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REVIEW, EVALUATION AND OPTIMISATION OF THE SOUTH AFRICAN WATER RESOURCES MONITORING NETWORK

Scientific Review Report

Final
August 2016

REVIEW, EVALUATION AND OPTIMISATION OF THE SOUTH AFRICAN WATER RESOURCES MONITORING NETWORK

SCIENTIFIC REVIEW REPORT

August 2016

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LIST OF ABBREVIATIONS

AMSL	Above mean sea level
AMD	Acid mine drainage
ARC	Agricultural Research Council
CD: WIM	Chief Directorate: Water Information Management
CMA	Catchment Management Agency
DT	Discharge table
DWS	Department of Water and Sanitation
EIES	Ecological Importance and Ecological Sensitivity
EWR	Ecological water requirements
MAR	Mean annual runoff
NAEHMP	National Aquatic Ecosystem Health Monitoring Programme
NCMP	National Chemical Monitoring Programme
NEMP	National Eutrophication <u>or</u> National Estuarine Monitoring Programme
NGA	National Groundwater Archive (replaced the NGDB)
NGDB	National Groundwater Database
NMMP	National Microbiological Monitoring Programme
NRMP	National Radioactivity Monitoring Programme
NTMP	National Toxicity Monitoring Programme
PES	Present Ecological State
RDM	Resource Directed Measures
REMP	River Ecostatus Monitoring Programme (replaced the RHP)
RHP	River Health Program
RQIS	Resource Quality Services
SAEON	South African Environmental Observation Network
SASS	South African Scoring System
SAWS	South African Weather Service
WMAs	Water Management Areas
WMS	Water Management System
WR2005	Water Resources of South Africa 2005 (Study)
WR2012	Water Resources of South Africa 2012 (Study)
WRC	Water Research Commision

1. INTRODUCTION

The Chief Directorate: Water Information Management (CD: WIM) of the Department of Water and Sanitation (DWS) has initiated a study for the Review, Evaluation and Optimisation of the South African National Water Resources Monitoring Network. The technical tasks identified for this study are as follows:

- Requirements Assessment (Task 4).
- Network Inventory (Task 5).
- Data Integrity Assessment (Task 6).
- Scientific Review (Task 7).
- Strategy Development (Task 8).

The first three technical tasks of this study (Tasks 4, 5 and 6) have been completed. This document is the report for Task 7, which covers the nine Water Management Areas (WMAs) in South Africa.

2. PURPOSE AND STRUCTURE OF REPORT

This report provides the Scientific Review results and recommendations regarding the existing surface and groundwater monitoring sites for all nine Water Management Areas following the Regional WMA Network Design Workshops held in Nelspruit, Cape Town, Durban, King Williams Town, Bela-Bela and Bloemfontein from March to June 2016.

During these workshops theoretical monitoring network considerations for each WMA were presented to various stakeholders, and the considerations were used to review the existing networks and obtain changes and improvements to the networks as recommendations.

The main objectives of the workshops were to review the existing monitoring networks against the prioritised National Monitoring Objectives in terms of:

- Existing sites meeting the identified objectives;
- Redundancies in the existing monitoring network;
- Gaps in the spatial coverage with regards to meeting important monitoring objectives; and
- Possible physical constraints associated with existing and potential new monitoring sites.

The results from these analyses are reported in the following sections:

- **Section 3**: Scientific Review Approach.
- **Section 4**: Outcomes of the WMA workshops. Contained in this section is a national summary of the scientific review outcomes and recommendations for both surface and groundwater monitoring.
- **Section 5**: Recommendations.

Accompanying this report is an Annexure that contain more detailed information with regards to the scientific review workshop outcome for South Africa's nine Water Management Areas.

Also included in the Annexure are appendices which also contain the design workshop agendas and attendance registers for nine aforementioned Regional Scientific Review Workshops.

The national monitoring network covers the terrestrial, subterranean and coastal fresh water hydrological cycle components of South Africa. The network should ensure adequate national and regional spatial coverages and scientifically sound measurement of quantity, quality and biophysical properties of water resources at appropriate time intervals.

Water resource quantity monitoring includes water flow rates, groundwater and reservoir levels, streamflow levels, tidal elevations and discharge volumes. Water resource quality is monitored in terms of chemical, nutrient, microbiological, radioactivity and sediment properties. Water quality is usually expressed in terms of concentration, but may also be in terms of load. Biophysical monitoring includes, amongst others, assessments of macro-invertebrates, fish, habitat, geomorphology and riparian vegetation.

3. SCIENTIFIC REVIEW APPROACH

This section describes the Scientific Review process in preparation for a Spatial Design Review Workshop. The process and anticipated outcomes of the workshop are also described. The detailed spatial information generated for the workshop is provided in **Section 3.2.4** of this document.

3.1 OVERVIEW

Subsequent to the Spatial Design Workshop, a Regional Spatial Design Workshop was held to review the existing water resources monitoring network against the theoretically designed network. The workshop was represented by:

- DWS Head-Office Sections with experience in the use of data from the existing hydrological monitoring network and network design;
- DWS Regional Offices with the responsibility for data management and infrastructure maintenance;
- Specialists that were involved in the development of the theoretical network; and
- Relevant stakeholders (Catchment Management Agencies, Water Boards, Universities and Research Institutions).

At the onset of each workshop, the representatives were briefed on the criteria and limitations to be adhered to during the workshop, such as:

- The spatial coverage should include both quantity and quality aspects of the monitoring. At this stage it was presumed (with some exceptions) that water quality monitoring will only be conducted in combination with flow recording at the site. Microbial monitoring and other hotspot monitoring could however be exceptions to this, but such monitoring will only be sporadic as a result of specific conditions and reviewed more frequently than national monitoring networks.
- This process followed at the workshop only included the spatial positioning of sites and did not necessarily include the type of parameters and measurement frequencies at the site which will be dictated by the reasons for selecting the site and whether the objectives will be met by the location of the site.
- Existing surface water regulation dams are the most important sites in the monitoring network, and it is recommended that all components of the DWS dams be monitored to the highest accuracy possible. The large DWS dams were therefore excluded, from the regional workshops discussions, except where shortcomings of the current monitoring were identified such as not measuring all components downstream of the dams and where regional surface water regulation dams used for domestic supply were not included in the current network.
- No other constraints should be considered except for physical constraints (access, vandalism, no foundations, etc.) when identifying new sites. The best possible networks will be the network that meets as many as possible of the national monitoring objectives.

The aim of the workshop was to:

- Provide an overview per secondary catchment of the theoretical site' spatial coverage that would meet the prioritised National Water Resources Monitoring objectives.
- Reviewing existing sites against the proposed theoretical spatial coverage by:
- Assigning importance and functions to the existing sites;
- Identifying redundancies and problems at existing sites (vandalism, structural problems etc.);
- Identifying gaps in the existing spatial coverage compared to theoretical coverage (new or replacement sites, improvements to existing sites); and
- Possible physical constraints of new sites (vandalism, foundations, access, etc.).

The review is discussed in more detail below:

3.1.1 Present the theoretical sites per category

At the onset of the workshop, the Study Team provided an overview of the datasets used to determine the theoretical sites per category and the overall spatial distribution of the sites per WMA. All the base information was provided on Google Earth for querying the detail. Adjustments and comments on each of the theoretical sites were recorded. All discussed and agreed-upon changes to the theoretical sites were made on Google Earth for use at a later stage.

3.1.2 Review the current monitoring network

The review of all the existing monitoring sites was then interpreted per secondary catchment. The comments and recommendations of each site were captured using the notes function in Google Earth. Issues of accuracy and the need for improvement to the sites were noted, as well as other physical constraints such as access and vandalism.

3.2 DESIGN OF THE THEORETICAL MONITORING NETWORK

The spatial design of an "ideal" theoretical network was the first step in the scientific review process. The theoretical network had to be developed independently of what currently is being monitored to ensure an unbiased review of the existing network. The theoretical monitoring network design process consisted of the following three main aspects (which are described in the following sections):

- Define National Water Resources Monitoring Objectives
- Develop optimal site positioning criteria for theoretical sites
- Apply optimal positioning criteria to spatial data sets to select theoretical sites that meet the Monitoring Objectives.

3.2.1 National Water Resources Monitoring objectives

During previous tasks of this project water resources monitoring objectives were developed and classified according to the national network priorities.

The national monitoring network provides baseline, status (up to near-real-time) and historical trend reporting of water resources in support of four key strategic monitoring objectives. These are summarised and prioritised in **Table 3.1** with descriptions of each main objective.

Table 3.1 Summary of prioritised National Water Resources Monitoring Objectives

Priority class	Objective	Description
1	Resource and infrastructure planning	To provide adequate monitoring data for determining the availability and quality of current and future water resources, aimed at providing strategic decision support for the equitable and sustainable allocation of resources to the population, environment and other economic sectors of society through planned infrastructure development and other interventions.
2	Resource operations and management	To provide timely monitoring data for the efficient operation and management of water resources to ensure the protection of resources and water users and to allocate water equitably and sustainably.
3	Early warning systems	To provide timeous water resources monitoring data for early-warning systems to mitigate negative impacts on humans, infrastructure, the economy and riverine and coastal ecosystems.
4	Compliance and auditing	To provide water quality and quantity monitoring data to ensure compliance and auditing functions required for water use licensing, and other functions.

