ORANGE - SENQU RIVER COMMISSION
BOTSWANA LESOTHO
ORASECOM
NAMIBIA SOUTH AFRICA
Established 2000

IMPROVING GROUNDWATER KNOWLEDGE IN SELECTED TRANSBOUNDARY AQUIFERS

Monitoring Framework Report

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ORASECOM SECRETARIAT

IMPROVING GROUNDWATER KNOWLEDGE IN SELECTED TRANSBOUNDARY AQUIFERS

MONITORING FRAMEWORK REPORT

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IMPROVING GROUNDWATER KNOWLEDGE IN SELECTED TRANSBOUNDARY AQUIFERS

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DOCUMENT INDEX

Index Number	ORASECOM Report Number	Report Title
1		Inception report
2		Draft final report with updated groundwater recharge estimates in the main recharge

Index Number	ORASECOM Report Number	Report Title
		areas in the Karroo Sedimentary and the Khakhea/Bray Dolomite Aquifers
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

A background monitoring report summarised 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.

This report presents a framework for future monitoring of transboundary aquifers.

In 2014 ORASECOM refined a Terms of reference for a Ground Water Hydrology Committee (GWHC). The objective of the GWHC is to oversee and advise on the development and management of ground water resources of the Orange-Senqu River Basin.

The mandate of the GWHC should be modified or expanded with an objective to:

- Provide a regular reliable assessment of the quantitative status of groundwater in transboundary aquifers (Member States must provide maps illustrating the quantitative status of all aquifers including natural Harvest Potential, Natural and current water levels etc.);
- Estimate the direction and rate of flow in groundwater bodies that cross Member States' boundaries;
- Jointly define an impact assessment procedure;
- Identify long term trends both as a result of changes in natural conditions and through anthropogenic activities;
- Establish the chemical status of all groundwater bodies or groups of bodies determined to be transboundary; and
- Prepare annual reports on the status of transboundary aquifers.

An outline for the mandate of using the GWHC to function as a transboundary monitoring group is provided.

Four transboundary groundwater bodies have been identified as lying within the Orange-Senqu River Basin. A summary table for monitoring requirements has been derived for consideration.

Member States will need to submit summary reports of the monitoring programmes of transboundary aquifers. A proposed template of a format for reporting is provided.

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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**.

A background monitoring report summarised 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.

Based on the findings from the literature review and consultations with stakeholders, captured in the ORASECOM Document No 003/2018, a way forward to implement transboundary is proposed.

2 PROPOSED APPROACH TO TRANSBOUNDARY MONITORING

2.1 Status for Enabling Transboundary Monitoring

To enable joint monitoring, firstly comprehensive bi- or multi-national level agreements/treaties must exist. The relevant Governments in the ORASECOM area joined other Southern African Development Community (SADC) Governments and signed the SADC's Revised Protocol on Shared Watercourses on 7 August 2000 in Windhoek, Namibia. The objective of the Protocol is to "foster closer cooperation for judicious, sustainable and coordinated management, protection and utilization of shared watercourses and advance the SADC agenda of regional integration and poverty alleviation". The Protocol defines a watercourse as a "system of surface and ground waters consisting by virtue of their physical relationship a unitary whole normally flowing into a common terminus such as the sea, lake or aquifer".

Following the signing of the Protocol, the Governments of Botswana, Lesotho, Namibia and South Africa established the Orange-Senqu River Commission (ORASECOM) through the signing of a formal Agreement on 3 November 2000 in Windhoek, Namibia.

There are no specific transboundary aquifer management legal instruments in the SADC Region. However, the SADC Revised Protocol on Shared Watercourses and the ORASECOM Agreement are holistic instruments providing a legal basis for the management of transboundary waters, inclusive of surface water and groundwater. Article 7.4 of the ORASECOM agreement (currently under revision) mentions hydrogeological data as data which the countries are obliged to share. Thus, a legal basis exists for joint monitoring.

Regarding institutional capacity in groundwater management, the mandate and capabilities of member countries vary significantly. ORASECOM was established to serve as an advisory body to the State Parties on matters relating to the development, utilisation and conservation of the water resources (including ground water resources) in the River System, and such other functions pertaining to the development and utilisation of the water resources as the State Parties may agree to assign to the Commission. Although ORASECOM has a multilateral mandate to manage water resources of the Orange-Senqu basin, no group or panel exists for joint monitoring of aquifers. and such a Group will need to be formed, or existing structures adapted.

ORASECOM could play a key role in supporting monitoring initiatives. The capacity of ORASECOM to oversee projects for transboundary groundwater management will depend on the personnel and financial capacities made available by the relevant Departments in Member States. At present, the riparian countries appear to assign only low priority to transboundary groundwater management and obtaining the assignment of the relevant personnel to a transboundary body and obtaining funding will be the first task.

2.2 Responsibilities of a Transboundary Task Group

In 2014 ORASECOM refined a Terms of reference for a Ground Water Hydrology Committee (GWHC). The objective of the GWHC is to oversee and advise on the development and management of ground water resources of the Orange-Senqu River Basin. Each member Country provides one official and one alternate official, both with ground water resources development and management background.

The functions of the GWHC are to oversee and advise the TTT and the Commission on:

- the development and management of the ground water resources of the Basin;

- o the implementation of the relevant provisions of the ORASECOM Agreement and its revised versions, including the standardised form of collecting, processing and disseminating ground water data or information;
- o the implementation of the ground water activities and projects in the Integrated Water Resources Management (IWRM) Plan for the Orange-Senqu River Basin;
- o the implementation of the activities, projects, and programmes aimed at the development and management of the trans-boundary aquifers of the Basin; and
- any other activities that may be assigned to it by the Commission.

Given the lack of any dedicated transboundary monitoring at present, transboundary monitoring has not fallen under the ambit of the GWHC. The GWHC would need to ratify:

- The monitoring requirements which should be implemented in future and can only be recommended in this report.
- The current status of groundwater resources and the state of Groundwater monitoring in the respective transboundary aquifers, and any new monitoring sites required.
- The future need for further harmonisation to improve the joint monitoring efforts and data collection.

In order to ensure the appropriate management of transboundary groundwater resources, the mandate of the GWHC should be modified or expanded with an objective to:

- Provide a regular reliable assessment of the quantitative status of groundwater in transboundary aquifers (Member States must provide maps illustrating the quantitative status of all aquifers including natural Harvest Potential, Natural and current water levels etc.);
- Define important recharge and baseflow generation areas that have a transboundary component;
- Estimate the direction and rate of flow in groundwater bodies that cross Member States' boundaries;
- Define groundwater vulnerability hotspots where groundwater contamination could have transboundary impacts;
- Jointly define an impact assessment procedure;
- Identify long term trends both as a result of changes in natural conditions and through anthropogenic activities;
- Establish the chemical status of all groundwater bodies or groups of bodies determined to be transboundary; and
- Oversee the preparation of annual reports on the status of transboundary aquifers. The annual reports could be compiled by a technical task team, or by the use of consultants. In this case, the GWHC will need to identify the need for and motivate for the appointment of consultants, or a technical task team from within staff at national departments to full fill these tasks.

The agreed upon monitoring programmes must provide the information necessary to assess whether the SADC water sharing protocols will be achieved and cater for environmental requirements. The monitoring programmes should therefore be based on accepted conceptual models of the aquifers, which include the entire recharge-flow path-discharge cycle.

An outline for the mandate of using the GWHC to oversee the technical transboundary monitoring team is provided in Table 2-1.

