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

DETERMINATION OF WATER RESOURCE CLASSES, RESERVE AND RESOURCE QUALITY OBJECTIVES STUDY FOR SECONDARY CATCHMENTS A5 – A9 WITHIN THE LIMPOPO WATER MANAGEMENT AREA (WMA 1) AND SECONDARY CATCHMENT B9 IN THE OLIFANTS WATER MANAGEMENT AREA (WMA 2)

LINKING VALUE AND CONDITION OF WATER RESOURCE REPORT

No. WEM/WMA01&02/00/CON/RDM/0422

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Report Title: Linking the value and condition of the water resource

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Professional Service Provider: Myra Consulting (Pty) Ltd
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Director

DOCUMENT INDEX

Reports that will be produced as part of this project are indicated below.

The bold type indicates this report.

REPORT INDEX	REPORT NUMBER	REPORT TITLE
01	WEM/WMA01&02/00/CON/RDM/0122	Inception Report
02	WEM/WMA01&02/00/CON/RDM/0222	Water Resources Information Gap Analysis Report
03	WEM/WMA01&02/00/CON/RDM/0322	Delineation and Status Quo Report
04	**WEM/WMA01&02/00/CON/RDM/0422**	**Linking the value and condition of the Water Resources Report**
05	WEM/WMA01&02/00/CON/RDM/0522	Site Selection and verification EWR Report
06	WEM/WMA01&02/00/CON/RDM/0123	EWR Report - Rivers
07	WEM/WMA01&02/00/CON/RDM/0223	EWR Report - Groundwater
08	WEM/WMA01&02/00/CON/RDM/0323	EWR Report - Wetlands
09	WEM/WMA01&02/00/CON/RDM/0124	Main EWR Report
10	WEM/WMA01&02/00/CON/RDM/0224	Ecological Base Configuration Scenarios Report
11	WEM/WMA01&02/00/CON/RDM/0324	Scenarios evaluation and Draft Water Resource Classes Report
12	WEM/WMA01&02/00/CON/RDM/0125	Final Scenarios Report
13	WEM/WMA01&02/00/CON/RDM/0225	Evaluation of Resource Unit Report
14	WEM/WMA01&02/00/CON/RDM/0325	Preliminary Resource Quality Objectives and Confidence Report
15	WEM/WMA01&02/00/CON/RDM/0425	Monitoring Programme to support RQOs and Reserve Implementation Report
16	WEM/WMA01&02/00/CON/RDM/0525	Water Resources Classes, Reserve and RQOs Gazette Template
17	WEM/WMA01&02/00/CON/RDM/0625	Project Close-Out Report

TERMINOLOGY AND ABBREVIATIONS

ACRONYMS	DESCRIPTION
CNRM-CM5	National Centre for Meteorological Research Coupled Global Climate Model
DWS	Department of Water and Sanitation
EC	Ecological Category
EHI	Ecosystem Health Index
EWR	Ecological Water Requirements
EGSA	Ecosystem Goods Services and Attributes
GCM	Global Circulation Models
GDP	Gross Domestic Product
GFDL-CM3	Geophysical Fluid Dynamics Laboratory Coupled Model
GRAII	Groundwater Resource Assessment II
GVA	Gross Value Added
GW	Groundwater
GWBF	Groundwater Contribution to Baseflow
IUA	Integrated Units of Analysis
LEIP	Limpopo Eco Industrial Park
LIMCOM	Limpopo Watercourse
MCA	Multi-Criteria Analysis
MPI-ESM-LR	Max Planck Institute Coupled Earth System Model
NORESM1-M	Norwegian Earth System Model
PES	Present Ecological State
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RQO	Resource Quality Objectives
RWQO	Resource Water Quality Objectives
SAM	Social Accounting Matrix

ACRONYMS	DESCRIPTION
SEZ	Strategic Economic Zone
SSP	Shared Socio-Economic Pathway
SW	Surface Water
ToR	Terms of Reference
WC/WDM	Water Conservation and Water Demand Management
WMA	Water Management Area
WRCS	Water Resources Classification System
WRPM	Water Resources Planning Model
WRSM	Water Resources Simulation Model
WRYM	Water Resources Yield Model

EXECUTIVE SUMMARY

SCENARIO EVALUATION APPROACH

Following the Delineation and Status Quo, Linking the Value and Condition of the Resource is the next step required in terms of the Classification Procedure for Water Resources. The objective of this report is to define the relationship that will link the change in the configuration of the water resource class scenario to a resulting economic value and social wellbeing across the study area. This is done using scenario analysis, which is the process covering the development of scenarios, the comparison of scenario results, and the evaluation of their consequences. The overarching aim of the scenario evaluation process is to find the appropriate balance between the level of environmental protection possible and the use of the water to sustain socio-economic activities. Three main elements to consider in this balance are the ecology, economic and societal benefits obtained as a result of the Classification choices made.

The sequential activities (Figure I) carried out to evaluate the scenarios starts with the vision setting per Integrated Unit of Analysis (IUA) and describing the scenarios to be analysed. The status quo information is applied to identify the components requiring evaluation and defining the relevant parameters to be quantified. Water availability analyses are carried out for the scenarios, and this feeds into the activity to determine the consequences on Water Quality, Ecology, Ecosystem Services, Economy and Society. The scenarios are ranked, first, for the individual variables and then as an overall integrated ranking derived based on multi-criteria analysis methods.

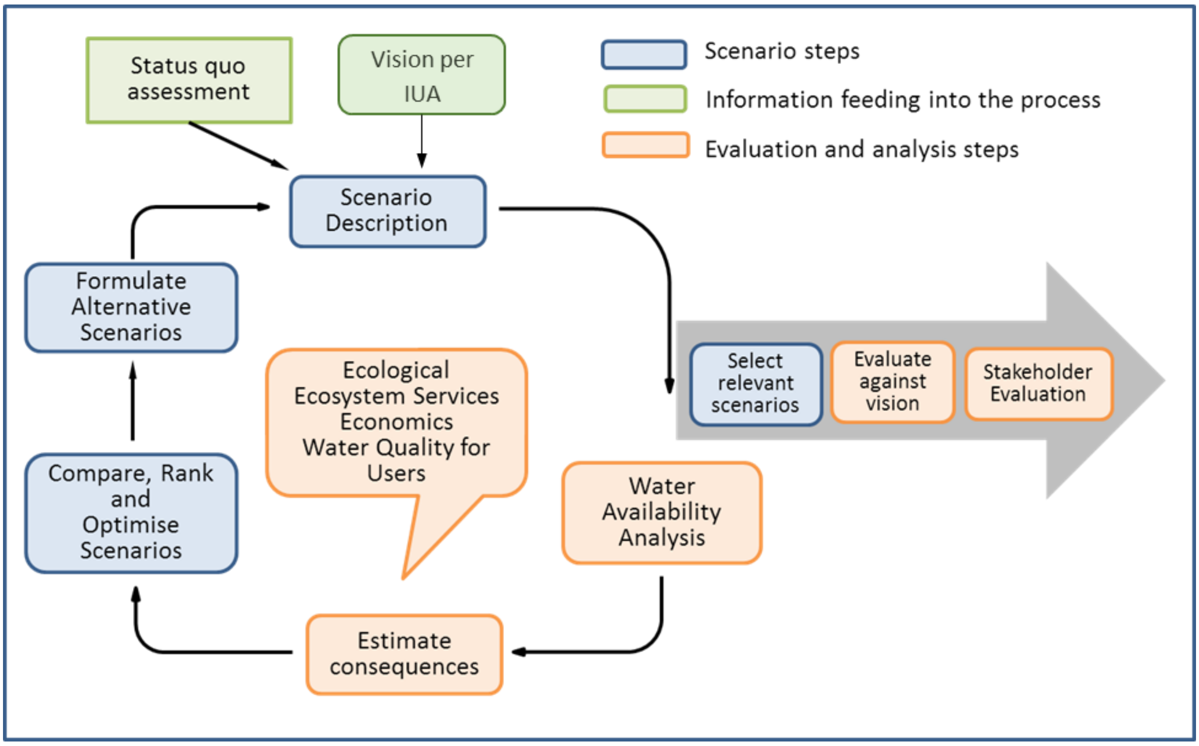

Figure I. Schematic presentation of the scenario evaluation process. Source: DWS, 2017.

A range of Classification Scenarios are defined that describe alternative Water Resource Classes and Ecological Category (EC) configurations for the study area, the outcomes of which will be analysed over a defined time period, under a range of assumptions regarding projected population and economic growth, climate, water demand management measures and overall water demand. The result will be to estimate the costs of additional water supply measures that would need to be brought online to meet the demands. This cost will be compared to the benefits of the Reserve. A preliminary set of scenarios are presented in this report (Table I) to be finalised in the *Ecological Base Configuration Scenarios Report*.

Table I. Preliminary scenarios

#	Scenario	Description
1A	Maintain Present Ecological Status (PES) + low growth (=Baseline)	River and wetland systems are maintained in their present condition.
1B	Maintain PES + high growth	
2A	Bottom line + low growth	The maximum volume of water is made available for abstraction from the system for economic activities, with the proviso that all water resources are maintained in a D class (the ecological "bottom line").
2B	Bottom line + high growth	
3A	Recommended Ecological Category (RECs) + low growth	The RECs determined for rivers and wetlands based on present health and conservation importance (but without any consideration of socio-economic effects) are applied in these scenarios.
3B	RECs + high growth	
4A	Targeted conservation + low growth	High ECs are given to areas of high conservation importance, but for other areas, the ECs can be below REC. It may end up that this scenario set is similar to the above.
4B	Targeted conservation + high growth	
5A	High conservation + low growth	This scenario represents the situation where conservation targets are met, with an emphasis on an eco-tourism-based economy, with most resources in a good condition and a significant proportion in Classes A or B.
5B	High conservation + high growth	

DETERMINING FLOWS AND WATER FOR USE

To relate the flow requirement per EC to surface and groundwater availability for use, information is required on the groundwater and surface water contribution to flow. The water resource simulation model incorporates groundwater contribution to baseflow, and these numbers will be verified against all available information to establish likely groundwater contribution to baseflow per quaternary catchment, and where possible disaggregated to the biophysical nodes. Knowing what portion of flow derives from groundwater and surface water enables a decision to be taken as to whether to meet the required flow from groundwater versus surface water, or whether a combination of both is required.

The water resource simulation model will be applied to determine the volume of surface water that is available for abstraction from the water resource for economic use, given a particular flow regime in the river is required to achieve a certain EC. A groundwater balance model will be used to relate the change in baseflow per EC to groundwater availability in the aquifers surrounding a biophysical node and contributing to baseflow. Note that depending on how the scenarios are set up, the present EC configuration may be used to define flow requirements, which then determine how much surface and groundwater is available for use, or a development scenario may be defined and related to particular water requirements, in which case the resultant EC configuration would be derived, subject to a constraint of minimum flows to maintain D category.

IMPACTS ON WATER QUALITY

The classification process requires that water quality for users be assessed at two levels: present-day water quality requirements for all water users (fitness for use); and water quality implications of different scenarios for different users.

The present-day water quality assessment for water users was conducted for the *Delineation and Status Quo Report*. The assessment used water quality data collected in the study area by DWS over a ten-year period (2008 to 2018) to describe the present water quality status. The fitness for use was described using four water quality categories (ideal, acceptable, tolerable and unacceptable). Users that were considered were domestic water use, agricultural water use (irrigated crops, livestock and game watering), recreation, and aquatic ecosystem requirements.

Assessing the change that a particular scenario would have on water quality and specifically the implications on the fitness for use for the key water users in an IUA is done using a qualitative assessment of the water quality impacts for each scenario. This will be performed based on an examination of the relationship between key water quality parameters and flow at water quality sampling sites where flows data are also collected, the nodes, on knowledge of the behaviour of the constituent with flow, and local conditions in the IUA that may affect the in-stream concentration (e.g. presence of point or non-point sources of pollution).

The water quality specialist will adjust the information on water available for use to provide detail on changes of availability of water for use in different sectors and subsectors, based on their water quality requirements. This will be fed into the economic analysis.

ASSESSING SOCIO-ECONOMIC CONSEQUENCES

The allocation of the ecological Reserve is central to the environmental, economic and social outcomes of a region. Water is not only directly critical to social and economic development, but also indirectly, by supporting key ecological systems which provide essential ecosystem goods and services that underpin development and human wellbeing.

