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)

FINAL SCENARIOS REPORT

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The project reports are indicated below.

Bold type indicates this report.

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TERMINOLOGY AND ABBREVIATIONS

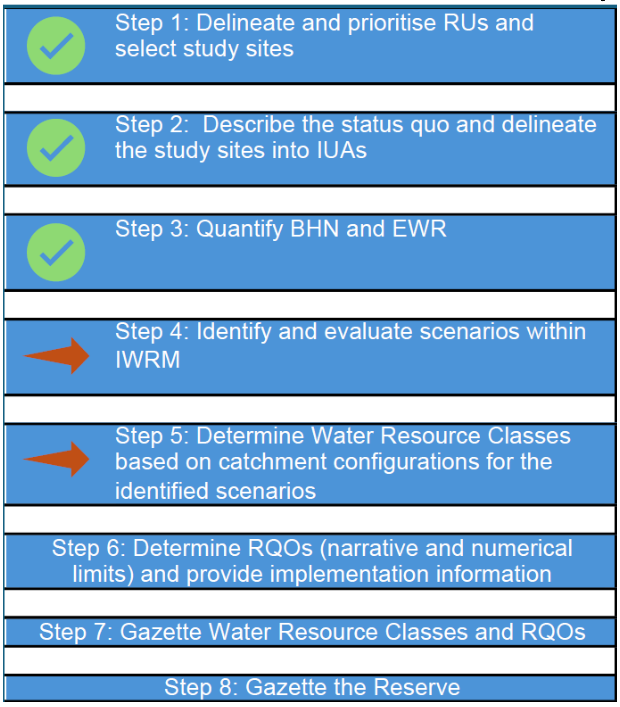
ACRONYMS	DESCRIPTION
BAS	Best attainable state
BE	Biodiversity Economy (scenario)
BHN	Basic human needs
BHNR	Basic human needs reserve
CBA	Critical Biodiversity Area
DEV	Development (scenario)
DFFE	Department of Forestry, Fisheries and the Environment
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Ecological category
EGSA	Ecosystem goods, services and attributes
EI	Ecological Importance
ESA	Ecological support area
ESBC	Ecologically Sustainable Base Configuration
EWR	Ecological Water Requirement
FEPA	Freshwater Ecosystem Priority Areas
FS	Flow state
FSA	Fish Support Area
GDP	Gross Domestic Product
GIS	Geographic Information System
GRDM	Groundwater Resource Directed Measures
GW	Groundwater
HGM	Hydrogeomorphic
IUA	Integrated unit of analysis
IWMI	International Water Management Institute
LCP	Limpopo Conservation Plan
LIMCOM	Limpopo Watercourse Commission

ACRONYMS	DESCRIPTION
LEDET	Limpopo Department of Economic Development, Environment and Tourism
LPAES	Limpopo Protected Areas Expansion Strategy
MCA	Multicriteria analysis
MCM	Million cubic metres
MMSEZ	Musina Makhado Special Economic Zone
NPAES	National Protected Areas Expansion Strategy
NWA	National Water Act
PAN	Protected Area Network
PES	Present Ecological Status
PHNR	Philip Herd Nature Reserve
RDM	Resource Directed Measures
REC	Recommended ecological category
RQOs	Resource Quality Objectives
SI	Stress index
STCD	Spatially targeted conservation and development (scenario)
SWSA	Strategic Water Source Area
UMA	Upstream Management Area
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VBP	Vhembe Bioregional Plan
WC/WDM	Water Conservation and Water Demand Management
WMA	Water Management Area
WRCS	Water Resources Classification System
WWTW	Wastewater treatment works

EXECUTIVE SUMMARY

Introduction

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 Water Management Area (WMA) and B9 in the Olifants WMA.



The Integrated Framework for incorporating the gazetted steps for the Classification, Reserve and Resource Quality Objectives (RQOs) is being used to guide this study. This report describes steps 4 and 5 in the classification process, which is the analysis and evaluation of alternative scenarios and determination of water resource classes. The results of the evaluation of scenarios are then discussed with stakeholders and results in a final recommended water resource class for the water resources of each Integrated Unit of Analysis (IUA) in the study area that will then be taken forward to the next phase of the study which is to determine associated RQOs.

Stakeholder visions for IUAs

Stakeholder engagement forms an important part of the scenario evaluation process. Stakeholders were invited to respond to a series of questions regarding the future of the catchment. The questions were organised along three broad themes - economic development, conservation, socio-cultural importance and ecological goods and services.

Most stakeholders highlighted the importance of the study area as being rich in biodiversity, important for conservation and providing opportunities for nature-based economic development which focuses on developing the biodiversity economy and protecting the regions renewable natural resources. Many described the importance of eco-tourism sites and activities for the regional economy and how this could be strengthened, as well as important social and cultural areas that they would like to see preserved for future generations. Stakeholders expressed that economic growth should be in line with international agreements and South Africa’s Constitution, national policies including its climate policies, the Environmental Management Act and the National Water Act. It was suggested that the proposed growth in coal and mineral mining in the area would ignore national climate policies and commitments and would contribute further to climate change. Moreover, that the expectations that water can be made available to enable these developments were thought to be doubtful, at best.

During the visioning process, a group of stakeholders proposed that at least three alternative economic development scenarios be modelled and the outcome on revised water resource class recommendations compared, and consideration of such varying outcomes be given in the final recommendations. These suggestions were reviewed and considered, and where possible and practical were included in the development of the scenarios developed for evaluation.

Scenario analysis 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 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 variables to consider in this balance, namely the biodiversity, 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 I. 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 Biodiversity, 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.

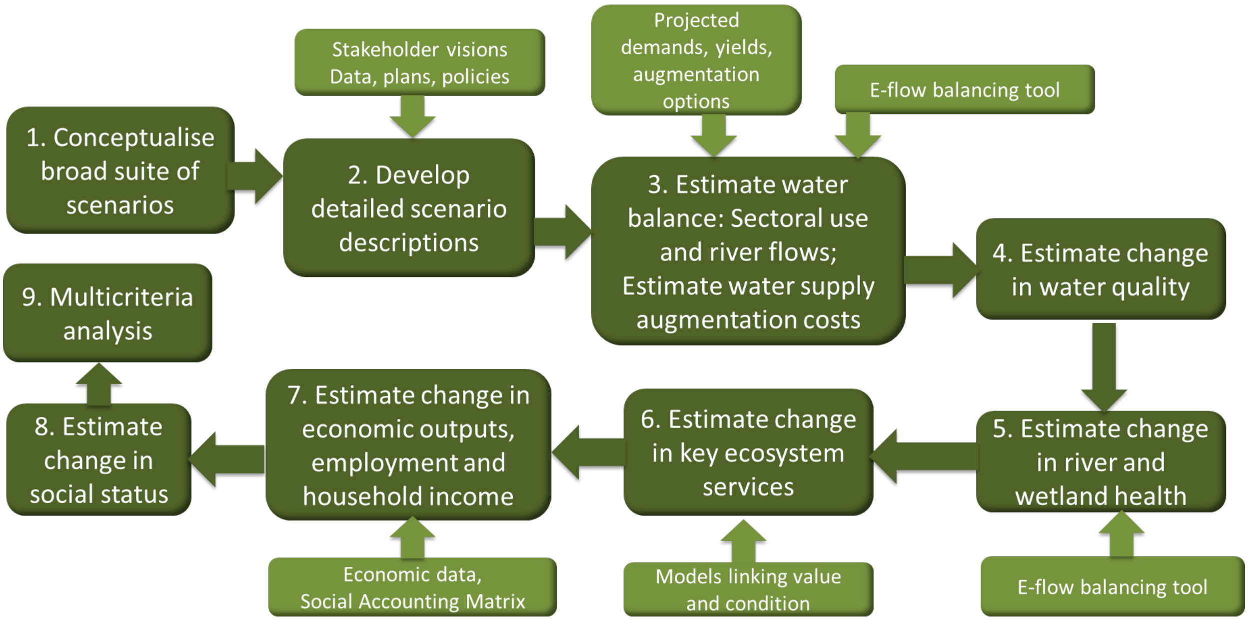


Figure I. Schematic presentation of the scenario evaluation process. Source: This study.

Defining the Classification Scenarios

The rationale for the scenario analysis was to explore the potential water supply, biodiversity and socio-economic outcomes of a range of potential scenarios (ranging from high to low levels of ecosystem protection) against a range of demand contexts. It is important to test against future demands, since the choice of water resource classes made in this process should be robust (i.e. should remain the best choice) for the foreseeable future. There are many potential combinations of the level of protection and contexts, thus a useful and straightforward subset had to be chosen. Five different scenarios have been considered:

1. **Maintain Present Ecological Status (PES)**: requires that efforts are made to maintain river and wetland systems in their present condition in spite of economic and population growth.
2. **Ecological Bottom Line (ESBC)**: or “Bottom-line” Scenario in which the maximum volume of water is made available for abstraction from the system for economic activities, with the proviso that all water resources are just maintained in a D category (i.e. the “bottom line”).
3. **Biodiversity Economy (BE)**: a conservation scenario which aims to determine the best attainable state (BAS) for rivers and wetlands, based on reducing demands on water and the subsequent predicted improvement in river and wetland health in response to increased river flow, prioritising the study area as a conservation area. Growth in sectors that involve extraction and pollution of water would be strongly curtailed in order to maintain and restore the condition of rivers and wetlands to their best attainable state. The area would be prioritised for ecological restoration and protection, biodiversity economy activities, and the development of biodiversity products, and activities such as climate smart agriculture and increased water use efficiency and improved environmental management in existing developed areas.
4. **Unconstrained Development (DEV):** considers the effect of future development on the resulting ecological condition at all nodes with no constraints applied in terms of making water specifically available for EWR flows. The development scenario (DEV) considers all current planned future development options.
5. **Spatially targeted conservation and development (STCD):** is based on spatial considerations of priority objectives to achieve a blend of targeted ECs for all nodes ranging between BAS and ESBC. It is important to consider a spatially distributed solution, where different priorities can be recognised in different parts of the WMA.

