
- CHART – Analysis tool using data from WMS and HYDTSRA which is accessible via the internet. It includes current water levels of monitored boreholes. Over 36 000 analyses are available for groundwater. http://www.dwa.gov.za/chart/home/default.aspx
- WARMS - Water Use Authorisation Registration Management System database on registered water use
- DWS GH (Geohydrology) Reports - A repetoir of downladable geohydrological reports, with some dating back to the 1930s http://www.dwa.gov.za/ghreport

The Groundwater Resource Assessment Project (GRAI and GRAII) produced hydrogeological map sheets at 1:500 000 scale (GRAI), and catchment and grid based (km^2) data on aquifer storage, water level, harvest potential, exploitation potential, recharge and surface subsurface interactions (GRAII).

The following challenges can be identified:

- Practically what sometimes happens is that data gathering at regions not always passed up so is not on the national database.
- Only Limpopo Province puts out regular reports on water level trends
- The National Water Act determines who needs a licence, however, General Authorisations and Schedule 1 users are not obliged to register, and hence are not on WARMS. Many Existing Lawful Users are also not registered. Use in WARMS is defined not actual use but licenced use which must be protected whether used or not. This is suitable for legal compliance, but is a detriment when water levels need to be compared to actual use
- There is a need to covert groundwater level monitoring data into knowledge products such as water level change maps to present the benefits of monitoring to decision-makers to stop the erosion of monitoring networks

Regional Issues

To address the issue of transboundary groundwater, the SADC framework comes into play. The Protocol is the SADC legal instrument that promotes the concept of Integrated Water Resources Management.

Several obstacles can be identified which hinder the implementation of the SADC protocols on practical grounds:

1. The lack of ack of Information and Data and declining monitoring networks.
2. Limited Capacity of trained personnel in groundwater or remaining severely under resourced is often cited.
3. Monitoring systems in member countries, except South Africa, have been drawn up for regulation and compliance at wellfields, and not for strategic background monitoring
4. Implementation of transboundary aquifers has not featured in monitoring system designs.
5. Differing groundwater polices between member states regarding groundwater monitoring with regard to data base systems and monitoring purpose and network design results in no common strategic network or formats of storing data.
6. Groundwater resource evaluation and a water balance has not been undertaken on a catchment scale (Harvest or Exploitation Potential), except in South Africa, hence the quantification of resources and the prediction of aquifer behaviour cannot be implemented in transboundary aquifers. There is no baseline of natural groundwater resources versus current conditions and water levels.
7. River Basin Organisations and other organizations like ORASECOM are limited or in their infancy.
8. There is a Poor Appreciation of Shared Aquifers.
9. Responsibility for management of water resources is often fragmented between different authorities and at different scale

Key Preliminary Elements that Need to be Addressed

Prior to a monitoring effort, it is essential that all parties have an assessment of existing resources.

Monitoring data collected in transboundary aquifers should be comparable, available for integration with information from a variety of sources and easily aggregated spatially and temporally. Data produced by groundwater monitoring programmes should be validated, stored and made accessible. Monitoring in Botswana and Lesotho is geared towards regulatory monitoring of wellfields, whereas South Africa and Namibia have a strategic monitoring network for reference conditions. Reference conditions cannot be established on both sides of the border, making resource assessment problematic.

The most crucial element in integrating data from country database is similar field naming of data tables. There are currently no naming standards set or used in the basin countries as such each country data table for similar feature has different field names. Initial data that is required for regional groundwater monitoring are:

- Resource status Monitoring – Rainfall, groundwater levels and abstraction
- Chemistry – TDS, nitrates and fluoride etc
- Coordinates – referenced to a common grid system

All these data are tied to a borehole number, and each national database consists of general borehole information using different field names, using different formats (i.e. text, numbers) for this field, thus making integration of the data tables difficult. Therefore, editing of the data tables is required prior to integration. Furthermore, fields used in water level monitoring tables are different except for the water level field.

If the database is not on the internet, like the South African NGA, to get data from one database there will have to be an individual in the respective country contacted to send the required data.

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In the Region's shared river basins complex relations between surface and groundwater exist and are not fully understood nor quantified. Where baseflow exists into international rivers, groundwater use in such aquifers may have adverse impacts across international boundaries by impacting downstream river flows and recharge to transboundary aquifers.

The objectives of data management are collecting and processing data and distributing the findings to those requiring the information. This would be facilitated by using standard forms, similar formats, data dictionaries and software to improve data exchange, but this is not the case.

It is clear that groundwater information for the Orange-Senqu River Basin is currently held by various institutions in many forms and formats, and dissemination of information is a tedious process. Availability of timely, adequate and valid geohydrological data and information will be crucial to the success of the ORASECOM's work programme. A number of computer-based systems are available for storing and sharing of the geohydrological data and information, in addition to libraries and technical reports in the four basin member countries.

A very large problem is that a groundwater resource assessment does not exist on a catchment scale for all the member countries, nor does baseline information. This makes it impossible to quantify how much groundwater is available, and hence to determine impacts of abstraction on resources, both on baseflows and water levels.

As some national data bases are not internet-based, data cannot be collected remotely by ORASECOM, and will have to be collected through contacting country database managers. Database integration should allow the data from Botswana, Lesotho, Namibia and South Africa to be brought together in one table. A system will have to be developed which will import data tables from the various databases through export files that can either be in Comma Separated Value (CSV) Files or through Microsoft Excel or SQL Server Database, or any other common data transfer and integration medium.

The report has identified the following data gaps that need to be addressed for a monitoring programme:

- A recharge, baseflow and Exploitation Potential data base of catchments on a Quaternary level is required so that resource allocation per country can be undertaken and downstream impacts be quantified.
- A shared Groundwater use data base of all transboundary countries, and assessment of impacts so that groundwater resources can be equitably allocated across borders. This shared use can be on a use by sector and Quaternary catchment basis to avoid releasing confidential information about water users.
- Baseline groundwater level monitoring is required on both sides of borders so that hydraulic gradients and flow directions can be determined, as well as any flow reversals that occur resulting in cross border impacts.
- Baseline groundwater quality for macro and trace constituents is required to determine baseline conditions against which to identify pollution.

The status of monitoring is shown below.

Monitoring Status	Botswana	Lesotho	Namibia	South Africa
Groundwater Resource Assessment		Not available Priority	Historic and coarse. Required on a catchment basis	Available
Baseflow	Available only for transboundary rivers bordering South Africa	Available only for transboundary rivers bordering South Africa	Available only for transboundary rivers bordering South Africa	Available
Baseline reference water levels	Not available Wellfield monitoring only	Not available Wellfield monitoring only	Available but not focussed on transboundary. Network needs to be evaluated for ability to meet SADC water sharing protocols	Available but not focussed on transboundary. Network needs to be evaluated for ability to meet SADC water sharing protocols Network declining rapidly

				Does not cover all catchments
Water quality	Not available	Not available	Not available	Available but not of uniform density
Groundwater Use	No data base	No data base	Allocations available in GROWAS	WARMS data base has only licence allocations and some General Authorisations Not public domain
Reference Monitoring plan/framework	None	None	None	Available

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LIST OF ABBREVIATIONS

Abbreviation or Acronym	Definition
CRD	Cumulative Rainfall departure
GRES	Groundwater Recharge Estimation Study
GWHC	Groundwater Hydrology Committee
IWRM	Integrated Water Resources Management
JBS	Joint Basin Survey
ORASECOM	Orange-Senqu River Commission
QC/QA	Quality control/ Quality assurance
SADC	Southern African Development Community
STAS	Stampriet Transboundary Aquifer System
SWI	Shared Watercourse Institutions
WR2012	Water Resources South Africa 2012
WRSM2000	Water Resources Simulation Model 2000 (Pitman Model)

LIST OF DEFINITIONS

Abstraction	The removal of water from a resource, e.g. the pumping of groundwater from an aquifer.
Aquifer	A geological formation, which has structures or textures that hold water or permit appreciable water movement through them.
Aquifer hydraulic properties	The properties of permeability and specific yield, or transmissivity and storativity that determine the rate at which an aquifer transmits water, and the volume of water it releases from storage
Baseflow	The contribution of subsurface water to surface water channels to maintain dry season flows
Groundwater baseflow	The contribution to baseflow from the regional aquifer
Interflow	The contribution of subsurface water to surface water courses as baseflow before entering the regional aquifer
Ephemeral river	Rivers that do not flow continuously and have limited if any baseflow
Fault	A zone of rock displacement resulting from tension or compression forces
Formation	A sequence of rock layers of similar lithology deposited continuously
Harvest Potential	the maximum volume of ground water that may be abstracted per area without depleting the aquifers. It is based on estimated mean annual recharge and a rainfall reliability factor, which gives an indication of the possible drought length.
Permeability	The rate at which a permeable material transmits a fluid, expressed as a length per unit time
Recharge	Rate of ingress or replenishment of water into an aquifer expressed as a volume or depth per unit of time
Static (Rest) water level	Water levels are not influenced by pumping and constitute the water table influenced only by atmospheric pressure.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.
Transmissivity	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average

hydraulic conductivity (K) and thickness (b) of the saturated portion of an aquifer (T = Kb).

1 INTRODUCTION

1.1 Background

ORASECOM is one of the first Shared Watercourse Institutions (SWIs) established in 2000, under the SADC Protocol on Shared Watercourses. ORASECOM provides technical advice to its State Parties on matters relating to the development, utilisation and conservation of the water resources in the Orange-Senqu River System. ORASECOM comprises of the Council of Commissioners, the Secretariat, the Groundwater Hydrology Committee (GWHC) and four Task Teams responsible for technical, communications, finance and legal issues. There is also a working group responsible for water resources quality management in the Basin, which meets on an ad-hoc basis. The 2000 ORASECOM Agreement is also being revised to include a Committee of Ministers Responsible for Water in the Basin, known as the Forum of the Parties.

The management and development of the water resources of the basin essentially takes place at three levels:

- **National level**: The basin states have the primary responsibility for the development and management of water resources within their territory. The ORASECOM Agreement obliges the parties to:
- utilise the resources of the River System in an equitable and reasonable manner with a view to attaining optimal and sustainable utilisation thereof, and benefits therefrom, consistent with adequate protection of the River System;
- take all appropriate measures to prevent the causing of significant harm to any other Party
- exchange available information and data regarding the hydrological, hydrogeological, water quality, meteorological and environmental condition of the River System
- notify the ORASECOM Council and provide all available data and information on any project that may have a significant adverse effect upon any one of the parties.
- **Bilateral level**: A number of bilateral agreements pre-date ORASECOM. Bilateral agreements and institutions have come into existence for a specific reason, essentially to implement or manage a project. They include:
- The Lesotho Highlands Development Authority (LHDA) in Lesotho and the Trans-Caledon Tunnel Authority (TCTA) in South Africa supervise and coordinate the work on the Lesotho Highlands Project
- The Permanent Water Commission (PWC), formed by Namibia and South Africa in 1992, advises both governments on the development possibilities of the Lower Orange, the section of the river that forms their mutual border
- **Transboundary level**: At the regional level, the SADC Water Division has been tasked with creating an enabling environment for the integrated management of shared watercourses. Supporting this integrated approach are the Revised Protocol on Shared Watercourses and the Regional Strategic Action Plans. The ORASECOM Agreement is strongly influenced by the SADC Protocol.

This project falls under the ambit of this third transboundary level.

The ORASECOM Integrated Water Management Plan lists as a Strategic Action:

- Improve reliability, usefulness, transboundary confidence areal coverage of groundwater monitoring networks at the transboundary and national (sub-catchment) levels

The objective of monitoring is to address this strategic action. This was defined in the TOR as sub task ii:

***development of a robust framework for monitoring* of important features and characteristics of all transboundary aquifers in the Basin**.

1.2 Methodology

The actions undertaken include:

- Undertake a Literature review of groundwater monitoring studies undertaken in the Basin, including those mentioned in the project TOR;
- Visit the State Parties and their relevant national departments, and assess & reach agreement on their needs & priorities for monitoring, reporting and management of features & characteristics of transboundary aquifers, groundwater quantity and quality in the Orange-Senqu River Basin;
- Draw up a list of priority transboundary aquifer features & characteristics, and groundwater quantity and quality parameters, and variables of concern, and areas (sub-catchments) that require special attention for each State Party, and assess the extent to which current monitoring programmes are appropriate and sufficient for these features, characteristics, parameters, variables and areas of concern;
- Review existing data acquisition and storage systems in each State Party as well as systems used elsewhere to identify best practice;
- Define all protocols and procedures for data sharing between State Parties and acceptability to the wider public;
- Develop a detailed product specification for an internet-based, groundwater quantity & quality and characterisation system in response to the identified needs of each State, which have been agreed by the relevant national departments within each State Party. The system should be compatible with existing national systems or should incorporate recommendations for the upgrading of existing national systems to ensure smooth basin wide integration;
- Validate the proposed transboundary aquifer characterisation, and groundwater quantity & quality monitoring programme/framework with the key stakeholders through a workshop; and
- Develop a final report on the agreed transboundary aquifer characterisation, and groundwater quantity & quality monitoring framework/programme based on inputs from the stakeholders' workshop.

1.3 The Need for Monitoring

Groundwater data – water levels, geosite locations, groundwater quality, and other parameters – is the foundation of groundwater management. Without data, managers and users cannot "see" the resource, determine allocations, ensure compliance with regulations or quantify impacts.