The economic impacts in this study will be considered in terms of changes in the two main macro-economic indicators of Gross Domestic Product (GDP) and employment, as well as changes in cost savings due to changes in relevant ecosystem services. This requires estimating the relationships between water use and economic outputs as a result of production in water user sectors, stream flow reducing sectors and sectors relying on ecosystem services. The social impacts are considered in terms of a composite index of societal wellbeing that takes impacts on household income, health and happiness into account.

In order to evaluate the impact on ecosystem value, it is necessary to understand the underlying links between ecosystem structure and function and the supply of ecosystem services as well as their demand. The condition of the aquatic ecosystems in the study area will vary under each of the Classification Scenarios. This will be expected to have an impact on their attributes that are valued by society as well as their capacity to deliver goods and services.

Aquatic ecosystems are rich and productive systems that produce a wide range of benefits to society. The main ecosystem services provided by rivers and wetlands of the study area that will be assessed are the harvesting of wild plant and animal resources, informal water supply, wetland contribution to rural livestock production, carbon storage and sequestration, flood attenuation, and tourism value. The value of the aquatic ecosystems within the study area is estimated to be in the order of R410 million per year. This study will use independent flow-related variables (e.g. fish abundance, water quality, plant abundance, extent of riparian vegetation etc.) to estimate changes in the capacity of aquatic ecosystems to deliver these services, by assessing the change in these variables with a change in EC and simple heuristic models for each service.

The economic costs and benefits are considered for the main water users in the study area as urban and domestic household use, industry and mining, irrigation agriculture, livestock and game watering, and commercial forestry. The economic impacts are described in terms of value added to the economy (= contribution to GDP) and employment. These impacts are described in terms of direct and total impacts (which include multiplier effects). In this study, we will use water supply costs (augmentation of water supply at increasing cost) to estimate the costs of increasing the Reserve, where appropriate. None of the water user sectors are expected to be limited by water availability per se, but they would be affected by increasing costs under scenarios involving increased water allocation to the Reserve because of supply augmentation costs or demand management.

It is particularly difficult to describe and quantify changes in societal wellbeing. Peoples' wellbeing is affected by a very wide range of factors, only a few of which are being considered in this study, while the rest are 'held constant' as for the economic analysis. The proportional influence of the factors being considered in this study is fairly subjective. Moreover, for several indicators or measures, establishing a clear relationship between water resources and well-being is difficult.

The social impacts of water allocation will come from changes in employment, changes in the abundance of harvested resources, changes in human health risks as a result of water quality, and the more intangible amenity values associated with natural systems. The cultural, spiritual and recreational values associated with natural systems are extremely difficult to measure, but very important for peoples' health and wellbeing. Changes in these benefits are described qualitatively using a scoring system to evaluate relative changes under the different scenarios. Changes in income to poor households are estimated based on changes in economic outputs and multipliers derived from the Limpopo SAM.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

The Department of Water and Sanitation (DWS), Chief Directorate: Water Ecosystems Management initiated a three-year study for the Determination of Water Resource Classes, Reserve and Resource Quality Objectives for Secondary Catchments A5-A9 within the Limpopo Water Management Area (WMA 1) and Secondary Catchment B9 in the Olifants Water Management Area (WMA 2).

The suite of Resource Directed Measures tools being implemented in these catchments aims to ensure sustainable utilisation of water resources to meet the ecological, social and economic needs of the communities dependent on them.

1.2 Objectives of the Study

The overall objective of this project is to classify and determine the Reserve and Resource Quality Objectives for all significant water resources in the Secondary catchments (A5-A9) of the Limpopo WMA and B9 in the Olifants WMA.

The Scope of Work as stipulated in the Terms of Reference calls for the following:

- Coordinate the implementation of the Water Resources Classification System (WRCS), as required in Regulation 810 in Government Gazette 33541, by classifying all significant water resources in the Limpopo WMA (secondary catchments A5-A9) and Olifants WMA (secondary catchment B9).
- Determine the water quantity and quality components of the groundwater and surface water (rivers and wetlands) Reserve.
- Determine Resource Quality Objectives (RQOs) using the DWS Procedures to Determine and Implement RQOs.

1.3 Purpose of this report

Following the Delineation and Status Quo phase, Linking the Value and Condition of the Resource is the next step required in terms of the Classification Procedure for Water Resources. This work builds on the earlier status quo assessment of the value of both water use and freshwater dependent ecosystems in the study area in order to develop estimates of:

(i) the way in which economic outputs and societal wellbeing change in response to changes in water available for use by households or productive sectors, and

(ii) the way in which economic outputs and societal wellbeing change in response to changes in ecosystem characteristics (with a focus on the effect of flow-related characteristics).

The objective of this report is to define the relationship that will link the change in the configuration of the water resource class scenario to a resulting economic value and social wellbeing across the study area. To achieve this objective, the following activities are undertaken:

- A description of the methodology for evaluating scenarios;
- The selection of aquatic ecosystem values to be considered, based on ecological and economic data; and
- A description of the relationships that determine how economic value and social wellbeing are influenced by the ecosystem characteristics and the sectoral use of water.

2 SCENARIO EVALUATION APPROACH

2.1 Overview of scenario evaluation process

The overarching aim of the scenario evaluation process is to find the appropriate balance between the level of environmental protection and the use of the water to sustain socio-economic activities. Once the preferred scenario has been selected, the Water Resource Class is defined by the level of environmental protection embedded in that scenario.

There are three main elements (variables) to consider in this balance, namely the ecology, economic and societal benefits obtained as a result of the Classification choices made. The scenario evaluation process therefore estimates the consequences that a set of plausible scenarios will have on these elements by quantifying selected metrics to compare the scenarios with one another.

The sequential activities carried out to evaluate the scenarios are presented in Figure 2-1. The status quo information will be applied to identify the components requiring evaluation and defining the relevant parameters to be quantified. Water availability analyses will be carried out for the scenarios, and this feeds into the activity to determine the consequences on Water Quality, Ecology, Ecosystem Services, Economy and Society. The scenarios are ranked, first, for the individual variables and then as an overall integrated ranking derived based on multi-criteria analysis methods.

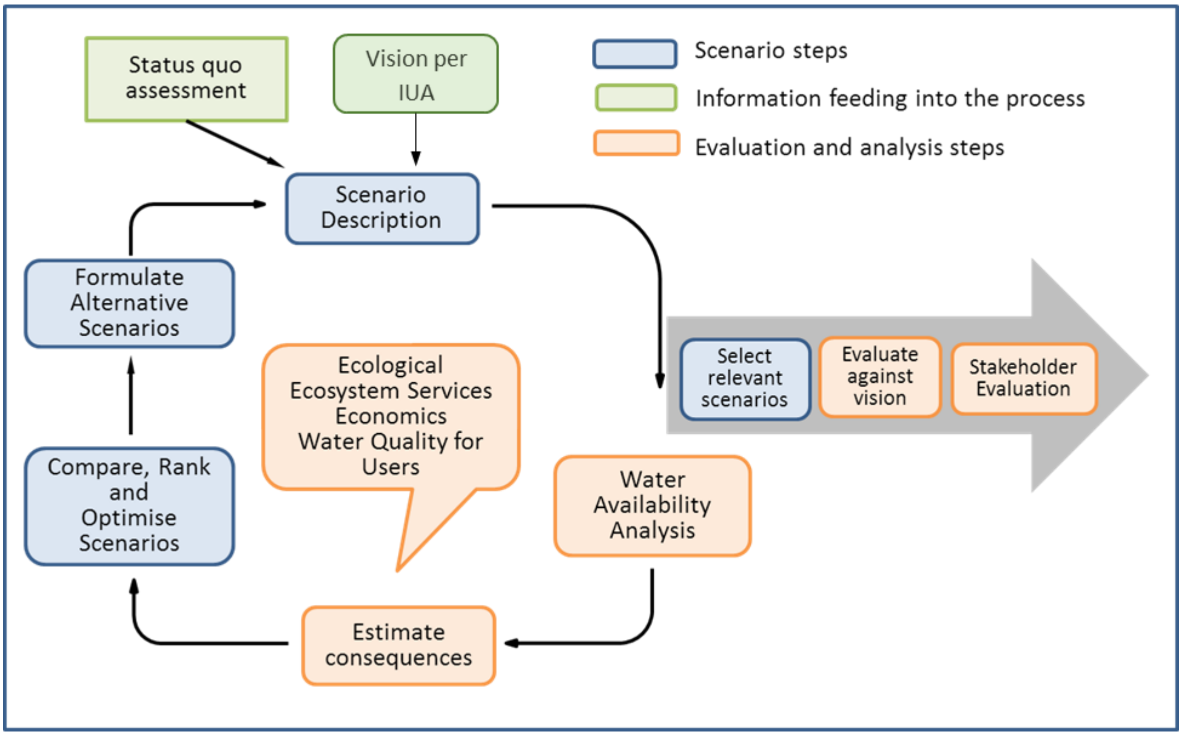

Figure 2-1. Schematic presentation of the scenario evaluation process. Source: DWS, 2017.

It is important to understand the evaluation process at this step as the outcomes of the linking value and condition assessment inform the technical process and the scenario analysis. The approach defined and outlined at this step feeds into the next step of quantifying the ecological water requirements and changes in ecological goods, services and attributes (EGSAs), as well as defining the ecological base configuration scenarios and finally the evaluation of Classification scenarios. During the evaluation process stakeholders will be engaged at various stages, initially by providing their inputs on defining and selecting the scenarios for evaluation and finally to assess the consequences with the aim to make a recommendation of which Water Resource Class should be implemented.

A range of Classification Scenarios will be defined that describe alternative Water Resource Class and EC configurations for the study area. In this report a preliminary set of scenarios are presented to be finalised in the *Ecological Base Configuration Scenarios Report*. The outcomes of these scenarios will be analysed over a defined time period, under a range of assumptions regarding projected population and economic growth, water demand management measures and overall water demand. The result will be to estimate the costs of additional water supply measures that would need to be brought online to meet the demands. This cost will be compared to the benefits of the Reserve.

Given the objectives of the study, most scenarios are likely to be set in terms of the EC configurations, from which the available water for use will be determined, based on the Ecological Water Requirements (EWRs) for the specified ECs (Figure 2-2).

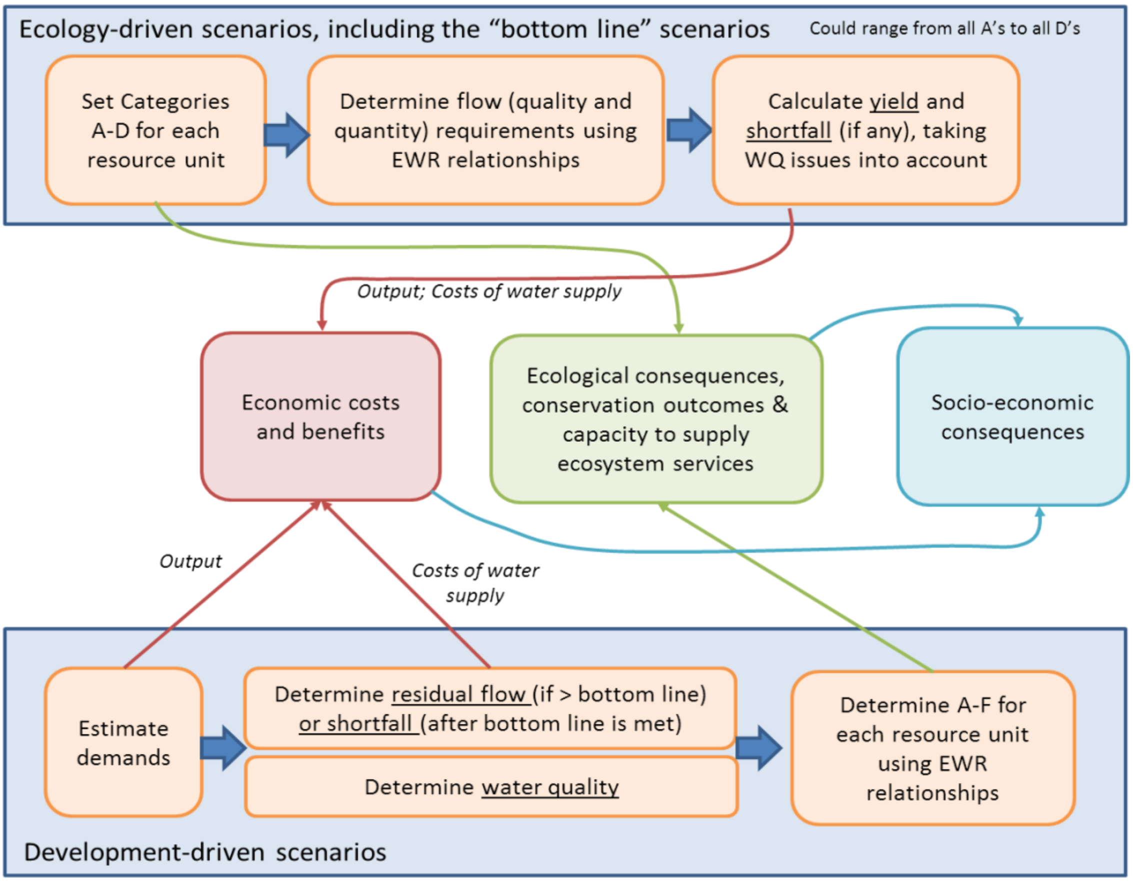

Figure 2-2. Summary of technical processes for classification scenario assessment. Source: DWS, 2017.