Of the four priority objectives, the national network design primarily focusses on the Resource and Infrastructure Planning Objectives (Objective 1), while the Compliance and Auditing objectives (Objective 4) forms part of localised monitoring activities, such as done by DWS Regions and Catchment Management Agencies. Although Resource Operations and Management objectives (Objective 2) falls under the responsibility of other sections in the Department, it was also included in this analysis to identify overlapping or single responsibility sites, thus indicating relative importance.

Although it was endeavoured to make the objectives as inclusive as possible, there might be some considerations omitted or not stated explicitly.

Reported in **Sections 3.2.1 a)** to **3.2.1 d)** are more detailed descriptions of the prioritised National Water Resources Monitoring Objectives used to evaluate the relative importance of the theoretical monitoring sites.

a) Objective 1: Resource and infrastructure planning

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. The infrastructure in question includes dams, water conveyance systems, as well as water and wastewater treatment works.

Water resources assessments are dependent on ongoing monitoring of:

- Hydro-meteorological data to estimate long-term rainfall (especially at higher altitudes and in high rainfall areas), evaporation, constituent transport (such as salt wash-off), agricultural water use and groundwater recharge characteristics. These data are also essential for estimating the possible impacts of climate change on the future availability and quality of water resources.
- Surface water quantity data for rivers and reservoirs, with adequate spatial coverage and of sufficient period lengths for the calibration of rainfall-runoff models and estimation of long-term resource availability.
- 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.
- Reservoir and other infrastructure characteristics data, such as dam capacities, dam basin characteristics, river gauge discharge tables and the capacities of conveyance infrastructure.
- Surface and 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.
- Sedimentation data to assess sediment loads and associated pollutant transport, as well as to assess the impact of sediment deposition on reservoir storage capacities and yields over time.
- Biophysical data to determine the Reserve for both surface and groundwater resources, in conjunction with all the data sets mentioned above to determine historical, present-day and future projected resource availability and quality.
- Current and historical catchment water use in order to assess current and projected future water requirements. The National Water Resources monitoring programme focusses mainly on bulk water use associated with abstractions at large reservoirs and for irrigation schemes. This includes pipelines (e.g. linking water treatment works with reservoirs or well fields), canals and other bulk conveyance infrastructure.

b) Objective 2: Operation and management

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 monitored of the following:

- 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, groundwater levels at well fields and tidal levels at estuaries. This also includes the quality of resources to allow for the implementation of blending rules, if and where applicable.
- Surface water and groundwater use and return flows at abstraction sites, pipelines and well fields to allow for the supply of water resources according to planned allocations.
- Quantity and quality indicators for complying with Reserve and Resource Quality Objectives (RQOs) and to implement operating rules according to the resource status.

c) Objective 3: Risk mitigation

Risk mitigation includes monitoring of surface water droughts and floods as well as low groundwater levels and seawater encroachment (from a quality perspective), all driven by adequate rainfall measurements. Furthermore, water quality risk mitigation is supported by warnings of the failure of surface and groundwater resources to meet fitness for use criteria. This includes the effects of acid mine drainage (AMD) and hydraulic fracturing as well as industrial and agricultural return flows on the water resources.

d) Objective 4: Compliance and auditing

Ongoing monitoring of various parameters is required to ensure compliance with the legal requirements associated with the relevant legislation, water use licences and international treaties and agreements. These are summarised below:

- Although there is a responsibility on the individual users to measure their water use and return flows, the national monitoring network has to allow for the monitoring of bulk water use and compliance with water quality criteria.
- Certain parameters must also be monitored for complying with the Reserve and RQOs at particular sites, including river flows and groundwater levels, associated water quality and biophysical data.
- South Africa has several shared river basins, and trans-boundary aquifers with associated internationally agreed flows and levels that must be monitored and maintained.

3.2.2 Monitoring sub-objectives

To spatially design a theoretical network that met the objectives as described in Section 3.2.1 each of the four main categories of objectives was disaggregated into multiple sub-objectives which contribute towards achieving the main objectives. For instance, in order to successfully achieve resource and infrastructure planning two examples of sub-objectives are (a) determine the availability of water resources and (b) determine the fitness of use of the resources, as illustrated in **Figure 3.1**.

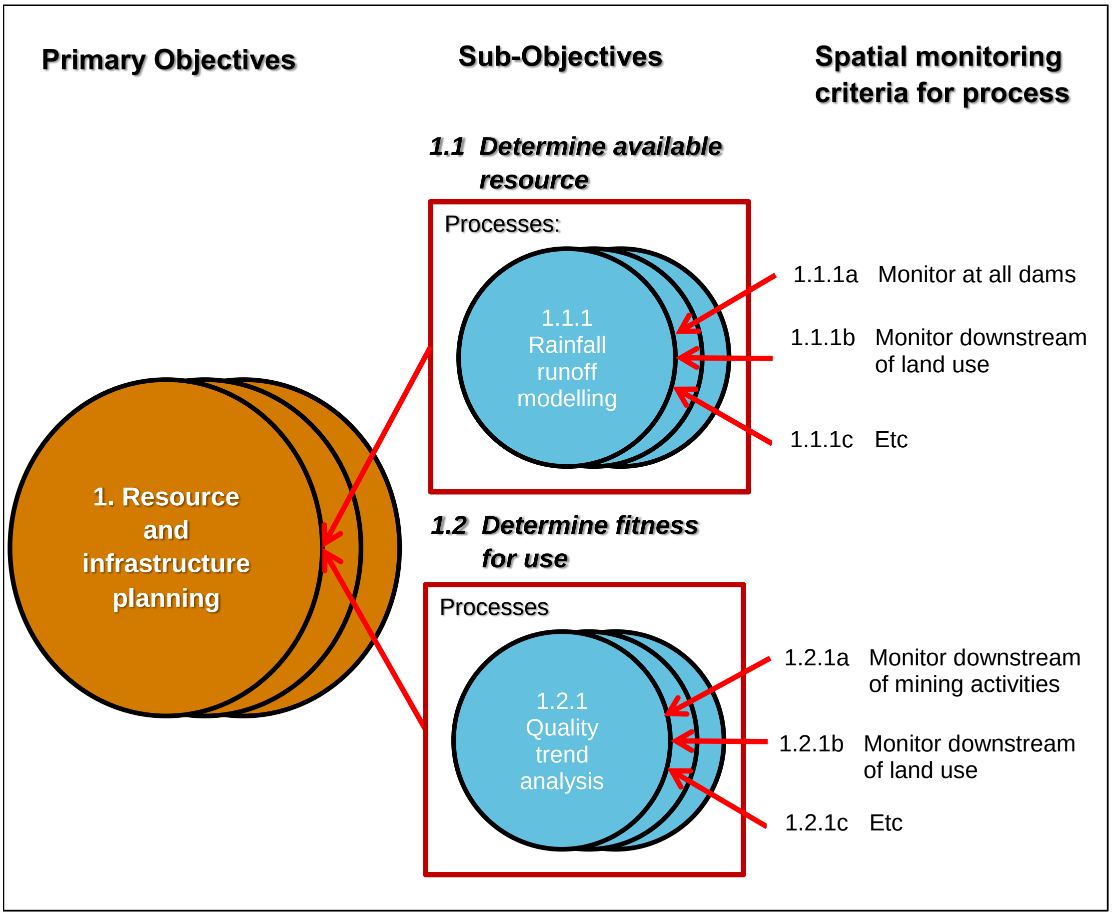

Figure 3.1 Translating monitoring objectives into optimal site positioning design criteria

3.2.3 Optimal site positioning criteria for theoretical sites

A link had to be established between the sub-objectives for monitoring and spatial position of theoretical monitoring sites that would meet the sub-objectives, and therefore the main objectives. This was done by identifying legal, administrative and scientific processes that are undertaken by DWS and other institutions to meet the needs of each sub-objective. **Table 3.2** provides a summary of the non-exhaustive list of processes that contribute to sub-objectives and subsequently primary water resources monitoring objectives in the South African water resources monitoring context.

Table 3.2 Processes contributing to national water resources monitoring objectives

Main objective	Sub-objective	Process
Resource and infrastructure planning	Quantify available resource	Rainfall-runoff modelling
		Groundwater modelling
		International obligations
		Research and baseline catchments
		Reserve requirements
		Estuarine requirements
	Determine fitness for use of resources	Quality trend and threshold analyses
		Salinity modelling
		Eutrophication modelling
		Groundwater modelling
	Development options analysis system operating rules	Water resource systems modelling, including demand projections
	Infrastructure design	Sediment analysis
		Flood analysis
Resource operations and management	Systems operation	Bulk system operating rule implementation.
		Implement International obligations
		Operational quality target actions
		Reserve implementation
		Estuarine flow requirement implementation
	System management	Short-term allocation decisions
		Estuarine operational decisions
Early warning systems	Flood management	Flood mitigation decisions
		International obligations warning
	Resource availability	Drought early warning systems
	Fitness for use	Estuarine early warning systems
		Surface water early warning systems
		Groundwater early warning systems
	Critical levels	Impact analysis: Fracking
		Impact analysis: AMD
Compliance and auditing	Compliance checking	Water user licences / waste water discharges
		International obligations
	Auditing	Water user licences/waste water discharges
		Reserve implementation

Theoretical spatial criteria for monitoring sites that best meet the needs of each process were then identified, as illustrated for surface water in **Figure 3.1**. Spatial placement criteria were expressed in terms of relative positioning of sites (upstream, at or downstream) in relation to physical features such as land use, infrastructure etc. for river systems or in terms of densities for other networks such hydro-meteorological or groundwater.