Only scenario 4 (DEV) is a development-driven scenario, in that what happens to water resource condition is an outcome of the scenario. The remaining scenarios are ecologically driven, in that the ecological decisions are set first, and then the level of development possible under the scenarios is determined based on the resulting constraints on water yield and water quality.

Methodology for scenario evaluation

The process of model configuration and evaluation of the different scenarios is described in this report and is outlined in terms of the following steps used in the analysis:

- Determine the natural and current day surface water flows at all river nodes.
- Assess effects on groundwater condition (stress levels) in terms of groundwater usage on baseflow and the potential for further groundwater development.
- Determine target ecological category (EC) at priority EWR and river nodes based on the specific scenario under consideration: (1) PES, (2) ESBC, (3) BE (4) DEV and (5) STCD.
- Use the “balancing tool” to determine flow requirements at all nodes needed to meet the “target” EC or to determine the ECs for the high demand flows.
- Determine the “shortfalls” in surface water availability necessary to meet the target EC.
- Determine how much of these “shortfalls” can be met from other sources.
- Determine a provisional cost for supplying shortfalls from other sources (e.g. re-use, transfers).
- Evaluate the likely effect on water quality and wetlands for the different scenarios.
- Evaluate the overall socio-economic and well-being outcomes for each scenario.
- Undertake scoring and multicriteria analysis for overall ranking of scenarios.

A multicriteria analysis (MCA) involved scoring the scenarios based on the change in a range of ecological, economic and social criteria or indicators. Not all of these could be measured in comparable units such as money. The MCA approach allows for both monetary and non-monetary outcomes to be assessed. This was done through score normalisation, ensuring equal importance in the data. A normalised score was generated for biodiversity (based on wetland and river health and importance), for economy (based on value added gains or losses to the economy and water supply costs), and for society (based on change in household income and ecosystem goods and services).

To generate an overall score and ranking of scenarios, the variable scores are weighted. In this analysis, biodiversity was given a weighting of 0.5 and the variables of economy and society were weighted as 0.25 each. It was deemed appropriate to give a higher weighting to biodiversity because of the important intangible elements associated with biodiversity that are not being captured through the scenario process. However, a sensitivity analysis was also undertaken which explored the changes under different weightings.

Summary of Overall Outcomes of Scenarios

When considering the overall health of the Limpopo tributaries, *viz.* the whole study area, it is predicted that there could be a large decrease in health under the ESBC scenario relative to PES, and a relatively small decrease under the DEV scenario. On the other hand, there is a relatively large improvement in health under the BE scenario with a smaller improvement under the STCD scenario.

When considering the overall water quality status of the Limpopo tributaries, there is predicted to be an overall deterioration in the water quality status for the ESBC scenario relative to the PES water quality status. The same applies for the DEV scenario which would probably result in an even poorer water quality status than that of the ESBC scenario in some sub-catchments, in many cases at least one category poorer. On the other hand, there is a relatively moderate improvement in the water quality status under the BE scenario and a small improvement under the STCD scenario. These outcomes differ from catchment to catchment and are affected by local sources of pollution and operational challenges faced by domestic WWTWs.

The overall value of ecosystem goods and services are expected to increase under the BE and STCD scenarios relative to the PES scenario, with positive outcomes on household livelihoods and overall wellbeing, and in terms of meeting national climate targets and contributing towards climate change mitigation and adaptation. The estimates are considered to be conservative given that they do not account for all ecosystem services and do not include the intangible biodiversity values which are inherently difficult to measure. Many of the catchments, especially to the north-east, are recognised as being high priority biodiversity areas and play a very important role in attracting both international and domestic tourists to the region, contributing to economic growth of the study area by creating jobs and diversifying rural economies through investment in nature-based and cultural and heritage tourism. Furthermore, aquatic ecosystems play an important role in supporting the livelihoods of the rural populations living in these areas, many of which still do not have formal access to water supply. The degradation of these water resources would have a significant negative effect on human wellbeing and health.

Under the ESBC and DEV scenarios there would be significant loss in the overall ecosystem goods, services and attributes (EGSA) value. Relative to a scenario where the PES is maintained, the value of ecosystem services would be 32% lower for the ESBC scenario and 29% lower for the DEV scenario. This could have significant negative outcomes on the wellbeing of people who rely heavily on natural ecosystems for additional income, and for basic resources such as water, particularly those in rural areas who are already the most vulnerable. Furthermore, the degradation of water resources in the study area would likely result in significant negative outcomes downstream on the Limpopo River and into Mozambique. Under the DEV scenario which proposes a significant increase in mining and industrial activity, the degradation of biodiversity and loss in ecosystem services downstream as a result of deteriorating water quantity and quality is expected to be severe.

Investing in the protection and restoration of aquatic ecosystems is critical for water security in the long term, especially in an area that is already water stressed and where water resources are over allocated. The long-term effects of aquatic ecosystem degradation include habitat disturbance, biodiversity loss, harmful algal blooms and other health impacts, all of which are incredibly difficult and costly to fully remedy and restore. Investing in ecological infrastructure (natural ecosystems that provide important services and save on built infrastructure costs) can have significant positive outcomes in terms of hydrological services and water security, particularly in water-scarce areas.

The economic consequences of the scenarios were assessed in terms of the costs of water supply infrastructure and water supply management activities needed to meet increasing demands or Ecological Water Requirements (EWRs), and in terms of contribution to Gross Domestic Product (GDP) (value added) through increased output from water using sectors or water dependent sectors. Total infrastructure costs to meet shortfalls as a result of increased water demands and EWR requirements, is highest under the ESBC and DEV scenarios. This is because under the ESBC and DEV scenarios water demands into the future are significantly higher than under the other scenarios and this will require significant investment in water supply infrastructure to meet these demands. The cost of supplying future demands is highest in the Upper and Lower Sand IUAs and Nzhelele/Ṅwanedi IUA where higher levels of water intensive development have been proposed. It is important to note that these costs are based on proposed options which have not been fully assessed or finalised, and which fall beyond the scope of this study. The values presented in the report are indicative only and illustrate the likely order of magnitude difference in costs based on the levels of development assumed under each alternative scenario.

Under the BE scenario, water supply costs are lower than the other scenarios, as this scenario only considers increases in domestic demand as a result of population growth and management interventions such as water conservation and demand management (WC/WDM) which would be needed in some IUAs to achieve the EWRs under this scenario. In the Upper Sand, a water reuse system was costed as a way to reduce transfers and return flows into the Sand Catchment and to improve water quality. These costs were applicable under both the STCD and BE scenarios. The costs under the STCD scenario lie between the BE and DEV scenario due to the reduced demands associated with development under this scenario.

Value added to the economy is highest under the DEV scenario (for all other sectors held equal), which is associated with the significant gains in industrial and mining production, particularly in the Sand Catchment. However, the gains under this scenario are only slightly higher than under the STCD and BE scenarios which have sustained growth in nature-based tourism. Under the DEV scenario, losses in tourism value are expected to be significant, as shown by an assumed loss of tourism across the broader area due to irreparable environmental degradation under this scenario. Intensive mining, such as open cast coal mining, could result in prolonged and irreversible environmental degradation as well as air pollution which would likely lead to significant losses in nature-based tourism in the broader geographical landscape and lead to significant downstream biodiversity and ecosystem service losses.

Under the BE and STCD scenarios, the higher flow volumes needed to maintain EWRs resulted in the need for curtailment of irrigation and mining in some IUAs. This resulted in some losses to the overall contribution to GDP under each of these scenarios. It is important to note that the overall gains under the DEV scenario have a high level of uncertainty attached to them as the level to which such development can be sustained into the future remains unknown given the current levels of water scarcity in the region and a likely drier future under climate change.

In terms of household income, development of irrigation agriculture, mining and industry would have some positive outcome on household income under the DEV scenario. While household incomes will increase under the BE scenario, this will be slightly lower than under the DEV scenario given the lower levels of development across the whole study area under this scenario but higher than maintaining the PES due to the likely increase in household income associated with the investment in nature-based tourism and associated biodiversity economy activities. Household incomes under the STCD scenario will be higher than under the BE and DEV scenarios. This is due to the lower levels of development in the high priority ecological catchments compared to the DEV but still maintaining some development outside of the conservation areas and with increases in incomes associated with nature-based tourism.