Table 2-1 Template for Establishment of Transboundary aquifer monitoring team

Core Tasks	• Facilitate the collation and exchange data • Manage the flow of data to the Transboundary Information System • Attract funding for the Transboundary system • Advise national governments on issues of transboundary relevance • Liaise with SADC and ORASECOM • Identify the need for and motivate for the appointment of a technical task team or external consultants
Legal Arrangements	• The current ORASECOM Agreement and SDAC protocols provide sufficient legal tools and a mandate for monitoring
Funding	• Each country would need to bear the cost of hosting regular meetings which will rotate between countries, as is currently occurring. • ORASECOM should continue to provide administrative support to the Committee
Structure of Task Team	• Technical staff or consultants who compile the national annual reports reporting to the steering committee • Staff in each country providing the monitoring data to the National Steering Committee representative for the technical task team • A Steering Committee forming the core of Task team should be made up of officials in the GWHC and should meet at regular intervals (annually) • A dedicated groundwater expert at ORASECOM is required to increase capacity

2.3 Objectives

The objectives of transboundary groundwater monitoring should include current and potential future issues.

2.3.1 Groundwater Quality Monitoring Objectives

It is important to derive an overview of water quality on either side of international borders in order to:

- detect future long-term anthropogenically induced trends in groundwater quality;
- support the chemical status assessment of the transboundary groundwater bodies;

- perform a trend analysis and to support the design and evaluation of the monitoring programme; and
- characterise environmental impacts on surface water bodies where baseflow occurs to ensure there is no degradation in the ecological or chemical quality of surface water fed by the groundwater body.
- Identify indicators of aquifer health that can be jointly monitored. These could indicate maximum permissible changes in aquifer water quality parameters
- Develop aquifer vulnerability maps identifying areas where aquifers are more vulnerable to contamination.

2.3.2 Groundwater Quantity Monitoring Objectives

A transboundary quantitative groundwater monitoring network is required to:

- assist in characterisation of transboundary groundwater bodies;
- to determine the quantitative status of the transboundary groundwater bodies;
- to perform a trend analysis and to support the design and evaluation of the monitoring programme;
- assess if the available groundwater resource is not exceeded by the long-term annual average rate of abstraction; and
- assess if the groundwater levels and flows are sufficient to meet environmental objectives for associated surface waters and groundwater dependent terrestrial ecosystems.

The requirements identified for each country to make a joint monitoring programme feasible are listed in table 2-2.

Table 2-2 Requirements for each country to make a joint monitoring programme feasible

Requirements	Botswana	Lesotho	Namibia	South Africa
Delineation of catchments for monitoring	Quaternary delineation required	Already delineated into Quaternary catchments (WR2012)	Delineated into major aquifers. Quaternary delineation required	Already delineated into Quaternary catchments (WR2012)
Recharge by catchment	Required	Required. An initial assessment was performed for each gauging station catchment as part of this project. GRAII results questionable	Required	Complete (GRAII) although in some catchments results questionable and need to be backed up ny Harvest Potential
Harvest Potential	Required	Required	Required	Complete

Baseflow volumes	Required	Required. An initial assessment was performed for each gauging station catchment as part of this project but needs consensus	Required	Complete (GRAII)
Groundwater Use by catchment	Required	Required	Required	Licenced and registered use by quaternary catchment available from WARMS
Water Quality By catchment	Required	Required	Required	Complete and has been updated for many catchments during the Reserve studies
Aquifer Vulnerability mapping	Required	Required	Required	Several versions exist, based on DRASTIC, and aquifer classification
Strategic Groundwater level monitoring	Required	Required	Master stations exist[1]	Strategic network exists[1]
Khakea/ Bray aquifer monitoring	No data	Not Applicable (N/A)	N/A	Suitable but an additional monitoring point is required
Coastal sedimentary aquifer	N/A	N/A	No data	No data
Karoo Sedimentary aquifer	N/A	Gauging station data and rainfall data No regional water levels	N/A	Gauging station data and rainfall data No regional water levels
Stampriet Transboundary	Only 1 borehole for water level	N/A	Extensive borehole data but few have	Few water level boreholes. Ecosystems

Aquifer System (STAS)	monitoring. More required		water levels. Water level monitoring needs to be continued. Suitable borehole locations exist.	dependent on upwelling water but long-term monitoring not available

1: the monitoring networks are described in in the accompanying monitoring network background report.

2.4 Proposed Groundwater Monitoring Areas and Existing Sites

Four transboundary groundwater bodies have been identified as lying within the Orange-Senqu River Basin. These are characterised in table 2-3.

The criteria used to identify the monitoring sites are based on three main factors:

- the conceptual models, including the assessment of the hydrological, hydrogeological and hydrochemical characteristics of the body of groundwater, including the characteristic groundwater travel times, & the distribution of the different types of the land uses;
- an assessment of risk and the level of confidence required in the assessment of the groundwater body; including the distribution of the key pressures and;
- practical considerations relating to the suitability of the individual sampling points. Sites need to be easily accessed, secure and be able to provide long-term access agreements.

Table 2-3 Characterisation of Transboundary aquifers

Aquifer	Size (km^2)	Aquifer type	Confined	Main use	Thickness (m)	Criteria for importance	Quantity Risk	Quality Risk	Priority	Monitoring requirements
Karoo Sedimentary Aquifer	165,900	Fractured and weathered/local	Semi confined	Domestic	~120	Baseflow to Orange-Senqu river system	Localised centres of high abstraction adjacent to perennial rivers	No	Low Moderate High	Water level trends Abstraction Baseflow Rainfall, Water Quality
Coastal Sedimentary Basin	undefined	Intergranular /Limited /local	Unconfined	Not used	<50	Role in maintaining Orange-Senqu River estuary	No	No	Low Low	Water Level Water Quality
Khakhea / Bray Dolomite	29,700	Dolomitic /karst/ compartmentalised	semiconfined	Irrigation / domestic	450	Irrigation and sole source of water supply	Yes	No	High High	Water Level trends Abstraction rainfall, water quality
Stampriet Transboundary Aquifer System (STAS)	85,100	Intergranular	Confined	Irrigation	350	Irrigation and sole source of water supply, water hole maintenance in South Africa	Yes	No	Moderate Moderate	Water Level trends Abstraction Rainfall Water Quality

2.4.1 *The Khakea/Bray Transboundary Aquifer (Botswana/South Africa)*

The proposed location where monitoring is shown in figure 2-1. The objective of monitoring should be to assess the impact of abstraction from irrigation on international flows, which requires monitoring of the hydraulic gradients on both sides of the border. There is a high potential for the natural transboundary flow regime to be altered by groundwater abstraction.

The existing groundwater monitoring stations are shown in table 2-4 and figure 2-1. Suitable monitoring stations exist on the South African side to determine a hydraulic gradient towards the border, however, with only 2 boreholes being monitored a hydraulic gradient cannot be ascertained. An additional borehole is required. No data is available on the Botswana side and 2 to 3 monitoring boreholes need to be established in the area indicated in figure 2-1.