After the spatial positioning criteria were identified for processes that would support optimal water resources monitoring, many overlaps were identified between the criteria for different processes. Duplications were removed and an integrated list of spatial positioning criteria was developed for application in the theoretical sites identification process.

3.2.4 Theoretical site identification based on spatial datasets

Theoretical site positions were determined using the integrated site positioning criteria and available national spatial data. A list of spatial datasets obtained or generated (derived) from other datasets or reports are provided in **Table 3.3**.

Table 3.3 Spatial datasets used in the design of a theoretical network

Dataset description	Origin	Source	Status
Hydrological considerations			
Quaternary, tertiary, secondary and primary catchments	Source	Water Resources of South Africa 2005 (WRC, 2008)	Used
1:500 000 primary and secondary rivers	Source	Water Resources of South Africa 2005 (WRC, 2008)	Used
Catchment outlet points	Derived	Generated from NASA ASTER 30m GDEM and Quaternary Catchment Data (WRC, 2008)	Used
International boundaries	Source	CD NGI. Municipal Demarcation Board (2011)	Used
Natural cumulative mean annual runoff (million m^3/a)	Derived	Generated from Water Resources of South Africa 2012 (WRC, 2015) MAR Data and WSAM Catchment Tree	Used
Natural incremental mean annual unit runoff (mm/a)	Derived	Generated from Water Resources of South Africa 2012 (WRC, 2015) MAR, Area and WSAM Catchment Tree data	Used
Natural incremental mean annual runoff as %MAP	Derived	Generated from Unit Runoff data and Water Resources of South Africa 2005 (WRC) MAP data	Not-used
Topography (slopes)	Derived	Generated from NASA ASTER 30m GDEM	Not used
River network stream-orders - 30 m DEM	Derived	Generated from NASA ASTER 30m GDEM	Not used
Inter-basin transfers	Source	Water Resources of South Africa 2005 (WRC, 2008)	Complete

Dataset description	Origin	Source	Status
Dams (including DWS dams)	Origin	DWS Hydstra Coordinates for active and inactive dams, Land Cover and DWS registered dam safety database.	Used
Sedimentation	Source	Water Resources of South Africa 2005 (WRC, 2008)	Used
MAP	Source	Water Resources of South Africa 2005 (WRC, 2008)	Used
MAE	Source	Water Resources of South Africa 2005 (WRC, 2008)	Used
Geo-hydrological Considerations			
Geology	Source	Council for Geosciences	Used
Transboundary aquifers	Source	Hydrogeology map of Southern Africa 2010 (SADC)	Used
Vegter aquifer regions	Source	An explanation set of national groundwater maps (WRC)	Not used
High yielding aquifers (aquifer classifications)	Source	1:500 000 Hydrogeological map series (DWAF)	Used
Aquifer vulnerability	Source	Groundwater Resource Assessment: Phase 2 (DWAF)	Used
Groundwater quality (EC, N, F)	Source	Groundwater Resource Assessment: Phase 2 (DWAF)	Used
Baseflow sensitive groundwater areas	Source	Groundwater Resource Assessment: Phase 2 (DWAF)	Used
Environmental considerations			
Ecological water requirement (EWR) Sites	Source and derived	Resource Classification and RQO Study EWR sites obtained from DWS: Water Ecosystems. Other EWR sites obtained from various consultants	Used
South African protected areas database	Source	SAPAD, (DEA, 2015)	Used
Present Ecological Status, Ecological Importance and Ecological Sensitivity	Source	Desktop PES, EI + ES (DWS, 2014)	Used
Groundwater Reserve areas	Derived	DWS: WES	Used
Anthropogenic Considerations			
Landcover and negative landcover	Derived	Generated from SA Landcover © Geoterraimage (2014): Reduced classes and area summary per class	Used
Eskom Power Stations	Derived	Generated from www.eskom.co.za	Used
Fracking Geo-exploration Zones	Source	Petroleum Agency of South Africa	Used
AMD Zones and Treatment Plants	Source	TCTA, 2011.	Used
WWTW and WTW	Source	DWS: Water Services	Used
Drought vulnerability map	Source	DWS:GI	Not used
Groundwater dependent towns	Source	DWS:GI	Used
Current and future bulk water regional schemes RBIG	Source	DWS: Water Services	Used

Although most of the spatial datasets were national datasets, some of the spatial data were derived for each area from individual reports obtained from DWS and Consultants.

Google Earth was used as the main tool to identify theoretical sites by the Study Team specialists based on all the spatial datasets, which were converted from shapefiles into the Google Earth kml/kmz format. Google Earth was also used during the Regional Scientific Review Workshops as the main communication tool with stakeholders and for the identification of new sites.

The list of criteria in the report will provide for different weights / gauging densities being considered to cater for key resource areas, development nodes, existing and potential pollution loads and spills, environmentally important areas, etc.

a) *Procedures for surface water*

The identified theoretical sites were grouped into three categories:

- Hydrological / geo-hydrological;
- Aquatic ecosystem; and
- Anthropogenic (human induced impacts).

Each specialist worked systematically through the catchment and used the spatial data and positions criteria to identify theoretical sites (independently of existing monitoring activities). A labelling notation was developed to capture the relative priorities of theoretical sites, the data on which the site selection was based and the cumulative priorities (importance) of individual sites.

The notation consists of two parts separated by an "|". The first part states which objectives are being satisfied by the theoretical monitoring sites. It consists of a four letter code that indicates which of the four primary objectives are being met and are summarised with a single letter as follow:

- **P** - Resource and Infrastructure **Pl**anning
- **M** - Resource Operations and **M**anagement
- **E** - **E**arly warning systems\Risk mitigation
- **C** - **C**ompliance and auditing

The second part of the notation indicates which spatial dataset was used to apply the positioning criteria to. The codes describing the spatial data are summarised in **Table 3.4**.

Examples of the notation derived from a combination of the spatial dataset and the positioning criteria of the sites are provided in

Table 3.5.

The notation could also be applied cumulatively per theoretical category, i.e. hydrological, ecosystem and anthropogenic. Identifying sites usually involves taking each spatial criterion and identifying sites for the particular criteria.

As new criteria are being added there would be overlapping sites with different design criteria and therefore objectives. The same site might be required for fitness for use early warning and planning purposes for forestry, urban and mining/industrial purposes, i.e. PE|F,Ur,MI.

Table 3.4 Codes describing the spatial criteria and data used for selection surface water sites

Abbreviation	Description
Hydrological considerations	
Base	Sites that would contribute towards a representative distribution of natural flows throughout the catchment
HR	Sites that have high incremental unit runoff areas (>= 200 mm/a) upstream
IntObl	Sites where river cross into or originate from neighbouring countries
Ecosystem considerations	
ExistResC	Sites close to RQO EWR sites
ExistResR	Sites close to Comprehensive/Intermediate Reserve Studies EWR Sites
PosResR	Possible EWR sites based on PESEIES study data
EcoImpSen	Sites with high PESEIES values upstream
UpPA	Sites that are upstream from protected areas (National Parks, RAMSAR and World Heritage).
GW	Surface water sites that are required to be monitored for groundwater RQOs
BaselineSen	Sites that could serve as baseline catchment due to high PES values
BaselinePA	Sites downstream from upper catchment protected areas that could serve as baseline catchment
PriorEstReq	Sites on rivers upstream from the top 10% of priority estuaries
PriorEstReqImp	Sites on rivers upstream from the top 10% of priority estuaries that has a dam that can control the estuary inflows
EstFFU	Sites on rivers upstream from the top 20% of priority estuaries with significant human development around the estuaries
EstImpFFU	Sites on rivers upstream from the top 20% of priority estuaries with significant human development around the estuaries and that has a dam that can control the estuary inflows
Anthropogenic Considerations	
Sup	Sites where water supply (use) should be measured
Div	Sites where there are river diversion weirs – this is the measurement of the flow at the weir itself

Abbreviation	Description
WComp	Dams without W-components (downstream weirs)
Ur	Sites either upstream or downstream of urban abstraction or urban runoff areas, respectively
IR	Sites either upstream or downstream of irrigation abstraction or return flow areas, respectively
F	Sites downstream from major commercial forestry areas
DDam	DWS dam sites
Inf	Sites upstream or downstream from rural or information settlement
MI	Sites downstream of mining activities
AMD	Sites downstream from AMD decanting
RSupply	Regional bulk water supply dams
WTW	Sites at or upstream from RoR WTW take-offs
WWTW	Sites downstream from individual or a series of WWTW
Esk	Sites downstream from ESKOM Power Stations

Table 3.5 Examples of theoretical site notations for anthropogenic sites

Anthropogenic factor	Spatial dataset	Rivers		
		Upstream (Availability and fitness for use)	At monitoring activity (Fitness for use)	Downstream (Impact)
Storage	Dams: DWS			PME|WComp
	Dams + blending			PME|WComp
	Dams: Rural supply		PME|RSupply	
	Diversion weirs		PME|Div	
Landuse	Irrigation areas	PE|IR		P|IR
	Forestry			P|F
Direct human	Peri-urban and urban areas	PE|Ur		P|Ur
	Informal	PE|Inf	PE|Inf	P|Inf
	WTW (RoR abstraction or diversion)		PME|WTW	
	WWTW			PEC|WWTW
Mining and industry	Mining			PE|M
	AMD			PEC|AMD
	Fracking zones			PEC|Frac
	ESKOM Power			PEC|Esk

Anthropogenic factor	Spatial dataset	Rivers		
		Upstream (Availability and fitness for use)	At monitoring activity (Fitness for use)	Downstream (Impact)
	Stations			

The notation could also be applied cumulatively per theoretical category, i.e. hydrological, ecosystem and anthropogenic. Identifying sites usually involves taking each spatial criterion and identifying sites for the particular criteria. As new criteria are being added there would be overlapping sites with different design criteria and therefore objectives. The same site might be required for fitness for use early warning and planning purposes for forestry, urban and mining / industrial purposes, i.e. PE|F,Ur,MI

b) Procedure for groundwater

Spatial design procedure

A spatial density criteria based approach was followed in setting up the theoretical sites for the national groundwater monitoring network. This approach allowed for the incorporation of best-practices and expert knowledge.