In summary, the results of multicriteria analysis reveal that the STCD scenario is ranked the highest followed by the BE scenario (Table I). Whilst there is some trade-off in terms of biodiversity under the STCD scenario (compared to the BE scenario), this is relatively small, and the overall economic and societal impacts are highest under this scenario. When the weightings of the variables are changed to be equal (i.e., 0.33 weighting across the three variables) the STCD scenario remains the highest ranked scenario (score 0.80), and this is followed by the BE scenario (0.75) and DEV scenario (0.45). The BE scenario scores higher than the ESBC and DEV scenarios for economy as it has very low water supply costs associated with it and the difference between water costs is much greater than the difference between value added to the economy under these scenarios.

Table I. Overall scores and ranking of scenarios.

Variable	ESBC	BE	DEV	STCD
Biodiversity	0.11	0.92	0.41	0.84
Economy	0.54	0.67	0.55	0.76
Society	0.38	0.65	0.40	0.81
Overall score and ranking	**0.28**	**0.79**	**0.44**	**0.81**

Figure II shows the normalised score across the three variables for each of the scenarios. This clearly illustrates the trade-offs involved. For example, under the BE scenario, a trade-off is made in terms of the economy and to some extent society through changes in household income, for higher biodiversity gains. Societal gains are highest under the STCD, and the economy and biodiversity scores are higher than under the DEV and ESBC scenarios which score poorly in terms of biodiversity as well as in terms of society, the result of deteriorating ecosystem condition on biodiversity and ecosystem services.

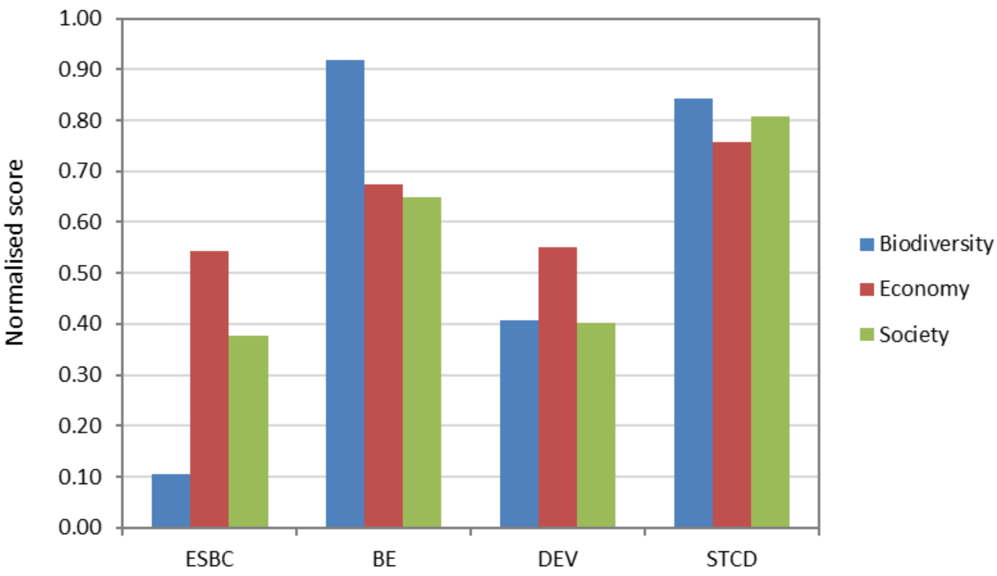


Figure II. The normalised score for each of the variables (Biodiversity, Economy and Society) for each of the scenarios.

Proposed Water Resource Classes

Water resource classes (WRCs) were determined for each IUA based on the proportion of river nodes falling within each ecological category within each IUA. These are presented in Table II and for the STCD scenario are shown spatially in Figure III. Under all scenarios, the IUAs are mostly in a Class II, except for the ESBC scenario, which is mostly Class III. The DEV scenario has three IUAs in a class III which is more than the STCD and BE scenarios which have one IUA in a Class III. The BE scenario has just one IUA (Upper Sand) in a Class III and the highest number of IUAs in a Class I. The STCD scenario is the same as the BE scenario but with one less IUA in a Class I.

Table II. Water resource classes for each IUA under each scenario

Variable	PES	ESBC	BE	DEV	STCD
Lephalala	II	II	II	II	II
Kalkpan Se Loop	I	III	I	I	I
Upper Nyl & Sterk	III	III	II	III	II
Mogalakwena	II	III	II	II	II
Mapungubwe	II	III	I	II	II
Upper Sand	III	III	III	III	III
Lower Sand	II	II	II	II	II
Nzhelele/Ṅwanedi	II	III	II	II	II
Upper Luvuvhu	II	III	II	II	II
Lower Luvuvhu/Mutale	II	III	II	III	II
Shingwedzi	II	III	II	II	II

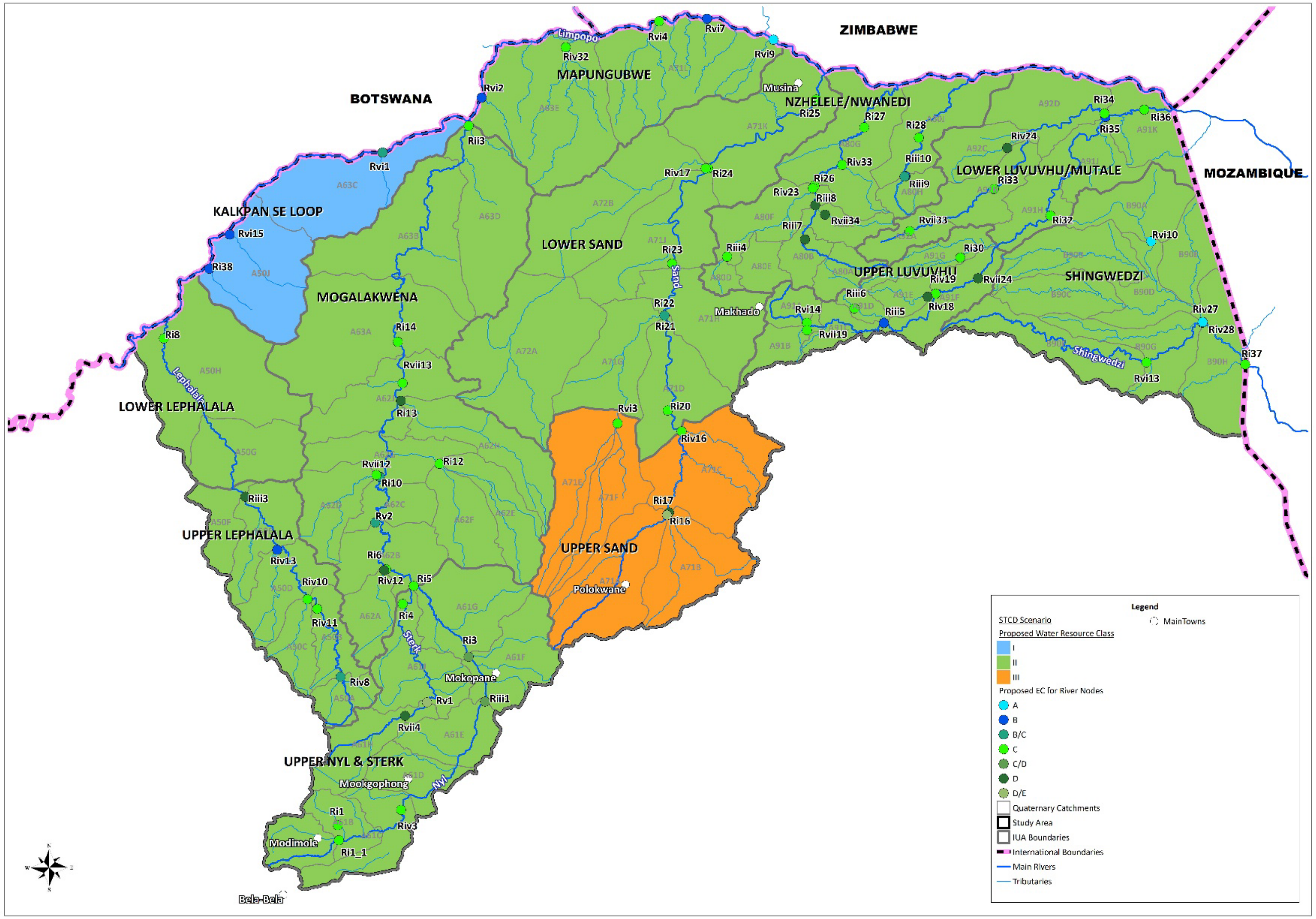


Figure III. The proposed water resource classes for each IUA under the STCD scenario showing the proposed EC for each of the river nodes. Class I represents higher ECs and minimal use, Class II represents moderate use and Class III lower ECs with heavy use.