Effective management of all water resources should be based on informed decisions from data, rather than on beliefs and assumptions. For this reason, monitoring and information systems are critical for successful resource management. Efficient and sustainable use of a catchment's groundwater resources cannot take place without adequate monitoring. Especially in the case of groundwater, where impacts are not immediately obvious, monitoring is required to quantify the effects of water and land use management decisions and to make adjustments where these are necessary.

When developing a monitoring strategy, it is important that the purpose of monitoring be well defined and communicated to the stakeholders who need to support the monitoring efforts. It is critical that monitoring needs are established at the outset and that all participants in groundwater monitoring understand the monitoring needs. No data should be collected simply for the sake of populating databases. Monitoring can be an expensive exercise and can only be valuable if the information generated is useful for purposes such as:

- The protection of an aquifer from undesirable impacts. Over pumping causes long-term depletion of groundwater and can damage the aquifer. Water quality can decline due to over pumping. Quality monitoring will determine if the aquifer is being contaminated from sources such as pit latrines, kraals, industry, mining, waste sites, etc.
- Understanding aquifer flow dynamics (i.e. recharge quantification, natural flow patterns and residence times of groundwater).
- The protection of the quality and quantity of water required satisfying the basic human need component of the ecological Reserve.
- The protection of groundwater dependant ecosystems as part of the ecological Reserve.
- Quantifying the effectiveness of pollution prevention measures.
- Quantifying the effectiveness of remediation measures.
- Acting as an early warning system to avoid unnecessary future remediation.

The information can be used for various purposes, e.g. being incorporated in water balance calculations or models, to prepare graphic presentations that communicate useful information to politicians or communities, to produce practical resource operational tools for risk management or as justification for management decisions.

One of the most important goals of catchment scale monitoring will be system characterisation and resource quantification i.e. to characterise the extent and functioning of groundwater resources in the catchment.

Groundwater monitoring data should be used to support decisions for taking actions that might lead to the improvement of resource protection and management. Information collected through groundwater monitoring programmes may also be useful in refining resource classification, delineating future protection zones or updating Resource Quality Objectives.

Reliable and continuous time series of data are key components in managing water resources. Quantifying, modelling, predicting and managing water resources require monitoring data for quantification and calibration of models to extend records and derive scenarios of future use. Monitoring should therefore be the essence of any national hydrological service. However, hydrological services face declining budgets and are shrinking. A World Bank survey of hydrological services in Africa in the mid-nineties, initiated because available hydrological data were often so inadequate found that monitoring networks did not allow for adequate water project feasibility studies and financing decisions.

In South Africa, i.e. both the National Water Act, 1998 and the Water Act Services Act, 1997, for the first time make explicit provision for national water resources monitoring, assessment and information systems. Yet the number of rain gauges and streamflow gauging stations continue to decline, indicating a split between legislation and practice.

Much time, effort and money are devoted to the establishment and maintenance of hydrological monitoring networks. Even more attention is given to elaborate storage and retrieval facilities in sophisticated data banks, and to depicting characteristics of aquifers by GIS image processing, which is often performed with limited or unreliable data. This has been clearly observed when examining reports and seeing data which is flawed and lacking a water balance. Too many officials, this is not evident and reports are implicitly trusted. However, even the best methodologies are hindered by a lack of reliable data. Full appreciation of the importance of good measurements is lacking, which leads to poor motivation of personnel, unreliable data collection, irregular observations, poor control of data quality, and indiscriminate closing of monitoring stations resulting in a loss of valuable information.

1.4 Monitoring Requirements

The data requirements for various purposes are summarise in table 1-1.

Table 1-1 Purpose of monitoring and data requirements

Purpose	**Methods**	**Monitoring data required**
Hydrological Modelling	Hydrological models e.g. WRSM2000)	Rainfall Runoff Spring flow Groundwater levels Abstraction Land use Evaporation
Recharge estimation	Water balance methods (saturated volume fluctuation, CRD, chemical balance, empirical relationships etc)	Rainfall Water levels Abstraction Chloride Storativity
Management	Water resource models (e.g. (WRYM, WRPM) Water level fluctuation assessment	Rainfall Recharge Abstraction Hydrological time series of water level or springflow Dam levels

Aquifer characterisation		Water quality Water levels Baseflow Hydraulic parameters Recharge

Groundwater level monitoring constitutes one of the major components of aquifer studies. A standard and frequent monitoring activity is also the measurement of major spring flow. These provide a visual, measurable indication of the response of groundwater recharge to rainfall fluctuation. An examination of the water level or flow records reveals the characteristics of the recharge. However, interpretation also requires that abstraction be known. The primary objective of the groundwater level monitor programme is to assess the trends in water levels due to large scale water abstraction on a regional level, or non-abstraction related trends, and to serve as early warning system for serious aquifer storage declines. This provides and should continue to provide drought monitoring and reporting functions.

Monthly observations of water levels and of rainfall are quite adequate for most groundwater interpretations and assessments. Regarding the distribution of monitoring points, a higher density would be required for studies of individual aquifers in order to derive the spatial characteristics of recharge and aquifer storativity, and to serve as reference points for reliable hydrodynamic modelling of the aquifers.

Often neglected is the monitoring of abstraction from groundwater aquifers, which is one of the key elements in water balance assessments to derive recharge and aquifer storativity (using the Saturated Volume Fluctuation or Hill method, for example) and other water balance components, or in modelling the hydrodynamic response of an aquifer. Irrigation from groundwater is one of the more uncertain components but could be inferred from rainfall and crop type.

The rainfall depth and quality monitoring are key for recharge calculations and should be supported on an ongoing basis. The scale of these measurements should be extended to a national scale.

Chemical data pertaining to natural groundwaters is useful for: characterising an aquifer in relation to aquifer type and climatic influences; indicating the degree of mixing between groundwaters of different chemical composition; determining recharge by means of the chloride method; establishing if an aquifer is still in a natural state; if it is not, the natural background levels of chloride may sometimes be inferred from the initial measurements.

The establishment of monitoring stations cannot be prescribed but depends to a considerable extent on the purpose for which the measurements are required, which should be clearly defined at the start. Monitoring boreholes are required prior to significant abstraction and need data for several years to assess the exploitation potential of the aquifer and impacts from abstraction.

A good areal distribution of monitoring points is preferable, but the density required would obviously have to be higher for a productive aquifer with abstraction than to monitor the regional piezometric response. As a general rule, approximately 6 to 9 well-spread monitoring points per aquifer or per selected area would provide a representative picture of the groundwater fluctuations in such an area. In such a case the production boreholes would serve as additional monitoring points in reliable hydrodynamic modelling of the aquifer.

The variability of rainfall is probably the least reliable factor and monitored monthly total rainfall at each monitoring station would increase the reliability of the regressions between rainfall and the piezometric levels. In all cases monitoring could be done monthly as this is not only logical and practical but would conform to the measurement of groundwater levels and of the input rainfall.

For Hydrogeological purposes, there is no need for rainfall and groundwater levels to be measured at shorter time intervals but the closer the rainfall is measured to the monitoring point the lower would be the uncertainty induced by spatial variability or unreliable rainfall.

2 GROUNDWATER MONITORING

The decision to establish a monitoring network must be based on:

1) the importance of groundwater as a primary/secondary water supply;
2) the existence of exploitable aquifers for irrigation or as urban water supplies, which is generally indicated by the occurrence of boreholes with high sustainable yields;
3) the sustainability of groundwater exploitation based on the average annual rainfall, with areas of high rainfall being of greater importance. However, exploitation of groundwater on a large scale also occurs in drier areas, where groundwater has been replenished over many years or during pluvial periods of the past;
4) because groundwater exploitation affects the base flow of streams and the ecology.
5) the objectives and criteria of monitoring should be clearly defined, e.g. whether the station would serve a purpose other than merely measuring the groundwater levels; whether rainfall records which date back several years could be utilised; whether it aids surface or groundwater impact studies or aquifer management; whether spring flows integrate rainfall variability over a larger area.

Selection of monitoring points also has certain criteria. Before a new monitoring station is opened:

1) all groundwater records in the area should first be evaluated; abandoned stations should be scrutinized and checked for reliability;
2) what additional information would be forthcoming from the assessment of the hydrological impact of drought intensities and duration should be determined;
3) the accessibility of the points must be evaluated;
4) whether the selected point would be sufficiently representative of a typical aquifer in a specific climatic environment should be considered;
5) if monitoring points are not already in operation and rainfall stations exist in the area;
6) whether monthly measurements would be adequate, but if more frequent monitoring is considered necessary, the objectives should be defined clearly, and the cost should be assessed.

A decision on whether or not to close a station, should be arrived at in a comparable way, using the same criteria mentioned above.

2.1 The Monitoring Process

Monitoring of groundwater comprises several aspects such as:

- identification of monitoring objectives
- identification of measuring sites
- collection of raw field data
- analysis of information including quality control
- interpretation/evaluation of data
- use of information.

2.2 Levels of Monitoring

Groundwater-monitoring networks can be classified into four types (table 2-1), each will have dissimilar needs for data collection, storage, interpretation, and analysis.

Table 2-1 Levels of monitoring

Level	Objective	Description
Reference Condition	Resource and infrastructure planning	Provide monitoring data to determine availability and quality of current and future water resources aimed at providing strategic decision support for the sustainable allocation of resources
Regulatory Compliance	Operations and management	Monitoring for the efficient operation and management of water resources to ensure protection resource and water users
	Compliance and auditing	Provide data to ensure compliance for water use licencing
Early Warning	Early warning notice	Data To mitigate negative impacts

Of the four priority objectives, national networks primarily focus on the Resource and Infrastructure Planning Objectives (2.2.1), while the Compliance and Auditing objectives (2.2.2) forms part of localised monitoring activities. Transboundary aquifer monitoring will fall under the natural condition monitoring and specific purpose monitoring (2.2.1 and 2.2.3)

2.2.1 Natural/Reference conditions baseline monitoring

This level includes collection and analysis of groundwater data on a national scale to provide a reference / background for other measurements. This network provides long term evaluation in terms of natural impacts such as droughts and resource assessment. Correlation between rainfall and aquifer response can be evaluated and a water balance derived. The monitoring points will be selected to represent ambient groundwater conditions that are not impacted by short-term fluctuations caused by human activity. This level of monitoring will measure the natural response of aquifers to conditions over the long term and will be used for resource planning and management purposes.

This data is of relevance at a national level and is essential to determine levels of impact, allocations, and resource quantity. Collection and analysis of groundwater data is on a national scale.

The assessment of available water resources is used to support planning decisions through the modelling of water resources systems that allow for the sizing, timing and phasing of future infrastructure developments and other interventions, and the optimisation of system operating rules.

Water resources assessments are dependent on ongoing monitoring of:

- Hydro-meteorological data to estimate long-term rainfall, water use and groundwater recharge characteristics. These data are also essential for estimating the possible impacts of climate change on the future availability and the quality of water resources.
- Groundwater levels and eye discharges data to determine recharge for the modelling of aquifers, as well as more complex catchment processes such as surface water-groundwater interaction.
- groundwater quality data to assess the allocable water quality, fitness of use, as well as to model the impact of catchment processes and pollution sources on water quality.
- Current and historical catchment water use to assess current and projected future water requirements.

2.2.2 Regulatory monitoring

Water resources systems should be managed and operated according to planned operating and allocation rules to ensure optimal use of the available water resources and the protection of high-priority water users. This requires the ongoing monitoring of impacted or regional conditions specifically for control, management of function and use of the resource. A special subset of this level of monitoring will be to monitor compliance to local regulations, specifically covering the initiation and subsequent compliance monitoring for well field and production boreholes, or for ground stability or contamination. The objective is aquifer system management by assessing water level trends from abstraction, water quality trends, well field interference etc.

This level focuses on groundwater resources that have been affected by human interference, but not the point of interference. In relation to groundwater abstraction, this monitoring will assess the groundwater response within the area of influence, but not at the point of abstraction. This should include the “functions and uses” of the aquifer system.

This monitoring focusses on quantity- and quality monitoring and is of local or regional significance. In relation to groundwater abstraction, this monitoring will assess the groundwater response within the area of influence (its functions and uses), but not at the point of abstraction. The objectives of data collection include:

- The status of surface and groundwater resources to allow for the adjustment of operations in accordance to long-term planning guidelines. Operating decisions are based on the status of reservoirs storage volumes, river flow at abstraction sites, or groundwater levels at well fields. This also includes the quality of resources to allow for the implementation of blending rules, if and where applicable.
- Surface water and groundwater use to monitor use versus licenced allocations.
- Quantity and quality indicators for complying with Reserve and Resource Quality Objectives (RQOs) and to implement operating rules according to the resource status.

Collection of appropriate data for the effective management of groundwater management units and to ensure compliance includes:

- ***quality monitoring***
    - impact monitoring of non-point sources in the catchment
    - seasonal changes (variability)

- impact monitoring near point sources
- compliance monitoring
- wellhead protection zone monitoring (precautionary measures)

- ***quantity monitoring***
  - impact monitoring of water levels for abstraction over an area
  - compulsory recording of abstraction volumes
  - impact monitoring of water level drawdown near wellfields
  - rainfall interaction
  - compliance monitoring (where set as a condition of the abstraction license)

2.2.3 Specific Purpose monitoring

In these networks specific aspects/issues/functions of groundwater and its link to the surface water environment and its components are monitored. Issues like groundwater recharge and water balance are also addresses under this monitoring type. Project- specific and site-specific monitoring of potential human impacts on groundwater in the areas close to abstraction or potential contamination sources are also included. This monitoring is the user's responsibility. It will be defined in the license or water use authorisation.