It is also possible that some scenarios could be development-focused, in which case the water requirements for development will be met, and the resultant ECs will be determined (Figure 2-2). For ecology-driven scenarios, the ecology team will provide outputs which the hydrologists will use to determine the full flow distribution, and from this the surface and groundwater available for use will be determined. For surface water availability this requires consideration of the existing water supply infrastructure. For development-driven scenarios, a set of ground and surface water requirements will be established related to a development scenario, and the resultant flow and hence EC configuration would be derived.

The factors to be considered in the formulation and evaluation of the scenarios and scenario assumptions are described in the following sections.

2.2 Defining the Classification Scenarios

The definition and evaluation of scenarios are undertaken in the context of the prevailing and proposed water resource management activities in the study area. With the understanding that a scenario, in the context of water resource Classification, comprises a potential configuration of ecological categories for the water resources in each Integrated Units of Analysis (IUA), together with plausible definitions (settings) of all the factors (variables) that influence the water balance and water quality in the study area, the preliminary list of scenarios has been derived through consultation with the project team. This preliminary list will be discussed with DWS and external stakeholders through a stakeholder evaluation process, after which a final list will be compiled for assessment in the *Ecological Base Configuration Scenarios Report.*

The approach for establishing the suite of scenarios to be provided for hydrological analysis will consider different EC configurations in which environmental flows vary spatially and in their overall levels. Some of the spatial configurations would be driven by conservation priorities for rivers and wetlands. The preliminary range of scenarios to be developed is shown in Table 2-1. The only variation will be (a) the ecological water requirements (EWRs) and (b) the water demands that must be met. This will allow evaluation of the trade-offs between ecological and socio-economic consequences.

2.3 Determining ecosystem characteristics of rivers and wetlands

By applying the relationships which will be defined in the *Quantification of the EWR and changes in ecological EGSAs* report, all the relevant ecosystem characteristics, including those relating to ecosystem health, biodiversity conservation targets and the delivery of Ecosystem Goods Services and Attributes (EGSAs), will be determined for each of the biophysical nodes relating to the significant rivers and wetlands, for each scenario.

Table 2-1. Preliminary scenarios

#	Scenario	Description
1A	Maintain Present Ecological State (PES) + low growth (=Baseline)	River and wetland systems are maintained in their present condition.
1B	Maintain PES + high growth	
2A	Bottom line + low growth	The maximum volume of water is made available for abstraction from the system for economic activities, with the proviso that all water resources are maintained in a D class (the ecological "bottom line").
2B	Bottom line + high growth	
3A	Recommended Ecological Category (RECs) + low growth	The RECs determined for rivers and wetlands based on present health and conservation importance (but without any consideration of socio-economic effects) are applied in these scenarios.
3B	RECs + high growth	
4A	Targeted conservation + low growth	High ECs are given to areas of high conservation importance, but for other areas, the ECs can be below REC. It may end up that this scenario set is similar to the above.
4B	Targeted conservation + high growth	
5A	High conservation + low growth	This scenario represents the situation where conservation targets are met, with an emphasis on an eco-tourism-based economy, with most resources in a good condition (Classes A or B).
5B	High conservation + high growth	

2.4 Describing the consequences

The ecosystem characteristics and the water available for abstraction form the basis for evaluating and estimating the consequences of each scenario. Figure 2-1 indicates the variables (ecological, water quality, economic, social wellbeing) that will be evaluated. Table 2-2 lists these variables and associated components and provides a brief description of the evaluation method and purpose.

2.5 Comparing and ranking scenarios

The consequences from the abovementioned activity are expressed numerically for the scenarios and compared separately for each variable and then the results are combined for all variables to derive overall scores, which give effect to the ranking of scenarios. The methodology employed for this is based on multi-criteria analysis (MCA) approach where weighting factors are applied, firstly to give effect that certain nodes are more important than others and secondly that the variables listed in Table 2-2 may differ in their relative importance.

Each scenario is compared to the baseline to estimate change in a range of ecological, economic and social measures and/or indices which are referred to as criteria or indicators. Not all of these can be measured in comparable units such as money. Therefore, the Classification Process uses a multi-criteria analysis approach in which both monetary and non-monetary impacts can be assessed.

This study will express values in monetary terms where possible and relevant and other units or scales for those criteria for which monetary values are irrelevant or impractical to measure. For example, ecological and social variables may be described in terms of state, e.g., % of biodiversity targets met; % of households that are poor, while economic variables will be described in terms of gains or losses in income.

Table 2-2. Variables to be considered in the scenario evaluation

Variable	Components	Evaluation method and purpose
Ecological	Overall state of aquatic ecosystem health % Freshwater conservation targets met (national obligation)	Determine the EC and indicate the degree in which the scenario achieves the REC.
Water quality for users	Empirical impacts on salinity and nutrient enrichment Qualitative impacts on constituents of concern in a particular IUA	Consider the consequences of having to achieve elevated water quality standards for users other than the ecology (fitness for use). This may involve determining the economic implications of such elevated standards.
Economic	Losses/gains in Value Added + Costs saved/incurred Losses/gains in Total Employment	Determine the economic benefit of utilising the available water (abstractions) in terms of Gross Domestic Product (GDP) and Employment (number of jobs).
Society	Impact on livelihoods Income to poor households Intangible benefits to society	Determine the extent that each scenario changes the livelihoods, income to poor households, and intangible benefits to society.

2.6 Scenario assumptions

2.6.1 Water supply infrastructure

This is fixed as at the situation for 2022, for all scenarios. The need for new infrastructure is then calculated for each scenario based on the shortfall calculated (see section 2.6.5).

2.6.2 Time frame

The time horizon for the analysis is also important. Most water-demand forecasting studies use a time horizon of about 25 years (e.g., the "All Towns" study). Furthermore, economic forecasts beyond the short (3-4 years) or medium term (5-10 years) are very difficult because of unknown technological innovation etc. In this study it is proposed to use a time horizon of 2022 to 2041 (20 years). In all cases, the scenarios would be evaluated in the near term (as if the change was already in place), and the long term (after 20 years).

2.6.3 Climate

South Africa's climate is expected to change substantially over the next century (Turpie *et al.*, 2021b). Therefore, climate change is considered in the future development scenarios and is not specified separately as a stand-alone climate change scenario, which has been the case in previous Resource Directed Measures (RDM) and Classification studies. Climate change is predicted to be a major driver of ecological change in South Africa which will exacerbate existing threats to biodiversity and ecosystem services, such as habitat loss and degradation, hydrological alteration, the spread of invasive alien species, overexploitation of resources and pollution (Turpie *et al.*, 2021b). Indeed, South Africa has experienced shifts in climate over the last century that include decreased overall precipitation and number of days of rain, a 1.2 to 1.5°C increase in mean temperature in every month, a decrease in the occurrence of extreme cold days and nights by 3.7 and 6.0 days/nights and an increase in extreme hot day and night occurrence by 9.2 and 8.6 days/nights per decade, respectively, and significant increases in rainfall intensity and the duration of climatological drought in the region (Turpie *et al.*, 2021b).

Variable changes over the next century, depending on the shared socioeconomic pathway (SSP) trajectory, are expected across Southern Africa (Turpie *et al.*, 2021b). The SSPs are possible major future global development and governance scenarios that would lead to different challenges for adaptation and mitigation. The latest climate models (based on the global climate model from the Coupled Model Intercomparison Project CMIP6, 2020) show generally that there will be continuous and increasing warming across the region of between 0.04°C (SSP1) and 0.68°C (SSP5) per decade and a decrease in precipitation by between 2.4 % and 5.4% in the near (long)-term period (2030-2100) under SSP1 and 5, respectively (Figure 2-3).

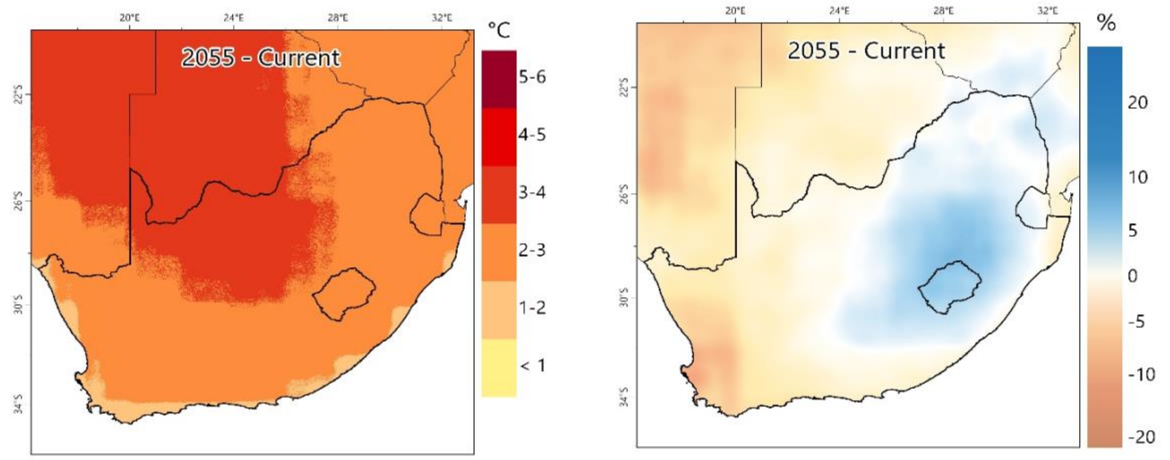

Figure 2-3. Anomalies (changes from current) for mean annual temperature (left) and mean annual precipitation (right) for the 2040-2070 time period under SSP 5-8.5. Source: Turpie et al., 2021.

Significant increases in overall mean annual temperature of 5.1°C are expected in the Savanna biome which cover most of the study area. These changes will alter the structure, composition, and spatial configuration of the country's ecosystems, and with it, the suitability of current land uses (Turpie *et al.*, 2021b). Therefore, incorporating expected changes to surface water availability as a result of changing climate into the water resources modelling is imperative. The modelling will be carried out for present-day conditions and for projected future climate conditions as at the final date (2041).

The World Bank Group Climate Change Knowledge Portal houses climate change projections up to 2099 for 34 global circulation models (GCM). The selected climate projections of the following four individual GCMs (which have been recommended for use in Southern and Eastern Africa) as they provide a reasonably wide range of outcomes in terms of various climate metrics, will be used in this study:

- Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3).
- National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5).
- Max Planck Institute Coupled Earth System Model (MPI-ESM-LR).
- Norwegian Earth System Model (NORESM1-M).

The Portal provides calendar month precipitation changes in mm (hereafter called "precipitation deltas") for each future decade relative to the above Reference Period (1986–2005). Using the appropriate decadal data (1940-1950) for each of the above four selected GCM projections, a simple smoothing and re-scaling operation will be undertaken on these decadal monthly precipitation deltas to yield a continuous monthly time series of precipitation deltas. These will then be respectively applied to the original rainfall files in the calibrated Water Resources Simulation Model (WRSM)-Pitman configurations.

Similarly, the potential changes (deltas) in average calendar month maximum and minimum air temperatures will also be obtained from the Portal to determine projected climate change S-Pan evaporation used in the hydrological model. The WRSM-Pitman model will then be used to generate climate change-based time series of monthly flow. These climate change scenario flows can also be combined with future demand scenarios.

2.6.4 Changes in water demand

Water demand projections will be based on assumptions about population and economic growth. Only one population growth scenario will be used for the analysis. Two economic growth scenarios will be used: low growth and high growth. The demands under projected population growth and alternative economic growth assumptions will be estimated for each IUA.

Current water use was described by IUA in the Status Quo Report. Future water requirements and growth projections will be taken from the latest reconciliation strategy reports. The main water use in the study area is irrigation (about 70%), with urban (domestic, industry and mining; 23%) water use also being significant. The impacts of afforestation, invasive alien plants, irrigation/wastewater treatment return flows and nett evaporation from water bodies are considered in the hydrological modelling.