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1 INTRODUCTION

1.1 Background

The Department of Water and Sanitation (DWS), Chief Directorate (CD): Water Ecosystems Management (WEM) initiated a study to determine Water Resource Classes, the Reserve and Resource Quality Objectives for Secondary Catchments A5-A9 in 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 Study area

The study area is the Secondary catchments (A5-A9) of the Limpopo WMA and B9 in the Olifants WMA (Figure 1-1). The study area quaternaries are divided into twelve integrated units of analysis (IUAs) as follows:

- Upper Lephalala (A50A-A50F)
- Lower Lephalala (A50G-A50H)
- Upper Nyl & Sterk (A61A-A61H, A161J)
- Mogalakwena (A62A-A62H, A62J, A63A, A63B, A63D)
- Kalkpan se Loop (A50J, A63C)
- Upper Sand (A71A-A71C, A71E, A71F)
- Lower Sand (A71D, A71G, A71H, A71J, A71K, A72A, A72B)
- Mapungubwe (A63E, A71L)
- Nzhelele/Ṅwanedi (A80A-A80H, A80J)
- Upper Luvuvhu (A91A-A91G)
- Lower Luvuvhu/Mutale (A91H, A91J, A91K, A92A-A92D)
- Shingwedzi (B90A-B90H)

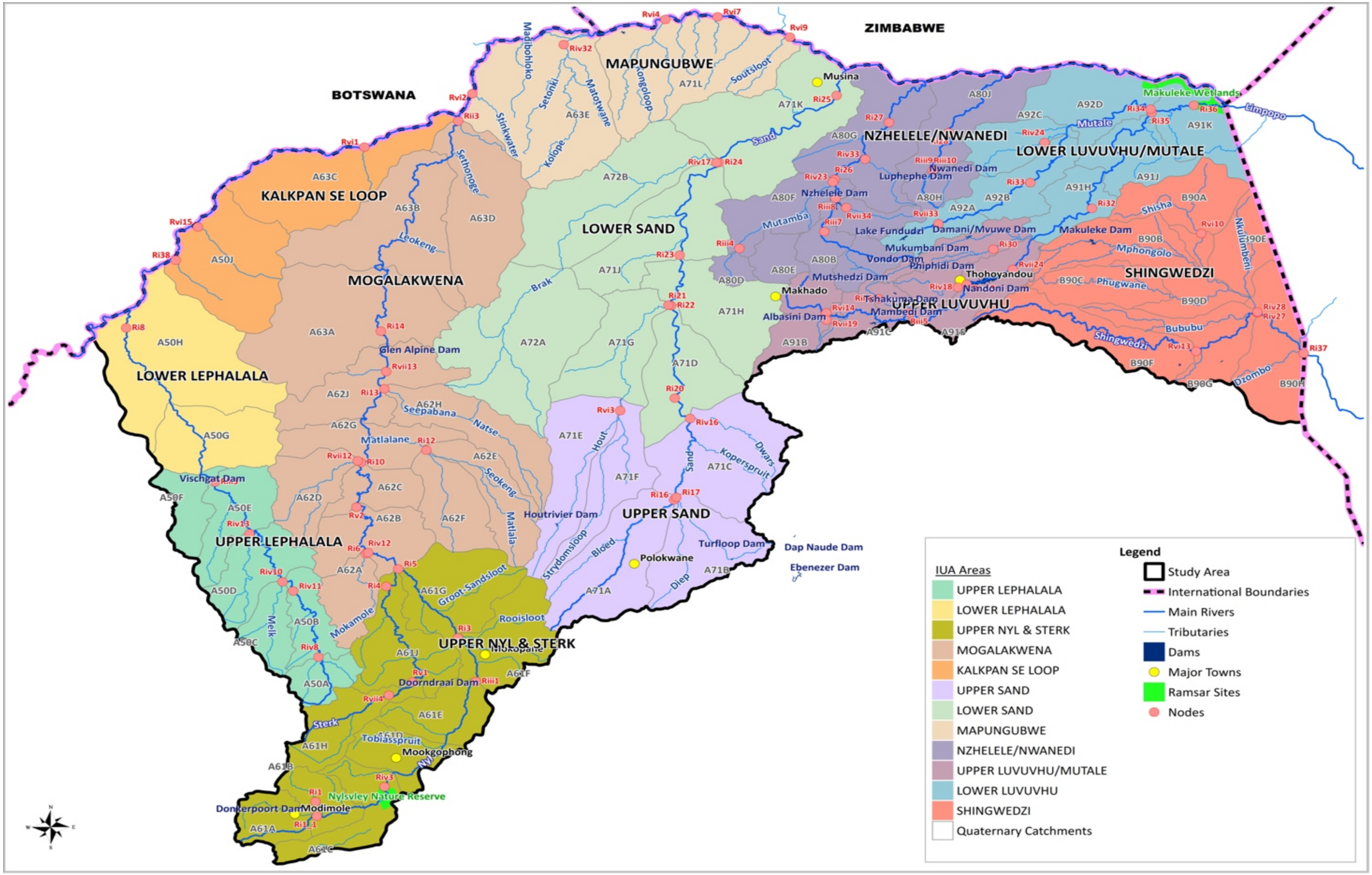


Figure 1-1. Locality map of the study area showing the twelve IUAs and quaternaries.

1.4 Purpose of this report

This report describes the final step in the classification process, which is the analysis and evaluation of alternative scenarios. The results of the evaluation of scenarios are then discussed with stakeholders and culminate in a final recommended water resource class for the water resources of each IUA in the study area that will then be taken forward to the next phase of the study which is to determine associated RQOs.

2 STAKEHOLDER VISIONS FOR IUAS

2.1 Introduction

Stakeholders were invited to respond to a series of questions regarding the future of the catchment as follows:

Economic development:

1. Would you like to have economic development and growth in the IUA?
2. In which sectors (Agriculture, Mining, Tourism, Forestry, Industry, Other, All) do you anticipate growth over the next 25 years?
3. Considering the sectors selected in point 1 above, which of these sectors would you consider most important for economic development of the IUA?
4. What level of development do you envisage in each sector (High, Medium, Low)?
5. Are there any proposed developments you are aware of? List these and the location of the proposed development.

Conservation:

1. List the areas in the IUA that you consider important from an ecological perspective (such as sensitive river reaches, wetlands, areas that contain protected riparian vegetation or aquatic species).
2. Do you want the ecological condition of the water resources in the IUA to be maintained or improved? Provide reasons for your choice.
3. Would you allow deterioration of the present ecological state for the purpose of development?

Socio-Cultural Importance and Ecological Goods and Services:

1. Are there areas within the IUA that contribute to cultural, spiritual, recreational, educational or existence values that should be preserved? Provide the names and locations of these areas.
2. Are there communities dependent on the ecosystem for provisioning services, such as for food, raw materials and instream water for basic needs that need to be preserved? Indicate the areas within the IUA where this is predominant.
3. Are there communities dependent on the regulating services afforded by the ecosystem, such as flood attenuation, refugia/nursery for fisheries, control of pathogens that must be protected? Indicate the areas were this is dominant in the IUA.

The responses to these are summarised in the following sections.

2.2 Economic development

Stakeholder inputs received on economic development in the study area are summarised in Table 2-1. All stakeholders expressed a desire for economic development, and all specified that this should be sustainable development. Several suggested that it should be nature-based and should benefit both nature and the rural poor. The importance of the biodiversity economy was highlighted for Vhembe District in particular by the stakeholders. The stakeholders felt that economic development should be through implementation of the National Biodiversity Economy Strategy and Biodiversity Economy programmes, and strictly in accordance with Limpopo's Department of Economic Development, Environment and Tourism (LEDET) Bioregional Plan for this district. Sustainable, nature-based economic development in Vhembe District was considered to have unrivalled potential to benefit both nature and the poor rural community custodians of Vhembe's rich natural capital endowment. Here the biodiversity economy opportunities include:

- Carbon capture and carbon production for sale of carbon credits;
- Protected Areas and Protected Areas Expansion and biodiversity credits;
- Nature-based tourism;
- Wildlife economy – full value chain; and
- Bioprospecting and trade – the sustainable wild harvesting and cultivation of high-commercial value indigenous plant and insect species, beneficiation and export.

These sectors conserve Vhembe's abundant natural capital and from a water resource perspective, are still viable in a catchment that is already in deficit in a water-scarce region. A biodiversity focus was justified in terms of the significant biodiversity value of the area, including large areas of Kruger National Park and Mapungubwe making up 30% of the total area, and 39% of the district being classified as Critical Biodiversity Areas of the Limpopo Province. Moreover, 84% of land cover is still natural, but is under threat from coal mining and fragmentation. It was further argued that most of the catchments are already water-stressed and remote, limiting the development and expansion of large-scale agriculture, mining (especially coal) and heavy industry.

Stakeholders believe that Vhembe is ideally positioned to take advantage of new opportunities for trade in biodiversity and carbon credits as well as other ecosystem services. What was once a weakness through the prism of economic development has become a strength. The Vhembe's abundant natural assets and natural infrastructure have the potential to generate direct income for local communities and to create downstream economic opportunities in tourism and the consumptive biodiversity-based economy, for comparatively little capital investment and no collateral damage to either other industries or the environment – in sharp contrast to exploitation of coal and mineral resources, which will cause severe and irreversible environmental degradation with potent negative spillovers. The South African government has recognized the opportunity and has developed a sound policy and planning framework to support and enable the growth of these emerging sectors supplying the domestic and global markets for nature, including carbon markets, as well as stimulating the growth of tourism and the biodiversity economy. The Great Vhembe Conservation Area project would give effect to the Vhembe District Bioregional Plan spatial planning framework and serve as the underpinning of a thriving nature-based economy in the region as envisaged in the National Biodiversity Economy Strategy.