Groundwater monitoring includes:

- ***quality monitoring***
  - detection monitoring (effectiveness of mitigation measures)
  - remediation monitoring (effectiveness of clean-up)
  - specific license conditions (e.g. upcoming of saline water or sea interface, percent of time water quality below a specific threshold)

The density of sampling sites, frequency of data collection and type of measurements will be site specific and will need to be appropriate to the value and vulnerability of the water resource and the threat posed by the water use (e.g. groundwater abstraction, waste disposal, irrigation, etc.).

- ***quantity monitoring at individual production boreholes or wellfields***
  - recharge and discharge characterisation
  - artificial recharge impacts on the environment
  - quantification of groundwater-surface water interaction
  - transboundary aquifer management and compliance
  - sea water intrusion
  - mine dewatering

2.2.4 Early Warning and Surveillance monitoring

This type of monitoring programmes address point source type impacts and will have a short life time. Monitoring may include:

- **quality monitoring at point sources of pollution**

    - detection of pollution mitigation
    - detection of spillage
- **quantity monitoring**
    - impacts at artificial recharge sites
    - impacts of canals, dams, other structures on the resource

This monitoring also includes risk mitigation, which requires monitoring of groundwater levels and seawater encroachment (from a quantity perspective), all driven by adequate rainfall measurements. Failure warnings of surface and groundwater resources to meet fitness for use criteria supports water quality risk mitigation.

2.3 Designing a Monitoring System

Most network evolved organically and weren't designed to answer specific questions, especially with regards to water quality. Optimisation of a network should be done without considering the current status of the network. The critical and optimal networks should be designed upfront based on what is known of the catchment. Only once an optimal network has been designed should the existing network be evaluated against the optimal/critical networks. The optimisation will have to be done against a set of objectives for the networks. The objectives and sub-objectives should be integrated and agreed upon before implementation.

National monitoring programmes objectives should be primarily for status and trend analysis of the resources and then for other specialised purposes including operational and limited compliance monitoring when international issues are involved. The needs of current and future groundwater users will also guide these objectives.

The development of a conceptual model of the groundwater resource is an essential prerequisite for the design of a groundwater observation network. Without some conceptual understanding of how the system works (e.g. where groundwater is recharged, what direction it flows in, relative rates of flow, etc.), the monitoring network is bound to be haphazard. As a first approach, the system designer needs to have at least some background knowledge on how the aquifer system is hydraulically connected to the regional hydrological cycle in the catchment.

Planning a monitoring network can be considered a 7-step process described below. The outputs form the 7 steps are drawn up in a planning document covering all the monitoring activities and identifying responsibilities of various role players. The items also need to be budgeted to derive an implementation plan

2.3.1 Set monitoring goals

This step selects the monitoring objectives (2.2). It requires establishing current and potential groundwater use in the catchment and establishing requirements for the Environmental Reserve and for future needs (Basic Human needs and Resource Quality Objectives). It also requires establishing areas and requirements for non-point source pollution monitoring. From these statements of monitoring goals are derived.

2.3.2 Establish the monitoring status quo

This step involves collecting information on existing systems and available financial/human resources. It includes establishing what data is currently collected, what infrastructure exists, the length of records, and the available resources and capabilities in terms of manpower, vehicles, analytical facilities, etc.

2.3.3 *Coordination with other monitoring activities*

This step aims to develop a multi-media approach, taking into account monitoring of all natural resources in the catchment by consulting with surface water & water quality managers in other agencies and departments. It aims to find out who is involved in monitoring resources in the catchment e.g. surface water, wetlands, air quality, meteorology, biological indicators (invertebrates, fish tissue), soil/sediments, waste/effluent discharge, etc. to look for areas of overlap, possible cooperation and sharing of resources and coordination of monitoring sites.

2.3.4 *Establishing conceptual model*

The objective is to develop conceptual model of groundwater behaviour on which to base decisions on network requirements and sampling and data collection protocols to achieve monitoring goals. This requires an understanding if aquifer boundaries, and flow characteristics, resource classification or land-use/cover type.

From this conceptual mode, a decision can be made on the number and location of monitoring points, type of installation, the use of new, dedicated sites or existing boreholes, and the sampling frequency.

2.3.5 *Monitoring plan*

The objective should be to develop standardised protocols for sampling, data capture, retrieval and analysis for consistency across the catchment management area. The protocols should consider all the activities that are likely to require monitoring, including land use, change, transboundary conditions, and climate change.

The monitoring plan needs to consider:

- The Network design including sampling station location, parameter or variable selection, sampling frequency, representivity;
- Sample collection needs to consider sampling technique, field measurement methods, sample preservation, sampling point, sample transportation;
- Data handling needs to consider data reception, laboratory to be used, outside sources that collect data, screening and verification, data storage and retrieval, reporting and data dissemination;
- Data Analysis considers basic summary statistics, water quality indices, quality control interpretation, time series analysis;
- Information Utilisation considers the data collection vs information needs, reporting formats.

To determine monitoring point location and sampling frequency, it is essential to have a conceptual model of the system to be monitored.

2.3.6 *Support services and training requirements*

The objective is to identify gaps in the monitoring plan above. These would include gaps in analytical capabilities, resources to capture data and maintain the database, and staff requirements and skills. This may require additional staffing or training.

2.3.7 *Quality assurance and quality control procedures*

The objective is to ensure the collection of high quality data. This includes ensuring staff are trained to collect good quality representative samples, to identify possible anomalous readings, and include methodologies to ensure quality control, such as the use of duplicates and blanks and data checking procedures.

2.4 The Special Case of Transboundary Aquifers

When establishing transboundary groundwater monitoring strategies, the following need to be identified and jointly agreed:

a) the transboundary aquifer and relations to surface water and associated ecosystems;

b) specific human uses of transboundary groundwaters that require monitoring;

c) ecological function of transboundary groundwater resources;

d) pressures which have an impact on the above-mentioned human uses and on the functioning of ecosystems that are dependent on groundwater;

e) quantified, or otherwise clearly defined, management targets which should enable the establishment of restrictions and which can be implemented within a specified time period.

f) Legal considerations, such as SADC Water Sharing Protocols, which stipulate how water is distributed. This requires knowledge of the volumes of the resource available in each country, and its use, which impact on other countries.

When it comes to management strategies for transboundary aquifers, a participatory approach is essential. National groundwater monitoring networks play a key role in transboundary aquifer management. Cooperation and connecting national networks is a first step towards transboundary water management.

2.5 Monitoring Groundwater Use

A major aspect of groundwater monitoring, and one of the most problematical, will be groundwater use. For any resource to be optimally managed, the current levels of utilisation as well as the maximum available quantity (recharge and exploitation potential) need to be known. Without monitoring use, the resource manager has no support for decisions on whether the resource is over-utilised, and measures are needed to limit use, or whether it is underutilised, and use can be promoted.

Groundwater use data is a major uncertainty in water balance calculations. Even small users can collectively constitute a very large volume. Hence licencing of large users alone may not be enough.

Obtaining information on how much groundwater is being abstracted is always difficult, as groundwater abstraction volumes are often not measured. Even when meter installation is mandatory, if this data is not submitted or not captured, it is of little value.

The abstraction volumes measured also must be checked against license conditions, to refine understanding of the water balance within a catchment and to assess the status of groundwater allocation. It will also provide a means of checking that licensed volumes are being adhered to.

Besides flow meters, assessments can also be undertaken based on power consumption records or mapping irrigated land areas and calculating water use from expected crop requirements and from population records where the population is on groundwater. If there is sufficient motivation for an accurate water use assessment, a detailed hydrocensus (validation and verification studies) can be undertaken.

2.6 Selection of Monitoring Sites and Data Collection

The obvious goal is to select representative sites where to monitor to gather meaningful data. National and catchment monitoring make wide use of existing boreholes to avoid excessive cost. The network plan should consider:

- Sites representative of geographic distribution
- Sites representative of predominant land uses or changes in land use
- Sites representative of differing geologies and flow regimes
- _Sites representative of main aquifer units
- Sites in close proximity to other monitoring sites e.g. surface water stations or rainfall stations
- Sites representative of the use of groundwater
- Ease of access and permission from land owner
- The age, type and condition of the installation (borehole, gauging station, etc.)

Monitoring should be focussed at the interface areas where groundwater enters or leaves the aquifer i.e. recharge and discharge (or abstraction) zones, or where legal obligations require information, such as national borders in transboundary aquifers. Water balance calculations on stream flow may be useful in identifying where groundwater is a major contributor to surface water systems (and vice versa) as well as areas where little value would be gained from detailed groundwater monitoring.

2.7 Frequency of Measurement

Selection of monitoring frequency depends on the Intended use of the data and the rate of response of the aquifer to transient events. For water use monitoring, monthly intervals are sufficient where water use varies greatly by season. Annual accumulations are sufficient for water balance calculations. When monitoring water levels for a national network, bi-annual monitoring is the minimum required to observe trends in water level in background network. If analysis for recharge is required, then monthly readings are required. For a regulatory monitoring network, at least quarterly monitoring would be required.

Rainfall data is required to relate to water level data. Rainfall should be collected daily, or at a minimum as monthly accumulation.

2.8 Water Quality Monitoring

Water quality monitoring is generally conducted at a lower frequency than water level (quantity) monitoring, chiefly because of the time and costs involved in sample collection and analysis.

For national monitoring of water quality, when not related to site specific contamination regulatory monitoring, biannual sampling is sufficient. These should correspond to the peaks and troughs of the water level measurements I.e. the recharge season and end of the dry season.

Boreholes used for public water supply should be sampled weekly or even daily, if possible.

Data related to quality incudes:

- Physical measurements (e.g. temperature, electrical conductivity)
- Chemical measurement (e.g. pH, alkalinity, species concentrations)
- Specialised measurements (e.g. stable isotope ratios)

The selection of which data to collect, particularly in the case of chemical variables are based on:

- determinants which affect the fitness of the water for a particular use,
- determinants or indicators which reflect the impact of known point and non-point sources in the area
- Use risk-based prioritisation to select determinants which have the greatest risk of damaging human or ecosystem health
- Resource based determinants which help to quantify various aspects of the behaviour of the aquifer, such as chloride or isotopes to help with recharge calculations and the relationship between them.

2.9 Types of Groundwater Data

4 types of data are generally collected:

1. Site data: Coordinates of monitoring points and method of measurement and accuracy of coordinates, Coordinates of production boreholes, springs, etc., Geometry of the aquifer system, Elevation of ground surface, Elevation of top and bottom of aquifers and aquitards, length of casing and screens, Diameters and depths of boreholes, geology and lithology
2. Variables or dynamic data: Piezometric head (groundwater level), Pumping rate/injection rate, Sspring flow rate, Abstraction volume, Precipitation, Temperature, Electrical conductivity, pH, Concentrations of chemical elements, ions and compounds (macro and trace elements), Stable and radioactive isotopes, Microbiological variables
3. Aquifer parameters: Hydraulic parameters used in groundwater flow models or yield assessment e.g. hydraulic conductivity, transmissivity, storage coefficients, borehole yield
4. Owner Information: Owners details, access information, abstraction equipment, Licence information, use of water, Water allocated volumes

Types 1, 3 and 4 are collected once off to populate a geosite, and have a date recorded. Type 2 requires regular monitoring and a date attached.

3 MONITORING IN ORASECOM COUNTRIES

3.1 Botswana

3.1.1 Background

Groundwater supplies two-thirds of the national water consumption. Groundwater resources are used throughout the country for livestock, municipal supply, and for small areas of irrigation. In most parts of Botswana, groundwater abstraction is depleting limited resources. It is estimated that over 21,000 boreholes exist in the country, but many are not used and capped. Just over half of the registered boreholes in the country are owned by the government, the remainder by private individuals.

All groundwater use requires a permit and metre, but this only happens for large users. The permit application must state purpose of use and volume. Permit approvals are made based borehole yields from test pumping. There is no set target of maximum abstraction per area based on a harvest or exploitation potential.

All areas with wellfield (> 5 borehole) are considered groundwater control areas and no further permits or abstraction is allowed.

3.1.2 National groundwater monitoring network

Groundwater level monitoring in Botswana suffers from split responsibilities. The Water Utilities Corporation monitor only abstraction holes, while the DWA (Department of Water Affairs) monitors background holes. The Department of Geological Survey (DGS) was monitoring undisturbed areas but it was suggested this has stopped. These departments fall under the Ministry of Mineral Energy and Water Resources. The objectives of DGS were to observe long-term groundwater level behaviour under natural conditions and to accumulate data for future economic development and resources management. The DWA focuses on observation of long-term groundwater level behaviour under pumping conditions to observe changes and to see the aquifers' responses to stress. As such, the DGS monitoring can be considered background (2.3.1) and the DWS network as regulatory (2.3.2), and the WUC networks as compliance (2.3.2).

According to the DWA, there is no national background monitoring framework currently operating and they are only monitoring wellfields with some background boreholes. The strategic or background network was established only on a project basis. None of the networks monitor transboundary flow, nor surface-groundwater interactions.

The network consists of about 800 boreholes. Figure 3-1 shows the 27 major wellfield being monitored. 57 boreholes have continuous recorders.