Baseline monitoring

The first step was to setup the baseline monitoring site network, where the United States recommendation is to have borehole density of one to eight sites per 2 500 km^2 *(Subcommittee on Ground Water of The Advisory Committee on Water Information, 2013*). The baseline sites must reflect ambient conditions and thus be located in pristine areas. A “negative land cover” spatial data set was generated using the national land cover GIS coverage and creating a negative image of areas where there are currently impacts by land/water use. This was then used to generate a grid of monitoring sites at the mentioned recommended spatial densities.

The aquifer yield class map produced by DWS was overlaid over the grid. In the aquifer yield class of 4 and above the spatial density was increased to 1 000 km^2 per site. In the lower yield aquifer classes, the spatial density was decreased to 7 500 km^2 per site, and the density might increase in heavily utilized aquifers.

The GRA 2 recharge dataset was used to increase the spatial density to 1 000 km^2 in the areas of effective mean annual recharge above 80 mm/a. This produced the first iteration of the baseline groundwater monitoring sites. This iteration takes into account:

- Monitoring localities for transboundary aquifers.
- International obligations in terms of both quantity and quality.
- Baseflow sensitive groundwater areas.
- Sites for background monitoring related to groundwater reserve determinations and setting RQOs.

- Sites for baseline water quality measurements, including alternative energy exploration zones and fracking as discussed later in **Section 3.5**.

Associated with each baseline groundwater monitoring site is a rainfall monitoring gauge. The current configuration of rainfall monitoring gauges allows for higher density in mountainous areas, areas of high groundwater interchange with surface water and dolomitic areas. The baseline groundwater monitoring network will take into account the major spring or major groundwater outflows, specifically the dolomite springs. The rainfall monitoring gauges associated with baseline groundwater monitoring sites will be used for Cl and isotope sampling to allow recharge estimations.

Trend monitoring

The theoretical trend monitoring sites were selected downstream of baseline monitoring sites. In higher productive aquifers the spatial density was set at one site per 100 km^2 around baseline monitoring points. A similar exercise was done around towns to incorporated groundwater dependent towns. The trend monitoring sites allow for trends to be determined in terms of the following:

- Over-exploitation/abstraction of groundwater;
- Groundwater quality degradation from various land use practices (including fracking as discussed later in **Section 3.5**); and
- Groundwater water use.

Design criteria aspects to be taken into consideration

The folowing aspects should be discussed in the ***Implementation Strategy Workshop*** to be held in September 2016:

- The way that groundwater sampling is handled in practice often leads to biases in the interpretation of data, which can result in serious over-estimation of regional groundwater resources. Generally, only water yielding boreholes are monitored with no account taken of dry boreholes, which obviously skews the sampling. Furthermore, boreholes are typically sited at fracture zones in favourable geology and topography, nowadays selected with the aid of sophisticated instrumentation, which further skews the sampling. The results from such monitoring may clearly not be representative of the wider area and should only with great caution be extrapolated to determine regional aquifer characteristics.
- The storage and yield characteristics of different aquifer types can vary widely. It would therefore be informative if provision could be made in the groundwater data base table, for the general aquifer type/geology to be recorded (sandy, fractured rock, dolomitic, TMG).
- Consideration may also be given to the compulsory registration of drillers with DWS, requiring that all boreholes drilled be reported on, including dry boreholes. Coordinates, geology, depth etc to be recorded and reported.

3.3 ASSESSMENT OF EXISTING MONITORING NETWORK

The identification of theoretical sites as described in **Section 3.2.4** is preceded by a detailed inventory of the 10 DWS national monitoring programmes, the SAWS rainfall and ARC agro-meteorological monitoring networks (see *Network Inventory Report WP10871 - Task 5*), as well as the evaluation of the data integrity for the aforementioned monitoring programmes (see *Data Integrity Assessment Report WP10871 - Task 6*). The objectives met through these evaluations are summarised as follows:

3.3.1 Data Inventory evaluation

A detailed inventory of the 10 national DWS monitoring programmes, the SAWS rainfall and ARC agro-meteorological monitoring networks was presented, in terms of:

- The variable/s being monitored.
- The frequency of observations.
- How data sets are being stored.
- The current status of individual monitoring stations (i.e. open or closed).
- The spatial distribution and coverage (or density) of monitoring stations.

The network inventory is presented in the following formats:

- Electronic data catalogue providing detailed information on each individual monitoring station across all monitoring networks.
- A map book showing the spatial distribution of monitoring stations within each of the nine recently-defined Water Management Areas (WMAs).
- Summaries of the current status of the national monitoring network based on the number of monitoring stations that are currently classified as “open”.
- Historical trends in the national status of monitoring based on the total number of stations actively recording data at the time in question.

A summary of the 10 existing DWS national monitoring programmes and associated elements presented in the aforementioned formats are provided in **Table** 3.6, with the programme names indicated in red.

Table 3.6 Existing DWS national monitoring programmes

Monitoring Classification	Elements	Approximate number of key points
Hydrological	Surface water gauging stations	770
	Reservoirs levels (with water uses at key reservoirs and meta-data on reservoir configuration data)	
Hydro-meteorology (part of Hydrological Programme)	Rainfall (including mountainous rainfall)	275
	Evaporation	184
Geo-hydrological	Groundwater Levels	2 233 (30 automatic)
	Yields (historical, once-off)	Unknown
Water Quality	Surface water	
	Chemical	337 (plus 563 low frequency)
	Microbial	180
	Eutrophication	112
	Radioactivity	18
	Toxicity	3
	Groundwater (part of Geo-hydrological Programme)	412
	Rainfall (part of Geo-hydrological Programme)	100
Ecosystems	**Aquatic Health**	639
	Estuaries	72
	Wetlands	28

3.3.2 Data integrity assessment

Data Integrity (also referred to as data quality) indicators were formulated and agreed upon with the DWS Monitoring Network Managers and the indicators were generated from available metadata at active monitoring sites. The report further describes the assessment results from evaluating national indicators (indicators where there were data for all the active sites) and partial indicators (where data only existed for some areas). Recommendations on additional indicators that could be added in future are also provided, to improve on the current assessment of data integrity.

The outcomes reported in the *Network Inventory* and *Data Integrity Report* are used in conjunction with the datasets reported in **Table 3.3** to conduct a systematic comparison of the theoretical monitoring sites against the existing monitoring network (See **Section 3.4**).

3.4 COMPARISON OF THEORETICAL AND EXISTING MONITORING NETWORKS

The theoretical networks were evaluated per catchment against what is being monitored in the catchment, both in terms of water quality and quantity, as well as open and closed sites.

The networks were evaluated against each other to:

- Identify the importance or redundancy of existing monitoring sites.
- Identify gaps in the existing network based on theoretical sites that have potential high information yields.
- Evaluate practicalities such as access to potential new sites, vandalism issues or other physical issues, such as foundations or past experience in the particular area.

All the decisions and considerations during the discussions were captured as much as possible electronically, using Google Earth. At the end of this process the existing networks were reviewed in detail by the stakeholders and input provided to the last step, which was the drafting of recommendations for each WMA.

3.4.1 Identifying the importance or redundancy of existing sites

As stated in the introductory paragraph of **Section 3.4**, one of the main objectives of the Regional Scientific Review Workshops was to identify, based on the positioning of the theoretical monitoring sites and knowledge from the DWS Regional Offices, possible gaps, redundancies and relative importance of the existing monitoring sites.

This process was communicated to the stakeholders via Google Earth, a screenshot of which is shown in **Figure 3.2**.

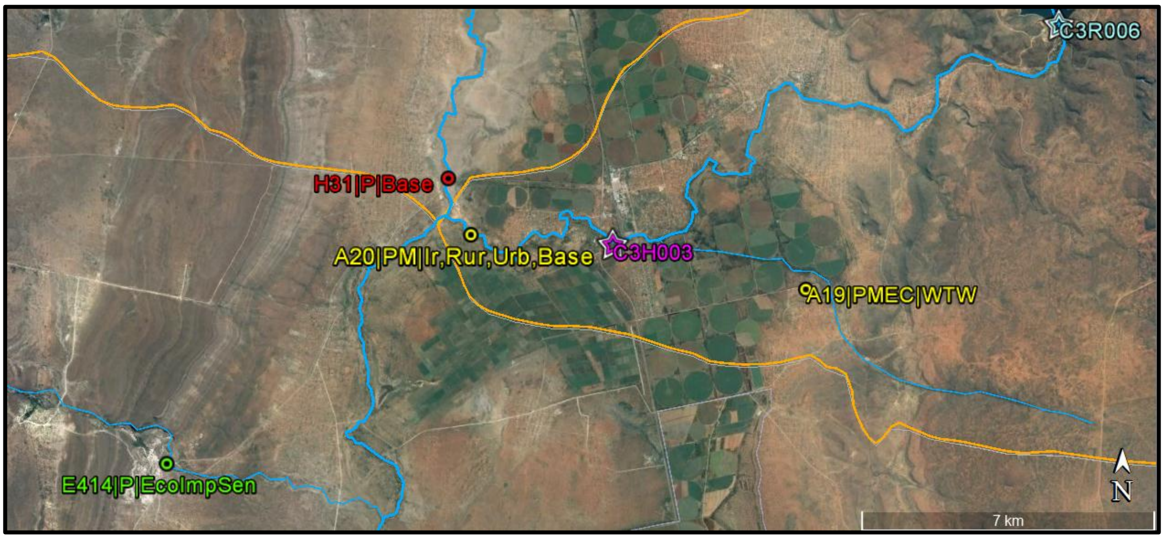

Figure 3.2 Screenshot of the Google Earth display used to compare the networks

Screenshot of a stretch of the Harts River downstream of Taung Dam in secondary catchment C3 with the river flowing in a south-west direction.