It is not expected that significant further allocations for irrigation will be made, except to meet transformation targets. Farmers typically expand their irrigation practices horizontally by becoming more efficient on-farm, and vertically by planting higher-value crops. (Geo)hydrological water resource zones where surplus water balances are identified may be targets for the expansion of irrigation, or where bulk water infrastructure such as dams can be cost-effectively developed to allocate water for new irrigation, should suitable soils and other enabling conditions be in place, or can be put in place.

The Reconciliation Strategy Studies take potential growth in future urban water requirements into consideration through the development of future water requirement scenarios. Domestic water requirements are typically a function of economic circumstances and population growth. Mining is expected to grow in the study area. A growth in mining is usually associated with population growth and therefore increased domestic water requirements.

2.6.5 Options for meeting water supply shortfall

Based on the difference between system yield using current infrastructure and projected demand, the shortfall in meeting demands will be estimated (after meeting the Reserve), which is then translated into costs of increasing water supply to the level required in 2041 (Figure 2-4).

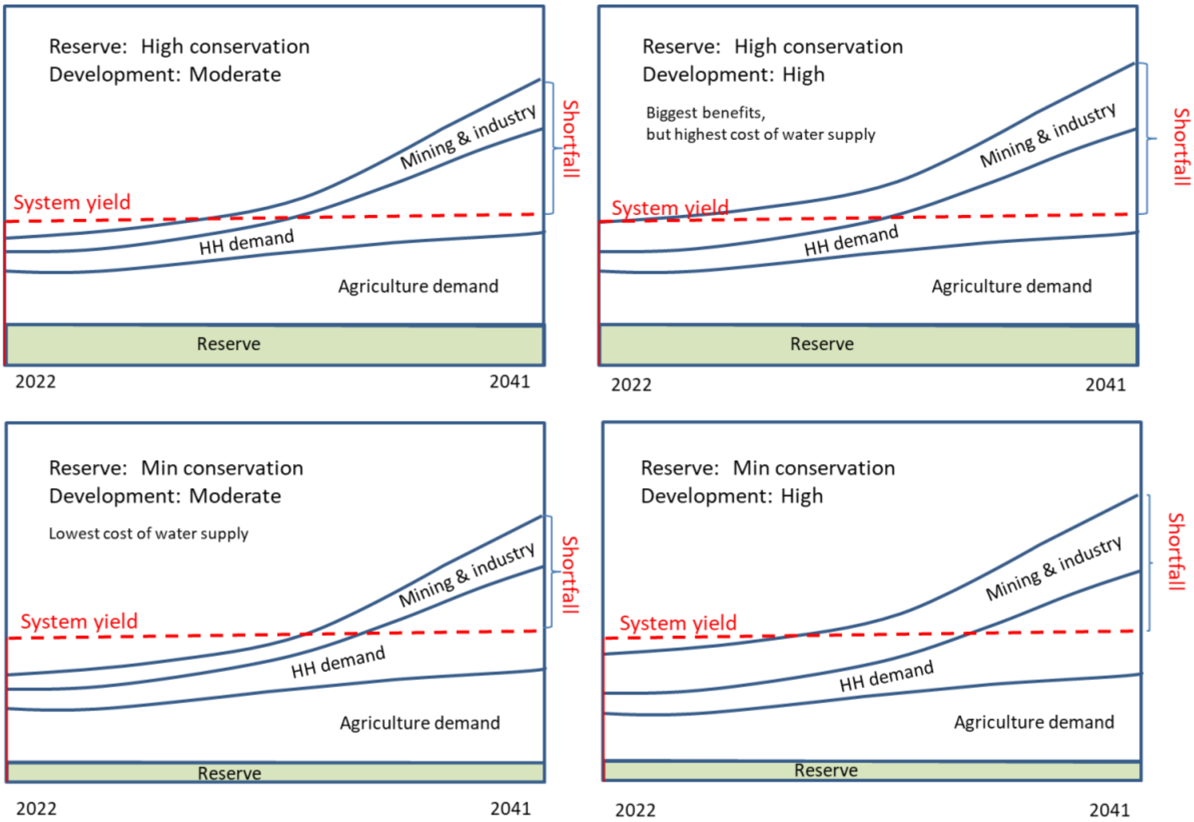

Figure 2-4. Simplified examples of classification scenarios

Water supply infrastructure is prioritised in relation to projected rate of growth in demand relative to current demand. So, it will be necessary to work out an equation (or set of area-specific equations) to estimate the cost of water supply under different scenarios.

Under the Reconciliation Strategy Studies for the Limpopo WMA North, the Luvuvhu and Letaba Water Supply System (DWA, 2015a; DWS, 2017b), and the All-Towns Reconciliation Strategy Studies, intervention options have been identified for consideration as measures to reconcile potential future water requirements with availability. An intervention is a measure that must be timeously implemented, either by reducing water requirements or by increasing water availability, to prevent the risk of a water shortage becoming unacceptable. Potential intervention may include the following:

- Water conservation and water demand management (WC/WDM), reducing water demand as a result of increasing water use efficiency.
- Reuse of effluent, reducing water demand from other sources, i.e. providing treated effluent in lieu of water previously provided from other water sources.
- Improved operational practices of existing water infrastructure, reducing water demand as a result of improved operational efficiency.
- New or increased run-of-river diversions from rivers (dams, levees, pumping stations, canals, tunnels, or any other manmade structure that routes or diverts surplus flow for water supply).
- Construction of new dams (instream or off-channel) or raising of existing dams.
- Increased demands placed on existing supply sources, that are not yet fully utilised.

- Increased groundwater abstraction from existing sources or new groundwater development.
- Conjunctive use of surface and groundwater.
- Transfer schemes, either transferring water in or out of the WMA.

In the development of the Limpopo WMA North Reconciliation Strategy individual water balances with potential intervention options were generated for each catchment in the study area (Lephalale, Sand, Mogalakwena and Nzhelele; Figure 2-5) because they rely on their own water resources and are managed independently from neighbouring catchments. These catchments are generally dry and over exploited. In the Lephalale catchment there are no significant developments planned due to the already scarce water situation and the presence of large wilderness areas. In the Mogalakwena catchment, the development of new platinum mines is expected which will increase urban and mining water demand. In the Sand catchment major developments such as the Musina Strategic Economic Zone (SEZ) and Limpopo Eco Industrial Park (LEIP) are expected to go ahead which will increase industrial water requirements. Mining prospecting sites have also been identified in the Sand catchment. In the Nzhelele catchment, coal mining is growing, and water requirements are expected to increase here too.

In the Luvuvhu and Mutale catchments, water resources are already over allocated with future demands (urban and rural domestic and irrigation) expected to increase significantly. The Shingwedzi catchment is situated almost entirely in the Kruger National Park and as such no sustainable yield is derived from surface flow in this catchment (DWA, 2015a).

A list of potential intervention options, and potential implementation dates (if available) will be compiled, following scrutiny of the Reconciliation Strategy studies and other potential sources, such as known initiatives by municipalities that may not yet be fully integrated in the Reconciliation Strategies.

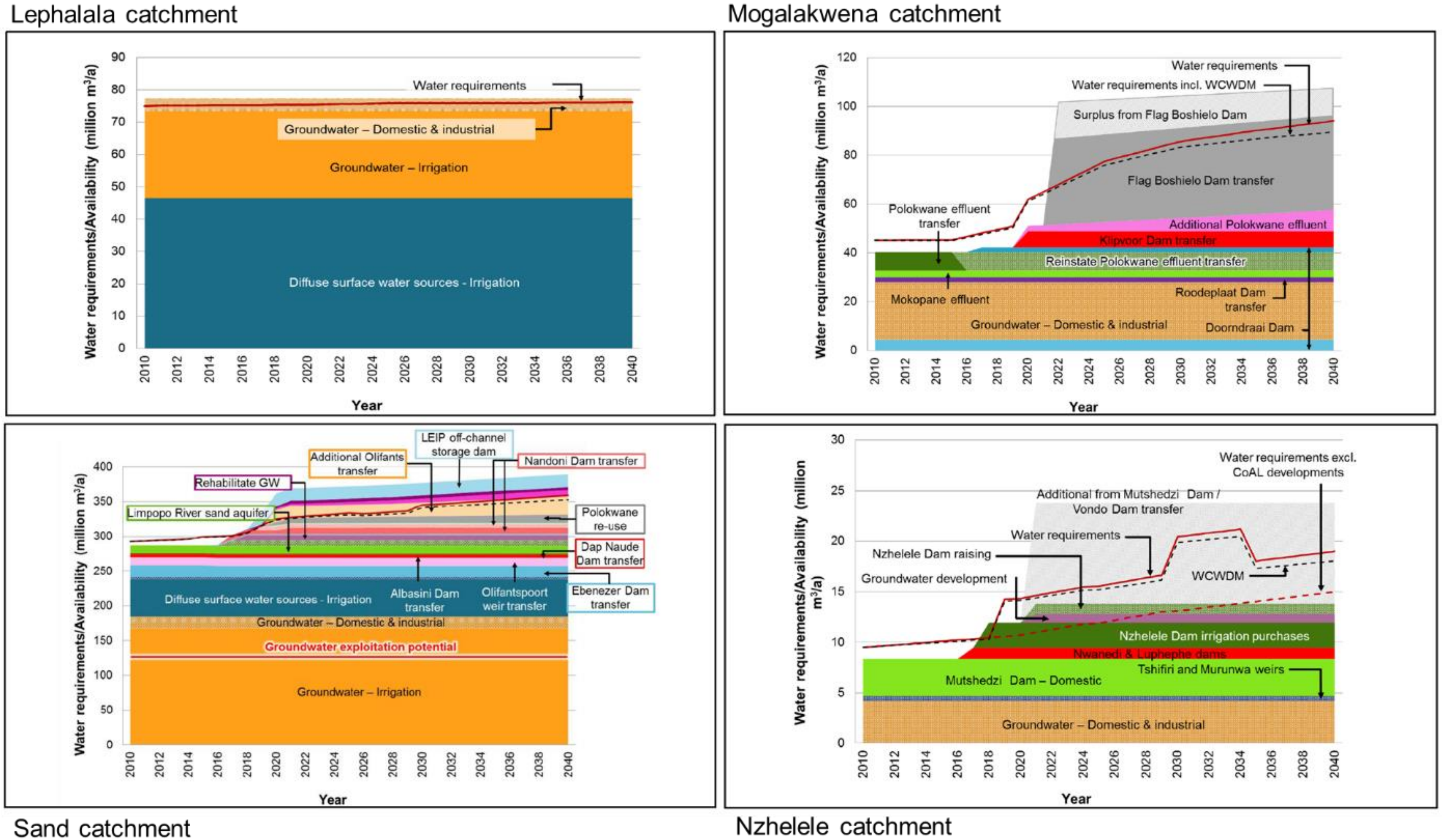

Figure 2-5. Water balance for the catchments of the Limpopo WMA North that fall within the study area. Source: DWS, 2017b.

3 DETERMINING FLOWS AND WATER FOR USE

3.1 Overview

By applying the relationships which will be defined in the *Quantification of the EWR and changes in ecological EGSAs* report, all the relevant flow and water quality requirements will be determined for each of the biophysical nodes relating to the significant rivers and wetlands, for each scenario. To do this, the flows required to achieve a particular ecological state will be defined at selected nodes (key biophysical nodes or EWR sites). Another key prerequisite for this activity will be to incorporate these nodes into the water resource simulation model to enable the generation of monthly time series of flow data at the nodes for the scenarios where appropriate.

The ecological state is defined by the particular EC specified for the scenario under consideration, which could be the REC, PES or any appropriate EC between A and D. Some portion of the flow (to maintain a particular EC) is derived from surface water (runoff), and some from groundwater (via groundwater contribution to baseflow). Use of groundwater can reduce baseflow and therefore impact surface flow (and EC). To relate the flow requirement per EC to surface and groundwater availability for use, information is required on the groundwater and surface water contribution to flow.

The water resource simulation model incorporates groundwater contribution to baseflow, and these volumes will be verified against all available information to establish likely groundwater contribution to baseflow per quaternary catchment, and where possible disaggregated to the biophysical nodes. Knowing what portion of flow derives from groundwater and surface water enables a decision to be taken as to whether to meet the required flow from groundwater (impacting on groundwater availability for abstraction) versus surface water (impacting on surface water availability for abstraction), or whether a combination of both is required.