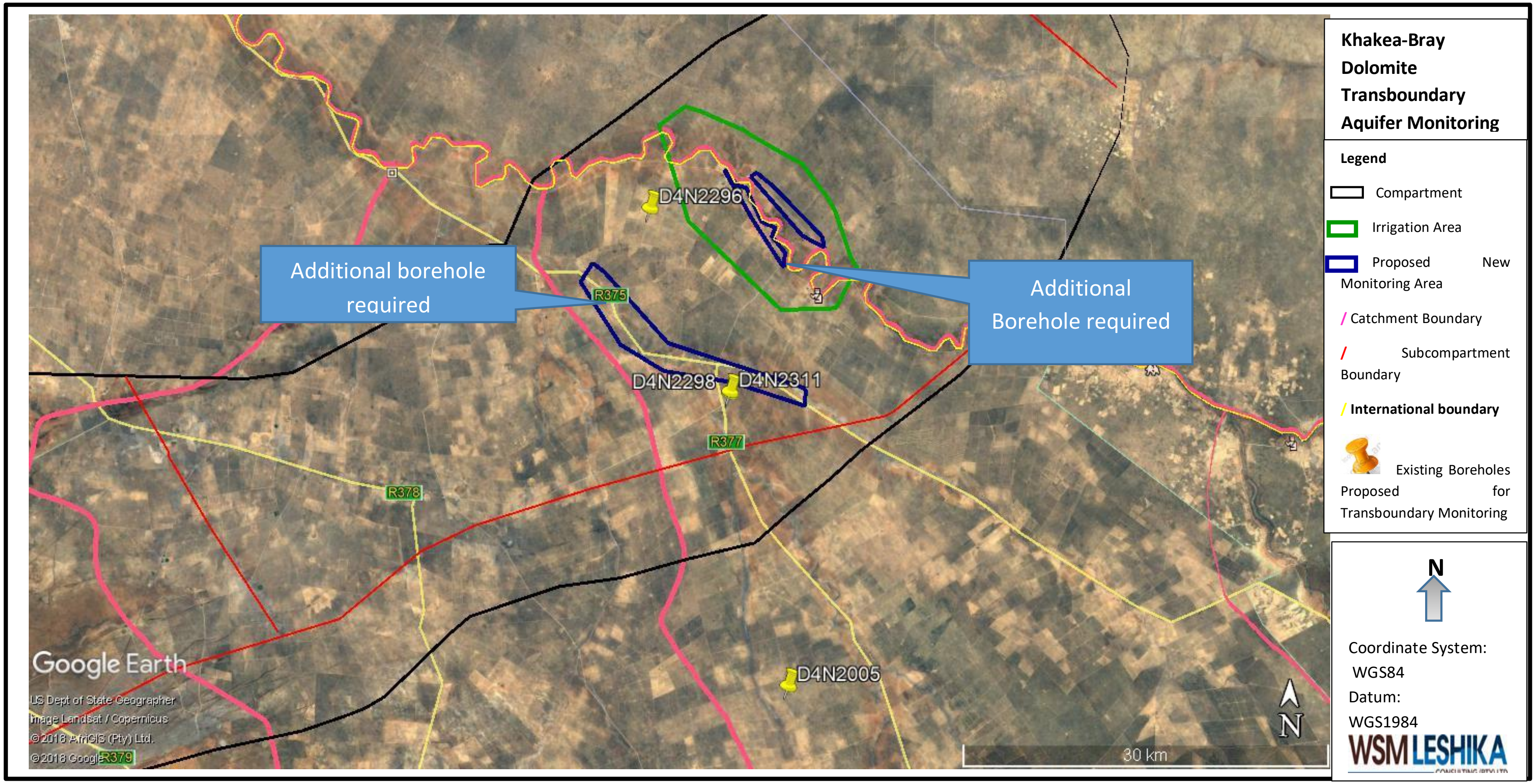


Figure 2-1 Location of Proposed Monitoring Areas and Existing Monitoring Boreholes in the Khakea-Bray Dolomite Transboundary Aquifer

Table 2-4 Borehole Water Level Monitoring Data Available in the Khakea-Bray Aquifer on the South African NGA

Latitude	Longitude	Station Number	Open / Closed	Begin Date	Frequency	Status	Monitoring Equipment
-26.02250	24.26389	D4N2005	Open	1998/04/01	Twice Yearly	In use	Dip meter
-25.67389	24.14278	D4N2296	Open	1991/07/09	Twice Yearly	In use	Dip meter
-25.72083	24.23917	D4N2297	Closed	1991/06/14	Twice Yearly		Manual
-25.80889	24.21111	D4N2298	Open	2004/06/18	Twice Yearly	In use	Dip meter
-25.80750	24.21111	D4N2311	Open	2004/09/02	Twice Yearly	In use	Dip meter

2.4.2 *The Coastal Sedimentary Transboundary Aquifer (Namibia/South Africa)*

The aquifer is difficult to access, and not utilised. Oranjemund may be pumping on the Namibian side. Although this is not certain. Monitoring of this Aquifer could assist in determining the role of groundwater in maintaining the estuary salinity. No monitoring boreholes exist. Proposed areas for monitoring are shown in figure 2-2. Water level and water quality monitoring would indicate if the water balance between the estuary and the aquifer are being altered. Water level readings and water quality samples would have to be taken during similar tidal conditions (high or low) to be comparable.

Use of groundwater and mining activities can alter the ground water contribution to these systems. Minor changes in water level have a large impact on the location of the sweater interface. Reduced surface water and groundwater input to an estuary can result in changes to the salinity profile.

The estuary has experienced a decrease in the frequency of small and moderate floods. Higher low flows than natural in the dry season prevent mouth closure and related back flooding. Agricultural return flows cause water quality problems. Road infrastructure (crossing the salt marsh) and levees affect the hydrodynamics of the estuary. Improvement requires decreased (from present) dry season base flows and droughts to be reinstated, i.e. decreased flow at times during the dry season to facilitate mouth closure two to four times in 10 years. Non-flow-related measures (e.g. remove causeway, reduce nutrient input and fishing pressure) also need to be instituted at the River Mouth. Higher than natural agricultural low flows can also be causing rising water levels in the aquifer and reduce groundwater discharge, altering salinity patterns.

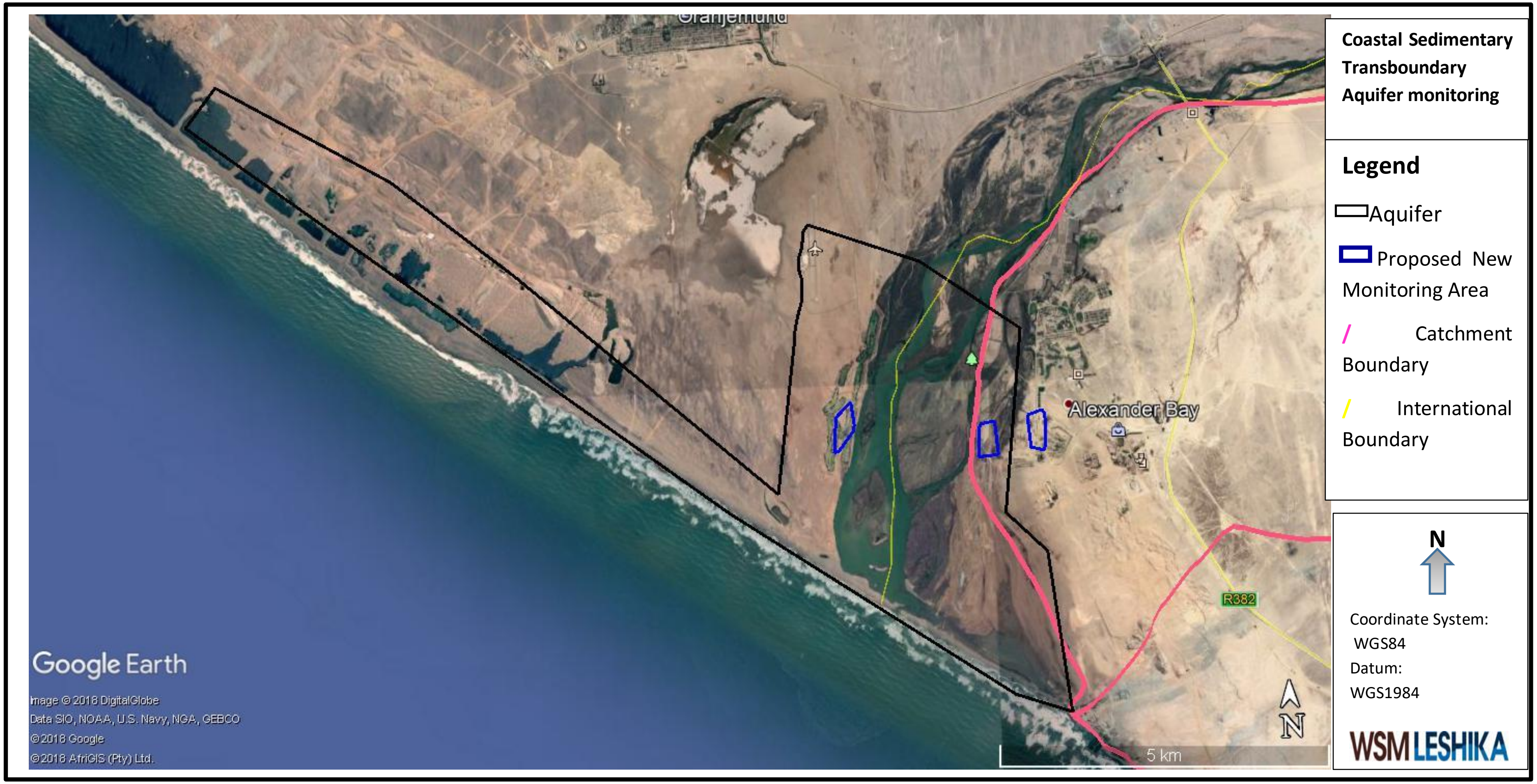


Figure 2-2 Location of Proposed Monitoring Areas and Existing Monitoring Boreholes in the Coastal Sedimentary Transboundary Aquifer