Relevant initiatives include the Limpopo Protected Areas Expansion Strategy; UNESCO Vhembe Biosphere Reserve Biodiversity Conservation Strategy; Biodiversity Economy nodes located in Vhembe (Operation Phakisa initiative). African Ivory Route initiative; Soutpansberg2Limpopo initiative; and Greater Kruger Strategic Development Programme.

Stakeholders expressed that economic growth should be in line with international UNDP procedures and South Africa's Constitution, national policies including its climate policies, the Environmental Management Act and the National Water Act. It was suggested that the proposed growth in coal and mineral mining in the area would ignore national climate policies and will contribute further to climate change. Moreover, that the expectations that water can be made available in the following ways to enable these developments were thought to be doubtful, at best:

- New dams are assumed to be built but a) without any indication of the ability to finance such dams at sufficiently short term, without the notorious problem of increasing costs beyond initial planning; and b) ignoring serious doubts about the technical feasibility of dams in already over-allocated catchments and horizontal landscapes, as already expressed in the DWS 2017 Reconciliation Strategy;
- The expectation that more water becomes available from re-use policies ignores that re-use is, obviously local and not for downstream users; and
- The proposed transfers ignore often informal and invisible but widespread current water uses by many citizens, especially in the informal water economies of former homelands, not only for domestic uses (as recognized in the Basic Human Needs Reserve document) but also for livestock and irrigation. These uses have the third highest legally binding priority according to the National Water Resource Strategy (1. Reserve; 2. International obligations; 3. Water contributing to poverty eradication, livelihoods and racial and gender equity; 4 Strategic Uses; and 5: commercial mining, industry and agriculture).

Another concern raised by stakeholders from Vhembe was that it remains unclear how water pollution from mining would be addressed, implying a serious risk that water resources of sufficient quality will be further reduced.

Table 2-1 Summary of stakeholder inputs on visions for economic development. Columns indicate the catchment groupings specified by different stakeholders as being of interest to them.

	Nzhelele/ Ṅwaneḓi	Lower Luvuvhu	Upper Luvuvhu	Nzhelele/Ṅwaneḓi , Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu	Nzhelele/Ṅwaneḓi , Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu, Mogalakwena, Shingwedzi	Nzhelele/Ṅwaneḓi, Upper Sand, Lower Sand, Mapungubwe, Mogalakwena	Sand-Nzhelele-Luvuvhu	Nzhelele/Ṅwaneḓi , Upper Luvuvhu, Upper Sand, Lower Sand, Lower Luvuvhu, Shingwedzi, Mapungubwe, Mogalakwena
Desire for economic development and growth	Yes, but only on a sustainable basis and focusing on biodiversity economy development in Vhembe District	Yes	Yes	Yes, but sustainable and nature-based, benefiting both nature and the rural poor	Yes, but at a scale that is environmentally sustainable, and which does not have an unacceptable environmental outcome.	Not if it leads to more people living in poverty and having their air and water polluted as witnessed in Sekhukhune and Marikana	Yes, if compatible with South Africa's Constitution, national policies and laws and does not increase carbon emissions	Yes, if sustainable and meets need for conservation of the biodiverse and socio-culturally rich areas
Which sectors should grow	Tourism and the broader biodiversity-based economy sectors	Agriculture Forestry Tourism	Agriculture	Biodiversity Economy Sectors	Conservation, Tourism, Agriculture	All but following legal frameworks and existing policies such as the relevant bioregional plans to reduce corruption.		Agriculture and tourism
Most important for economic development	Tourism; the wildlife trade; sustainable wild harvesting and cultivation of high commercial value indigenous plant species and edible insects.	Agriculture and tourism; Agriculture and Forestry; Agriculture	Agriculture	Biodiversity Economy Sectors	Tourism	Tourism and mining but with strict compliance control with DWS taking the lead	Economic growth that meets constitutional and national goals, especially in the low-income rural areas of former homelands.	Tourism
Level of development envisaged	High	Agriculture: Medium, High Tourism: Low, Medium Forestry: Low, High	Agriculture: Medium	High	Conservation: High Tourism: Medium Agriculture: Low	Medium	As high as possible and reducing inequalities.	Low

	Nzhelele/ Ṅwanedi	Lower Luvuvhu	Upper Luvuvhu	Nzhelele/Ṅwanedi , Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu	Nzhelele/Ṅwanedi , Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu, Mogalakwena, Shingwedzi	Nzhelele/Ṅwanedi, Upper Sand, Lower Sand, Mapungubwe, Mogalakwena	Sand-Nzhelele-Luvuvhu	Nzhelele/Ṅwanedi , Upper Luvuvhu, Upper Sand, Lower Sand, Lower Luvuvhu, Shingwedzi, Mapungubwe, Mogalakwena
Any proposed developments you are aware of?	Limpopo Protected Areas Expansion Strategy; UNESCO Vhembe Biosphere Reserve Biodiversity Conservation Strategy; Biodiversity Economy nodes located in Vhembe African Ivory Route initiative; Soutpansberg Limpopo initiative Greater Kruger Strategic Development Programme	No	No	The Great Vhembe Conservation Area. DFFE's Operation Phakisa for the Biodiversity Economy through a bioprospecting industry initiative. A number of conservation financing initiatives by NGOs	Several conservation and tourism projects are proposed or envisioned across the Northern Bushveld (from the Soutpansberg to the Limpopo River, and from Makhado/Louis Trichardt to Vivo).	Musina-Makhado Economic zone Several solar farms Platinum mining near and under the Makgabeng plateau	Integrated Development Plans are available.	No specific areas

2.3 Conservation

Stakeholder inputs on conservation in the study area are summarised in Table 2-2. Several areas were pointed out as being of conservation value:

- The Upper and Lower Nzhelele River as well as the Ṅwaneḓi River is in a C Ecological Category (moderately modified) due to the presence of the Nzhelele Dam and the Ṅwaneḓi and Luphephe dams and is important for biodiversity. It was noted that the Nzhelele catchment is still a rich biodiverse landscape containing areas of endemism and high biodiversity. The area encompasses an extensive protected areas network (PAN) comprising provincial and privately-owned nature reserves as audited in the Vhembe Bioregional Plan (VBP) and substantial areas are classified as Critical Biodiversity Areas (CBAs) as per the VBP and Limpopo Conservation Plan (LCPv2) targeted for protection in the Limpopo Protected Areas Expansion Strategy (LPAES) and form part of the UNESCO Vhembe Biosphere Reserve's "Core Areas" (as per its updated zonation plan). In particular its upper and lowest reaches are important from an ecological perspective:
    - The upper Nzhelele comprises a perennial reach upstream of the Nzhelele Dam which flows through the high-rainfall areas on the slopes of the Soutpansberg mountains still covered by montane forest that are classified at Critical Biodiversity Area (CBA) Quadrant 1 as per the LCPv2 and the VBP and which forms part of the core area of the UNESCO Vhembe Biosphere Reserve.
    - In a mirror of the river's headwaters, the lowest reaches on the Nzhelele River (A80G) pass through areas classified as critically biodiverse (CBA Q1 as per the LCPv2 and the VBP) and are protected by the Philip Herd Nature Reserve (PHNR) (in the process of being re-declared as The Herd Reserve with altered boundaries), which contributes towards the 15% conservation target for Limpopo Ridge Bushveld under LCPv2, the Limpopo Protected Areas Expansion Strategy (LPAES) and the National Protected Areas Expansion Strategy (NPAES), 2016. The reserve's aquatic and riparian zone terrestrial habitats support numerous rare and endangered floral and faunal species.

- The Limpopo, Sand, Luvuvhu, Shingwedzi and Mogalakwena Rivers contain critical biodiversity and sensitive riverine vegetation. It was also highlighted that it is critical to maintain biodiversity corridors between the Limpopo and Olifants Rivers and their tributaries.

- The Soutpansberg Mountain Range was also highlighted as a Biodiversity Hotspot and important river catchment area and groundwater source area.

- The Makgabeng plateau was highlighted as having valuable resources such as mopane worms, baobabs and marula, that could help develop the biodiversity economy.

The majority of stakeholders wanted the health of rivers to be improved, but some were happy for them to be maintained in their current condition. Some stakeholders wanted river condition to be maintained in order to secure the flows upon which they depended for their livelihoods. It was expressed that since South Africa is a water scarce country, every effort should be made to protect our water resources for the current and future generations. Stakeholders noted that the improvement of all water resources in the study area is both feasible and desirable in the context of a biodiversity-based economy i.e.

developing the biodiversity economy as the primary sector in the region both requires water resource improvement to the highest possible ecological condition – and will enable it. It was also pointed out that the biodiversity economy sector avoids the conventional trade-off between supporting economic development and water resource condition to a large extent.