The water resource simulation model will be applied to determine the volume of surface water that is available for abstraction from the water resource for economic use, given a particular flow regime in the river is required to achieve a certain EC. A groundwater balance model will be used to relate the change in baseflow per EC to groundwater availability in the aquifers surrounding a biophysical node and contributing to baseflow. Note that depending on how the scenarios are set up, the present EC configuration may be used to define flow requirements, which then determine how much surface and groundwater is available for use, or a development scenario may be defined and related to particular water requirements, in which case the resultant EC configuration would be derived, subject to a constraint of minimum flows to maintain D category.

In practice, once the Reserve is gazetted, Reserve allocations need to be sufficient to meet the river reach to which the Reserve is allocated, as well as downstream allocations. The Reserve allocations in the upper reaches are generally set to be higher than what is required to maintain the ecological condition to balance flows across a catchment. To meet downstream Reserve allocations, it is often necessary to source additional water from undeveloped tributaries by both increasing these tributaries Reserve requirements and by limiting increases in more developed areas to certain months.

The methods used to generate the EWR data to construct the EC scenarios will be described in the *Quantification of the EWR and changes in ecological EGSAs* report. The scenarios and the methods used to generate the time series of scenario flows will be described in the *Ecological Base Configuration Scenarios* report. However, a broad overview of the approach to estimating surface and groundwater flows is provided below.

3.2 Surface water decision support models

The Hydrological Analysis Report for the Limpopo Water Management Area North Reconciliation Strategy (DWA, 2015b) and Hydrology Report for the Luvuvhu and Letaba Water Supply System Reconciliation Strategy (DWA, 2014a) provide the latest available hydrological information. Both studies use the WRSM suite of software and generate time series for the period 1920 to 2010 at all quaternary catchment boundaries. Both these sets of hydrology have been obtained and thoroughly checked. Improvements to the model need to take place and these include:

- Improving the simulation of low flows; and
- Extending the hydrology to include the recent drought.

The WRSM configuration will also be adjusted to generate flows at nodes that do not coincide with quaternary catchment boundaries. The required time series will then be generated by developing separate configurations. Natural flows are generated by ignoring all water demands. Current-day flows can be generated by simulating a constant water use based on the most recent data. Future (scenario) flows can be generated using information obtained from the relevant Water Resources Yield Model (WRYM) and Water Resources Planning Model (WRPM) reports (DWA, 2014a, 2015b), the All-Towns Reconciliation Study (2011) as well as liaison with DWS. Climate change will be included in the future scenarios.

In addition, the Water Resource Model configurations for the Limpopo Watercourse Commission (LIMCOM) (2013) study have already been obtained. These configurations cover the full extent of the Limpopo River Basin including tributaries located in Botswana and Zimbabwe. Both natural, current day and future configurations can be used to generate monthly hydrology at locations on the main stem Limpopo River should they be required.

3.3 Groundwater models

Although the theory describing the dynamic relationship between groundwater contribution to base flow (GWBF, and therefore ability to meet EWR) and groundwater use is widely accepted, the simplifying assumptions required to implement the theory, and the associated scale, data availability and modelling challenges, mean that methods to quantify the relationship still vary greatly between studies. The method applied also varies between studies naturally based on the location of the study. In areas where groundwater-surface water interaction is minimal, and as such the impact of the groundwater use (and changing abstraction rates) on GWBF (and meeting the EWR) is minimal, greatly simplifying the dynamic relationship between groundwater use and GWBF may be acceptable.

In other cases, groundwater is recognised as playing an important role in maintaining low flows, and as such, it is assumed that the groundwater contribution to baseflow should be maintained in its entirety (when setting the Reserve & RQOs), in order to ensure groundwater's role to meeting the EWR is met (DWA, 2014b). This is also a simplification to some degree, as the low flow may be met in part by interflow (or even discharges from WWTW in altered systems), and the EWR for the agreed category may be less than groundwater contribution to baseflow. As such, there may not be the need to maintain all of groundwater's contribution to baseflow (Riemann, 2013).

The study area includes areas where groundwater – surface water interactions are important; for example, 31% of all (GW) geothermal springs in the country are found in the Limpopo province. Groundwater is heavily utilised in the Sand and Mogalakwena catchments, where there are current and/or future impacts on GWBF from groundwater use, and the relationship between groundwater use and impact on GWBF has not been quantified. Therefore, in this study, attempts will be made to fully accommodate the potential role of groundwater in classification. In order for a Water Resource Class to be related to groundwater use and availability (and hence the groundwater Reserve), the relationship between groundwater status (associated to groundwater use), and groundwater contribution to baseflow will need to be established.

Quantifying this relationship requires the use of a numerical groundwater model. There is no other method feasible to derive the relationship between use and GWBF, and to discretise the GWBF data to specific points of interest within the quaternary catchment (springs, vleis). Other RDM studies have begun to realise the necessity of a numerical groundwater model; for example, DWS recently initiated a study for development of a numerical model for quantifying SW-GW interactions in the Lower Vaal Catchment. The development of a numerical groundwater model however was not specified in the Terms of Reference (ToR), and the proposed approach therefore includes the development of numerical groundwater model(s) for selected prioritised areas, in which there is high groundwater use (and therefore impact of use on GWBF). This is likely to include the upper reaches of the Mogalakwena and Sand River catchments as well as the upper reaches of the Nzhelele and Nwanedi Rivers, in which there are priority ecological systems that are at risk from high groundwater abstraction for irrigation and expanding mining activities.

The numerical groundwater model(s) will be calibrated in steady state with zero bulk centralised abstraction and pre-abstraction recharge (from Groundwater Resource Assessment II; GRAII) and historically stable groundwater levels (~1990), to provide the naturalised discharge to points of interest (springs and vleis). All current abstraction will then be accommodated in the steady state model to provide the maximum (future, after response time) reduction in GWBF based on current abstraction rates. Three additional model scenarios with varying abstraction rates will be tested to populate the relationship between use and GWBF.

The remaining areas have either much lower groundwater abstraction rates or an absence of groundwater-dependent ecosystems, and therefore quantification of the relationship between groundwater use and GWBF is less critical. For these areas, a static quaternary catchment-scale groundwater balance will be developed in which the relationship between availability and groundwater contribution to baseflow is highly simplified and groundwater availability is equated to recharge minus current use minus groundwater contribution to baseflow (GWBF). Data from this water balance will be used to inform the present status. Where various limitations (scale, and associated data) have prevented fully accommodating groundwater's theoretical role in classification, at least the intended analysis is described, along with the necessary simplifications applied. The primary dataset for the static groundwater balance model is information from GRAII (DWAF, 2006), and groundwater use based on WARMS data. Where available, data will also be sourced from the DWS regional office. The output of the hydrological modelling completed on the study will also generate GWBF data, and expert analysis of these GWBF datasets will resolve the most applicable on a quaternary catchment-scale basis. Differences in approach often come from how the data is manipulated, and to what scale (i.e. quaternary catchment, aquifers within catchments, or disaggregated and summed to aquifer boundaries).

Whilst the development of a numerical groundwater model is recommended as critical to achieve the requirements of the Reserve study, there will remain limitations to the study. The model limitations arise largely due to the following:

- Distribution of groundwater levels and actual groundwater use (i.e. flow meter measurements).
- There is a lack of data on groundwater contribution to baseflow (particularly on the vleis and river systems) with which to calibrate the model (flow rates will be used where they are available). The implicit assumption therefore is that recharge is correct, and the model essentially apportions this recharge to the various prescribed discharge points. This remains a useful exercise given it would not be feasible to disaggregate the flow regime without a numerical model.

4 IMPACTS ON WATER QUALITY

As part of the scenario evaluation, the classification process requires that water quality for users be assessed at two levels:

- The present-day water quality requirements for all water users (fitness for use); and
- The water quality implications of different scenarios for different users.

4.1 Present day water quality

To assess the water quality consequences of different catchment scenarios, it is necessary to assess the present water quality status and the degree to which the water quality requirements of users are satisfied. This then forms the basis of predicting how a specific catchment scenario would change the water quality, and then assess how this change would affect water user requirements.

The present-day water quality assessment for water users was conducted for the *Delineation and* Status *Quo Report*. The assessment used water quality data collected in the study area by DWS over a ten-year period (2008 to 2018) to describe the present water quality status. The assessment was aligned with the methodology that was used in the Olifants WMA classification study. The water quality targets used for the assessment were derived using the Resource Water Quality Objectives (RWQOs) Model (Version 4.0) which uses as its basis, the 1996 South African Water Quality Guidelines, Quality of Domestic Water Supplies: Assessment Guide, Volume 1 and Methods for determining the Water Quality Component of the Reserve and are based on the strictest water user criteria (thus represent fairly conservative limits). The fitness for use was described using four water quality categories:

- **Ideal**: water quality that is fit for all uses and that would have no impacts on any of the users.
- **Acceptable**: water that is fit for most uses, but the most sensitive users or crops might be slightly affected.
- **Tolerable**: water quality that is moderately fit for use but certain impacts such as a reduction in crop yield may occur.
- **Unacceptable**: water that is unfit for most use and that will definitely have a negative impact on water users.

Users that were considered were domestic water use, agricultural water use (irrigated crops, livestock and game watering), recreation, and aquatic ecosystem requirements.

4.2 Water quality impacts of different scenarios

This component of the WRCS process requires assessing the change a particular scenario would have on water quality and specifically the implications on the fitness for use for the key water users in an IUA.

The concentrations of chemical constituents and values of physical variables are often dependent on flow. For example, salinity is often inversely related to flow in a river (as the flow increases the salt concentrations decrease) while phosphates or suspended sediments are often directly related to flow (as the flow increases so do the phosphate or suspended sediment concentrations). Likewise, use of greater volumes of groundwater would reduce base flow, and where groundwater has a significantly different quality to surface water, the changing groundwater use could impact on surface water quality. Therefore, a change in the flow regime (i.e., the scenarios) could cause a change in water quality.

The WRCS recommend that water quality be modelled along with the flows if a water quality model has been set up alongside the flow assessment model. However, the WRSM2000-Pitman model that will be used to assess the flow scenarios in the study, has not been configured to simulate water quality.

A qualitative assessment of the water quality impacts for each scenario will be performed based on examination of the relationship between key water quality parameters and flow at water quality sampling sites where flows data are also collected, the nodes, on knowledge of the behaviour of the constituent with flow, and local conditions in the IUA that may affect the in-stream concentration (e.g. presence of point or non-point sources of pollution). Likewise, quantification of the relationship between groundwater uses and groundwater or surface water quality is not possible at a regional scale within the project. Nevertheless, where groundwater quality is known to differ significantly to surface water, a qualitative assessment of the potential impacts of groundwater use on surface water may be possible.

By default, the water quality management objective is to not allow further deterioration in water quality, that is, maintain water user requirements in at least their present state. If a specific catchment scenario results in a poorer water quality category for users, then the catchment scenario can be modified by changing a combination of three options. These are:

- Reduce the constituent loads from the point and nonpoint pollution sources (implying management intervention to reduce constituent loads);
- Provide more water for dilution (implying a better ecological category); and
- Change water user requirements (implying water users must accept poorer quality water and develop mechanisms to cope with the consequences).

Using the above analysis, the water quality specialist will adjust the information on water available for use to provide detail on changes of availability of water for use in different sectors and subsectors, based on their water quality requirements. This will be fed into the economic analysis.

5 ASSESSING SOCIO-ECONOMIC CONSEQUENCES

5.1 Rationale

The overall aim of the scenario analysis is to evaluate the consequences of allocating different amounts and quality of water to the environment (i.e., different levels of environmental protection), by evaluating the costs and benefits thereof. The benefits of allocating more water to the Reserve are in the form of biodiversity conservation and ecosystem services which contribute to the economy and societal wellbeing, for example through tourism, while the costs would take the form of increased cost of supplying water for use in economic activities (e.g., by having to build new infrastructure and adopt other technologies sooner), and reducing overall value added in the economy from water using activities. This requires evaluating different EC configurations, in the context of different scenarios of economic development, over a defined planning time frame, with a given set of options for augmenting water supply as demand increases over time.

To undertake the scenario analysis, the linkages that arise from the trade-off between water abstracted for use and water retained for the Reserve need to be formulated and their associated impacts determined. The following sections outline these methods.