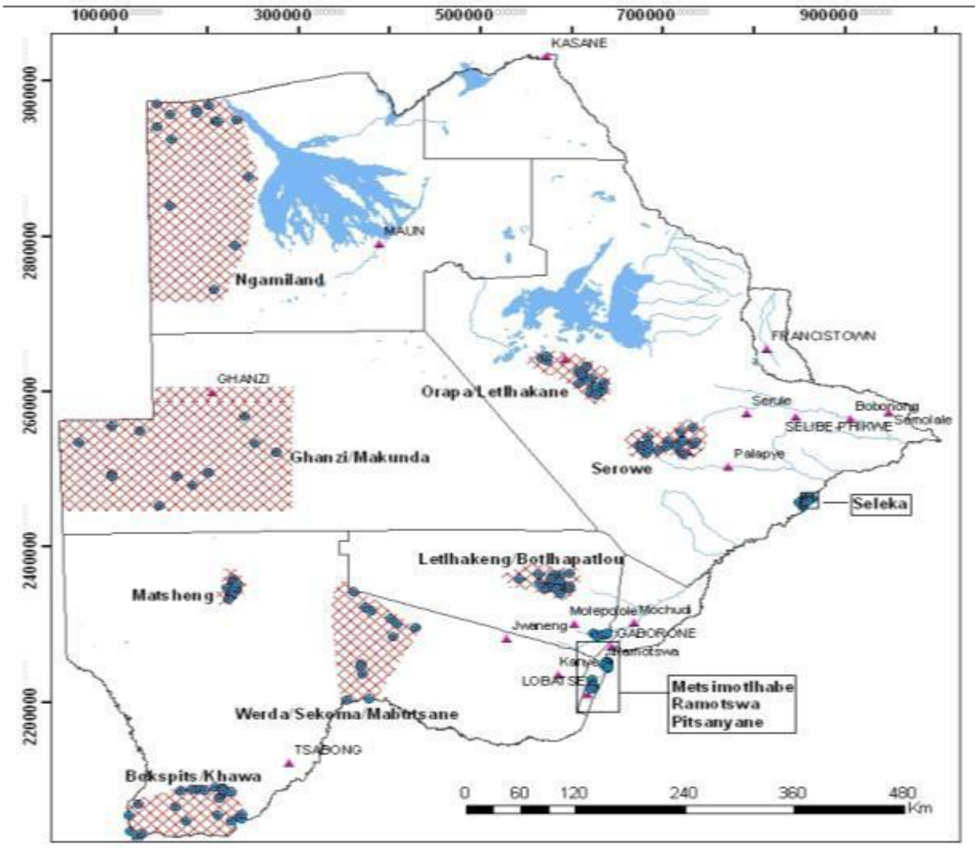


Figure 3-1 Wellfields monitored in Botswana

Monitoring activities include groundwater levels observations, estimation of abstraction rates, and specialized (project related) monitoring. Most groundwater levels are measured on a monthly basis. Observation wells equipped with digital loggers are measured daily. Water quality is only monitored as hoc.

3.1.3 Data management and assessment

DGS records the groundwater data into a national borehole archive (NBA) as paper records and some on the MS-DOS NBA (Nation Borehole Archive) with some on spreadsheets. This contains general borehole information as from construction (borehole Completion certificates). The Department of the Geological Survey (DGS) has not entered much of the data that were collected over the years.

DWA stores their data into WELLMON software. The various databases are currently not properly linked. WELLMON is a software package for groundwater monitoring data, meteorological data and other parameters, which produces groundwater hydrographs. Currently, WELLMON only contains groundwater level and abstraction data. In general monitoring data are of good quality, however, the quantity and quality of the data obtained from the automated charts is often very poor. Data is graphed to check for consistency and continuity before it is entered into the system.

Abstraction data is stored in WELLMON and the data sets are from time to time somewhat problematic and generally the data within the WELLMON is poor.

The ad hoc water quality data is stored in the AQUABASE database. The database contains water quality analyses of surface and groundwaters. This database does not contain and detailed positional data.

3.1.4 *Institutional arrangements*

- Ministry of Mineral Resources and Water Affairs: coordinate activities related to water and mineral exploration, exploitation and management
- Department of Water Affairs (DWA): providing drinking water to all villages and towns (including groundwater exploration, development and management)
- Department of Geological Survey (DGS): regional scale exploration and resource assessment based on long term development and management plans
- Water Apportionment Board: award water rights to various users
- The government established the Water Utilities Corporation (WUC) in 1970 which is responsible for supplying water to mostly urban areas (mainly using surface water from dams)
- The Joint Permanent Water Commission (JPWC) between Botswana and Namibia (1990)

3.1.5 *Challenges*

The following challenges were identified

- Some government departments do not recognize the need to monitor.
- the spatial density of observation wells in Botswana is not yet adequate since it focuses on wellfields
- Additional challenges stem from lack of coordination between departments
- Delay in data processing has resulted in inconsistent data series, which subsequently has generated time series with numerous data gaps.
- Data analysis is not undertaken to add value, such as recharge estimation, and staff only look at trends in water level
- There is no water quality monitoring network
- With no harvest potential available against which to base allocations, no cognisance is taken of existing groundwater use against available resources. The prevention of any further abstraction where a wellfield exists is severely limiting to future development,
- Only large abstractions from mine and industry report on water levels, abstraction and quality annually. The WUC often doesn't report
- Permit holders can pump over permit limits since there is no assessment of compliance.
- The WUC and nonindustrial users often doesn't submit data and there no legislative mechanism for legal enforcement only the land act. If person has an integrated land use permit the DWA cannot control abstraction in control areas.
- A Water Apportionment Board exists, but often there is no recommendation from DWA hydrogeology due to lack of capacity, so the Board cannot regulate water allocations. A Water Regulatory board is being established in future. Validation and verification of water use will fall under this new board

3.1.6 Recommendations

The following tasks are strongly urged to improve groundwater management and monitoring

- The development of recharge and harvest potential per units so that allocated permits can be compared to available resources without constant referral to a hydrogeologist and subjective evaluations
- An integrated database is required for capturing borehole data and monitoring data, hosted at one department
- A strategic network needs to be established in transboundary aquifers to at least monitor rainfall, abstraction and groundwater gradients towards the border

3.2 Lesotho

3.2.1 Background

In many rural and some peri-urban communities in Lesotho, groundwater is the only source of potable water. Groundwater is accessed through natural springs and boreholes. The majority of the boreholes are located in the lowlands of the country, whereas the natural springs are distributed throughout. There is limited potential for irrigation with groundwater in Lesotho since most aquifer yields are low.

Many households have privately owned boreholes from which they are tapping groundwater. These privately owned boreholes are multiplying, and the volume of groundwater being abstracted is unknown.

Efforts are being made to collect this information and to control and regulate borehole drilling in the country by involving the drilling community in national level groundwater meetings. A standard form for collection of drilling, construction and test pumping data has been produced by DWA based upon data input requirements but its use is limited to the DWA. The Department of Rural Water Supply (DRWS) used borehole completion forms produced by the Department of Water and Sanitation of South Africa. Although comprehensive, they are usually completed by drillers recording little meaningful data.

The DWA has a database contain 8070 records of which about 70% have been geo-referenced. The database is held in spreadsheets and is fully compatible with the Arcinfo based GIS system. This database can be imported into Access and thereby transformed into a series of component Excel spreadsheets.

The DWA is looking into the implementing the WISH software as a national data base.

The DRWS provides data from boreholes drilled for rural water supply in the National Database (NDB). The NDB is an administrative database listing information such as village name, borehole depth, handpump type and installation information. Although it is the largest database of borehole and spring data, the NDB lacks technical data such as georeferenced co-ordinates, geological logs, borehole yield, test pumping data and hydrochemistry.

To drill a borehole requires a construction permit. No limits exist on distance from a river where boreholes allowed. Boreholes can be drilled anywhere, which creates a potential for baseflow reduction.

Only non-domestic use needs an additional water use permit. Only safe yield from test pumping is registered, not use, in the permitting system. The only use calculation is based on based on 30 l/c/d

There have been signs of groundwater stress in the Caledon basin. During a recent drought, production boreholes dried up and some monitoring holes were converted to production holes, further reducing the network.

Yield is recommended by pump testing, hence considers borehole yield, not aquifer yield. Interference is not considered, nor Harvest or Exploitation Potential, which may explain wellfield failure.

3.2.2 National groundwater monitoring network

The Department of Water Affairs (DWA) in the Ministry of Energy, Meteorology and Water Affairs (MEMWA) is the executing agency for the national groundwater monitoring network. Groundwater monitoring started in the early 1990's with only a few springs across the country. Currently the network consists of 162 monitoring springs and 72 observation wells (figure 3-2). The network has since been reduced to 42 boreholes and 130 springs due to vandalism, collapse of boreholes, and conversion of monitoring boreholes to production boreholes.

Monitoring is of abstraction boreholes and monitoring boreholes near the wellfield. Hence is a compliance type of network, not a true background network. Seven wellfields are monitored. DWA doesn't analyse water level data for recharge; just evaluate data qualitatively for signs of stress.

Water quality monitoring is ad hoc and random and based on wellfields. Quality issues include iron, Mn, F No3 biological contaminants.

Both observation wells and springs are monitored every three months. Springs are monitored on their yield and physical parameters, such as pH, temperature, EC, salinity and redox potential. Chemical water quality parameters are measured once a year.

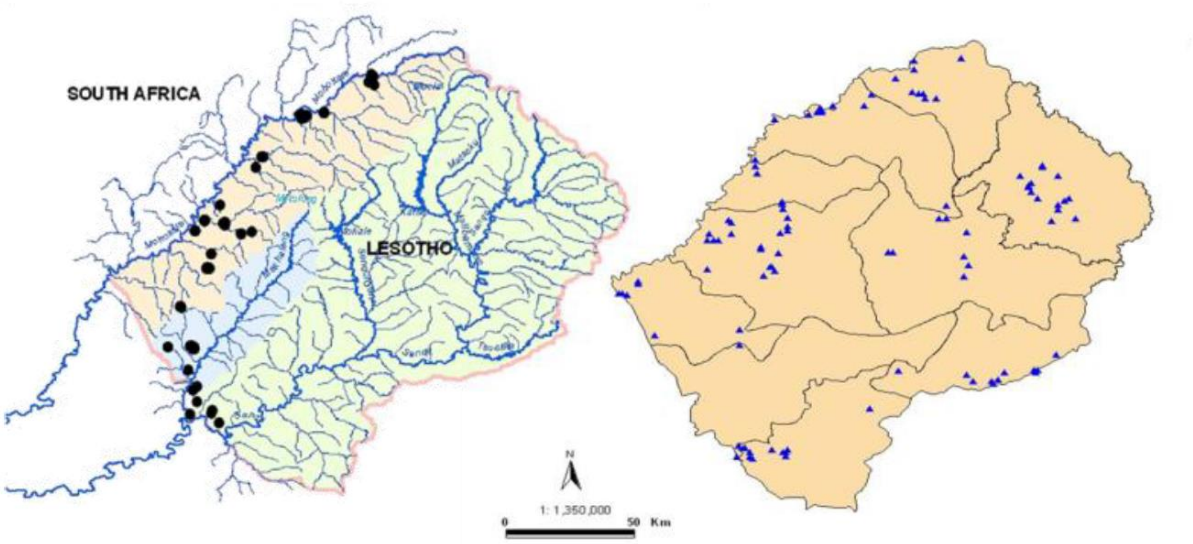


Figure 3-2 Location of monitoring boreholes (left) and springs (right)

3.2.3 Data management and assessment

The NDB Data base is not active. Data is now stored in excel spreadsheet. This data is available on request. The spreadsheet is uploaded to aGeographical Information System. Data is not publicly available online but can be given out publicly on demand. The groundwater division performs annual groundwater resources assessments. These assessments include determination of the seasonal fluctuations of the water table, determination of groundwater flow direction and sustainability of groundwater abstraction.

3.2.4 Institutional arrangements

- The legal framework for the transformation of the water sector was established only when Lesotho's King Letsie III signed the new Water Act of 2008. The institutional framework for an efficient water sector is being established
- Ministry of Natural Resources: coordinates development and operational activities in the energy, water and minerals sector
- Department of Water Affairs (Incl. Groundwater Division): responsible for water sector administration, policy and data collection
- Department of Rural Water Supply: responsible for supply of water to rural communities
- Water Tribunal: to adjudicate over disputes arising under the Water Act or any other law in relation to or in connection with the management of water resources
- Local Authorities: responsible for developing and implementing catchment management plans for the protection and use of water resources in line with water and sanitation strategies
- Water and Sewerage Company (WASCO): takes care of water treatment and distribution. Note that the Water and Sewerage Authority (WASA) was transformed into WASCO

3.2.5 Challenges

The following challenges can be identified:

- Due to financial and human resource constraints monitoring points and frequency of monitoring is limited.
- Lesotho needs public awareness on the importance of groundwater. There is a poor understanding of the importance of observation wells among local communities.
- Although a good density of boreholes and detailed geological maps (may) exist, data crucial for hydrogeological assessments are rarely recorded.
- With decentralisation of rural water supply and greater involvement of NGOs, there has been a tendency to use minimum standards of construction to reduce the borehole installation costs. The use of minimum diameter borehole components results in access of water level measuring equipment being sacrificed.
- With no harvest potential available against which to base allocations, no cognisance is taken of existing groundwater use against available resources. The prevention of any further abstraction where a wellfield exists is severely limiting to future development,
- The groundwater monitoring network is also hindered by a poor streamflow and rainfall network. Many gauge rating curves need to be recalibrated to obtain baseflow figures for recharge estimation. The rainfall network has been reduced from 120 gauges to 35, but this was not confirmed by the Meteorological services.