2.4.3 The Stampriet Transboundary Aquifer System (Botswana/Namibia/South Africa)

There are no negative transboundary impacts noted for this Aquifer. There is also no information available which might indicate that users in the down-gradient countries (Botswana & South Africa) need to reduce abstraction due to possible higher than normal groundwater use in the upstream area (Namibian part of the Aquifer). In addition, there is no decline in water quality along the groundwater flow from northwest to southeast caused by groundwater use in the upstream riparian area; it is assumingly due to natural processes which limit the usable volume of groundwater down-gradient.

Currently only Namibia makes significant uses of the groundwater, utilising 90% of the total of 20 Mm^3/a abstracted. Population density in the border regions is low. 66% of abstraction occurs from the Kalahari aquifer.

It is unlikely that South Africa will develop groundwater resources in this aquifer due to the poor natural quality. Botswana is planning a wellfield at Ncojane which may abstract up to 4000 m^3/d.

Namibia and Botswana have limited monitoring of the recharge areas of the aquifer (figure 2-3). The two existing boreholes (WW39854 & WW39856) in Namibia can be considered as potential monitoring boreholes of transboundary flow. There are boreholes close to the Namibia-Botswana borders that should also be considered for the joint monitoring for the two countries.

Monitoring in South Africa indicates a drop in water level of 0.4 m in 13 years, although two of the boreholes are recent (figure 2-4). Due to the low rates of recharge and infrequent recharge events, this water level drop cannot be confidently attributed to over abstraction. The boreholes are drilled into the Kalahari Group sediments and monitor water levels in the upper local aquifer, hence can only monitor lowering of Kalahari water levels due to reduction in upwelling groundwater. They cannot be used to determine hydraulic gradients in the STAS. Water level changes are therefore muted due to the high specific yield of the sediments and low recharge volumes.

A deep borehole to penetrate the STAS, cased off from the Kalahari sediments, and located adjacent to one of the existing Kalahari boreholes could provide data on changes in the upward gradient.

Namibia monitors the aquifer via multilevel piezometers in one borehole, or 3 adjacent boreholes drilled into the 3 aquifer layers. Such an approach is required in South Africa and Botswana.

A Proposed monitoring area in Namibia is indicated in figure 2-3 to determine if the gradient towards South Africa has been affected. Multilevel monitoring is required in order to draw any conclusions on groundwater flow. A similar monitoring area should ideally be located in Botswana to identify the transboundary flow component.

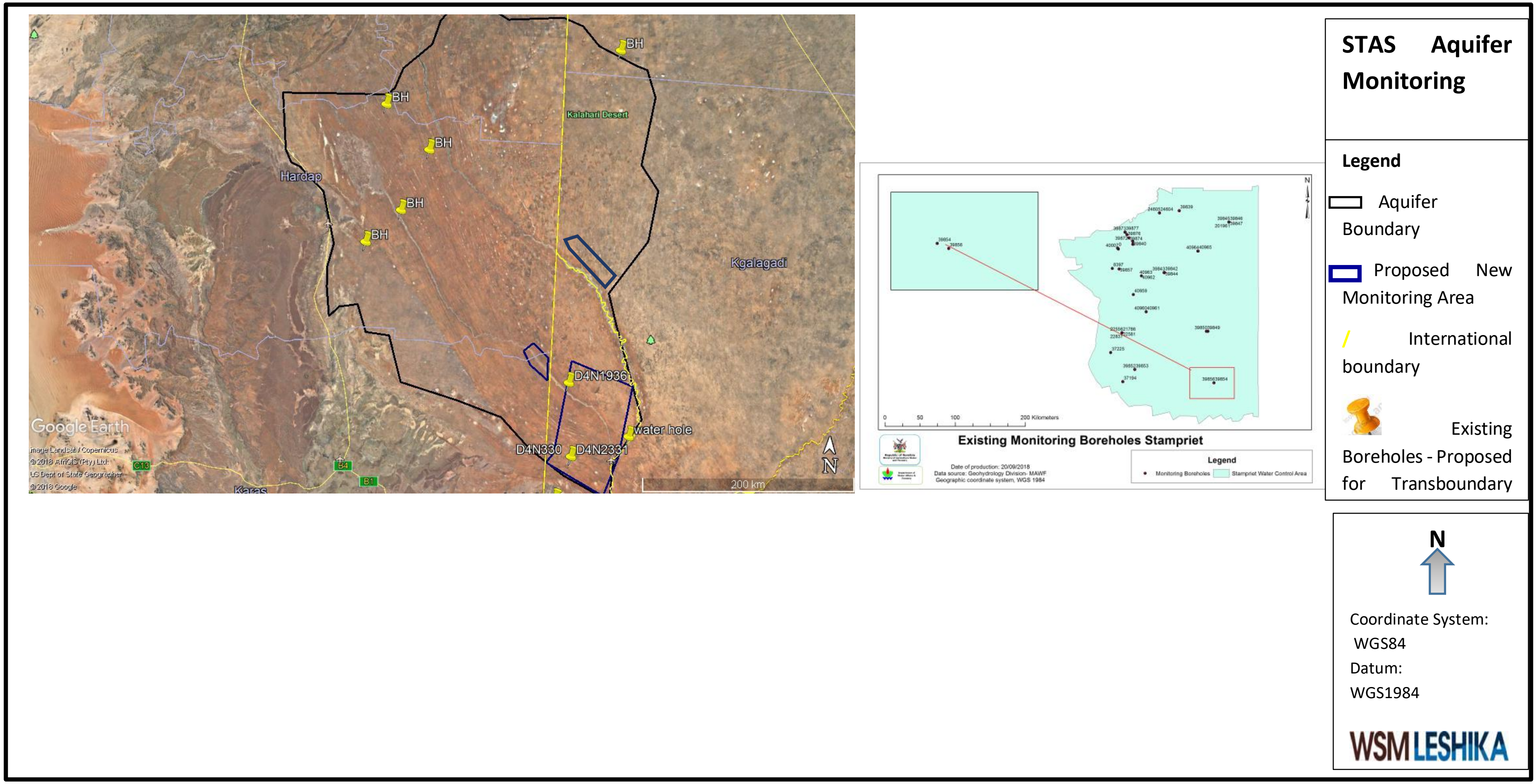


Figure 2-3 Location of Proposed Monitoring Areas and Existing Monitoring Boreholes in the Stampriet Transboundary Aquifer System

Table 2-5 Borehole Water Level Monitoring Data Available in the Stampriet Transboundary Aquifer System

Latitude	Longitude	Country	Station Number	Open / Closed	Begin Date	Frequency	Aquifer	Status	Monitoring Equipment
-25.90278	20.15556	South Africa	D4N1936	Open	2002/06/17	Quarterly	Kalahari	In use	Autographic Recorder
-26.77049	20.30947	South Africa	D4N1461	Closed	1991/12/11	Quarterly	Kalahari		Manual
-26.51167	20.21389	South Africa	D4N2330	Open	2014/06/02	Quarterly	Kalahari	In use	Manual
-26.51278	20.21222	South Africa	D4N2331	Open	2014/06/03	Quarterly	Kalahari	In use	Manual
-26.67806	20.21306	South Africa	D4N2332	Open	2014/06/03	Quarterly	Kalahari	In use	Manual
-23.68523	18.39241	Namibia	Olifantswater	Open	2000	Biannual	All		
-24.82056	18.25379	Namibia	Tugela	Open	1981	Biannual	All		
-24.04592	18.7934	Namibia	Steynsrus	Open	1986	Biannual	Kalahrai and Auob	Record ends in 2011	
-24.54949	18.56123	Namibia	Boomplaas	Open	1981	Biannual	Auob	Record ends in 2002	
-23.58778	20.52694	Botswana	Ukwi	Open	2005	Biannual	Kalahari		
-23.1477	20.47080	Botswana	Ncojane	Open	2008	Biannual	Auob		