5.2 Overview of condition-economy-society linkages

The allocation of the ecological Reserve is central to the environmental, economic and social outcomes of a region. Water is not only directly critical to social and economic development, but also indirectly, by supporting key ecological systems which provide essential ecosystem goods and services that underpin development and human wellbeing. In the study area, economic activities that depend on the licenced use of water include urban supply, irrigation agriculture, mining and industry. Economic activities whose outputs are linked to the quality of aquatic ecosystems include nature-based tourism, for example. In addition, the functioning of aquatic ecosystems also plays a role in overall economic productivity through ecosystem services that lead to cost savings, such as flood attenuation and water quality amelioration. These cost savings manifest in both the private and public sector. Similarly, social wellbeing within the study area is determined by both water supply and instream flows, namely the abstraction and supply of water for domestic purposes, the supply of abstracted or instream water to economic activities which provide employment opportunities, and the supply of instream flows which lead to the provision of instream water, natural resources and opportunities for recreation and spiritual fulfilment.

Ecosystem services are therefore an integral factor influencing the economic and social status of the different parts of the study area. The roles of water and aquatic ecosystem services in determining the economic prosperity and the social wellbeing of people living in the study area are summarised in Figure 5-1. The Classification of water resources will define their intended condition as well as the quantity and quality of water required to maintain that specific condition. This in turn, will determine the quantity of water that is available for use. The Classification of water resources in the study area will be decided at the IUA scale based on an analysis of a range of alternative scenarios in which the classes of each IUA are varied in different combinations.

The economic impacts are considered in terms of changes in the two main macro-economic indicators of GDP and employment, as well as changes in cost savings due to changes in relevant ecosystem services. This requires estimating the relationships between water use and economic outputs because of production in water user sectors, stream flow reducing sectors and sectors relying on ecosystem services (Figure 5-1). The social impacts are considered in terms of a composite index of societal wellbeing that takes impacts on household income, health and happiness into account.

The methods and assumptions used in estimating the changes in economic output and societal wellbeing as a result of changes in water use and ecosystem services under the different water allocation scenarios are presented in the following sections.

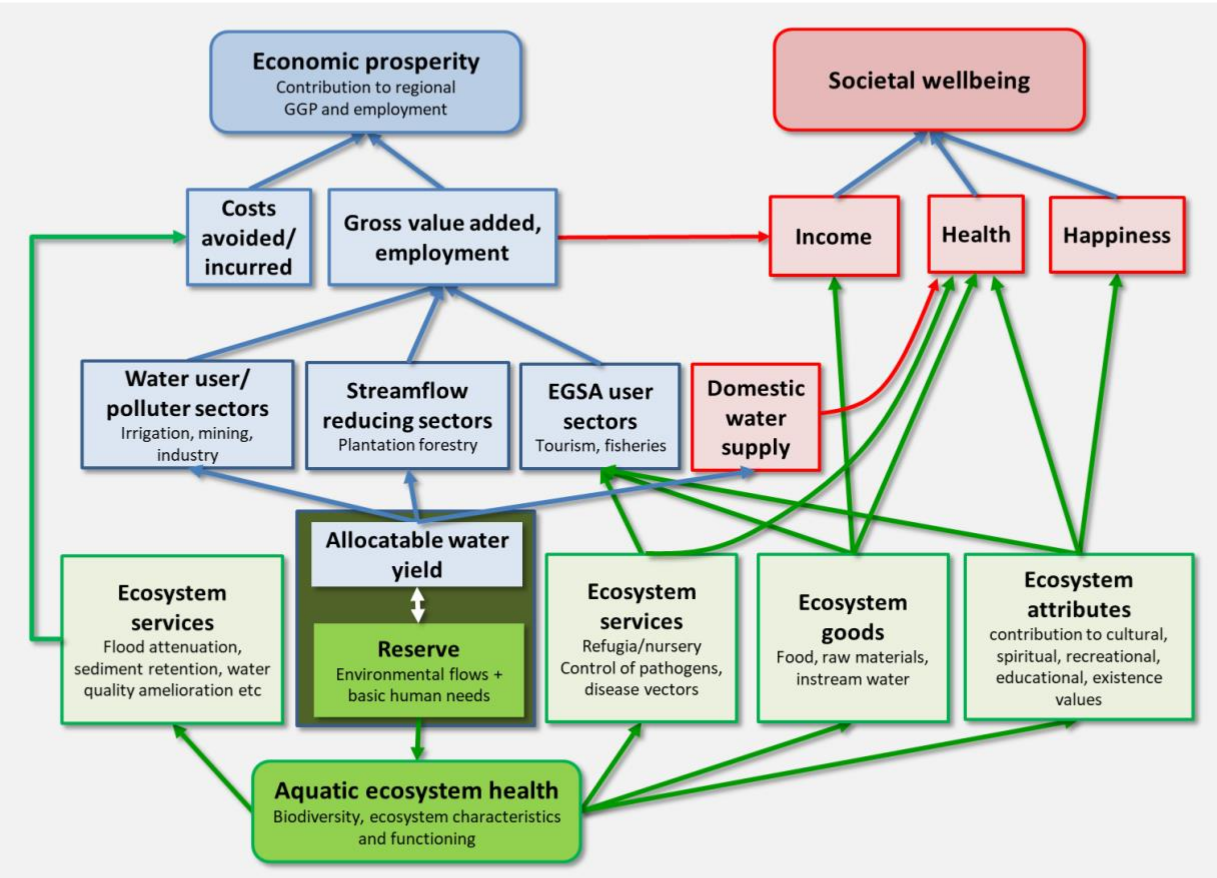

Figure 5-1. Linkages arising from the trade-off between water abstracted for use and water retained for the ecological Reserve. EGSA stands for ecosystem goods, services, and attributes. Source: DWS, 2017 modified from Turpie et al. (2006).

5.3 Assessing ecological consequences and capacity to supply ecosystem services

5.3.1 Ecosystem services considered

Ecosystem services are broadly defined as "the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2003, 2005). These benefits depend on the nature of the ecosystems, and their biodiversity. An ecosystem is a community of living organisms in conjunction with non-living components of their environment, interacting as a system. The biotic and abiotic components are linked together through nutrient and energy flows. Ecosystems can be defined in space, and range in size, e.g., from wetlands to a large rainforest.

The understanding of ecosystem services and benefits and their valuation has advanced considerably over the past decade. In general, managers and policy makers need to understand how changes in ecosystem extent and condition affect economic outputs and human welfare. This requires understanding more about the components of biodiversity and the underlying links between ecosystem structure and function and the supply of ecosystem services (Figure 5-2).

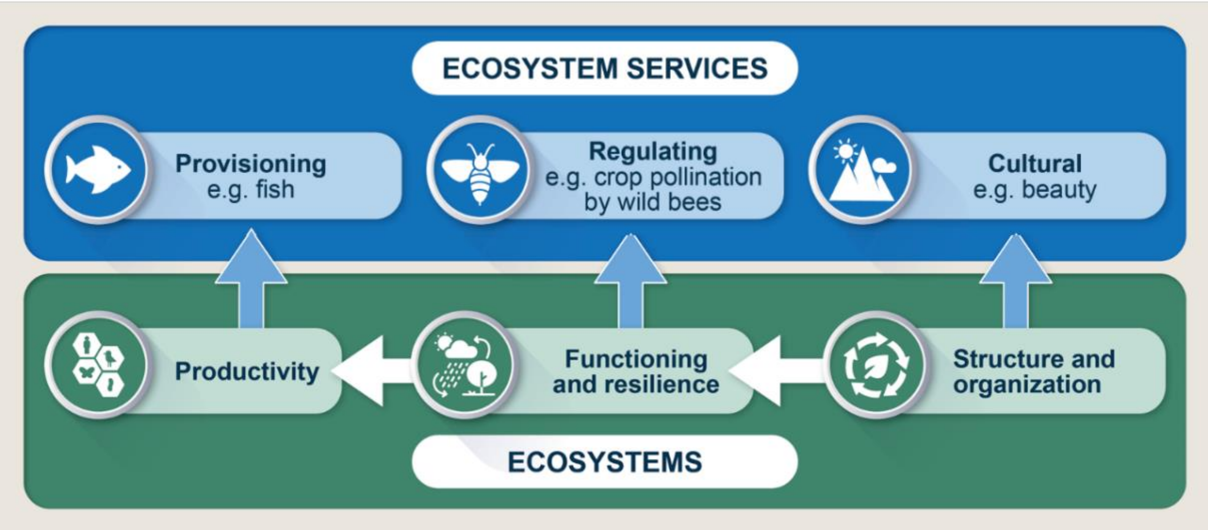

Figure 5-2. The link between ecosystems and the services they provide. Source: J.K. Turpie, unpublished.

Ecosystem services are fundamentally linked to biodiversity, which is the variability among living organisms and the ecological complexes of which they are part. This includes diversity within species, between species, and of ecosystems. The biological diversity found within an ecosystem is critically important to its functioning and value. In particular, an ecosystem's composition determines its productivity and resilience. Diversity within functional groups also helps to maintain ecosystem structure and functioning, such as its trophic balance (the ratios of predators to prey, etc.). Therefore, biodiversity plays the same role in ecosystems as diversity in a financial portfolio, in that it reduces variability (uncertainty) in yield. This is known as the "portfolio effect". In this way, biodiversity acts as "insurance" against climate change and other shocks. Biodiversity is the foundation of the vast array of ecosystem services that critically contribute to human well-being. Therefore, the delivery of ecosystem services and the benefits they provide depends on the condition of the ecosystem.

The productivity of a system gives rise to provisioning services and the production of wild biomass, such as fish and wild plants and medicines. The functioning and resilience of a system provides regulating services such as carbon storage and sequestration. Attributes relating to the structure and composition of a system, such as beauty, rarity and diversity, give rise to cultural services. Cultural services include the less tangible values such as spiritual, educational, cultural and recreational value which are associated with sense of place (Figure 5-2).

It is important to realise that ecosystem values are generated through the combined use of natural and man-made systems and other capital. For example, if one further developed the tourism infrastructure of a location or invested in more marketing, the tourism value would likely increase. The valuation of ecosystem services attempts to determine how changes in natural capital affect the values derived, holding other inputs constant.

Aquatic ecosystems are rich and productive systems that produce a wide range of benefits to society. The benefits that are assessed in this study are shown in Table 5-1.

Table 5-1. Summary of the main aquatic ecosystem services and their benefits

Broad category	Ecosystem service	Benefits
Provisioning	Harvested wild biomass products	Food, energy, medicine and raw materials
	Wetland/floodplain vegetative production	Livestock grazing
	River water for domestic use	Water for drinking
Regulating	Carbon storage and sequestration	Avoided climate change damages
	Flood attenuation	Avoided damage costs
	Water quality amelioration	Water treatment cost savings, health cost savings
Cultural	Opportunity for deriving satisfaction through active or passive use of the system for spiritual, recreational, or educational purposes, etc.	Experiential value manifested as tourism value, local recreational value.

5.3.2 Baseline valuation

The value of the aquatic ecosystems within the study area is estimated to be in the order of R410 million per year (Table 5-2). The nature-based tourism value accounts for just under half of the total value of aquatic ecosystems in the study area. The provisioning services (water for domestic use, harvested wild resources and wetland contribution to livestock production) account for 44% of the total value. The carbon value presented here represents the damage costs avoided to South Africa. The avoided damages at a global scale are much larger.

Table 5-2. Summary of values associated with the aquatic ecosystems of the study area in their present condition

Benefit	Value (2021 R millions)
Harvested wild aquatic resources	46.9
Wetland contribution to livestock production	96.5
Water for domestic use	37.5
Nature-based tourism value	203.2
Flood retention	8.5
Carbon sequestration and storage	18.48
Total	**411.00**

5.3.3 Relationship between ecosystem condition and ecosystem value

In order to evaluate the impact on ecosystem value, it is necessary to understand the underlying links between ecosystem structure and function and the supply of ecosystem services as well as their demand. The condition of the aquatic ecosystems in the study area will vary under each of the Classification Scenarios. This will be expected to have an impact on their attributes that are valued by society as well as their capacity to deliver goods and services. It is important to note that the relationships between river health and the benefits people acquire are complex, hence establishing the links can be challenging.

The ecosystem services considered are summarised below, along with the flow-related characteristics that are likely to be the main drivers of these values (Table 5-3). Most of these variables are assessed in the scoring of rivers and wetlands using the EHI.

In order to inform this analysis, the relationships between abiotic and biotic scores and the overall health score for aquatic ecosystems will be explored. The relationships that are identified will be used as a guide for the assumptions in this study. The relevant relationships and assumptions are broadly defined below and will be fully developed and evaluated as part of the *Main EWR Report.*

Table 5-3. Main ecosystem services provided by rivers and wetlands of the study area, and the main flow-related variables that can be derived from Reserve studies to estimate changes in the capacity to deliver these services.