- Since most abstraction occurs in the Lowlands, in catchments shared with South Africa, transboundary aquifers are important. To manage allocations, allocations on both sides of the border need to be known
- Software for monitoring is a priority since the current spreadsheet system is not suitable as a national data base
- Since most abstraction takes place near perennial rivers, the impact on baseflow needs to be quantified
- The current Monitoring holes are sited as production boreholes, nor for not monitoring
- Private sector use is not monitored. Only mines and utilities have records of use. Industrial water use is the biggest problem
- After issuing of a water use permit, only spot check of big users takes place. There is no set way of checking compliance
- No data on GW contribution to Baseflow exists, (But the South African GRAII does include Lesotho, albeit, it is uncalibrated)
- There is a challenge protecting wetlands, which have a high impact on low flows. They are now monitored with piezometers and for discharge. This is a sperate network. However, monitoring does not ensure protection.
- Some data is collected but not captured as it is not trusted. They are sensitive to bad data. They also have a problem of capturing data due to staffing
- Priority is how to incorporate private contractors for capturing data. Have standard forms but not used.

3.2.6 Recommendations

- The development of recharge and harvest potential per units so that allocated permits can be compared to available resources without constant referral to a hydrogeologist and subjective evaluations
- The development of a monitoring strategy (Where to monitor, how, which aquifers etc) is seen as a priority by the DWA
- The DWA expressed a need for drought recharge figures, however, this can be mitigated if harvest potential figures were available.

3.3 Namibia

3.3.1 Background

Namibia is the most arid country in sub-Saharan Africa and depends strongly on its groundwater resources. Rainfall is variable. The western part of the country is a desert, the southern part which lies within ORASECOM is arid. Groundwater is pumped for domestic, livestock and wildlife consumption, as well as for mining, industrial operations and irrigation.

Over 100 000 boreholes have been drilled for groundwater exploration. A large number of these boreholes were either dry or dried up over time. It is estimated that there are more than 50,000 production boreholes in use, as the country does not have any perennial rivers within the country apart from those that form the border with neighbouring countries.

There are some 40 000 records of Borehole Completion Forms of WW-numbered boreholes. The captured data records farm name and number, borehole depth, water strikes and associated yields, lithology and casing and more recently drilled boreholes include GPS data. The Department of Water Affairs owns the data sets. Some 90 000 water chemical analyses of mainly major ions plus some bacteriological data is also available. Many operational analyses from distribution networks and chemical data from numerous groundwater schemes are also available from DWA. In addition, there are some 30 000 groundwater samples analysed by the CSIR during the CSIR Water Quality Project between 1965 and 1981. NamWater reports on production borehole utilisation rates on a monthly basis. DWA water analyses done prior to the 1980s (about 50 000 records) exist only as paper copies.

More recent Water quality data is captured in an ACCESS database and other data as EXCEL spreadsheets. The CSIR Water Quality Map analyses data sheets have recently been captured and available in an EXCEL spreadsheet.

Under the existing Water Act of 1956, permits for large-scale groundwater abstraction are only required in Groundwater Control Areas of Namibia. In the Orange River sub-catchments these are the Windhoek – Gobabis areas; the Stampriet Artesian Basin, and the Maltahohe artesian area. Good records exist for the Stampriet Artesian Basin.

Any abstraction for more than 1 ha of irrigation requires a licence. For domestic consumption, an abstraction of > 200 000 m3/a needs licence. Every licence must have a water meter in theory and must submit quarterly. There are some spot checks but no set schedule.

Allocations are then based on a historic volume per compartment, equivalent to a basin. This is a coarse form of Harvest Potential on a large scale. This is a problem if abstraction occurs all in one place. They divide a basin into high and low productivity and have different allocations.

3.3.2 National groundwater monitoring network

The Department of Water Affairs and Forestry is responsible for national groundwater management. Groundwater level monitoring started in Namibia in the 1960s. The Monitoring Network consists of over 2000 stations. They are currently monitoring 630 of which 196 are digital. The rest are inactive.

The network consists of a master station network for representative sites in each major aquifer, and a Selective network for GWC areas where use and water level are monitored. Monitoring covers all high and moderate potential aquifers

Groundwater monitoring is carried out through manual measurement and downloading of digital loggers. The readings are supposed to be done on a quarterly basis in all basins, however in practice it is biannually. Over the past year, Namibia has invested in advancing groundwater monitoring by purchasing and installing digital loggers in most of the existing observation wells. Strategies have been developed to increase the numbers of observation wells in areas that were previously not monitored. Groundwater quality monitoring is ad hoc.

Borehole loggers and recorders have been in operation at selected groundwater dependant towns and villages. Water levels are also monitored in the Stampriet Artesian Basin (south of Gobabis and east of Mariental). During a Japanese funded development project, ten additional observation boreholes were drilled to monitor the hydraulic characteristics of various aquifers in the area (Kalahari, Auob and Nossob aquifers). The location of the monitoring boreholes is shown in figure 3-3.

They do put out status reports for aquifers.

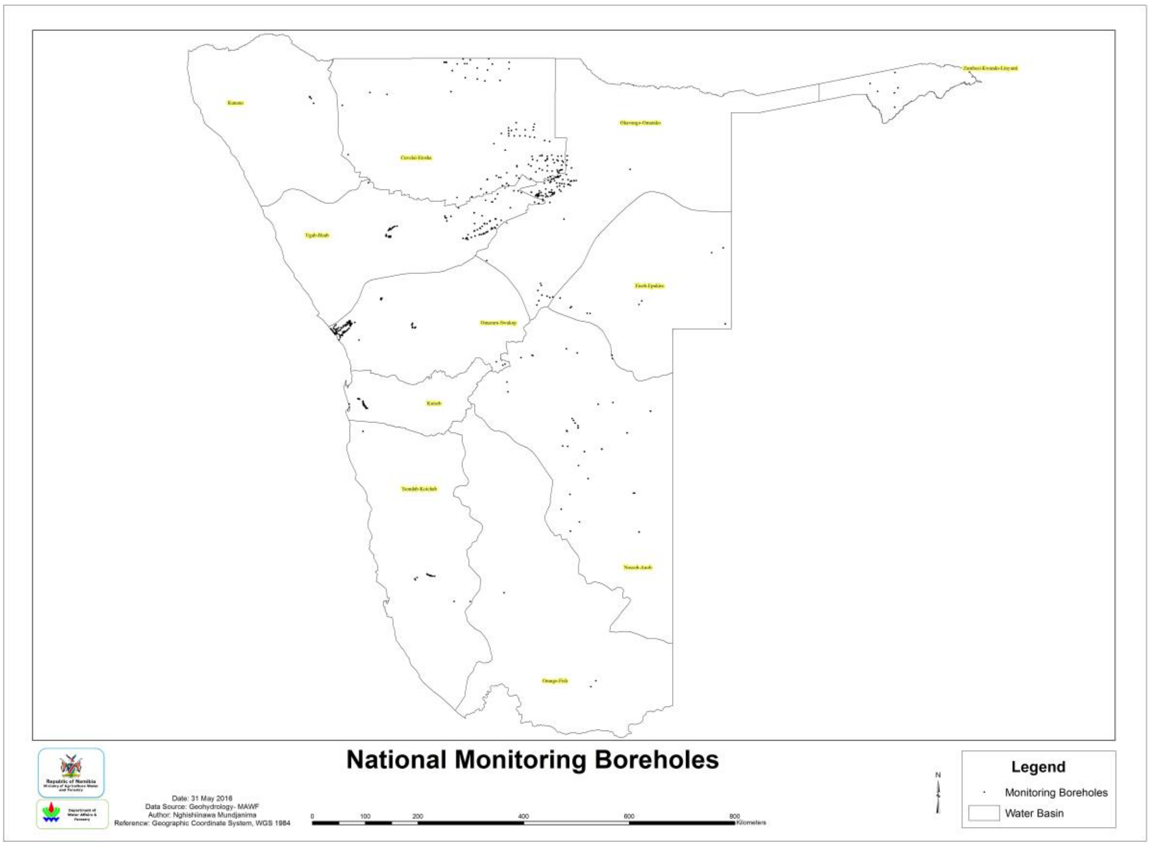


Figure 3-3 Locations of water level monitoring points

3.3.3 Data management and assessment

In Namibia the groundwater database is hosted in the Ministry of Agriculture, Water and Forestry (MAWF). The National Groundwater database called GROWAS, which has been superseded by GROWAS II, which is linked to a GIS. The database is used for storing groundwater data such as groundwater levels, groundwater quality, permits for abstraction and all the hydrogeological data in the country. The data is checked and verified before being entered in the database. The database is not publicly available, but data can be supplied on request as csv files or shp files.

The database contains:

Information from boreholes consisting:

- General Borehole Information
- Water Analysis
- Groundwater Monitoring of water levels
- Hydraulic Testing
- Geophysical Siting
- Permits and allocations
- Borehole Equipment

The database also contains a documents archive. The GROWAS front end is implemented in MICROSOFT Visual Basic 6.0, the database itself is running on MICROSOFT SQL Server 2000. The data model was designed by the Division Hydrogeology who is also the custodian of the database.

Each major aquifer is operated according to an aquifer management plan. However, the knowledge about the water balance, or recharge versus abstraction, is often insufficient due to short historical records of these aquifers. Regional groundwater reporting has not yet been done in the country, but plans are there to start with this.

Data can share data if an application to Permanent Secretary is made with a stated purpose.

3.3.4 *Institutional arrangements*

- The Ministry of Agriculture, Water & Forestry (MAWF): responsible for the entire water sector incl. waste water; Directorate Resource Management: general observation and management; Division of Geohydrology: groundwater investigations and groundwater management (incl. monitoring water quality and quantity); Directorate Rural Water Supply and Sanitation: coordination for rural usage
- NamWater: a parastatal responsible for bulk water supply throughout the country; Urban water supply is the responsibility of the regional or city councils except for the cities of Oranjemund, Tsumeb, and Grootfontein, where water supply is developed and managed by the private sector
- Permanent Joint Technical Commission (JPTC) between Angola and Namibia on the Kunene River
- Joint Permanent Water Commission (JPWC) between Botswana and Namibia (1990)
- Permanent Water Commission (PWC) between South Africa and Namibia on the lower Orange River
- Permanent Okavango River Basin Water Commission (OKACOM) between Angola, Botswana and Namibia

3.3.5 *Challenges*

- Human capacity is lacking to carry out the groundwater monitoring in all basins. Challenges are financial and rehab of network and staff. Only 22 of 48 posts are filled in geohydrology department
- There is a problem with the ability to undertake data analysis. They have some thresholds which function as an operating rule to limit abstraction in groundwater control areas, but no rigorous approach.
- Groundwater quality monitoring is inadequate as well as data processing.
- Four of the monitored aquifers in Namibia are of transboundary nature. For transboundary monitoring it is often politically difficult, and time consuming to amend legal provisions and make organizational arrangements.
- The harvest potential or natural recharge of the country has not yet been fully determined. For some schemes and projects, the safe yield has been determined but since recharge is

rainfall dependent and as rainfall is highly variable, such values must be viewed with caution. Harvest potential information for certain areas does exist in certain reports but is on a very coarse basin level. A qualitive overview is presented in the Hydrogeological Map of Namibia, however, this map is not quantitative, so of very limited value. A process to upgrade the map with quantitative data has been initiated.

3.3.6 Recommendations

- The staffing needs to be upgraded as the extent of the existing network is already large for the small existing staff
- The resource assessment needs to be upgraded to derive a harvest potential per sub-basin, or per km^2 so that allocations can be made on a quantitative basis, rather than on basins as a whole on historic information. The existing network can be utilised to derive such estimates and recharge values.

3.4 South Africa

3.4.1 Background

Groundwater resources in South Africa are limited, since large porous aquifers occur only in a few areas. Despite their limited availability, groundwater resources are extensively utilised in the rural and more arid areas. More than 400 towns and 80% of the rural settlements depend on groundwater. South Africa has several areas of large-scale abstractions for irrigation, which puts a lot of pressure on the groundwater resources. It is foreseen that groundwater use for human consumption will increase, especially in the western part of the country which lacks perennial rivers.

3.4.2 National groundwater monitoring network

The National Water Act (Act 36 of 1998) provides the Department of Water and Sanitation with the mandate to protect, use, develop, conserve, monitor, manage and control South Africa's water resources in an integrated manner. South Africa is advanced regarding its groundwater monitoring network. Groundwater is monitored to identify spatial and temporal trends as well as to understand the cause and effect relationship of groundwater changes in affected areas.

Groundwater level monitoring started in the 1950s and the number of active stations increased to almost 3 000 across the country in 2005. About 3800 stations have existed in total. However, since then this has decreased so that less than 2000 are still open (table 3-1) (figure 3-4).