Stakeholders were unanimous that no deterioration of water resources should be allowed, even if it was to achieve development objectives. It was argued that no degradation of any of the water resources' ecological condition from their present ecological state is acceptable under current circumstances, not only for the reason that degradation of the water resources would erode the real economic potential of the region as a biodiversity economic hub, but because further degradation conflicts with all other local, national and international environmental and economic interests and water users especially given the global climate and nature crisis, and the ongoing and severe water insecurity afflicting much of the region. Moreover, permitting further degradation of water sources would contradict national policy, planning and legislation governing climate change mitigation and adaption, biodiversity conservation, water resource protection and management and integrated economic development which is required to be sustainable. This is borne out in the National Water Resource Strategy.

It was also pointed out that water is a critical component of all life, and without it no animal, plant or human can survive. There are other parts of South Africa with less sensitive ecosystems and habitats that can rather be developed for economic growth.

Table 2-2. Summary of stakeholder inputs on visions for conservation. Columns indicate the catchment groupings specified by different stakeholders as being of interest to them.

	Nzhelele/ Ṅwanedi	Lower Luvuvhu	Upper Luvuvhu	Nzhelele/Ṅwanedi , Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu	Nzhelele/Ṅwanedi , Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu, Mogalakwena, Shingwedzi	Nzhelele/Ṅwanedi , Upper Sand, Lower Sand, Mapungubwe, Mogalakwena	Sand-Nzhelele-Luvuvhu	Nzhelele/Ṅwanedi , Upper Luvuvhu, Upper Sand, Lower Sand, Lower Luvuvhu, Shingwedzi, Mapungubwe, Mogalakwena
Ecologically important areas	Upper and Lower Nzhelele River and Ṅwanedi River; whole Nzhelele catchment has high conservation value.			Upper and lower reaches of catchments are equally important in an integrated water resource management framework.	Soutpansberg Mountain Range for water resources The Limpopo, Sand, Luvuvhu, Shingwedzi and Mogalakwena Rivers for biodiversity. Critical to maintain biodiversity corridors between the Limpopo and Olifants Rivers and their tributaries.	Makgabeng plateau Mopane bushveld for valuable harvested resources	As water resources flow and are managed in an integrated manner (e.g., transfers, water quality control), all areas are important from an ecological perspective.	Critical biodiverse areas in Vhembe Bioregional Plan; Environmentally sensitive Core Areas and Buffer Zones in the updated Vhembe Biosphere Reserve Zonation Plan
Preference for future condition of water resources	Improved.	Maintained. We depend on river flows, and pumping is costly.		Improved. This is needed to support the biodiversity economy.	Improved.	Maintained	A is the ideal. The B, C or D category needs to be maintained or improved. E-F category must be improved	Improved
Allow ecological deterioration to have development	No.	No		No, and this is not supported in the NWRS	No. Especially not in this part of the country.	No. Prior experience shows this is a mistake.	See the National Water Resource Strategy	No deterioration of the conservation and socio-culturally rich areas.

2.4 Socio-cultural importance and ecological goods and services

Stakeholders identified that there were some culturally important areas in the study area.

- In the Nzhelele/Ṅwanedi IUA, the Vhembe Biosphere Reserve part of the UNESCO Man and the Biosphere (MAB) Programme is an intergovernmental scientific programme that aims to establish a scientific basis for enhancing the relationship between people and their environments. There are a significant number of sacred sites in local Venda culture located in the upper reaches including Lake Fundudzi, Phiphidi Falls, Tshatshingo potholes and the Thathe Vondo Forest. There are a significant number of nature reserves across the catchment that offer nature-based recreation.
- Mukhase River within the Upper Luvuvhu IUA associated with Mphaphuli Nature Reserve.
- Important sites in the Lower Luvuvhu IUA include Dongodzivha Lake and surrounds.
- The entire Western Soutpansberg Mountain Range.
- The Limpopo River Valley.
- The Makgabeng plateau in particular the farms Bonne Esperance 356 LR and Too Late 359 LR approximately 30 kilometres to the west of Senwabarwana.

Stakeholders also commented that in the arid savanna biome, because water resources are so scarce, all water has tremendous value and importance culturally, spiritually, recreationally and educationally. In particular, much of Venda culture and spiritual practices are deeply bound with Dzomo la Mupo (nature) and many of the sacred sites are water bodies, including Lake Fundudzi. The indigenous culture, knowledge and practices cannot in fact be separated from nature; the culture ceases in the absence of the natural systems, including water systems. Threats to Dzomo la Mupo and the sacred sites are existential to traditional Tsonga and Venda culture, and harmful to South Africa's cultural heritage.

It was suggested that a comprehensive study is needed to identify areas that are important from a socio-cultural point of view prior to any major development decisions being taken.

In terms of important ecosystem services, the availability of water for subsistence and small-scale/informal farming seemed to be the main provisioning service of concern, but wild foods were also mentioned. Some inputs were:

- Smallholder farmers in the upper reaches of the Nzhelele/Ṅwanedi depend on instream water to supply run-of-river irrigation schemes as well as domestic requirements, although much of this abstraction is unlawful and urgently needs to be regularized;
- There is near-total dependency on ground and surface water resources of poor rural, often female-headed households and small-scale farmers particularly in Eastern Soutpansberg and the central Limpopo River Valley; and
- Communities depending on provisioning services include Kutama, Buysdorp, Kranspoort and Ndouvhada, and communities of the former homeland areas in general. Here, many households depend on streams and aquifers for domestic uses, livestock, irrigation and other productive uses that contribute to poverty eradication, livelihoods and racial and gender equity.

Table 2-3. Summary of stakeholder inputs on areas important for cultural reasons or for ecosystem goods and services. Columns indicate the catchment groupings specified by different stakeholders as being of interest to them.

	Nzhelele/ Ṅwanedi	Lower Luvuvhu	Upper Luvuvhu	Nzhelele/Ṅwanedi , Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu	Nzhelele/Ṅwanedi, Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu, Mogalakwena, Shingwedzi	Nzhelele/Ṅwanedi, Upper Sand, Lower Sand, Mapungubwe, Mogalakwena	Sand-Nzhelele-Luvuvhu	Nzhelele/Ṅwanedi, Upper Luvuvhu, Upper Sand, Lower Sand, Lower Luvuvhu, Shingwedzi, Mapungubwe, Mogalakwena
Culturally important areas	Vhembe Biosphere Reserve part of the UNESCO Man and the Biosphere (MAB) Programme	Lake Fundudzi Dongodzivha Lake; Tshatshingo potholes at Tshidzivhe;	Mukhase River; Phiphidi Falls; Thathe Vondo Forest	All water resources in the arid savanna biome are culturally important due to water scarcity	Western Soutpansberg Mountain Range, Limpopo River Valley.	The Makgabeng plateau in particular the farms Bonne Esperance 356 LR and Too Late 359 LR approximately 30 kilometers to the west of Senwabarwana.		
Areas important for aquatic ecosystem provisioning services	Smallholder farmers in the upper reaches			Widespread dependence, but particularly in Eastern Soutpansberg and the central Limpopo River Valley.	There are several communities, including Kutama, Buysdorp, Kranspoort and Ndhouvhada.	Yes especially wild sourced food	Communities in the congested former homelands.	No information, but a study of the communities should be a precondition before proceeding with any decision-making on major development projects
Areas or communities important for regulating services	Since flow in the lower Nzhelele is highly modified by the releases made from the Nzhelele Dam for irrigation (the GWS irrigation scheme) this is of relevance only in the upper reaches.			Given poor state of water supply infrastructure in densely settled areas, dependence on natural ecosystem services is total. But capacity for ecosystem services is declining due to overutilisation of surface and groundwater by commercial agriculture.	Same as above		As above. However, protection against flood is often insufficient in low-income areas.	As above

Further input was that informal irrigation is widespread. In particular: out of all 110 610 ha cropped area in former Venda, 50 426 ha (46%) was irrigated in the winter of 2015. The smaller uses unambiguously fit Constitutional rights as Basic Human Needs; the somewhat higher quantities fit the third priority of the National Water Resources Strategy. It was also suggested that a study of this should be a precondition before proceeding with any decision-making on major development projects.

There were fewer inputs on dependence on regulating services such as flood protection, except to say these would be the same communities as mentioned for provisioning services. It was suggested that in densely populated rural areas where there is an absence of built infrastructure, there was total dependence on natural ecosystem services. Concerns were raised about these services becoming compromised by overextraction of surface and groundwater resources for large-scale commercial agriculture.

2.5 Inputs on scenarios to be considered

Comments from stakeholders representing the Nzhelele/Ṅwanedi, Upper Sand, Upper Luvuvhu, Lower Sand, Lower Luvuvhu area included the following additional input, referring to the letter and interim comments submitted on 22 April 2024 by Living Limpopo, the IWMI, AWARD and the Sand-Nzhelele-Luvuvhu Water Resources Research Forum. They proposed that at least three alternative economic development scenarios be modelled and the outcomes on revised water resource class recommendations compared and consideration of such varying outcomes be given in the final recommendations. Their suggestions for scenarios to be included were as follows:

- *Scenario 1*: A 'worst case' scenario reflecting the water demands of the planned expansion of coal mining in the Greater Soutpansberg Coalfield and development of the Musina Makhado Special Economic Zone (MMSEZ) heavy industrial zones relative to current available water resources in the affected catchments in the absence of any infrastructure development to augment water supply from the Limpopo River or other catchments via the proposed inter-basin and inward transfer schemes. This should show the full water deficit exposure attached to these economic development plans as a baseline, before high-risk and high-cost water transfers are factored into the equation. (It was also noted that the developer of the Energy-Metallurgical Zone of the MMSEZ (Shenzen Hoi Mor Resources, the licensed operator of the MMSEZ) in its Internal Master Plan shows the full unabated water requirement deficit against allocated catchment yield as the baseline).