The colour notation used to generate the monitoring points as shown in **Figure 3.2** indicates the following:

- ***Purple star***: Existing river quantity monitoring station
- ***Purple star + white outline***: Existing river quantity and quality monitoring station.
- ***Red dot***: Theoretical monitoring site based on hydrological considerations.
- ***Yellow dot***: Theoretical monitoring site based on anthropogenic considerations.
- ***Green dot***: Theoretical monitoring site based on ecological considerations.
- ***Blue star***: Existing reservoir quantity monitoring station
- ***Blue star + white outline***: Existing reservoir quantity and quality monitoring station.

The relative importance of an existing station is determined by the objectives assigned to the site, with priority being given to the position of existing monitoring site over the position of theoretical sites.

For example, identified on the Harts River, before the confluence with the Droë Harts River, is one theoretical anthropogenic monitoring site, namely **A20|PM|Ir,Rur,Urb,Base**. The aforementioned theoretical objective is positioned near an existing monitoring site **C3H003**.

In this and similar situations, the theoretical monitoring objectives are then assigned to the nearby existing monitoring site, given that it is not exhibiting or subjected to severe defects or drawbacks (i.e. vandalism, poor access to the site, etc.)

Identified in the Droë Harts River is a theoretical hydrological monitoring site (**H31|P|Base**). There are, however, no existing monitoring sites in the vicinity of this monitoring requirement. This presents the potential for the implementation of a new monitoring site upstream, or in the vicinity of the aforementioned monitoring requirement.

In this and similar situations, a number of proposed stations are recommended to which the monitoring objectives are linked.

3.4.2 Relative importance of existing and proposed monitoring sites

The Study Team, as part of the scientific review process, developed a priority scoring system that uses the priority- and sub-objectives to calculate a relative priority score for all monitoring sites. Reported in

Table 3.7 is the scoring system used to determine the relative importance.

Table 3.7 Priority scoring system

Objective	Score
Resource and infrastructure planning	4
Resource operations and management	3
Early warning systems	2
Compliance and auditing	1
Sub-objectives	0.5 / sub-objective

Note: Complaince is a serious issue in large parts of the Country, but from a national monitoring perspective this should not be the main objective for monitoring at a specific site. However where sites contribute towards compliance montitroing such as EWR sites, additional weight will be provided by this consideration.

Using the scoring system defined in

Table 3.7, the relative importance of a monitoring station is calculated as the sum of the objective scores assigned to that monitoring site. For example, if the anthropogenic theoretical objective **A20|PM|Ir,Rur,Urb,Base** (see **Figure 3.2**) is assigned to a monitoring station, the associated relative priority would be calculated as

P(4)+M(3)+Ir(0.5)+Rur(0.5)+Urb(0.5)+Base(0.5)

thus resulting in a relative priority score of 9.0.

This process was applied to all existing and proposed monitoring sites and is reported for the nine WMAs in the accompanying Annexure.

3.5 SPECIALISED MONITORING PROGRAMMES

Earlier in **Section 3.2** a description is provided of the process to develop a theoretical network design based on prioritised national key strategic monitoring objectives. However, additional specialised monitoring information may be required to support the management of processes that present a unique set of requirements. This includes, most importantly, the possible impacts on national water resources of:

- Hydro-fracking;
- Acid mine drainage (AMD);
- Climate change; and
- Transboundary stream flow and aquifer water quantity and quality obligations.

Within this context the need for specialised monitoring programmes has been assessed in a process described in the following subsections. In order to ensure that they are addressed in the Implementation Strategy developed as part of this study, these needs were considered explicitly in the theoretical network design and are included as part of the Scientific Review outcomes presented in **Section 4**.

3.5.1 Hydro-fracking

Hydraulic fracturing, or “fracking”, is a technique used to recover gas from shale rock or coal beds. Fracking involves drilling, before a mixture of water, sand and chemicals is injected into the rock at high pressure, which allows the gas to flow out to the head of the well. The term fracking refers to how the rock is fractured apart in the process.

Currently there is significant interest in the use of fracking for the exploitation of alternative energy sources in South Africa, including shale gas, underground coal gasification and coalbed methane extraction. Areas where fracking exploration rights are being considered are shown in **Figure 3.3** and include parts of the Karoo, most of that in the Free State, parts of the Northern and Eastern Cape as well as a band in KwaZulu-Natal adjacent to the Drakensberg.

There is a concern that shallow groundwater will be polluted during the processes of drilling, fracking, gas production and subsequent abandonment of the well *(van*

Tonder, et al., n.d.). From a national water resource monitoring perspective fracking was therefore considered in the identification of theoretical baseline and trend monitoring sites (as discussed earlier in **Section 3.2.4**), specifically with the aim of ensuring that:

- Adequate spatial monitoring coverage of the proposed exploration zones is provided.
- Relevant groundwater quality indicators are included, so that the presence of pollutants can be monitored and possible degradation trends tracked. The indicators in question include methane as well as the chemicals used in the fracking fluid.

Furthermore, drilling muds, contaminated water (produced water) and a large percentage of the fracking fluid, return to the surface after use *(TEDX, 2012)* and have to be disposed of without causing harm to the environment. Produced water continues to surface for the life of the well (20 to 30 years) and it is commonly transferred to lined ponds, tanks or central evaporation pits for disposal.

While the management of these contaminants will form part of a specific water user's license conditions, the main aim of the national water resources monitoring network is to assess the status and trends of all water resources. As such, having baseline and trend surface water quantity and quality monitoring sites will be required, especially downstream of areas where significant fracking activities are expected to take place.