Table 3-1 Number of stations – South Africa

Open Stations			Coverage (km^2/station)		
Water Level	Groundwater quality	Rainwater quality	Water Level	Groundwater quality	Rainwater quality
1978	407	69	645	3135	18492

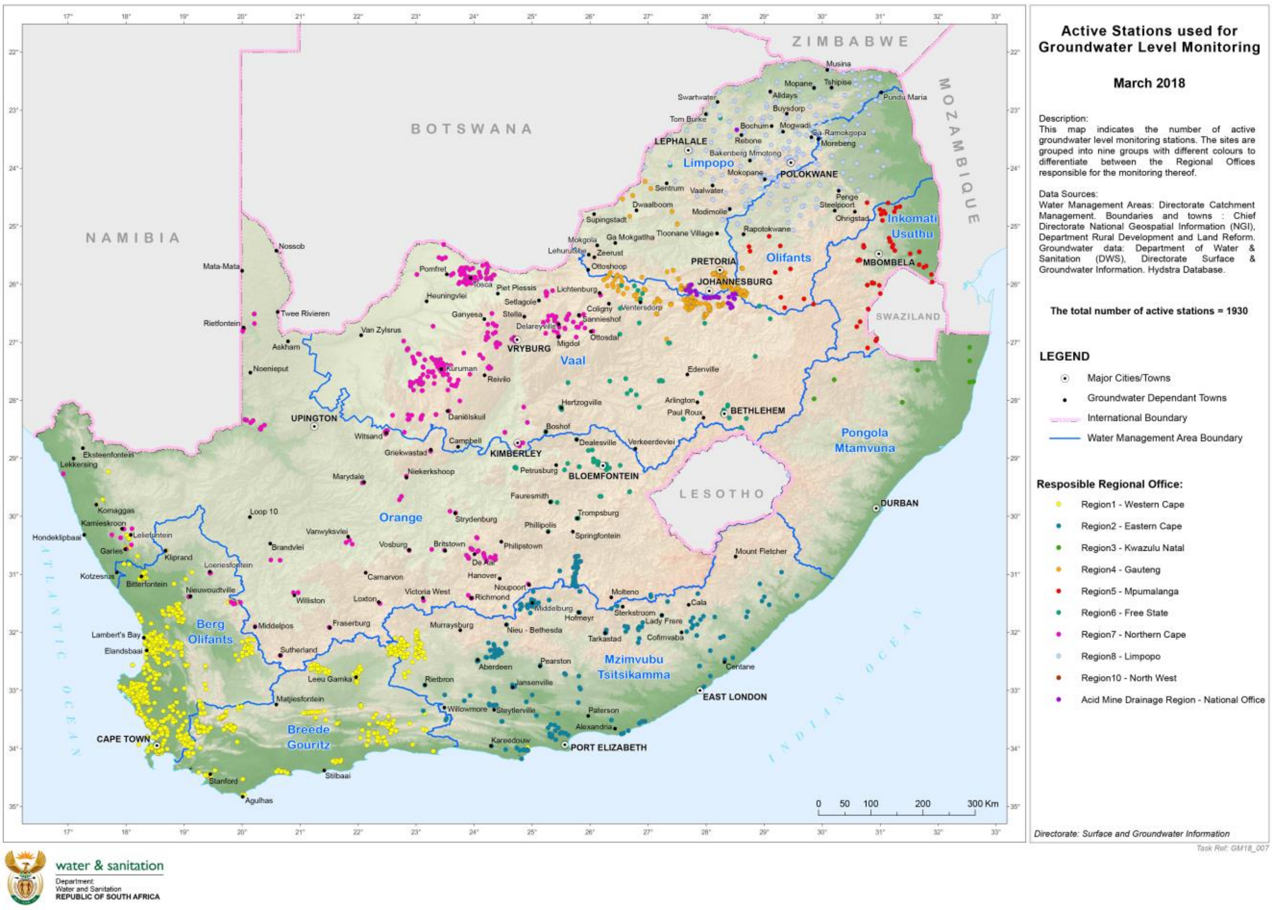


Figure 3-4 Groundwater level monitoring South Africa

This network includes a background monitoring network. About 450 have electronic recorders. The number of stations has been in rapid decline since 2010 (figure 3-5). Monitoring consists of electronic real time data while some monitoring points are still measured manually every three months. Of the open stations, almost 60% of the open stations water levels are still monitored manually. The declining number of stations is of concern as only 30% of the stations extend to present, or near present that include 2014 data in their records and over 3 000 stations have records that end before 2010. A data base is available of all monitoring stations and their status

https://www.dwa.gov.za/Projects/NWRM/doc/Copy%20of%20NWRM_Data%20Catalogue_20150430.xlsx

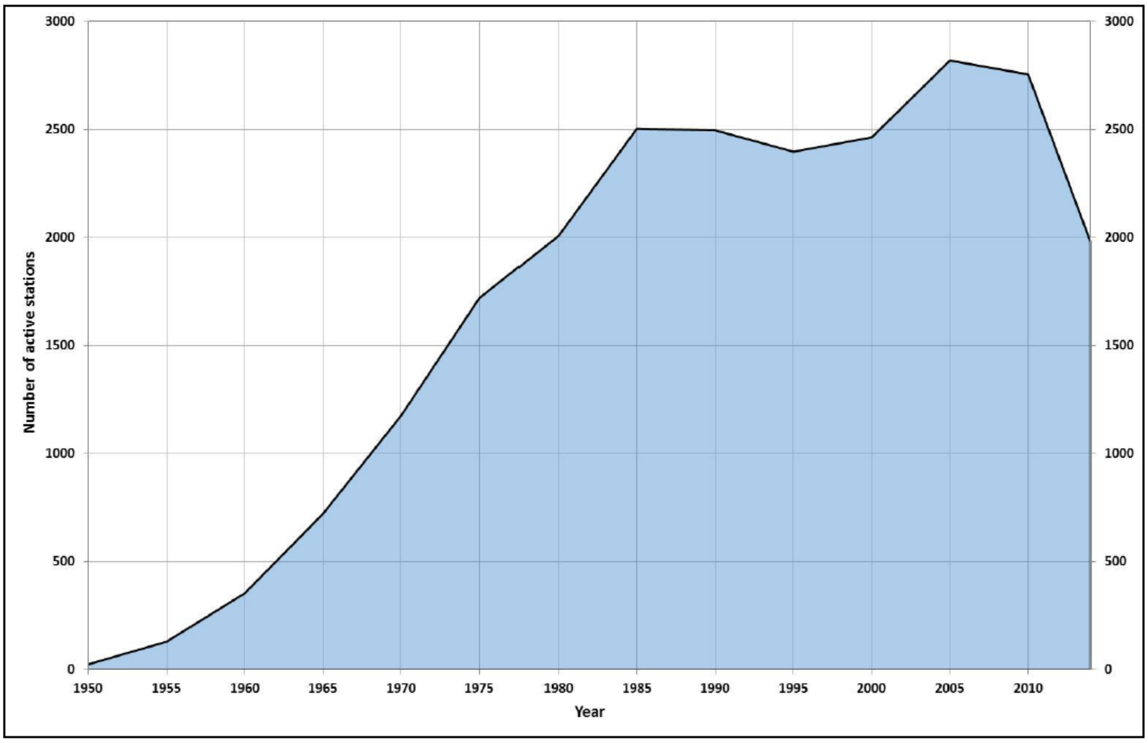
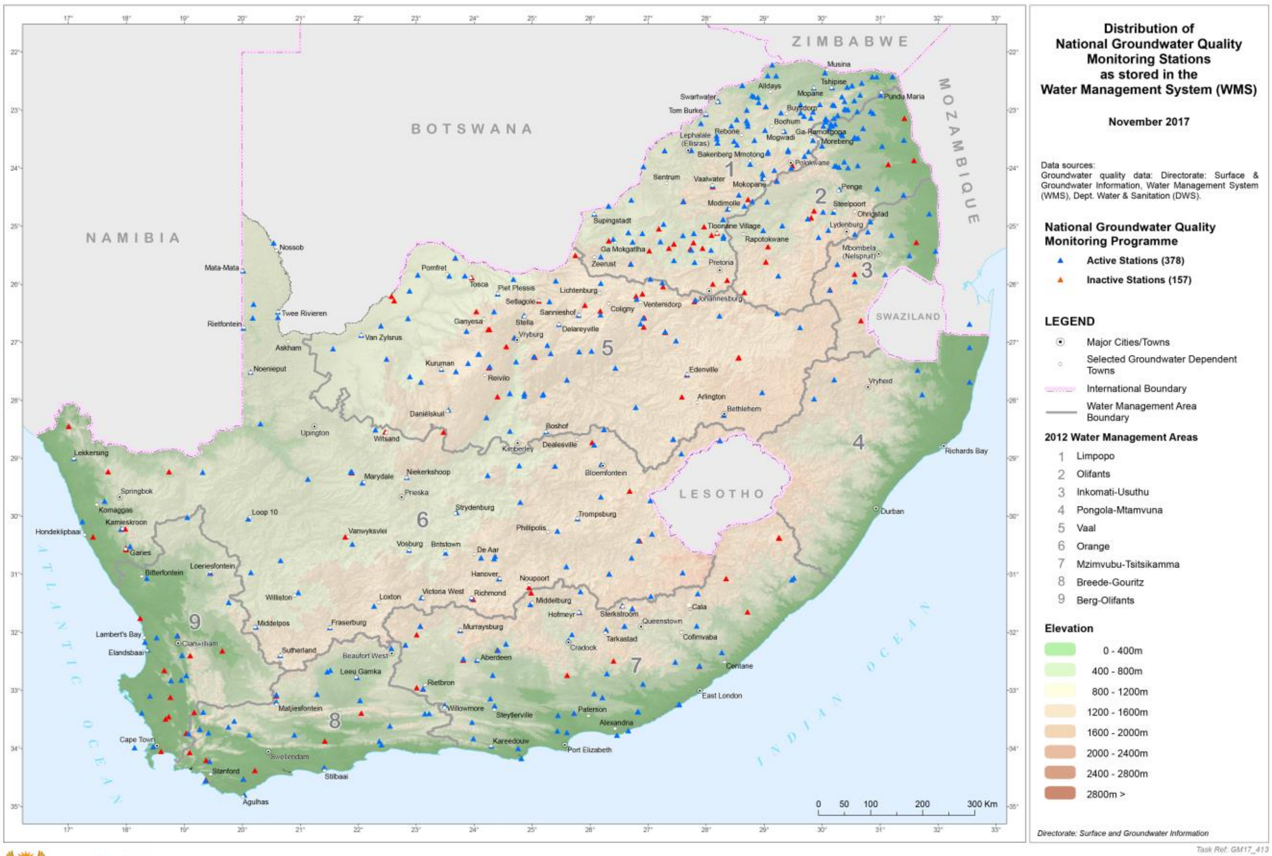


Figure 3-5 Number of active water level stations

Longer records are in general more useful in terms of presenting variability and trends, and very long records provide particularly valuable information about climate change and long-term hydrological trends. The number of borehole water level records with data series more than 30 years long is a suggested indicator of this quality.

There are 422 chemical monitoring points, which are sampled twice a year (end of dry - and end of wet season) (Figure 3-6). Samples are analysed on macro elements and trace elements. The number of water quality stations has gradually increased (figurer 3-7).



water & sanitation
Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Figure 3-6 South African water quality monitoring network

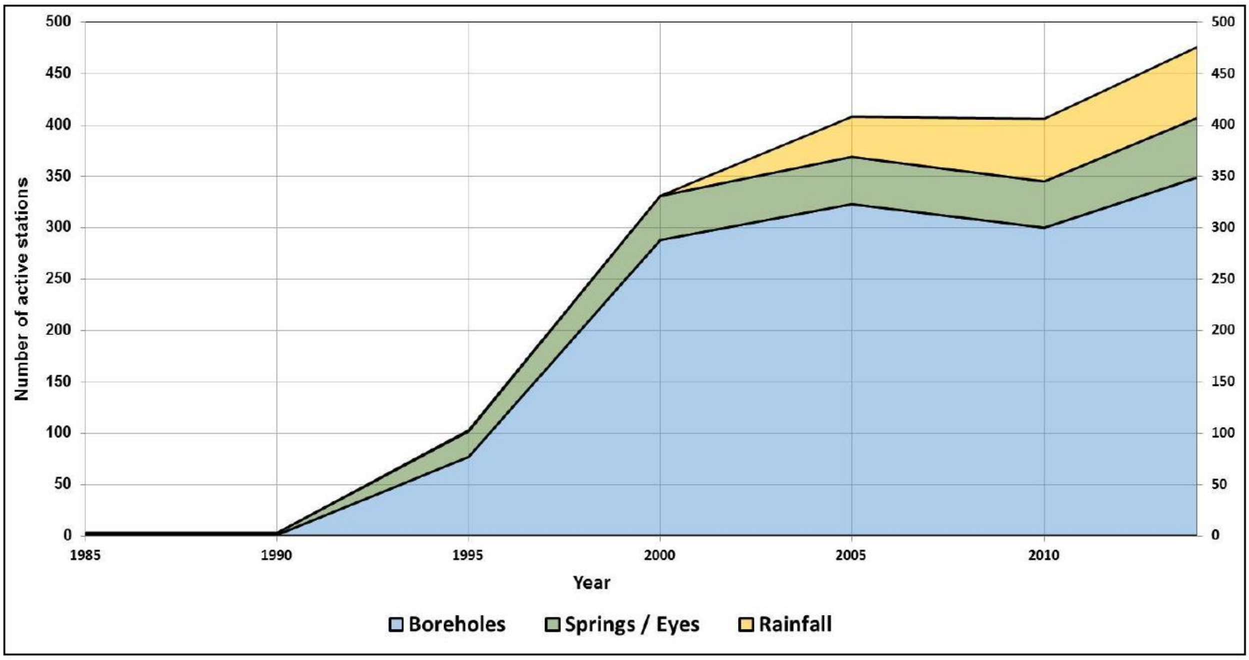


Figure 3-7 Number of water quality monitoring stations South Africa

In addition, rainfall and rainwater water is monitored at 150 stations independent on the South African Weather Service Network. Some of these include water quality data (table 3-1). The rainfall monitoring networks has been in a state of decline since 1945, with a rapid decline since the 1980s. The present number of stations is less than there were in 1920 (figure 3-8).