- *Scenario 2*: The scenario presented at the second Steering Committee Meeting on 14 March 2023, but assessing the effects of the planned development of water-intensive industries including coal mining and crude steel manufacturing on a very large scale under present and drier climatic conditions against the present ecological condition of the water resources, as assessed, and revised recommendations that aim for improvement across all catchments. Since little improvement has been recommended in the provisional recommendations for water EC's across the catchments, the baseline model mostly reflects the development of the coalfield and heavy industrial zones (albeit net of highly uncertain water transfers enabled by major supply infrastructure development including the Musina Dam on the Limpopo River) on the present ecological state of the water resources under present and a drier future climate – and predicts a degradation to category C/D of the Nzhelele catchment, which will host both the MMSEZ steel mega-project and many of the planned coal mines, even before modelled climate change effects. Stakeholders would like a re-assessment of the effects of the exploitation of the coal resources of the Greater Soutpansberg Coalfield and the related coal-consuming MMSEZ in a scenario where a general improvement in the ecological condition of the water resources is recommended.

- *Scenario 3*: A nature-based economic development scenario based on the implementation of government's spatial, integrated development and conservation plans to-
    i. protect the Vhembe region's renewable natural resources,
    ii. develop the biodiversity economy and
    iii. support the growth of a carbon market (in which carbon offset credits from land/nature-based solutions are allowed) as part of South Africa's climate response and meeting its UNFCCC Paris Agreement Nationally Determined Contribution to the reduction of Greenhouse Gas Emissions, as well as
    iv. discharge its binding obligations under the Kunming-Montreal Global Biodiversity Framework and meet its '30x30' target.

  This should reflect the support of green economy growth in national and provincial policies, plans, acts and regulations and the positive spillovers for water resources. It should have a strong focus on water- and climate change-resilience, and greater economic merits in terms of feasibility, costs and benefits, particularly in terms of creating accessible economic opportunities for rural communities. This cannot be excluded from the scenario evaluation that will inform final recommendations on water resource classes and quality objectives for the Limpopo WMA.

It was also suggested to consult the relevant bioregional plans for the study area. Reference above has been made to the Vhembe Bioregional Plan and the Vhembe Biosphere's updated Zonation Plan. While both these plans have not been formally approved, both have however been scientifically prepared by independent professional and experienced experts and therefore must be considered in this visioning project.

In response to the above proposal by the stakeholders on developing the scenarios for analysis, the following points are made:

- Proposed *Scenario 1* – it is not possible to have a scenario where there is development in the absence of supplying the water that is needed for it.
- Proposed *Scenario 2* – has been included in the evaluation as the Development (DEV) scenario.
- Proposed *Scenario 3* – has been included in the evaluation as the Biodiversity Economy (BE) scenario.

3 SCENARIO ANALYSIS APPROACH

3.1 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 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 biodiversity, 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 3-1. 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 Biodiversity, 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.

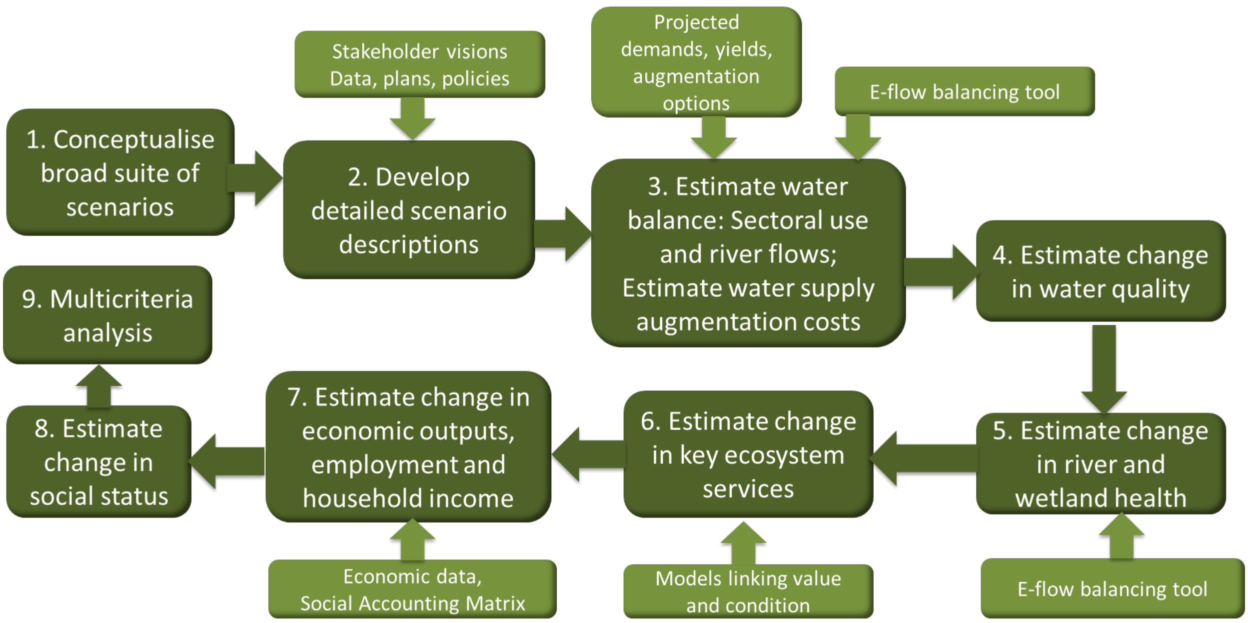


Figure 3-1. Schematic presentation of the scenario evaluation process. Source: This study.

A range of Classification Scenarios are defined that describe alternative Water Resource Class and EC configurations for the study area, the outcomes of which are evaluated in terms of costs and benefits. 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 either reducing or increasing 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.

3.2 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 3-2. The Classification of water resources defines their intended condition as well as the quantity and quality of water required to maintain that specific condition. This in turn, determines the quantity of water that is available for use.

The economic outcomes are considered in terms of changes in the two main macro-economic indicators of GDP and household income, as well as changes in cost savings due to changes in water supply costs and 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 3-2). The social outcomes are considered in terms of a composite index of societal wellbeing that takes household income, livelihoods and climate 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.

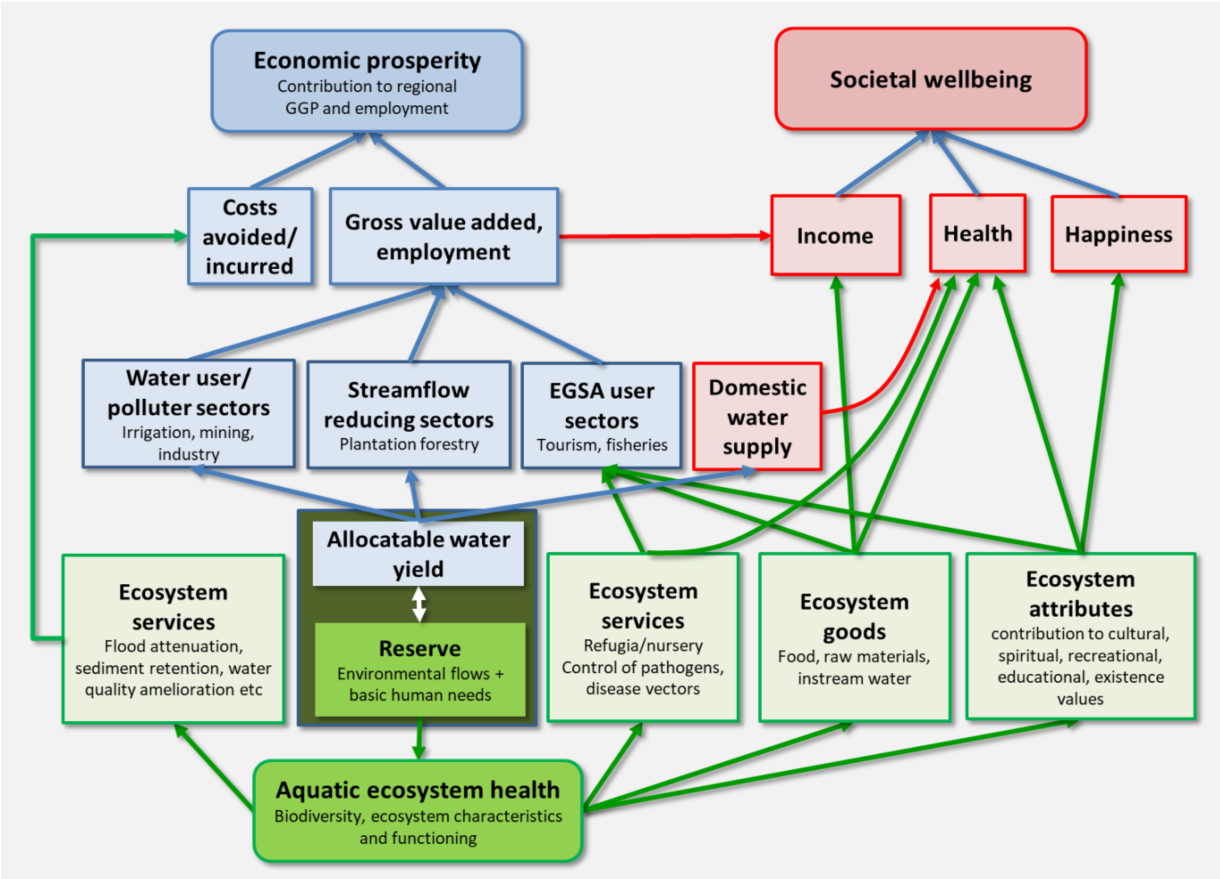


Figure 3-2. Linkages arising from the trade-off between water abstracted for use and water retained for the ecological Reserve. EGSA stands for ecosystem goods, services, and attributes. Source: (DWS, 2017a) modified from (Turpie et al., 2006).