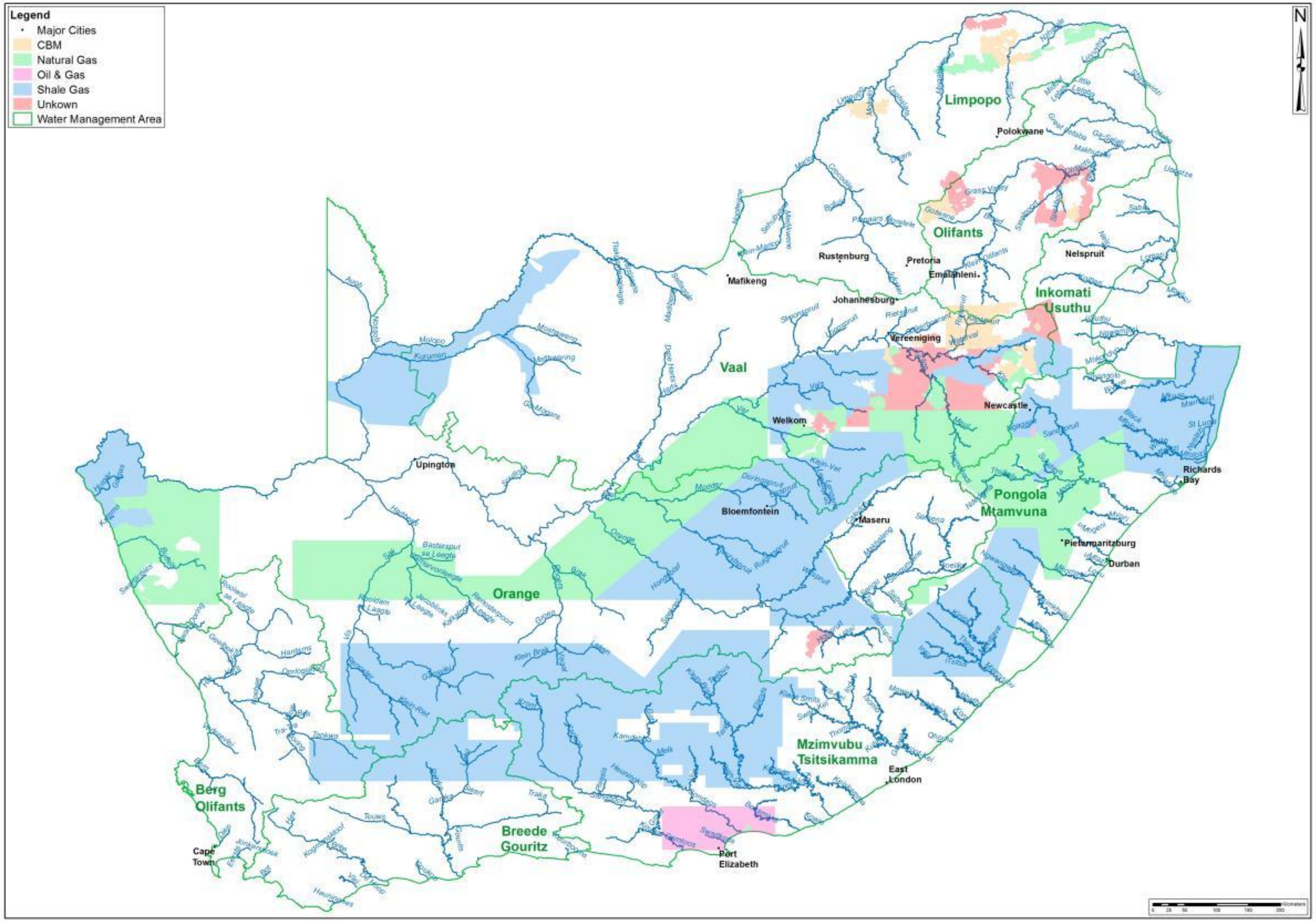

Figure 3.3 Fracking exploration zones

3.5.2 Acid mine drainage (AMD)

AMD is highly acidic water, usually containing high concentrations of metals, sulphides and salts associated with mining activities. The major sources of AMD include drainage from underground mine shafts, runoff and discharge from open pits and mine waste dumps, tailings as well as ore stockpiles *(CSIR, 2009)*. Drainage from abandoned underground mine shafts into surface water systems, or "decant", may occur as pumping ceases and groundwater floods the mine.

AMD has been reported from a number of areas within South Africa, including the Witwatersrand Gold Fields, Mpumalanga and KwaZulu-Natal Coal Fields as well as the O'Kiep Copper District in the Northern Cape. In 2010 an expert team of the Inter-Ministerial Committee on AMD *(Council for Geoscience, 2010)* identified the following risks, amongst others, with respect to the flooding of mines and the subsequent decant of AMD to the environment:

- Contamination of shallow groundwater resources.
- Regional water quality impacts on major river systems.
- Localised flooding in low-lying areas.

Furthermore, the Inter-Ministerial Committee identified the Western, Central and Eastern Basins on the Witwatersrand as priority areas requiring an expansion of existing monitoring programmes. In the Mpumalanga Coal Fields the impact on the freshwater sources in the upper reaches of the Vaal and Olifants River systems was also identified as a serious concern.

From a national water resource monitoring perspective AMD was considered in the identification of theoretical baseline and trend monitoring sites (as discussed earlier in **Section 3.2.4**) based on:

- The location of AMD "hotspots" identified from the known location of underground mining compartments, working and abandoned mining operations as well as existing and possible future decanting locations.
- Theoretical monitoring sites are identified according to the location and spatial distribution of hotspots.
- Monitoring focuses on:
  - mine water levels;
  - mine water quality;
  - surface water flow and quality; and
  - groundwater levels and quality.
- Relevant quality indicators including pH, metals, salinity, sulphides and radionuclides (atoms that have excess nuclear energy, making it unstable).

The location of AMD hotspots and associated theoretical and existing monitoring sites are shown in **Figure 3.4**.

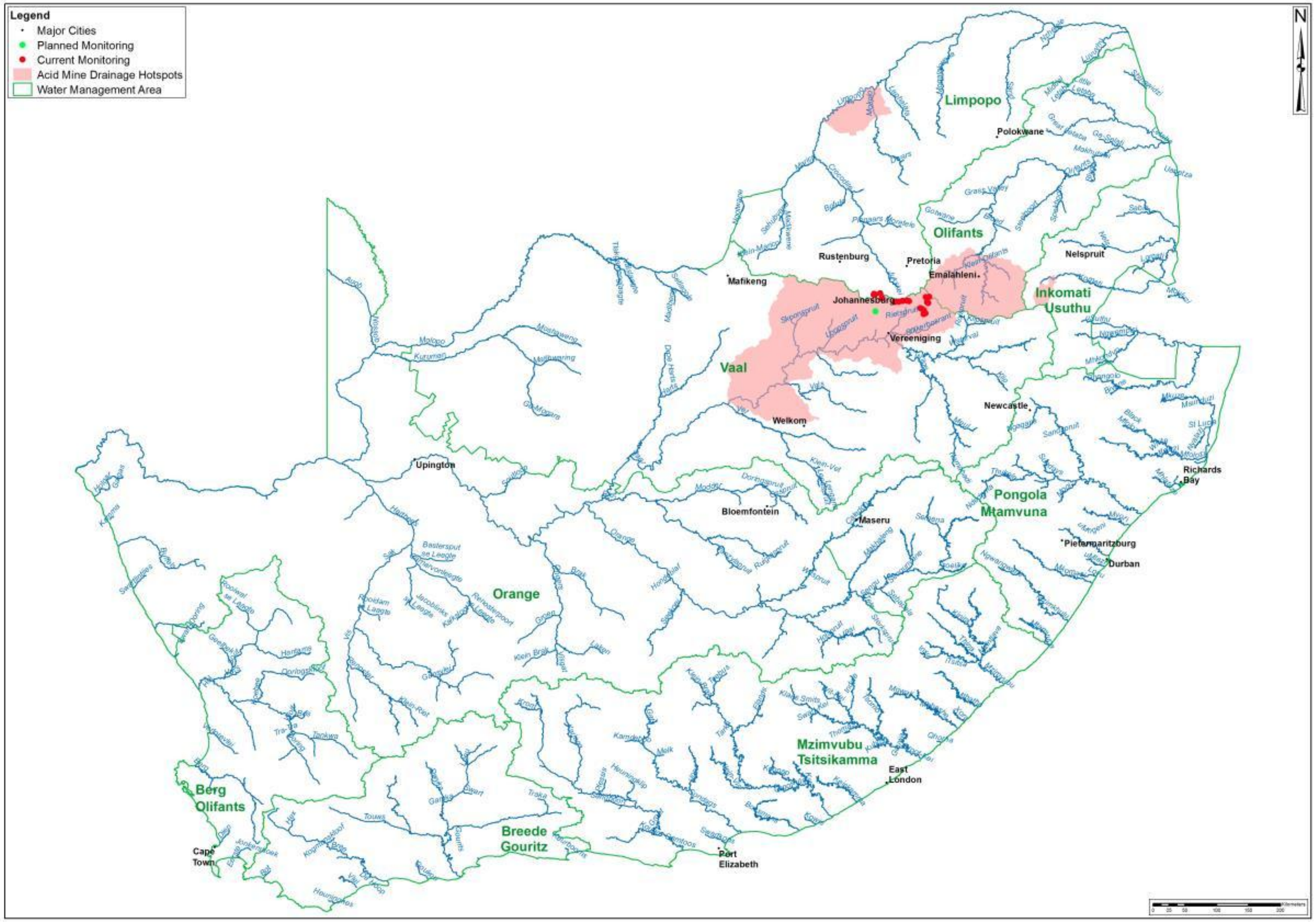

Figure 3.4 Existing and planned monitoring around AMD hotspots

3.5.3 Climate change

Indications are that the climate is changing globally and, according the National Water Resource Strategy 2 (NWRS2), the effects could include rising temperatures, more erratic rainfall and extreme weather events, flooding and droughts *(DWS, 2013e).* The Department of Environmental Affairs (DEA) is designated to lead the country's climate change agenda, guided by their Long-term Adaptation Scenarios Flagship Research Programme (LTAS) managed by the South African National Biodiversity Institute (SANBI) *(LTAS, 2014)*. Climate change features as one of several strategic national objectives in DEA's Strategic Plan, namely to respond and adapt to climate change impacts, which would otherwise threaten South Africa's ability to realise the goals of the National Development Plan (NDP) *(NPC, 2012)*.

From a national water resources perspective, monitoring plays a key role in climate change mitigation and adaptation initiatives by providing reliable, long and spatially representative data, used for both:

- Modelling of possible future climate change impacts (baseline information).
- Identifying the actual manifestation of climate change impacts (information on trends).

The process of developing the theoretical monitoring network design (as discussed earlier in **Section 3.2.4**) therefore implicitly contributes to climate change monitoring needs. It should be noted, however, that:

- Hydro-meteorological (including rainfall and evaporation) monitoring undertaken by DWS is limited largely to major dam sites and the mandate for this national monitoring lies with the South African Weather Service (SAWS).
- Surface water quantity and quality monitoring data reflect the impacts of (often significant) anthropological impacts, masking and / or skewing impacts that may be directly attributable to climate change.

In view of the above the national theoretical monitoring network design should account for and incorporate information from existing organisations responsible for monitoring and change detection, most notably:

- The South African Environmental Observation Network (SAEON) that obtains, integrates and disseminates atmospheric and climate data from a variety of data providers via their online data portal *(SAEON, n.d.)*.
- The CSIR that have undertaken extensive research on the application of satellite data to derive spatial information on reference evapo-transpiration (ET) *(Jovanovic, et al., 2014)* and rainfall *(Engelbrecht, 2012).* If proven to be reliable, the latter will be of immense value, specifically at high altitude and / or high rainfall locations, where in-situ monitoring is unsustainable, because of accessibility and cost considerations.

Furthermore, in order to understand the complex relationship between rainfall and runoff within changing climate, undeveloped experimental catchments, such as those managed by the CSIR at Jonkershoek in the Western Cape *(Chapman, 2007),* must be maintained within various climatic zones across the country. It should be noted that the process of assessing the location of surface water monitoring sites identified a number of existing and theoretical sites located within catchments that are either pristine or near-pristine. These sites are included in the monitoring network design referred to earlier and would therefore address the need for experimental catchments discussed here.