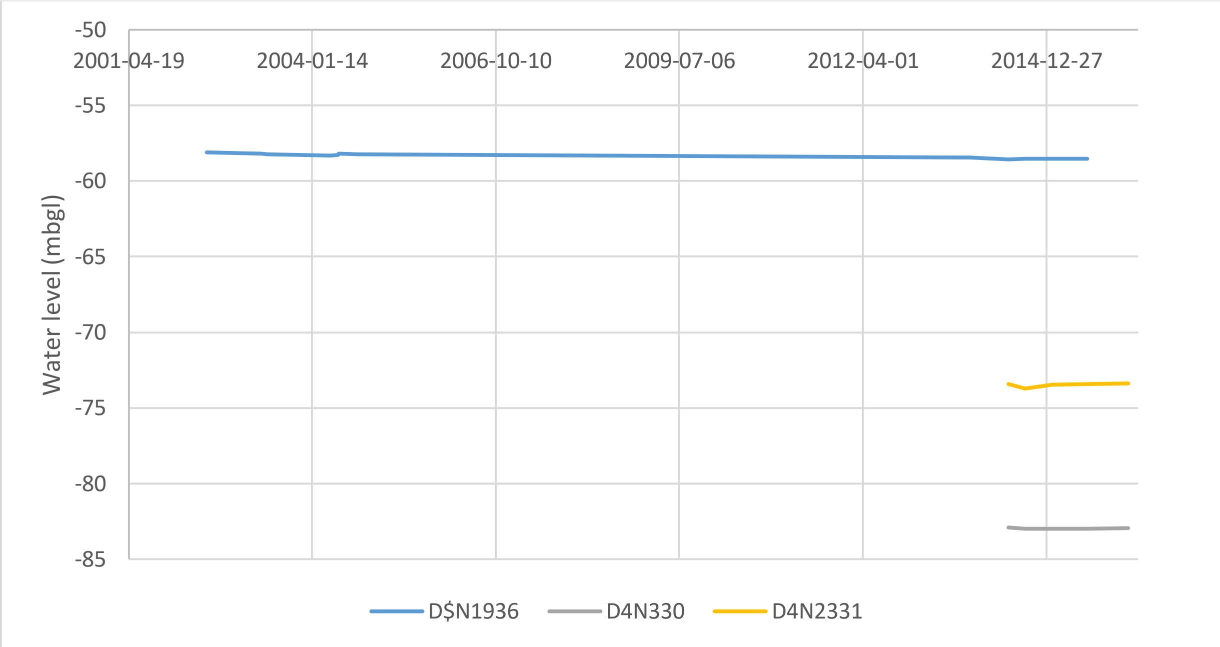


Figure 2-4 Groundwater levels in the Stampriet Transboundary Aquifer in South Africa

2.4.4 *Karoo Sedimentary Aquifer (Lesotho/South Africa)*

Although an extensive monitoring network exists for surface water flow from which baseflow trends can be derived (figure 2-5), no strategic monitoring boreholes exist in the entire catchment.

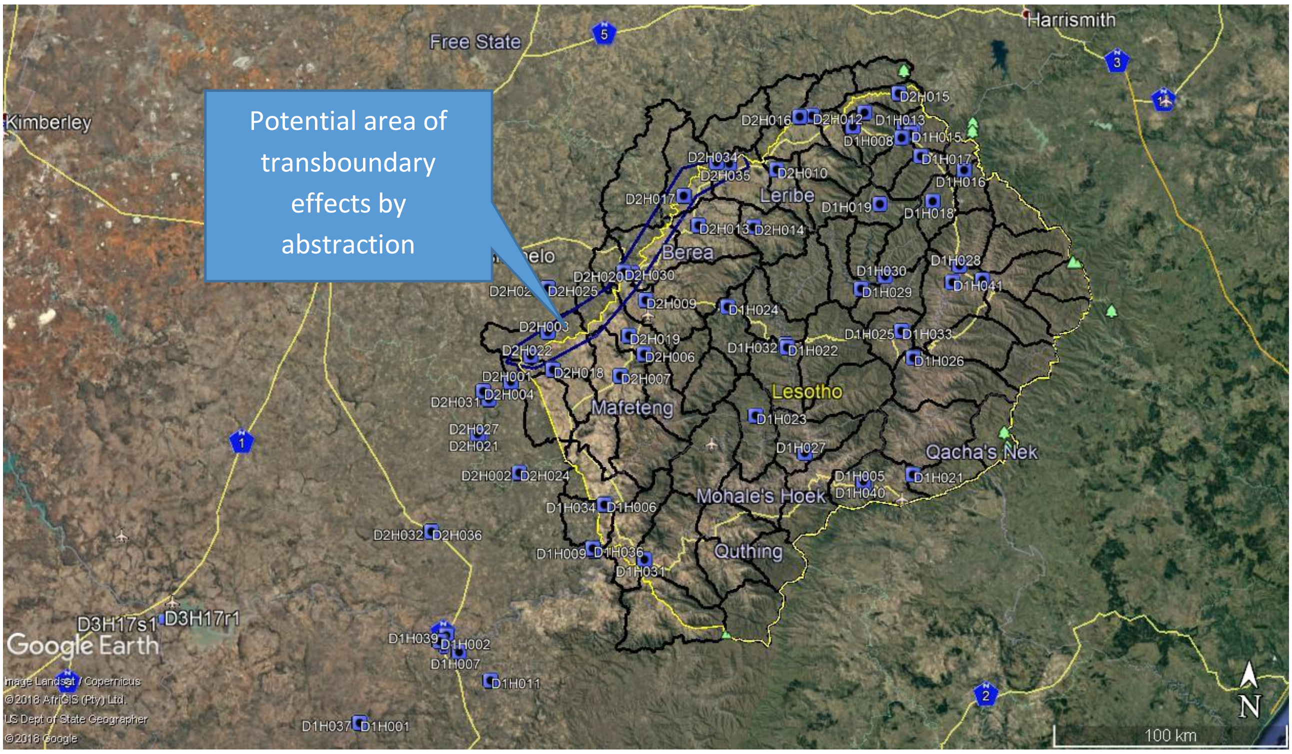


Figure 2-5 Network of Gauging Stations in the Karoo Sedimentary Transboundary Aquifer

Due to the low borehole yields, large scale abstraction is limited to alluvial aquifers, which are limited in extent. Aquifers are also localised in extent due to topography and the presence of dolerite intrusions, making regional impacts a minor consideration.

Alluvial sediments along the Caledon River form a transboundary aquifer where they occur as recent deposits associated with a perennial active river system. The Quaternary and Recent alluvial sedimentary aquifers have good hydraulic characteristics although their size is limited. The hydraulic characteristics are variable and often site specific.

Analysis of test pumping results from the Maputsoe well field indicated a potential yield of 40 l/s when first developed. Test pumping of boreholes installed to supply Butha Buthe township have potential borehole yields of 1.5 to 4.0 l/s An open well sunk in Quaternary age alluvium in Mohale's Hoek produces water at 3 l/s for the town's water supply system.

This suggests large transmission losses can be incurred by surface water flowing over dewatered alluvial systems. Abstraction can reduce baseflow and cause a hydraulic gradient reversal in the alluvial aquifer, which results in rivers losing water to the aquifer. In alluvial aquifers, the primary impact of abstraction for transboundary consideration is baseflow reduction, which can have a cumulative effect. If significant enough, baseflow reduction can affect environmental flow requirements.