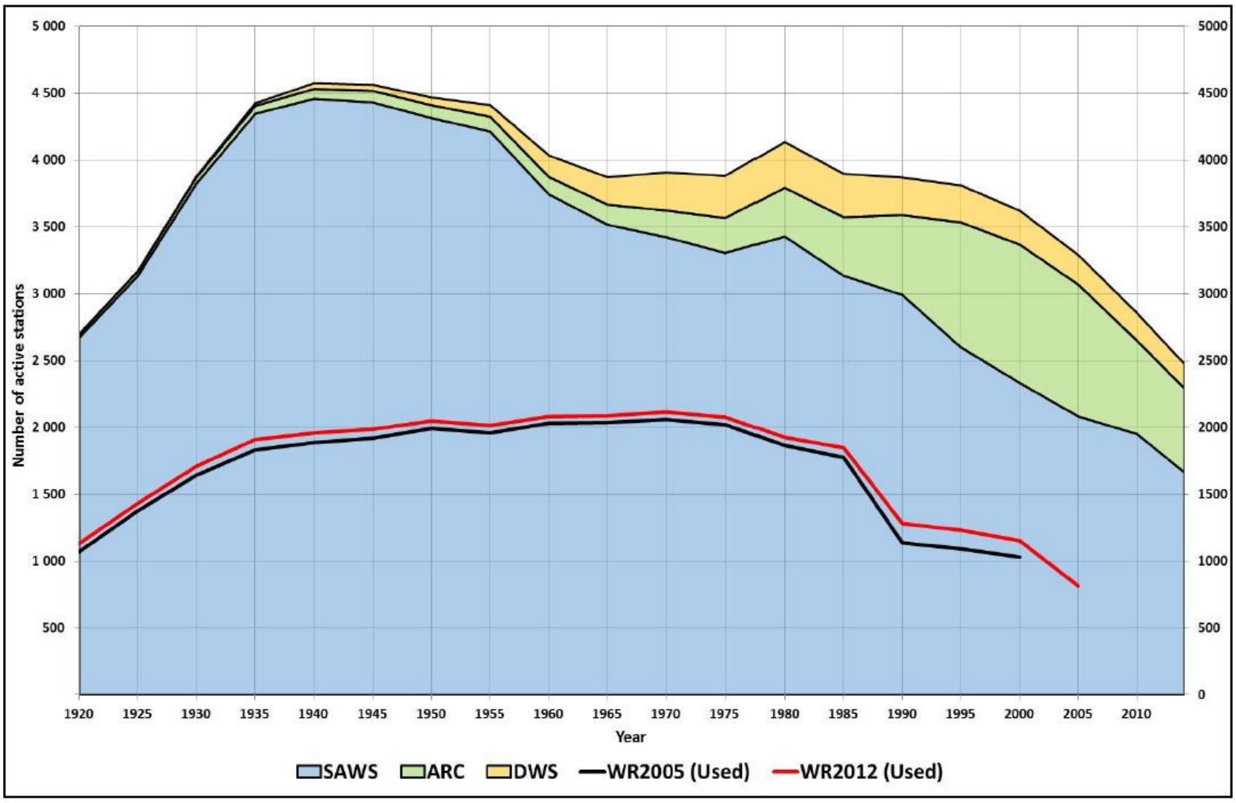


Figure 3-8 Rainfall stations monitored by the South African Weather Service (SAWS), the Agricultural Research Council (ARC) and the department of water and Sanitation (DWS)

3.4.3 Data management and assessment

The National Groundwater Information Systems (NGIS) portfolio includes the National Groundwater Archive (NGA). The latter is a relational database management system of boreholes and springs. The NGA contains in excess of 260 000 geosites, of which 242 000 are boreholes.

The NGA is a centralized web enabled database. People with a direct interest in groundwater can register to search, capture and store data. The database is an ArcGIS geodatabase storing all verified spatial hydrogeological data. Spatial data is available in GIS format.

Data sources from which groundwater related information can be obtained include:

- National Groundwater Archive – NGA, which includes a searchable archive of downloadable reports. This is a Borehole information database which is internet based but without a spatial GIS interface. Data is downloadable in CSV format. The database includes borehole information and historic water levels http://www.dwa.gov.za/Groundwater/NGA.aspx
- Water Management System - WMS [Water quality database including ZQM groundwater monitoring] https://www.dwa.gov.za/iwqs/wms/default.aspx
- Water monitoring database - HYDSTRA [borehole time-series data]

- CHART – Analysis tool using data from WMS and HYDTSRA which is accessible via the internet. It includes current water levels of monitored boreholes. Over 36 000 analyses are available for groundwater. http://www.dwa.gov.za/chart/home/default.aspx
- WARMS - Water Use Authorisation Registration Management System database on registered water use
- DWS GH (Geohydrology) Reports - A repetoir of downladable geohydrological reports, with some dating back to the 1930s http://www.dwa.gov.za/ghreport

CHART, the NGA and the GH reports are available online.

WARMS must be used with caution as it contains only registered water use, which is often different than actual use. This is based mainly on registered volumes - it is very difficult to verify actual use, since a licensing compliance model is not available, except where V&V studies are undertaken on a project basis. It is useful for determining the licenced water use that needs to be protected. WARMS excludes Schedule 1 water use and Existing Lawful Use, which are also legally entitled to protection.

Actual use is often found to be significantly higher than recorded in WARMS, or in some cases some users have double allocations of surface and groundwater to secure supply. These can account for well over 25% of total use in some rural catchments, Currently the available groundwater data is easily accessible via an excellent email service offered by the Department (georequest@dwa.gov.za), howver, users of WARMS have to justify the application, since the database contains confidential information on water licence holders' names, IDs, race and address and contact details.

The Groundwater Resource Assessment Project (GRAI and GRAII) produced hydrogeological map sheets at 1:500 000 scale (GRAI), and catchment and grid based (km^2) data on aquifer storage, water level, harvest potential, exploitation potential, recharge and surface subsurface interactions (GRAII).

http://www.dwa.gov.za/groundwater/GRAII.aspx

The GRAII projects and datasets include:

Project 1: Groundwater quantification – water level, depth of weathetred and fractured zones, volume in storage

Project 2: Planning Potential – storativity, harvest potential, exploitation potential, potabiliy

Project 3a: Recharge

Project 3b: Surface-subsurface interactions – recharge, aquifer recharge, interflow and groundwater baseflow

Project 5: Groundwater use

The Department of Water and Sanitation has several procedures that contribute towards ensuring data integrity. Groundwater level measurements are the responsibility of the relevant DWS Regional Office. Measurements are taken by field technicians and/or hydrogeologists who are trained and/or mentored in the work, but the exact arrangements and numbers of monitoring staff differ according to the Regional Office and the type of groundwater level recording device (e.g. hand-held dipmeter, electronic recorder, etc.). The field staff member responsible for the groundwater level measurement or download also record specific information about the borehole or geosite, including a reason for not taking a measurement (e.g. bee infestation, locked gate, security concerns etc). This information is very important since it can distinguish between a temporarily unavailable borehole and a permanently closed monitoring site.

Groundwater data collected by the Regional Offices is submitted to the Directorate: Surface and Groundwater Information at the Department of Water Affairs and Sanitation's Head Office in Pretoria on at least a quarterly basis. Although in practice this does not always happen, according to DWS at the meeting held by the project team.

This data is entered into the HYDSTRA database, from where a selection is exported to the National Groundwater Archive (NGA) where it is available to the public. This is because the raw data captured by HYDSTRA is frequently extensive (e.g. hourly or better measurements made by electronic divers) and there is a need to reduce it for practical purposes.

The Directorate: Surface and Groundwater Information monitors the incoming data and produces quarterly reports that summarise data submissions by the Regions. Regions which are "late" with their data are contacted by Head Office and every effort is made to ensure that all data is captured for each quarterly summary report. In practise, only Limpopo Province puts out quarterly groundwater level reports.

3.4.4 Institutional arrangements

- Department of Water and Sanitation (DWS)
- Catchment Management Agencies (CMAs)
- Water Research Commission (WRC)
- Water Boards
- Treaty on the Lesotho Highlands Water Project with Lesotho (1986)
- The Permanent Water Commission between SA and Namibia (1992)
- The Development and Utilisation of the Komati River Basin (KOBWA) with Swaziland (1992)
- Joint Water Commission with Swaziland (1992)
- Tripartite Interim Agreement on the Incomati and Maputo watercourses with Swaziland and Mozambique (2002)
- Trans-Caledon Tunnel Authority (TCTA)

3.4.5 Challenges

- Practically what sometimes happens is that data gathering at regions not always passed up so is not on the national database.
- Only Limpopo Province puts out regular reports on water level trends
- The National Water Act determines who needs a licence, however, General Authorisations and Schedule 1 users are not obliged to register, and hence are not on WARMS. Many Existing Lawful Users are also not registered. Use in WARMS is defined not actual use but licenced use which must be protected whether used or not. This is suitable for legal compliance, but is a detriment when water levels need to be compared to actual use

- There is a need to covert groundwater level monitoring data into knowledge products such as water level change maps to present the benefits of monitoring to decision-makers to stop the erosion of monitoring networks

4 REGIONAL CHALLENGES

4.1 SADC Framework

To address the issue of transboundary groundwater, the SADC framework comes into play. The ***SADC Protocol on Shared Watercourses (adopted 1995, revised 2000)*** was framed to set the rules for the joint management of regional water resources. The overall objective of this Protocol is to foster closer cooperation for judicious, sustainable and co-ordinated management, protection and utilisation of shared watercourses and advance the SADC agenda of regional integration. A watercourse is defined as a system of surface and groundwater consisting a unitary whole flowing into a common terminus.

The Protocol is the SADC legal instrument that promotes the concept of Integrated Water Resources Management. The ***Regional Strategic Action Plan on Integrated Water Resources Development and Management (RSAP, 1998***) includes seven areas of intervention identified as key issues for the Region: Legal and regulatory framework; Institutional strengthening; Linkages with sustainable development policies; Data collection, management and dissemination; Awareness building, education and training; Stakeholder participation; and Infrastructure Development. One of the priorities is the ***Regional Groundwater Management Programme (GMP, 1998),*** which strives to create an enabling environment for the joint management of shared aquifers by putting in place a framework and specific tools to enable effective resource management.

Several obstacles can be identified which hinder the implementation of the SADC protocols on practical grounds:

10. The lack of ack of Information and Data and declining monitoring networks outlined in Chapter 3 indicate not only noncompliance of groundwater guidelines and the submittal of hydrogeological data to relevant departments by groundwater users, but of national departments themselves overseeing a decline in networks. This is attributed to lack of legal enforcement mechanisms or split responsibilities, such as in Namibia, Botswana and Lesotho. finances.
11. Limited Capacity of trained personnel in groundwater or remaining severely under resourced is often cited.
12. Monitoring systems in member countries, except South Africa, have been drawn up for regulation and compliance at wellfields, and not for strategic background monitoring
13. Implementation of transboundary aquifers has not featured in monitoring system designs.
14. Differing groundwater polices between member states regarding groundwater monitoring with regard to data base systems and monitoring purpose and network design results in no common strategic network or formats of storing data.
15. Groundwater resource evaluation and a water balance has not been undertaken on a catchment scale (Harvest or Exploitation Potential), except in South Africa, hence the quantification of resources and the prediction of aquifer behaviour cannot be implemented in transboundary aquifers. There is no baseline of natural groundwater resources versus current conditions and water levels. The volumes of groundwater that can be reliably abstracted in the future is too vague because recharge and Harvest potential is not known, hence impacts of abstraction cannot be quantified.

16. River Basin Organisations and other organizations like ORASECOM tasked with the management of transboundary water resources have a key role to play in addressing the identification of transboundary aquifers, developing processes and creating the institutional setting for shared aquifer management; however, the aforementioned activities are limited or in their infancy.
17. There is a Poor Appreciation of Shared Aquifers. The international impact of groundwater abstraction/degradation has been neglected against a focus on national water resources planning, because there was no evidence of potential competition across the border. However, increased stresses on Regional water resources will require shared aquifer management as a component of long term planning.
18. Responsibility for management of water resources is often fragmented between different authorities and at different scale. This can be observed in Lesotho and Botswana, where monitoring is fragmented between different institutions.