Category of service	Types of values	Description of EGSA	Independent variables related to river and wetland condition
Goods (Provisioning services)	Harvesting of wild plant and animal resources	Wild plants and fish collected on a subsistence basis for consumption	Freshwater fish abundance Wetland plant abundance
	Informal water supply	Water collected from rivers and streams for drinking	Water quantity and quality
	Livestock grazing	Contribution to livestock production due to floodplain vegetation provided by wetlands	Water quantity and quality
Services (Regulating services)	Carbon storage and sequestration	Contribution to the amelioration of climate change damages through sequestration of carbon by riverine and wetland habitats	Overall health Extent of riparian vegetation Water quantity and quality
	Flood attenuation	Contribution of wetlands to ameliorating floods	Water quantity and quality
Attributes (Cultural services)	Tourism value	A river or wetland's contribution to recreation/tourism appeal of a location	Overall health Abundance of aquatic megafauna Abundance and diversity of waterbirds Abundance and diversity of riparian trees Riverscape appearance

5.3.3.1 Ecosystem goods collected on a subsistence basis for consumption

Rivers and wetlands provide numerous resources which can be harvested, including raw materials such as reeds, fish, and wild plant foods and medicines. The delivery of these ecosystem goods is a function of the productivity of the aquatic ecosystem. The value of this service depends on the extent to which it is demanded, which can be influenced by regulation, as in the case of protected areas.

Rural and peri-urban communities harvest a wide range of resources from rivers and wetlands in the study area. Extensive floodplains are particularly important for fish, as are rivers and dams in the study area. For this study, changes in the capacity to deliver this service will be estimated based on expert opinion on change in abundance of fish and plant populations that result from a change in EC, i.e., the proportional change in the size of fish populations with a change in ecological condition (Figure 5-3). This results in a proportional change in the value of the resource being harvested, assuming demand remains constant.

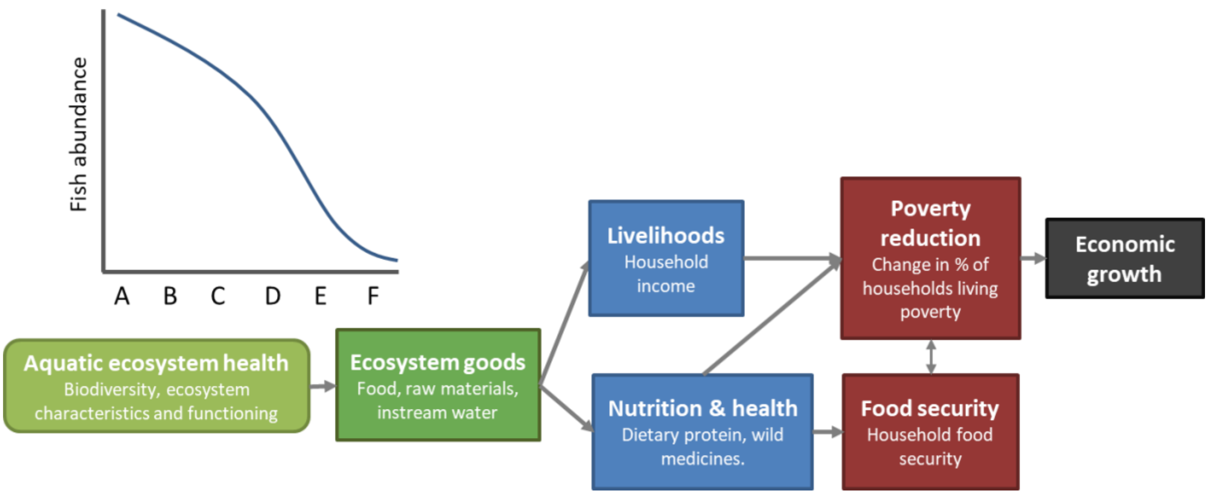

Figure 5-3. Linkages between aquatic ecosystem health, harvested resources, economic prosperity and societal wellbeing.

Estimating the change in value of informal water supply (instream use) will be estimated using methods developed by Turpie *et al.* (2021a). In determining the baseline value of instream use, the number of households depending on rivers and streams for water supply was extracted from Census 2011 at the sub-place level and matched to the sub-basins based on spatial data on human settlements. Water for Basic Human Needs (BHN) is stipulated in South Africa's National Water Act, recognising the right of access to basic water supply. We estimated the monthly BHN water demands by households within each sub-catchment assuming an allowance of 25 litres per person per day. These demands will then be compared with the modelled monthly flows into each sub-basin under each of the Classification Scenarios. We will determine the number of months in which demands are not met in each sub-catchment under each scenario, and then compute the extent to which the baseline scenario mitigates these shortages. These differences will be valued at the cost of purchasing water from water vendors, which is the most common reality for areas where water shortages occur.

5.3.3.2 Wetland contribution to rural livestock production

Small-scale (subsistence) farmers utilise wetland and floodplain areas for grazing livestock, with these areas providing fodder throughout most of the year. Changes in flows and the loss of floods that feed floodplains could have a significant impact on these grazing areas. Farmers would have to reduce livestock numbers due to the loss of floodplain grazing areas, which would have an impact on household income and household food security. For this study, changes in the capacity to deliver this service will be estimated based on expert opinion on change in extent of wetland grazing areas that result from a change in EC and the associated changes in carrying capacity.

5.3.3.3 Carbon storage and sequestration

Riparian vegetation in the study area is characterised by large trees and shrubs that flank rivers, wetlands and streams. This vegetation plays an important role in carbon storage and sequestration. Changes to flows could have a significant impact on riparian vegetation, with die back occurring over the long-term as the quantity and/or quality of surface water and groundwater deteriorates. In this study, the changes in the capacity to deliver this service will be estimated based on expert opinion of how riparian vegetation changes under different EC categories, and then assuming a proportional change in the carbon storage value.

5.3.3.4 Flood attenuation

Changes in the quantity and quality of flows can have an impact on the functioning of certain wetlands to provide flood attenuation services. Extended dry periods or extended wet periods can alter the physical attributes of valley bottom and floodplain wetlands in particular, which are important for regulating flows and attenuating flood peaks. Changes in condition can alter the wetland’s ability to attenuate and store peak flows and slowly release them (e.g., a sponge effect).

In this study, the proportion of sponge capacity that is lost from valley bottom and floodplain wetlands with a change in ecological condition will be estimated, based on expert opinion. Note that this will only be estimated in areas where there is downstream demand for the service.

5.3.3.5 Nature-based tourism

Rivers and wetlands may contribute to the tourism appeal of areas, and thus it can be expected that a change in their condition may affect tourism demand and values. In particular, rivers are a dominant feature of many protected areas in the study area, and have been investigated in some detail (see (Turpie & Joubert, 2001).

These attractions, combined with other attractions, provide the amenity values that drive people to visit these areas. The tourism values of rivers and wetlands in the study area have been estimated in the Status Quo assessment. However, the Classification Process also requires an understanding of how these values might change because of changes in the characteristics of the systems. Very little research has been carried out on this. However, a study undertaken in the Kruger National Park produced a useful model with which to estimate the impacts of change in river quality on tourism value (see Turpie & Joubert, 2001). A utility score is derived from a modelled relationship of four key attributes (aquatic megafauna such as crocodiles and hippos, the abundance of water birds, riverscape, and abundance of riparian trees). The utility score is then related to trip expenditure, expressed as follows:

Visitor expenditure (Rands) = 1038.3 + 80.92(Z) where Z=utility score (see Figure 5-4).

For this study, a change in ecological condition will be related to a change in each of the four attributes to generate a utility score which will be related to a change in visitor expenditure. The proportional change between scenarios will be used to generate changes in the overall tourism value of the study area.

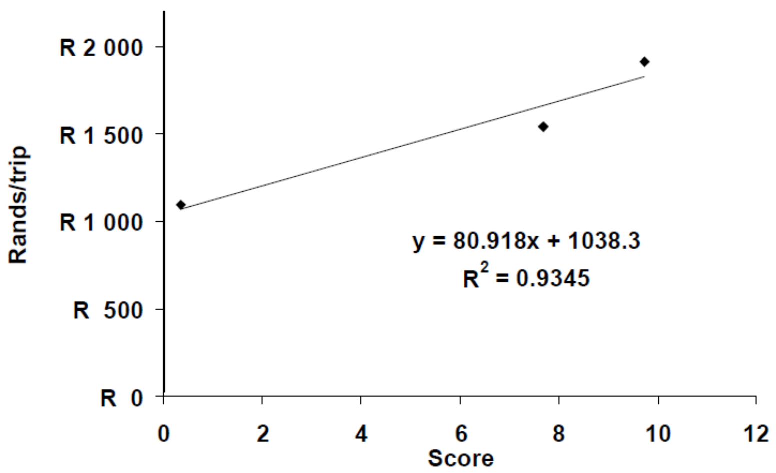

Figure 5-4. Relationship between utility indices and expenditure per trip for tourism in the Kruger National Park. Source: Turpie & Joubert, 2001.

5.4 Assessing economic costs and benefits

5.4.1 Sectors considered

The following **sectors,** as the main water users in the study area, are considered:

- Urban and domestic household use;
- Industry and mining;
- Irrigation agriculture;
- Livestock and game watering; and
- Commercial forestry.

There is a hierarchy for water allocation. Apart from the Reserve, the needs of strategic development projects and households are met before those of non-strategic industry and agricultural users. For this reason, it is assumed that domestic needs are fully taken care of, and that changes in water availability for use would most likely affect industrial/mining and/or agricultural users, if anyone.

5.4.2 Economic indicators

The economic impacts are described in terms of (1) value added to the economy (= contribution to GDP) and (2) employment. These impacts are described in terms of direct and total impacts (which include multiplier effects).

It should be noted that the economic indicators selected do not always provide the full picture of the impacts of changes on the economy. For example, some activities may not generate high outputs but might be important for food security or job creation. Some activities such as sub-tropical fruit production may create large numbers of jobs in the primary activity but have little in the way of knock-on effects because most of the fruit is exported. However, these exports are very important at a national scale for the Balance of Payments. It should also be noted that it is very difficult to predict economic impacts with any degree of certainty, as uncertainty is generally present when planning and maintaining water resource systems (Loucks & van Beek, 2017). Uncertainty arises because the eventual outcomes will be affected by several factors including rainfall, government policy, exchange rates, economic circumstances and the state of education systems. The use of scenarios helps address uncertainty and variation. It is important to remember that economic analysis of alternative scenarios works on the premise that all other things are equal.

Multipliers extracted from Pfunzo (2017) based on the Limpopo Social Accounting Matrix (SAM) will be used to estimate value added to GDP as a proportion of the gross output value of production, and to estimate income accruing to poor households. The SAM is an established economic modelling tool and is used in several water resource classification studies (see Box 1).

Box 1. Social Accounting Matrix and economic multipliers. Source: Prime Africa, 2011.

A SAM is a matrix that summarises the linkages that exist between the different role players in the economy i.e., business sectors, households and government. Thus, a SAM reflects all of the inter-sectoral transactions in an economy and the activities of households. A household is a very important economic definition, as it is the basic unit where significant decisions regarding important economic variables such as expenditure and saving are taken. A SAM enables modelling of changes in economic activity on economic growth (i.e., the impact on GDP); job creation (i.e., the impact on labour requirements); impact on capital formation; and income distribution (i.e., the impact on low-income, poor households and the total income households).

A SAM enables the simulation of changes in sector turnover to estimate macro-economic impacts using economic multipliers. Economic models fundamentally incorporate a number of “multipliers” that form the nucleus of the modelling system. A multiplier specifies the nature and extent of the impact of a change in a specific economic quantity (e.g., agriculture) on another economic quantity or quantities (e.g., food manufacturing or employment). Multipliers consist of direct, indirect and induced multipliers. The direct multiplier measures an economic effect occurring in a specific sector, whilst the indirect multiplier measures those effects occurring in the different economic sectors that link backwards and forwards to this sector. The induced effect measures the additional economic activity generated by the spending of additional salaries and profits generated.

The Development Bank of South Africa has published SAMs for each of the nine Provinces of South Africa. The Limpopo SAM was produced in 2006 by Conningarth Economists. More recently, a multiplier model using the Limpopo SAM was developed by Pfunzo (2017) producing output multipliers, income multipliers (for households with high, medium and low income and distinguished by race) and value-added/GDP multipliers.

5.4.3 Assessing change in water supply costs

To assess changes in the costs of infrastructure needed to supply water demands over the next 20 years, there is a need to link water supply to production outputs. Current sectoral economic outputs were estimated based on national accounting data (municipal level data disaggregated to socio-economic zones and IUAs), for the year 2017. Since national accounting data do not disaggregate the Agriculture, Forestry and Fisheries sector, value generated in Agriculture and Forestry was estimated based on highly detailed agricultural census data and spatial data on land use (see Status Quo report).