Although several alluvial aquifers exist along the Caledon that are transboundary in nature. some of the largest deposits of exploitable alluvial aquifers are in the Maputsoe wellfield area. (figure 2-6) Water is abstracted from these alluvial sediments using well point or gallery systems. This aquifer should be the priority for transboundary monitoring and the impacts of abstraction on baseflows based on its high yields, relatively large extent, and its situation on an international border.

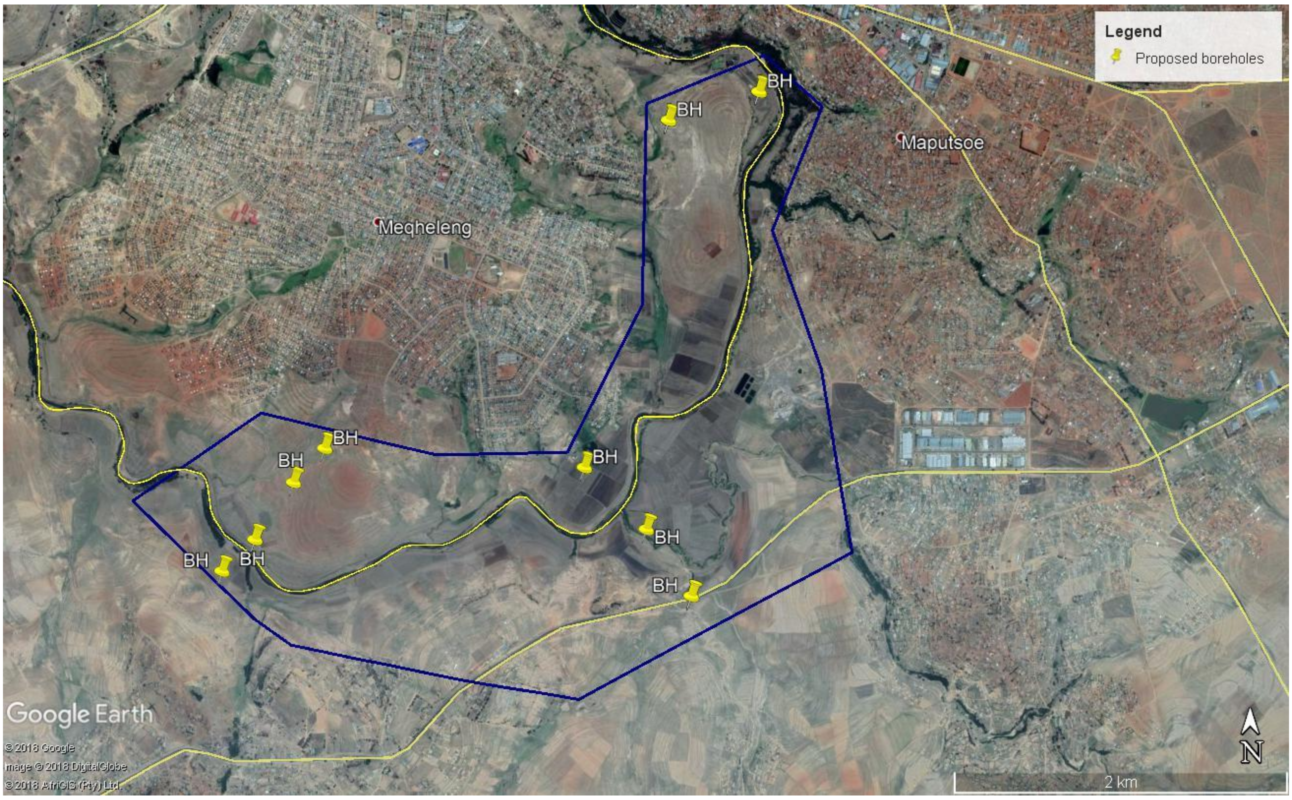


Figure 2-6 Maputsoe alluvium and proposed monitoring sites

Two approaches can be considered for monitoring this aquifer:

1. Establishing gauging weirs upstream and downstream of the alluvium to measure losses. This approach would be expensive, and the losses might be within the measuring error of the gauging structures.

2. Establishing transects of shallow wells in boreholes upgradient of the wellfield, in the vicinity of the wellfield, and down gradient, to determine natural gradients towards the Caledon River and gradients in the impacted zone (figure 2-6). These can be used to determine losses from the river, or baseflow reduction. 2 additional boreholes would need to be drilled into the underlying Karroo rocks to determine upwelling gradients and the contribution of the regional aquifer to baseflow. Calculating losses if water levels in the regional aquifer and the alluvium are known can be undertaken with a numerical model. Monitoring water quality in these boreholes would also assess the existence of contamination and hydraulic gradients towards the Caledon River.

Because of the localised nature of the aquifers, regional monitoring in the Karoo aquifers is probably unnecessary, and monitoring baseflow at river gauging stations to assess declining low flow trends is sufficient to identify transboundary trends. Abstraction rates from the Karoo aquifer are low relative to recharge and significant impacts on baseflow unlikely.

The role of wetlands in the Lesotho Highlands is significant on the distribution of baseflow, hence the wetland monitoring programme in existence needs to be supported as significant changes to the hydrology of the Senqu River has impacts on downstream water resources as well as on the distribution of flows in Lesotho, with environmental implications.

2.5 Selection of Parameter Sets

2.5.1 Chemical Monitoring

The recommended core set of determinants for background characterisation and indictor monitoring comprises dissolved oxygen, pH-value, electrical conductivity, nitrate, ammonium, temperature and a set of major and trace ions. Parameters such as temperature and trace ions will be useful as a once off survey to assess background levels.

Additional indicators of anthropogenic contaminants typical of land use activities in the area and with the potential to impact on groundwater will also be required on an infrequent basis to provide additional validation of impacts. In addition, at all water quality sites, monitoring of the water level is recommended in order to describe (and interpret) (seasonal) variations or trends in chemical composition of groundwater.

2.5.2 Quantity Monitoring

Recommended parameters for the purposes of quantitative assessment of groundwater include:

- Groundwater levels in boreholes. The network needs to be expanded as proposed in each section;
- Spring flows from the strategic wetlands currently being monitored;
- Baseflow from small headwater catchments to calibrate recharge and baseflow processes. Only 2 stations exist in the headwaters of the Senqu and Caledon Rives with catchments of less than ~ 500 km^2, one of which is closed (figure 2-6). Small catchments play a vital role in understanding hydrological processes
- Monthly baseflow during the dry season (i.e. when the flow component directly related to rainfall can be neglected and discharge is sustained substantially by groundwater). Many of the Lesotho gauging stations have very poor calibrations of low flows, which need to be

recalibrated; a problem identified during the ORASECOM Phase II project updating the Orange-Senqu Basin hydrology

- Groundwater abstraction
- Rainfall. Since a long record (>30 years) is required to establish statistics, new stations will not be as useful as reopening old stations that are closed or being closed. A large number of historic stations have been closed, and the selection of stations to reopen would have to consider length of record, elapsed time since closure, representivity, willingness of land owners, agreement of national weather services, etc.)

Table 2-6 Gauging stations in the Upper Caledon and Senqu rivers, with small catchments in yellow

Quaternary	WMA	Latitude	Longitude	Station Number	Name / Description	Open / Closed	Catchment Area (km^2)
D11D	Lesotho	-29.01704	28.53304	D1H019	Malibamatso River @ Lesotho	Closed	847
D11F	Lesotho	-29.33369	28.46637	D1H029	Bokong River @ Lesotho	Closed	395
D11J	Lesotho	-29.28369	28.56637	D1H030	Matsoku River @ Lesotho	Closed	
D11K	Lesotho	-29.48368	28.64970	D1H025	Malibamatso River @ Lesotho	Closed	
D11K	Lesotho	-29.48444	28.64472	D1H033	Malibamatso River @ Paray	Open	2714
D21C	Orange	-28.69485	28.23487	D2H012	Little Caledon River @ The Poplars	Open	518
D21C	Orange	-28.69444	28.23389	D2H039	Caledon River @ Caledonspoort	Open	

2.6 Monitoring frequency

2.6.1 Chemical Monitoring

Monitoring frequency selection will generally be based on the characteristics of the aquifer and its susceptibility to pollution pressures. Sampling quarterly or bi-annually is sufficient for background monitoring. Sampling takes place at the same time(s) each year, or under the same conditions, to enable comparable data for trend assessment and accurate characterisation and status assessment. This is especially important for rapid flow system like karstic aquifers and/or shallow groundwater bodies.