4.2 Implementing Transboundary Monitoring

When implementing a transboundary monitoring and assessment programme, it is essential to present the hydrogeology in conceptual models and/or in graphic schemes. This should comprise a characterisation of the transboundary aquifer (geometry), the flow conditions, including recharge and discharge areas, and the evolution of the groundwater quality. The conceptual model will dictate where monitoring is required. For example, monitoring transboundary flow will require hydraulic gradients across borders, whereas baseflow reduction due to abstraction will require an assessment of gradients near perennial rivers and baseflow monitoring. Features that influence the way groundwaters are monitored and assessed and that distinguish them from surface waters are:

- Where a transboundary aquifer is recharged by periodic floods, like the Molopo River between Botswana and South Africa, recharging the Khakea-Bray aquifer requires estimates of flow reductions in the river. When flow is not monitored, impacts cannot be assessed, except by uncalibrated simulations.
- Slow movement (long residence times) of groundwaters increases the potential for their quality to be modified by the interaction between the water and the surrounding aquifer material. Also, once groundwaters are polluted, they may remain so for many years and it is difficult to intervene effectively in this process.
- The interaction between aquifer material and water causes the natural hydrogeochemistry to evolve as the infiltrating groundwater moves downgradient. To be able to detect and quantify the superimposed impacts of human activities, the "baseline" quality of groundwater with its spatial and depth variations must be assessed. This is of significance in the Stampriet aquifer, which has fresh water in Namibia, which becomes more saline after long deep flow paths before discharging in South Africa.
- Groundwater flow can be intergranular and/or through fractures. Groundwater flow will be much more rapid but variable and difficult to estimate through intensely fractured rocks, as is the case with dolomitic aquifers. Intergranular groundwater flow increases the potential for interaction between aquifer material and groundwater.
- Recharge and discharge areas need to be determined and activities that might affect the quantity or quality of groundwater need to be understood. Knowledge of the groundwater flow system means the locations of groundwater recharge and discharge zones, and the way

groundwater flows through aquifers from zone to zone. Activities in the recharge areas on one side of the border might adversely affect the quality or quantity of groundwater on the other side. To determine recharge and discharge conditions in some areas, the interaction between surface and groundwaters need to be understood;

- Compartmentalisation of aquifers means that topographic and hydraulic boundaries applicable to surface water may not be the same as groundwater boundaries. This applies to the Khakea-Bray aquifer, where compartments extend across national boundaries and both countries tap 1 compartment, interlinked to others.
- Background conditions change over time and these spatial, temporal and depth variations must be determined before it is possible to detect any impact of human activity. This requires a long record which is usually lacking.
- Multi-layered systems can occur where there is more than one aquifer separated by aquitards of less permeable material. The possible pathways or connections between them need to be understood.

The above illustrates why it is essential to characterise groundwater occurrence, the hydrogeology and the dynamics of the groundwater flow system in transboundary systems prior to establishing a monitoring programme. The conceptual model should include aspects such as seasonal or longer-term responses and variations and changes in flow rate or direction caused by human activities, particularly groundwater abstraction.

The integration of surface water and groundwater monitoring networks must be envisaged, to manage and protect transboundary water resources effectively, especially where surface-subsurface interactions occur. Integration implies aspects such as low flow monitoring and groundwater levels should occur together, so baseflow reductions can be attributed to specific activities and so that the cause-effect relations between issues and uses can be understood.

For an integrated transboundary programme, the following aspects should be taken into consideration:

- *integration of data gathering and storage:* Monitoring of groundwater and surface water and of water quality and quantity is often performed by different directorates or even agencies, in addition to different countries and departments. information should be assessed in combination.
- *groundwater - surface water interaction:* Surface water and groundwater monitoring and assessment could be integrated further, especially when recharge is through seepage of surface waters or in the case of vulnerable ecosystems.
- *quantity – quality inter-relationships:* There are often clear relationships and interactions between the quantity and quality of groundwater, such as recharge rates and salinity, or interaction with surface water and quality. Therefore, water quality information would assist with interpreting measurements of groundwater quantity, such as levels and discharges.
- *Agreement on the trans aquifer boundary and relations to surface water and ecosystems:* Before implementing monitoring, the parameters and aspects that require monitoring, and the placement of monitoring sites should be agreed upon by member states. This will include agreement on uses to be monitored, and the ecological functioning of transboundary resources, and management targets to be set for the establishment of quotas or restrictions. These targets can guide the location and parameters to be monitored.

- *Prioritisation:* The aquifers to be monitored need to be prioritised taking into account stresses and international agreements. Priorities will d determine the level of investment, information needs and level of commitment.
- *Monitoring objectives*: Objectives can be providing data for characteristic the groundwater regime or providing date for detecting long term trends of quantity or quality. For transboundary groundwaters, monitoring will primarily be linked to agreements, which apply to the specific area. The following objectives for monitoring and assessment can dictate monitoring: national assessment responsibility; compliance with standards or provision of the agreement (related to functions/use); required response; special protection areas; remediation and restoration (table 4-1).

Table 4-1 Monitoring objectives

Objective	Types of monitoring	Data needs
Nation assessment of resources or compliance with agreements	Baseline/reference	Natural conditions and trends (chemistry and water level)
Compliance with special protection or remediation	Monitoring oinked to use or function	Quality standards, targets or thresholds
Response	Thresholds to alter use	Operating rules at specific thresholds, risks, impacts

Basic/reference monitoring includes monitoring for national resource assessment. This type of monitoring establishes a background (reference) situation to enable the determination of trends caused by 'beyond local' impacts and natural impacts. Long-term records are needed to determine the possible impact of changing land use and abstraction patterns, especially in semi-arid areas with highly variable climates. This type of monitoring is urgently required for all the transboundary aquifers in the ORASERCOM region.

Monitoring linked to compliance is linked to regulations, laws and directives related to the use of groundwater. This type of monitoring serves as a protection of functions and uses. This means that all countries sharing a resource must establish and agree upon the groundwater uses and functions in the transboundary aquifer. Monitoring results may be used as a basis for further action or measures.

4.3 Key Preliminary Elements that Need to be Addressed

4.3.1 National Groundwater Assessment

Prior to a monitoring effort, it is essential that all parties have an assessment of existing resources. Except for South Africa with its GRA II programme, none of the other states have a National resource inventory of available resources. This data provides the basic quantitative information needed to set up the monitoring programme. This is identified as a key shortcoming to a joint transboundary monitoring programme; there is no baseline of resources against which to assess impacts.

4.3.2 Data compatibility

Monitoring data collected in transboundary aquifers should be comparable, available for integration with information from a variety of sources and easily aggregated spatially and temporally. Data produced by groundwater monitoring programmes should be validated, stored and made accessible. The goal of data management is to convert data into information that meets the specified information needs and the associated objectives of the monitoring programme. This is currently not the case as monitoring in Botswana and Lesotho is geared towards regulatory monitoring of wellfields, whereas South Africa and Namibia have a strategic monitoring network for reference conditions. Reference conditions cannot be established on both sides of the border, making resource assessment problematic.

4.3.3 Elements in an integrated database system

The most crucial element in integrating data from country database is similar field naming of data tables. There are currently no naming standards set or used in the basin countries as such each country data table for similar feature has different field names. Initial data that is required for regional groundwater monitoring are:

- Resource status Monitoring – Rainfall, groundwater levels and abstraction
- Chemistry – TDS, nitrates and fluoride etc
- Coordinates – referenced to a common grid system

All these data are tied to a borehole number, and each national database consists of general borehole information using different field names, using different formats (i.e. text, numbers) for this field, thus making integration of the data tables difficult. Therefore, editing of the data tables is required prior to integration. Furthermore, fields used in water level monitoring tables are different except for the water level field.

If the database is not on the internet, like the South African NGA, to get data from one database there will have to be an individual in the respective country contacted to send the required data.

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4.3.4 Baseflow

In the Region's shared river basins complex relations between surface and groundwater exist and are not fully understood nor quantified. The South African GRAII project quantified baseflow and recharge. Transboundary effects were not considered in recharge estimates and exploitation potential aspects only used the area in South Africa, leading to gross errors in exploitation potential in transboundary aquifers. In addition, groundwater use across the border was not considered, leading to errors in estimates of remaining groundwater resources, and international allocations not being considered.

Where baseflow exists into international rivers, groundwater use in such aquifers may have adverse impacts across international boundaries by impacting downstream river flows and recharge to transboundary aquifers. Aquifer development and management should therefore be addressed in the context of international river basin management. Major transboundary aquifers are in general not coincident with the transboundary river basins. Some aspects of exploration, development and management in selected aquifers should be addressed at the National level because it would create synergies between countries and optimise scarce human and financial resources.

4.4 Data Management Issues

The objectives of data management are collecting and processing data and distributing the findings to those requiring the information. This would be facilitated by using standard forms, similar formats, data dictionaries and software to improve data exchange, but this is not the case.

In addition, the quality control of separate data collection procedures (drilling, sampling, testing, water level monitoring etc) varies, as does data validation. The control of newly produced data, including the detection of outliers, 'junk data' missing values and other obvious mistakes also varies.

The standardisation of the accessibility of data (interfaces to databases and GIS) is more important than the standardisation of the software used. If both the conceptual model and the basic data are reliable, the results will be comparable even when the software used is not the same. The enormous amounts of data collected from groundwater monitoring networks are preferably stored in relational databases. In this case, all countries enter data into a GIS relational data base format, mostly as point data of borehole attributes. In South Africa data is also available as polygons based on a Quaternary catchment or km^2 grid-based data base of Exploitation potential and aquifer storage.

4.5 Conclusion

It is clear that groundwater information for the Orange-Senqu River Basin is currently held by various institutions in many forms and formats, and dissemination of information is a tedious process. Availability of timely, adequate and valid geohydrological data and information will be crucial to the success of the ORASECOM's work programme. A number of computer-based systems are available for storing and sharing of the geohydrological data and information, in addition to libraries and technical reports in the four basin member countries.

A very large problem is that a groundwater resource assessment does not exist on a catchment scale for all the member countries, nor does baseline information. This makes it impossible to quantify how much groundwater is available, and hence to determine impacts of abstraction on resources, both on baseflows and water levels.

As some national data bases are not internet-based, data cannot be collected remotely by ORASECOM, and will have to be collected through contacting country database managers. Database integration should allow the data from Botswana, Lesotho, Namibia and South Africa to be brought together in one table. A system will have to be developed which will import data tables from the various databases through export files that can either be in Comma Separated Value (CSV) Files or through Microsoft Excel or SQL Server Database, or any other common data transfer and integration medium. The existing databases are shown in table 4-2.

Table 4-2 National data bases

		South Africa	Botswana	Namibia	Lesotho
Hydrogeology		NGA Database: Informix, SQL Data exchange: ASCII or csv, geo library as pdf REGIS (CHART) Mapping: shp Database: oracle	WELLMON Only contains water levels and abstraction data NBA Single user MS-DOS.	GROWAS II	Spreadsheet

		Data exchange: ETL tool, csv, time series diagrams			
Water Quality		ZQM and WMS Mapping: shp files Database: Informix Data exchange: ASCII or csv or kmz	AQUABASE No proper monitoring network and only ad hoc data	Ad hoc and varied storage	Ad hoc and varied storage
Groundwater Resource Assessment		GRAII Spreadsheet based, grid based and catchment polygons	None	Qualitative and historic use, subjective	None
Water Use authorisations		WARMS Mapping: none Database: Informix Data exchange: ASCII, csv	WELLMON	GROWAS II	Spreadsheet

The report has identified the following data gaps that need to be addressed for a monitoring programme:

- A recharge, baseflow and Exploitation Potential data base of catchments on a Quaternary level is required so that resource allocation per country can be undertaken and downstream impacts be quantified.
- A shared Groundwater use data base of all transboundary countries, and assessment of impacts is required so that groundwater resources can be equitably allocated across borders. This shared use can be on a use by sector and Quaternary catchment basis to avoid releasing confidential information about water users.
- Baseline groundwater level monitoring is required on both sides of borders so that hydraulic gradients and flow directions can be determined, as well as any flow reversals that occur resulting in cross border impacts.
- Baseline groundwater quality for macro and trace constituents is required to determine baseline conditions against which to identify pollution.

The status of monitoring is shown in table 4-3.

Table 4-3 Status of monitoring

Monitoring Status	Botswana	Lesotho	Namibia	South Africa
Groundwater Resource Assessment		Not available Priority	Historic and coarse. Required on a catchment basis	Available
Baseflow	Available only for transboundary rivers bordering South Africa	Available only for transboundary rivers bordering South Africa	Available only for transboundary rivers bordering South Africa	Available
Baseline reference water levels	Not available Wellfield monitoring only	Not available Wellfield monitoring only	Available but not focussed on transboundary. Network needs to be evaluated for ability to meet SADC water sharing protocols	Available but not focussed on transboundary. Network needs to be evaluated for ability to meet SADC water sharing protocols Network declining rapidly Does not cover all catchments
Water quality	Not available	Not available	Not available	Available but not of uniform density
Groundwater Use	No data base	No data base	Allocations available in GROWAS	WARMS data base has only licence allocations and some General Authorisations Not public domain
Reference Monitoring plan/framework	None	None	None	Available

5 APPENDIX A – COMMENTS REGISTER

Section	Report statement	Comments	Changes made?	Comment

Section	Report statement	Comments	Changes made?	Comment

6 APPENDIX B ATTENDANCE REGISTER OF COUNTRY VISITS

NAMIBIA

Divisional Meeting 5/7/2018 attendance list	
Name	**Division**
Amakali Sarti	Geo
Godfried Edward	Geo
Katjiuongua Alex	Geo
Menge Lothar	Geo
Molefe Mercy	Geo
Mudjanima Nghishiinawa F	Geo
Mulokoshi Gettie	Geo
Mutota Josephine	Geo
Nghipandulwa Mvula	Geo
Tsowaseb Alton	Geo
Swartz Bertram	Geo

South Africa

Botswana

Lesotho