3.5.4 Transboundary obligations

South Africa has several shared river basins and transboundary aquifers with associated internationally agreed flows and water levels that must be maintained. The theoretical monitoring network design explicitly considers the need for monitoring to support the management of transboundary obligations.

As discussed earlier in **Section 3.2.4** site positions were determined using the integrated site positioning criteria and available national spatial data as outlined below:

- The localities for transboundary aquifers.
- Sites on international rivers, or those flowing into other countries, were automatically assigned higher theoretical priorities to meet international obligations and to serve as early warning sites for flood and quality purposes.
- International inter-basin transfers.

The locations of existing monitoring sites associated with transboundary obligations are shown in **Figure 3.5**.

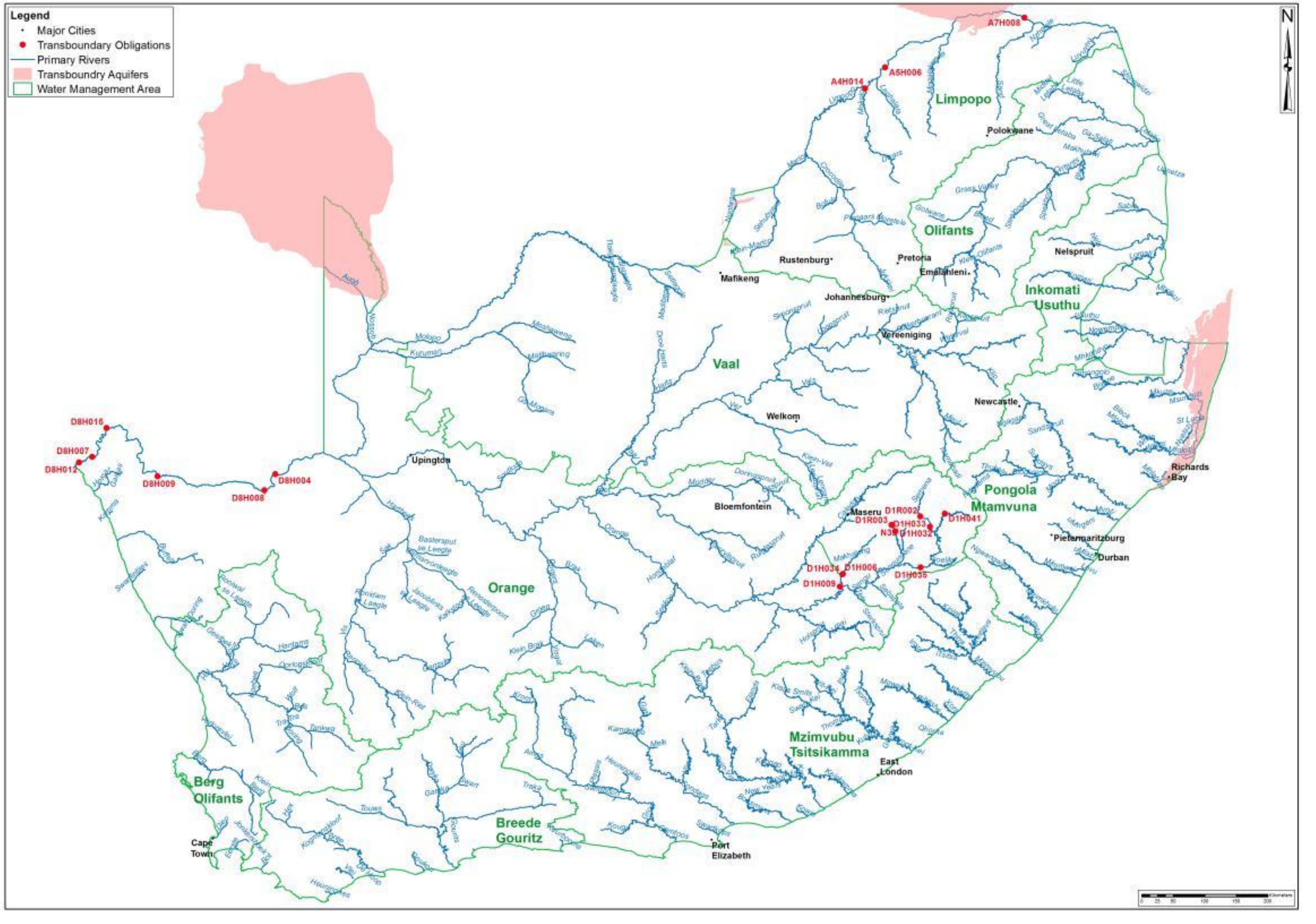

Figure 3.5 Existing transboundary obligation monitoring

4. OUTCOMES OF THE SCIENTIFIC REVIEW

Reported in this section is a summary of the outcomes obtained as a result of the process described in **Section 3**. The results are, in this section, reported on a national level.

The prioritisation (See **Section 3.4.2**) and comments from the Regional Scientific Review Workshops are reported in the accompanying Annexure.

4.1 SURFACE WATER MONITORING SITES

As part of the network optimisation procedure, the objectives of the theoretical monitoring sites near existing and new monitoring sites were assigned to the existing and new monitoring sites.

In this manner existing and new sites can be compared to each other in terms of meeting objectives and therefore relative importance.

Reported in this section is a summary of the number of river flow stations categorised per recommendation. All the recommendations are standardised into five categories.

- **New sites**: These are sites identified as brand new sites where no previous monitoring has taken place and where the sites would support improved spatial distribution of the network to meet national monitoring objectives.
- **Replacement sites**: Stations in this category are all proposed sites for the purpose of replacing existing sites that are old or exhibit severe defects.
- **Changes**: Stations in this category are all existing stations that require upgrading or other forms of improvements to overcome minor defects / restraints.
- **Not of national importance**: These are sites that are not important from a national perspective, but are, however, used to satisfy lower priority objectives at local and municipal level.
- **Redundant**: These are sites that, based on the Workshops findings, do not add any value to the national monitoring network. This could be due to severe deterioration of the site, poor quality data produced by the site or due to the site being near to monitoring points that are better equipped to satisfy theoretical site objectives.

The surface water monitoring sites categorised per WMA are summarised in **Error! Reference source not found.**.

It should be noted that the number of stations reported under the “Workshop recommendations” for Error! Reference source not found. is not equal to the total number of stations due to the following reasons:

- Reported in Error! Reference source not found. are new, redundant and stations that require changes (i.e. Upgrade or replacement). Stations that fully meet their monitoring objectives and therefore only require maintenance are not reported in this chapter but are captured in detail in the accompanying annexure reports.
- W-components were included or excluded from Error! Reference source not found. depending on the associated workshop recommendations. If a W-component requires changes, it is included in Error! Reference source not found.. If it meets all monitoring objectives, it is captured as part of the reservoir monitoring stations in the accompanying annexure report.

A summary of the workshop recommendations and comparison per WMA is reported in Error! Reference source not found.. The numbers of stations in the table does not add up mathematically due to the inclusion / exclusion of W-components in the current tables. If a W-component is to be changed it is included in the numbers, if not then if forms part of the reservoir stations.

Table 4.1 National surface water monitoring

WMA	Workshop recommendations					Total number of stations	
	New sites	Replace-ment sites	Changes (upgrade/ new)	Not of national importance	Redundant	Status quo (2014)	Proposed number of monitoring stations
Limpopo	11	2	38	7	9	128	134
Olifants	12	5	23	8	6	95	102
Inkomati-Usuthu	9	1	5	1	2	79	88
Pongola-Mzimkulu	12	3	9	2	5	146	157
Vaal	21	2	34	10	9	105	117
Orange & Lesotho	25	6	22	2	1	69	92
Mzimvubu-Tsitsikamma	23	3	24	4	7	137	154
Breede-Gouritz	12	3	11	1	8	153	157
Berg-Olifants	5	1	6	6	7	67	65
National	**130**	**26**	**172**	**41**	**54**	**979**	**1 066**

The comparison of the existing monitoring network (Status Quo - 2014) against the proposed National Surface Water Monitoring network indicates an 8.9% increase in the number of National Surface Water monitoring stations. This corresponds to 87 additional monitoring points in order to sufficiently meet the National Monitoring Objectives described in Table 3.2.

4.2 Reservoir Monitoring Sites

Reported in this section is a summary of the number of reservoir monitoring stations categorised per recommendation. All the recommendations are standardised into four categories.

- **New sites**: These are sites identified as brand new sites where no previous monitoring has taken place and where the sites would support improved spatial distribution of the network to meet national monitoring objectives.
- **Sites requiring improvements**: Stations in this category are all proposed sites for the purpose of replacing existing sites that are old or exhibit severe defects.
- **Not of national importance**: These are sites that are not important from a national perspective but are however used to satisfy lower priority objectives at local and municipal level)
- **Redundant**: These are sites that, based on the workshop findings, do not add any value to the national monitoring network. This could be due to severe deterioration of the site, poor quality data produced by the site or due to the site being near monitoring points that are better equipped satisfy theoretical site objectives.

The reservoir monitoring sites categorised per WMA are summarised in **Table 4.2**.