2.6.2 Quantity Monitoring

Sites with significant annual variability should be monitored more frequently than sites with only minor variability. In general, monthly to quarterly monitoring will be sufficient for quantity monitoring to detect recharge and dry season characteristics. The frequency should be revised as knowledge of the aquifer response and behaviour improves and in relation to the significance of any changes in pressures on the groundwater body. This will ensure that a cost-effective programme is maintained.

2.7 Monitoring for each Transboundary Catchment

A summary table for monitoring requirements in each catchment is shown in table 2-7.

Table 2-7 Monitoring requirements in the Transboundary Catchments

Aquifer	Parameters to Monitor		Frequency	
	Quantity	Quality	Quantity	Quality
Khakea/Bray dolomites	Bore Water levels Rainfall	Macroconstituents Microconstituents Rainfall Chloride	Quarterly – biannual Monthly	Biannual Annual Monthly accumulation
Coastal sedimentary	Bore Water levels Rainfall	Macroconstituents Microconstituents Rainfall Chloride	Quarterly – biannual. Occasional several times daily for tidal effects Monthly	Annual Once off Monthly accumulation
STAS	Bore Water levels STAS and Kalahari) Rainfall	Macroconstituents Microconstituents Rainfall Chloride	Quarterly – biannual Monthly	Biannual Annual Monthly accumulation
Karoo Sedimentary	Alluvial Bore Water levels Karoo water levels Rainfall Major springs and wetland discharge Baseflow at headwater gauging stations	Macroconstituents Microconstituents Microbiological Macroconstituents Microconstituents Macroconstituents Macroconstituents	Quarterly Biannual Binannual Annual Monthly Monthly Monthly volumes	Biannual Annual Quarterly Biannual Annual Monthly accumulation Biannual Annual during low flow

2.8 Proposed Reporting Format

2.8.1 Data Sharing Model

The proposed data management system is based on the individual basin states' common ability to provide data in spreadsheets. The member states will manage the data in their individual data management systems. The data will be output from these systems, in spreadsheet format, and can be sent to ORASECOM, where the WIS can be utilised to access data from member states.

ORASECOM can collate the data, carry out QA/QC on the data and produce the required reports to be shared or for distribution to the member states (figure 5-6). The proposed system does, however, rely heavily on ORASECOM having suitable capacity and funding to manage the data.

Ultimately a data management system for groundwater should be linked to the hydrology data management system.

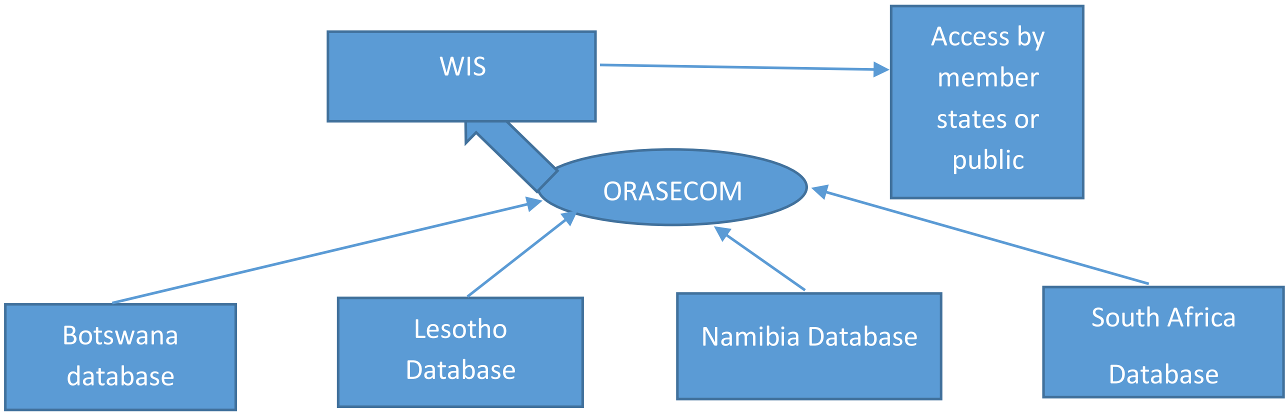


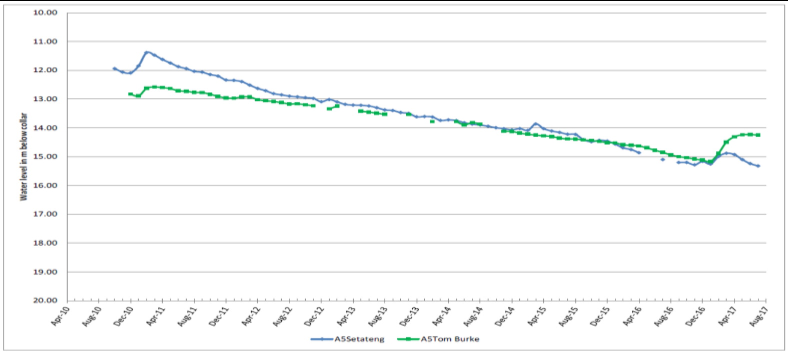
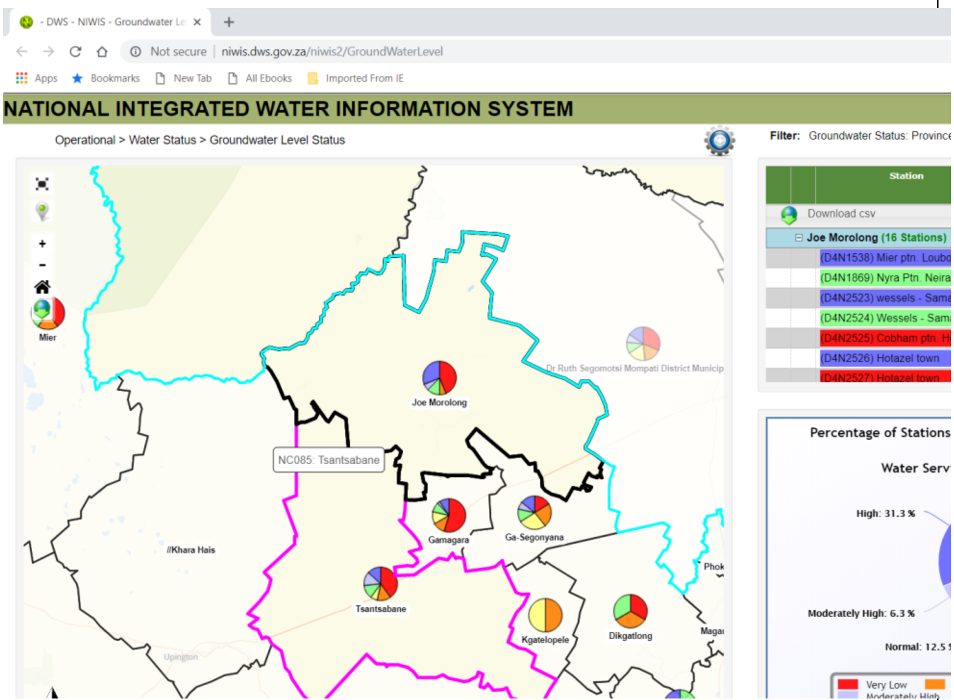
Figure 2-7 Proposed data flow