Demand for domestic household water use was expected to grow with the population growth of the study area, while the demand for irrigation and industrial uses is expected to grow in line with general economic growth. The gross output for irrigated crops was an estimated to be R5.0 billion in 2017 and covered approximately 45000ha across the study area. Gross value added (GVA) for irrigated agriculture was estimated to be about R2.4 billion. The commercial livestock (and game) sector which accounts for 3% of water requirements in the study area was estimated to have a gross output of some R1.5 billion in 2017 (GVA of R595 million). The forestry sector, which is a relatively minor water user in the study area, had a gross output of R222 million in 2017 (GVA of R110 million). For this study, it was assumed that there would be no or little change in the forestry sector in the medium term, and that this sector would not be impacted on by any operational scenarios. Other important water using sectors include mining and industry. Although growth in the mining sector has been slow over the last decade, there are several mining developments planned for the region. The mining sector had an estimated GVA of R1.9 billion in 2017.

Water supply infrastructure will grow to keep pace with increasing demands. There are already several planned and proposed infrastructure interventions for the study area (DWA, 2015a; DWS, 2017b). Over time, additional water is supplied at ever increasing marginal costs, because the system has to take on more expensive surface water and/or groundwater options and more expensive water treatment technologies such as recycling of wastewater or the reuse of mine water (Figure 5-5).

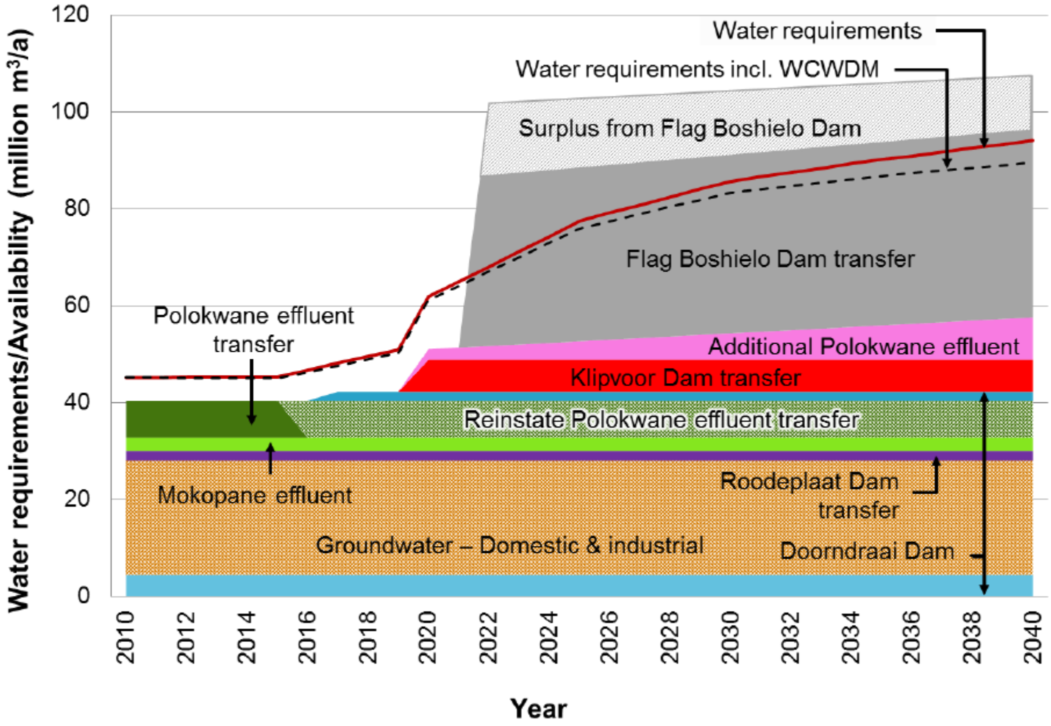

Figure 5-5. Augmentation Options for the Mogalakwena catchment. Source: DWS, 2017b.

The demands of the Reserve are just another one of these demands. If all other factors are held constant and the Reserve is increased, this could either lead to a reduction in the quantity allocated to certain users, or in the development of further infrastructure to be able to continue to meet the existing allocations. In this study the latter is assumed since the former is publicly infeasible. In the latter case, there are three options all of which involve increasing the cost of water to users. These are (1) the deliberate increases in water prices to force the adoption of more water-efficient farming and associated technological innovation, (2) introduction of water trading to achieve the same ends more efficiently but involving the devolution of water use licenses and control to the users, and (3) the augmentation of water supply at increasing cost. In this study, we have used the latter to estimate the costs of increasing the Reserve, where appropriate. None of the water user sectors was expected to be limited by water availability per se, but they would be affected by increasing costs under scenarios involving increased water allocation to the Reserve because of supply augmentation costs or demand management.

Note that water may not be used efficiently in the study area, because water is allocated rather than traded on the open market. Nevertheless, it is beyond the scope of this study to investigate the impacts of proper water pricing on efficiency and trade-offs involved in classification.

If the availability of water to discretionary sectors increases under any scenario, then potentially more water could be allocated to one or more of these (in this case irrigation, mining, or industry). Whether this affects irrigation, mining, and industry or all of them may be dictated by location to some extent, but for a given location, should be dictated by the relative potential value of supplying water to each of those sectors. Where there are multiple users, such as different irrigation subsectors and industry, the social planner should allocate water to the sector that delivers the highest GDP and/or employment benefits, until the marginal benefit of water in each use is equal.

Understanding marginal changes in production ideally requires estimating a production function (Nahman & De Lange, 2012). This is often difficult for a desktop study. Previous Classification studies have mostly used the average value added per m^3 water used, and the average number of people employed per million m^3, calculated on the basis of the estimated (presumably direct) value added per activity in relation to the amount of water used in different socio-economic zones or catchment areas (e.g., Mullins, 2014). In other words, it is assumed that the additional production resulting from a unit increase in water would be the same as the average production. This is not strictly correct, as the change in production at the margin (whether an increase or decrease) is likely to be lower than the average production.

In the case of increasing water availability, this study will use the approach where the magnitude of change will be first determined for each water user individually, ranked according to the magnitude of each entity's contribution to the economy, and then the allocation of the water use licenses will be adjusted accordingly before arriving at the final estimate of the impact of the change.

5.5 Assessing change in societal wellbeing

It is particularly difficult to describe and quantify changes in societal wellbeing. Peoples' wellbeing is affected by a very wide range of factors, only a few of which are being considered in this study, while the rest are 'held constant' as for the economic analysis. The proportional influence of the factors being considered in this study is fairly subjective. Moreover, for several indicators or measures, establishing a clear relationship between water resources and well-being is difficult.

Several past Classification studies have incorporated a qualitative assessment of the change in ecosystem services as a proxy for social impacts. In this study we have incorporated changes in ecosystem services into both the economic and social analysis since ecosystem services can impact on both.

The social impacts of water allocation will come from changes in employment, changes in the abundance of harvested resources, changes in human health risks as a result of water quality, and the more intangible amenity values associated with natural systems. The cultural, spiritual, and recreational values associated with natural systems are extremely difficult to measure, but very important for peoples' health and wellbeing. The ecosystem benefit can range from purely aesthetic appreciation for the river's presence to deep rooted cultural values with dedicated rituals and practices (Parker & Oates, 2016). Changes in these benefits are described qualitatively using a scoring system in order to evaluate relative changes under the different scenarios. Changes in income to poor households are estimated based on changes in economic outputs and multipliers derived from the Limpopo SAM (see section 5.4.2 above).

In the study area, communal land areas are relatively extensive and there are other areas where there are concentrations of rural poor that are dependent on the environment. Many households use rivers for collecting water and wetlands to harvest a range of natural resources. Impacts on the capacity of these ecosystems to deliver these resources would impact on those households. These impacts are estimated in terms of value, based on the estimated changes in for example the harvested populations derived from the ecological models (see section 0 above). The status quo description includes statistics on the proportion of poor households, the proportion of households that have piped water, and the proportion that depend on rivers for their water supply. Access to piped water is about municipal service provision and is not expected to change as a result of Classification. For those households depending on river water, however, changes in the quantity and quality of dry season flows may have an impact. This impact is quantified in monetary terms (see section 5.3.3 above).

6 REFERENCES

DWA. (2014a). *Development of a reconciliation strategy for the Luvuvhu and Letaba Water Supply System: Hydrology Report*. Prepared by: WRP Consulting Engineers, DMM Development Consultants, Golder Associates Africa, Worley Parsons, Kyamandi, Hydrosol and Zitholele Consulting. Report No. P WMA 02/B810/00/1412/5.

DWA. (2014b). *Determination of Resource Quality Objectives in the Olifants Doorn Water Management Area.* RQOs report. Prepared by Umvoto Africa in association with Southern Waters Ecological Research and Consulting.

DWA. (2015a). *Development of a Reconciliation Strategy for the Levuvhu and Letaba Water Supply System: Final Reconciliation Strategy*. Department of Water Affairs, Report No. P WMA 02/B810/00/1412/15.

DWA. (2015b). *Limpopo Water Management Area North Reconciliation Strategy: Hydrology Analysis.* Prepared by: AECOM in association with Hydrosol, Jones & Wagner and VSA Rebotile Metsi Consulting. Report No. P WMA 01/000/00/02914/3.

DWAF. (2006). *Groundwater Resource Assessment Phase II.* Department of Water Affairs and Forestry Suite of Reports and data published 2004-2006 accessible at www.dwa.gov.za/Groundwater/GRAII.aspx.

DWS. (2017a). *Determination of Water Resources Classes and Resource Quality Objectives for the Water Resources in the Breede- Gouritz Water Management Area: Status Quo*. Report No: RDM/WMA8/00/CON/CLA/0516.

DWS. (2017b). *The development of the Limpopo Water Management Area North Reconciliation Strategy*. Prepared by AECOM for the Department of Water and Sanitation.

LIMCOM. (2013). *The Limpopo River Basin Monograph: Surface Water Hydrology.* Limpopo Watercourse Commission.

Loucks, D.P. & van Beek, E. (2017). *Water Resource Systems Modeling: Its Role in Planning and Management*. *Water Resour. Syst. Plan. Manag.*

Millennium Ecosystem Assessment. (2003). *Ecosystems and Human Well-being: a Framework for Assessment.* Island Press, Washington.

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Synthesis.* Island Press, Washington.

Mullins, D. (2014). *Classification of water resources and determination of the comprehensive reserve and resource quality objectives in the Mvoti to Umzimkulu Water Managemetn Area. Volume 4: Economic Consequences.* Report to Department of Water and Sanitation.

Nahman, A. & De Lange, W. (2012). *Valuing water for South African industries: A production function approach, 1–15.* CSIR Report.

Parker, H. & Oates, N. (2016). *How do healthy rivers benefit society? A review of the evidence*. *Work. Pap. 430*. WWF-UK.

Pfunzo, R. (2017). *Agricultural Contribution To Economic Growth and Development in Rural Limpopo Province: a Sam Multiplier Analysis*. Stellenbosch University, South Africa.

Prime Africa. (2011). *Classification of significant water resources in the Olifants Water Management Area. Report 3b: Analysis scoring system.* Report to Department of Water Affairs.

Riemann, K. (2013). *'Groundwater Reserve' – a critical review.* Paper presented at the 13th Biennial Groundwater Conference of the Geological Society of South Africa, 17th-19th September 2013, Durban, South Africa.

Turpie, J. & Joubert, A. (2001). Estimating potential impacts of a change in river quality on the tourism value of Kruger National Park: An application of travel cost, contingent and conjoint valuation methods. *Water SA* **27**, 387–398.

Turpie, J.K., Dollar, E., Goldin, J., Mullins, W., Mallory, S., Rossouw, N. & Joubert, A. (2006). *Socio-economic guidelines for the 7-step classification procedure.* Contract report to the Department of Water Affairs and Forestry. CSIR.

Turpie, J.K., Letley, G., Schmidt, K., Weiss, J., O'Farrell, P.J. & Jewitt, D. (2021a). *Towards a method for accounting for ecosystem services and asset value: Pilot accounts for KwaZulu-Natal, South Africa, 2005-2011. NCAVES project report*. United Nations, New York.

Turpie, J.K., Weiss, J., Higgins, S., Wilson, L. & Letley, G. (2021b). *Climate Change Vulnerability Assessment and Adaptation Strategy for South Africa's Biodiversity and Ecosystems Sector*. Final report to DFFE as part of the DFFE Climate Support Programme (CSP).