Table 4.2 Reservoir sites

WMA	New sites	Sites requiring Improvements	Not of national importance	Redundant
Berg-Olifants	0	0	0	0
Breede-Gouritz	0	1	0	1
Inkomati-Usuthu	2	0	1	0
Limpopo	5	10	0	1
Mzimvubu-Tsitsikamma	1	0	0	0
Olifants	2	6	0	1
Orange & Lesotho	0	3	0	1
Pongola-Mzimkulu	1	1	0	0
Vaal	0	4	4	0
National	**11**	**25**	**5**	**4**

4.3 Estuarine Monitoring Sites

The evaluation of tidal stations is based on the assumption that all estuaries classified within the top 10% in the country must be monitored and that it is not deemed necessary to monitor estuaries ranked in the top 20% or lower.

This ranking system was developed as part of a 2002 RQIS study. This study *(DWS, 2002)* devised a method for prioritising South African estuaries on the basis of conservation importance, and presented the results of a ranking based on the collation of existing data for all South African estuaries. Estuaries are scored in terms of their size, type and biogeographical zone, habitats and biota (plants, invertebrates, fish and birds).

Reported in this section is a summary of the number of tidal monitoring stations categorised per recommendation. All the recommendations are standardised into two categories.

- **New tidal sites**: These are sites identified as brand new sites where no previous monitoring has taken place and where the sites would support improved spatial distribution of the network to meet national monitoring objectives.
- **Sites requiring improvements**: Stations in this category are all proposed sites for the purpose of replacing existing sites that are old or exhibit severe defects.

The estuarine monitoring sites categorised per WMA are summarised in **Table 4.3**.

Table 4.3 Estuarine monitoring sites

WMA	New tidal sites	Improvement / new upstream river sites*
Berg-Olifants	0	2
Breede-Gouritz	1	10
Mzimvubu-Tsitsikamma	0	2
Orange & Lesotho	0	0
Pongola-Mzimkulu	3	1
National	**4**	**15**

4.4 RAINFALL MONITORING SITES

Although the Department is not the primary custodian of rainfall data, recommendations of where rainfall gauging needs to be reinstated, will be made in the final Implementation Strategy.

4.5 GROUNDWATER MONITORING SITES

Reported in this section and reflected in **Table 4.4** Groundwater monitoring sites is a summary of the number of reservoir monitoring stations categorised per recommendation and status. All the recommendations and outcomes are, similarly to Section 4.1, standardised into two main categories as defined in Section 3.4.2 b.

Table 4.4 Groundwater monitoring sites

WMA	Existing baseline	New baseline	Existing Trend	New trend	Total
Berg-Olifants	0	28	0	177	205
Breede-Gouritz	0	40	54	111	205
Inkomati-Usuthu	2	35	0	113	150
Limpopo	82	48	41	367	538
Mzimvubu-Tsitsikamma	25	48	0	295	368
Olifants	164	23	0	229	416
Orange & Lesotho	76	86	127	489	778
Pongola-Mzimkulu	3	56	52	127	238
Vaal	40	63	47	814	964
Total	**392**	**427**	**321**	**2 722**	**3 862**

Detailed recommendations to improve the current groundwater monitoring network have been included in the accompanying Annexure reports, with recommendations per WMA.

5. RECOMMENDATIONS

The Scientific Review of the surface and groundwater monitoring networks was achieved by a rigorous comparison between the existing monitoring activities and a theoretical distribution of sites that meet most of the objectives of a national water resources monitoring network.

The Scientific Review optimised the existing network for each WMA to:

- Ensure adequate spatial coverage to eliminate gaps and redundancies in the network.
- Prioritise existing, new and sites that require alterations according to each site's contribution towards meeting national objectivesas well as each site's relative information contribution.

The recommendations in this report and the Annexures to the report can only be seen as preliminary, since further on-site verification of these recommendations will have to be done before actual implementation phase can start. The general recommendations are provided below.

Please note: Impacts of changes to water quantity sites on water quality monitoring are being assessed and full recommendations will be provided in the Implementation Strategy.

5.1 SURFACE WATER

The prioritisation of reservoir, river and tidal sites should be used as a guide during further implementation phases. The following is recommended in order of priority.

5.1.1 Reservoirs

DWS reservoirs should be seen as South African strategic national assets and should be monitored as such. It was shown in this analysis that reservoirs (and their components) always have the highest priorities due to their relative higher contributions in meeting national monitoring objectives and information yield at the site. Priority in maintenance and improvements should always be given to reservoirs. The following components are included in measuring reservoirs:

- **Water use**: All types of use must be measured to the best possible accuracy, even if a WSA or any other entity is measuring the water received from the reservoir. In this analysis lesser priority was provided measuring other local water abstractions (such as river diversions or from municipal dams) since this falls within the realm of Local Government.
- **Evaporation and rainfall**: It was found during the network integrity assessment that some evaporation and rainfall sites showed minor trends. The meteorological sites should be check to ensure that they are installed according to international standards and corrected/replaced if not (also see **Section 5.3**).

- **Surveys**: It is recommended that surveys for the larger dams be updated every 5 to 10 years. In areas where high siltation is experienced, 5 year intervals are highly recommended. Surveys are the only way in which bulk sedimentation transported by rivers can actually be monitored. This is essential not only to update dam balances but for planning of any similar infrastructure in the vicinity.
- **Spills and W-components**: During the analysis of each WMA all major reservoirs were assessed for accuracy of the spills calibrations as well as the presence of a W-component. W-components were given very high prioritisation due to the following considerations:
    - W-components are often seen as more accurate that for example calibrated spills ways. This will contribute towards higher accuracy in the dam balance calculations, i.e. measuring the inflows to the Reservoirs.
    - W-components can measure flows that spill from reservoirs, which might make less accurate downstream river sites redundant.

As can be seen from **Table 4.2** there are nationally a total of 9 reservoirs that were found to be redundant or not of national importance. Monitoring equipment from these sites might possibly be reused in the proposed 11 new reservoirs where monitoring is required. A further 25 reservoir sites require upgrades or replacement sites. Most of the reservoirs with recommendations are located in the Limpopo WMA, followed by the Vaal and the Olifants.

5.1.2 River sites

Each of the river sites per WMA was provided a priority according to which the site should be maintained or improved. Sites that meet more national monitoring objectives typically received higher priorities than others that merely contribute towards planning information. Stations found to be “not of national importance” aren’t recommended for closure since some lower priority use of the site has been identified during the workshops. On the other hand, sites that were identified as “redundant” were already identified at the workshop as such and further steps should be investigated to close these sites.

As can be seen from Error! Reference source not found. there are nationally a total of 95 rivers sites that were found to be redundant or not of national importance, with the Vaal, Olifants and the Limpopo WMAs having 52% of the total sites in these categories. Monitoring equipment from these sites might possibly be reused in the proposed 130 new river sites where monitoring gaps have been identified. 38% of the new sites are located in the Vaal, Orange and Mzimvubu to Tsitsikamma WMAs. A very large number of sites require either improvement or replacement, which will have to be verified through site inspections in order of priority, most of which are located in the Limpopo and Vaal WMAs.

5.1.3 Tidal sites

Tidal and river sites upstream from prioritised estuaries were assessed during the scientific review process. Although only 4 new tidal sites were identified (which were based on the top 10% of prioritised estuaries in South Africa), it is recommended that the remainder of the top 20% of South African Estuaries be considered as higher priority when deciding on new tidal stations. A total of 15 river stations upstream from priority estuaries were identified for improvement or for the construction of a new river site. Although there were a few more rivers identified, the physical constraints to river monitoring close to the estuaries were often a deciding factor. River stations upstream from estuaries have often very flat reliefs or have sandy geology which makes foundations for proper river monitoring site hard to find.

5.2 GROUNDWATER

The existing groundwater monitoring activities were evaluated against an independent theoretical network that was based on international accepted densities of groundwater monitoring networks, as well as the national spatial coverage of areas with high yield and recharge. These stations were identified as baseline sites and it was ensured that there were no land or water use activities close by these monitoring sites. The baseline site will provide natural/background water levels throughout South Africa. Existing baseline stations were then added or replaced theoretical monitoring sites.

Theoretical trend groundwater sites were initially identified around towns that depend on groundwater resources, but a large number of sites were identified at the workshops by regional specialist in known areas of high groundwater use or pollution. Existing sites were also assigned as trend monitoring sites in the same manner as baseline sites.

It is recommended that from a national monitoring network basis, that the baseline stations be implemented first to get a better understanding of regional based water levels. Trend monitoring sites should be prioritised per WMA and improved or installed accordingly.

5.3 HYDRO-METEOROLOGICAL SITES

In **Section 5.1.1** it was explained that the main purpose of the current hydro-meteorological network maintained by DWS is in support of dam balance calculations at all the major reservoirs in the country. Due to these stations being part of reservoir monitoring they have the same high priority as reservoirs.

The Scientific Review has shown the current gaps in rainfall and evaporation monitoring between SAWS, ARC and DWS sites that are currently active per WMA. In some areas the gaps are already extensive. This means that in future these areas will experience difficulties in water resources planning and operations studies.

It is SAWS primary mandate to maintain the rainfall monitoring network and it is therefore essential that this gap analysis is taken forward on an Inter-Governmental Department Committee to address these gaps and overcome the current issues regarding data ownership and costs. From a water resources perspective, the analysis from this Scientific Review will be adequate to address at least DWS requirements for an optimal rainfall monitoring network.

Evaporation data is shared between DWS and ARC. Once again a committee such as above will be required to address similar issues regarding evaporation data. It is possibly that some of the ARC stations could be used for dam balances in areas where DWS do not have adequate coverage of evaporation data, and vice versa.

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