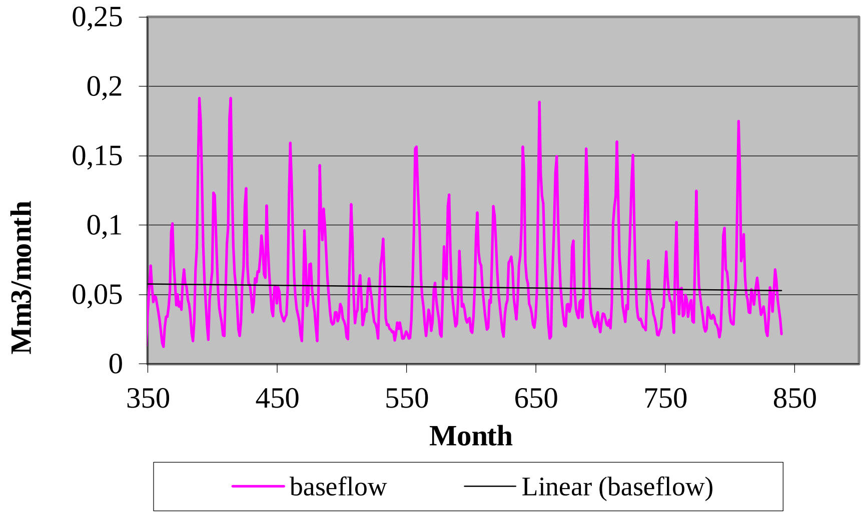
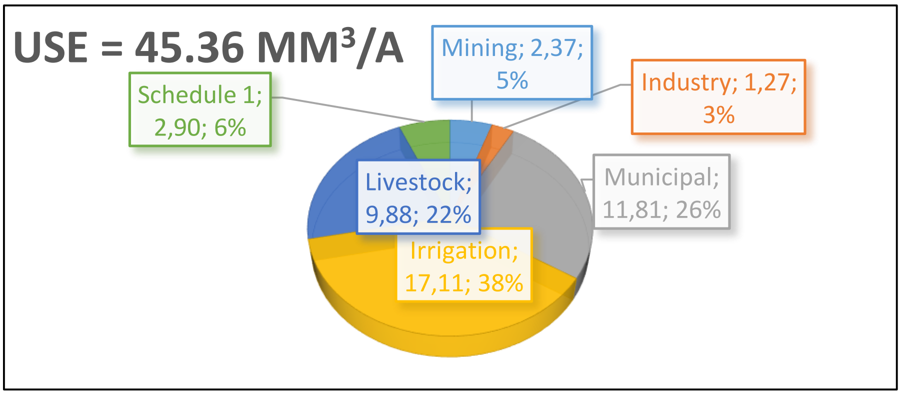
2.8.2 Reporting

Member States will need to submit summary reports of the monitoring programmes of transboundary aquifers. A template of content can be considered for an annual report. A proposed template is shown in table 5-7.

Figure 2-8 Proposed Contents of Transboundary Monitoring

Chapter	**Content**
Background	• Date covered by reporting period (annual) as per table 2-7 • Map of monitoring stations per transboundary aquifer • Changes to network due to additions, reductions • Instrument or data collection failures • Level of confidence in the data
Groundwater levels	• Difference in water levels per transboundary aquifer in the past period • Total stations with and without data • Number of stations with an increase or decrease in water level with map • Average increase or decrease in water level
	Groundwater level trend in each aquifer with graph e.g.

	
	• Current status of groundwater level e.g 
Rainfall	• Map showing rainfall for past period as a percentage of Mean Annual Precipitation (MAP) for each aquifer • Graph of rainfall trend (past 30 years)
Baseflow	• Baseflow at gauging stations derived from a hydrograph separation, with a trend line e.g.

	
Water Quality	• For each aquifer background statistics for indicator parameters such as: - Minimum - Mean - Maximum - Standard deviation - 10, 25, 50, 75, 90 Percentile • Trend analyses of changes over time
Water Use	• Aquifer stress index (use/recharge) • Water use by sector for each Quaternary catchment (graph) e.g. 
Summary and Conclusions	• Identification of stressed areas and causes • Identification of changes or trends • Transboundary issues arising
Recommendation	• Mitigation measures for identified issues

3 IMPLEMENTATION COSTS

The 34TH Meeting of the TECHNICAL TASK TEAM (TTT) of the GWHC held on the 9TH August 2018 identified that the costing and selection of priority monitoring areas be undertaken. This was based on typical implementation costs in each country.

Table 3-1 provides a cost summary of implementing the monitoring programmes described in 2-4, listed in order of priority. Test pumping is not included as the boreholes should not function as production boreholes nor be sized to be capable of high capacity pump installation, only as part of strategic monitoring of water levels and water quality.

Table 3-1 Implementation costs

Monitoring	Rank	Priority	Content	Cost (Euro[1])
Maputsoe Aquifer	1	• Utilised by Lesotho for Maputsoe and South Africa for Ficksburg • Currently not monitored • Impacts on low flows in the Caledon River • International water allocation not known	Lesotho: 6 shallow piezometers through the alluvium 3 60-80 m boreholes with water level dataloggers South Africa: 6 shallow piezometers through the alluvium 3 60-80 m boreholes with dataloggers	 **14 648** 15 258 **14 648** 18 310
Calibration of low flows of gauging weirs in Lesotho	2	• Calibration of low flows in Orange Senqu hindered by poor gauging weir calibrations, affecting water resource simulation and quantification, and impact on IFRs for the entire Orange-Senqu	Lesotho: Status quo assessment, review, site visits and structure assessment of 18 weirs	 **122 066**

[1] Used South African Rand to Euro Exchange Rate of 15th March 2019, of 16.38 Rands to 1 Euro.

		system above the Gariep dam • The hydrology of the Orange-Senqu and baseflows largely hinges on these weirs	Recalibration of 5 stations Minor repairs and recalibration of 8 stations Rebuild stations and calibrate for 5 stations	**61 033** 195 305 366 197
Khakea-Bray aquifer	3	• The aquifer is heavily utilized in South Africa but the impacts on Botswana are unknown.	Botswana: 2 boreholes to 200 m with data loggers across the Molopo River South Africa: 1 additional borehole to establish a hydraulic gradient, with data logger	**24 413** 15 258
Stampriet aquifer	4	• The aquifer is utilized by 3 nations, however, large scale abstraction in South Africa, where discharge occurs is unlikely	Botswana: 2 boreholes to 200 and 300 m with data loggers near the Nossob river South Africa: 2 boreholes to 200 and 300 m with data loggers	**42 723** **36 620**

			near the Namibian border Namibia: 3 additional boreholes to 300 metres if required	 67 136
TOTAL				993 615
TOTAL – minimum requirements				**316 150**

4 APPENDIX A – COMMENTS REGISTER

Section	Report statement	Comments	Changes made?	Comment
Section 2.4.3	A deep borehole to penetrate the STAS, cased off from the Kalahari sediments, and located adjacent to one of the existing Kalahari boreholes could provide data on changes in the upward gradient.	The recommendation being made in the statement is it for the Namibian side or the South African side of STAS?	The locality of the borehole referred to in the report statement should be indicated on the map of the final report	Changes were added to the rpeort
Section 2.4.3	Figure 2-3 location of the proposed monitoring areas and existing monitoring boreholes in the Stampriet Transboundary Aquifer System	STAS has a lot of monitoring boreholes that are not indicated on the map in figure 2-3. I have thus attached the map of all the existing monitoring boreholes in the STAS on the Namibian side in the email. The attached map also indicates two existing boreholes WW39854 and WW39856 in the proximity of the proposed monitoring area of figure 2-3.	1.The two existing boreholes (WW39854 & WW39856) should be considered as potential monitoring boreholes 2. There are boreholes close to the Namibia-Botswana borders that	

Section	Report statement	Comments	Changes made?	Comment
			should also be considered for the joint monitoring for the two countries.	

Section	Report statement	Comments	Changes made?	Comment