3.3 Defining the Classification Scenarios

3.3.1 Overview

The rationale for the scenario analysis was to explore the potential water supply, biodiversity and socio-economic outcomes of a range of potential classification options (ranging from high to low levels of ecosystem protection) against a range of demand contexts. It is important to test classification against future demands, since the classification choices made in this process should be robust (i.e. should remain the best choice) for the foreseeable future.

There are a large number of potential combinations of the level of protection and contexts, thus a useful and straightforward subset had to be chosen. Given the objectives of the study, most scenarios are set in terms of the EC configurations, from which the available water for use is determined, based on the Ecological Water Requirements (EWRs) for the specified ECs. However, some scenarios can be development-focused, in which case the water requirements for development will be met, and the resultant ECs will be determined. Scenarios are developed based on the ecological condition targeted at each node under the specific scenario (e.g. improving to the REC) and its associated EWR flows at all river nodes, the estimated water demands for the catchment based on future population growth, and the current or proposed future water supply infrastructure. A total of five different scenarios were initially considered and are summarised in Table 3-1. Each of the scenarios is described in more detail below.

Table 3-1. Scenarios considered, all with 2050 levels of population

#	Scenario	Abbreviation	Description
1	Maintain Present Ecological Status	PES	River and wetland systems are maintained in their most recently assessed condition[1].
2	Ecological Bottom Line	ESBC	The maximum volume of water is made available for abstraction from the system for economic activities, with the proviso that all water resources are just maintained in a D category (i.e. the "ecological bottom line") where possible. This can also be seen as a "constrained" development scenario.
3	Biodiversity Economy	BE	Rivers are maintained in their best attainable state (BAS) in order to maximise the possibilities of developing a sustainable biodiversity economy that is founded on a strong conservation outcome. In this scenario, ecosystem health is prioritised by limiting any further demands on water resources, and by increasing health where feasible.
4	Unconstrained Development	DEV	Water demands for all future planned or potential developments are met as far as possible without any limit on ecological condition (i.e. can have worse than a D category).
5	Spatially-targeted Conservation and Development	STCD	Areas of high conservation value are protected by meeting RECs (including at LIMCOM sites), while other areas allow up to maximum sustainable use of water, within the constraint of min D category.

3.3.2 Scenario 1: Maintain Present Ecological Status

The first scenario maintains present ecological status (PES) as at the most recent assessment. This requires that efforts are made to maintain river and wetland systems in their present condition in spite of economic and population growth.

3.3.3 Scenario 2: Ecological Bottom Line (ESBC)

The second scenario is what is termed the ecologically sustainable base configuration (ESBC) Scenario, or "Bottom-line" Scenario in which the maximum volume of water is made available for abstraction from the system for economic activities, with the proviso that all water resources are just maintained in a D category (i.e. the "bottom line").

[1] The PES of the EWR sites is 2022, but of all other nodes is from 2014 (Department of Water and Sanitation. 2014. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa. Secondary: W5 (example). Compiled by RQIS-RDM: http://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx)

3.3.4 Scenario 3: Biodiversity Economy (High conservation)

The third scenario is a conservation scenario which aims to determine the best attainable state (BAS) for rivers and wetlands, based on reducing demands on water and the subsequent predicted improvement in river and wetland health in response to increased river flow, prioritising the study area as a conservation area. There are many justifications for this, some of which are outlined in Section 2. Growth in sectors that involve extraction and pollution of water would be strongly curtailed in order to maintain and restore the condition of rivers and wetlands to their best attainable state. The area would be prioritised for ecological restoration and protection, biodiversity economy activities such as game farming and tourism, and the development of biodiversity products, and activities such as climate smart agriculture and increased water use efficiency and improved environmental management in existing developed areas. As such it would make a strong contribution to existing international commitments and national plans, including for ecosystem-based adaptation.

3.3.5 Scenario 4: Unconstrained Development

This scenario considers the potential outcomes of future development on the resulting ecological condition at all nodes with no constraints applied in terms of making water specifically available for EWR flows. The development scenario (DEV) considers all current planned future development options.

Future water requirements were estimated for domestic use, irrigation agriculture and mining and industrial activities in each of the IUAs. A description of current use and planned future development are provided in Table 3-2 and associated high priority development quaternary catchments are shown in Figure 3-3. In the Upper and Lower Lephalala IUAs there are no major future developments being planned for. Future developments in mining and industry are largely constrained to the Upper Nyl & Sterk IUA, Upper Sand IUA, Lower Sand IUA and Nzhelele/Ṅwaneḓi IUA. Mining and industry are currently important economic activities in the Upper Nyl & Sterk IUA and the Upper Sand IUA and these are expected to increase into the future. In the Lower Sand IUA, future water requirements are expected to be driven by growth in the population of the area due to the planned Musina-Makhado Special Economic Zone (MMSEZ). The future water requirements of the Nzhelele/Ṅwaneḓi IUA are driven by the potential development of coal mines as well as growth in the population of the area.

It is important to note that the developments planned for the MMSEZ that involve the building of dams on the Lower Sand, pumping of groundwater from the Limpopo River and transfers of flow from the Limpopo River are not modelled in the DEV scenario because the Limpopo River and its tributaries in the neighbouring countries are under the ambit of the ongoing Limpopo Watercourse Commission (LIMCOM) study. The flow scenarios modelled in this project are restricted to the tributaries of the Limpopo River that flow through South Africa. The most downstream nodes are those found at the junction with the Limpopo River, such as the lowermost Sand River node Ri25, which is the LIMCOM study EWR site SAND-A71K-R508B. This site is situated upstream of the tail of the upper Dam which is being considered as an option (one of many) for implementation on the lower Sand River.

Table 3-2. Description of assumptions made for the future water requirements under the Development Scenario.

IUA	Future Development
Upper and Lower Lephalala	No room for growth in irrigation agriculture, any increase is a result of efficiency gains.
	Domestic water requirements are assumed to grow at an annual rate of 1.45% for the Upper Lephalala and 2.65% for the Lower Lephalala.
	Livestock watering requirements expected to remain the same.
Upper Nyl & Sterk	Mining and industrial water requirements are expected to increase over the planning period with an annual average growth rate of 1.43%.
	No room for growth in irrigation agriculture, any increase is a result of efficiency gains.
	Domestic water requirements are assumed to grow at an annual rate of 2.24% per annum.
Mogalakwena	A small increase in irrigation agriculture of 3% over the assessment period with any further increase being a result of efficiency gains.
	Livestock watering requirements expected to remain the same.
	Domestic water requirements assumed to grow at an annual rate of 1.50% per annum.
Upper Sand IUA	A moderate increase in irrigation agriculture of over the assessment period with any further increase being a result of efficiency gains.
	Domestic water requirements assumed to grow at an annual rate of 3.0% per annum.
	Mining and industrial water requirements expected to increase over the planning period with an annual average growth rate of 4.96%.
Lower Sand IUA	A small increase in irrigation agriculture of 3% over the assessment period with any further increase being a result of efficiency gains.
	Domestic water requirements assumed to grow at an annual rate of 2.1% per annum.
	Mining and industrial water requirements expected to increase substantially over the planning period with an annual average growth rate of 10.5% to accommodate the MMSEZ.
Nzhelele / Ṅwaneḓi IUA	A moderate increase in irrigation agriculture of 10% over the assessment period with any further increase being a result of efficiency gains.
	Domestic water requirements are assumed to grow at an annual rate of 1.87% per annum.
	Mining and industrial water requirements are expected to increase over the planning period with an annual average growth rate of 5.6% to accommodate new coal mines.
Upper Luvuvhu and Lower Luvuvhu/Mutale IUAs	A moderate increase in irrigation agriculture of 10% over the assessment period with any further increase being a result of efficiency gains.
	Domestic water requirements assumed to grow at an annual rate of 2.35% per annum (Upper Luvuvhu) and 1.35% per annum (Lower Luvuvhu/Mutale IUA)
Shingwedzi IUA	Domestic water requirements are assumed to grow at an annual rate of 2.35% per annum. Small increase in irrigation agriculture.

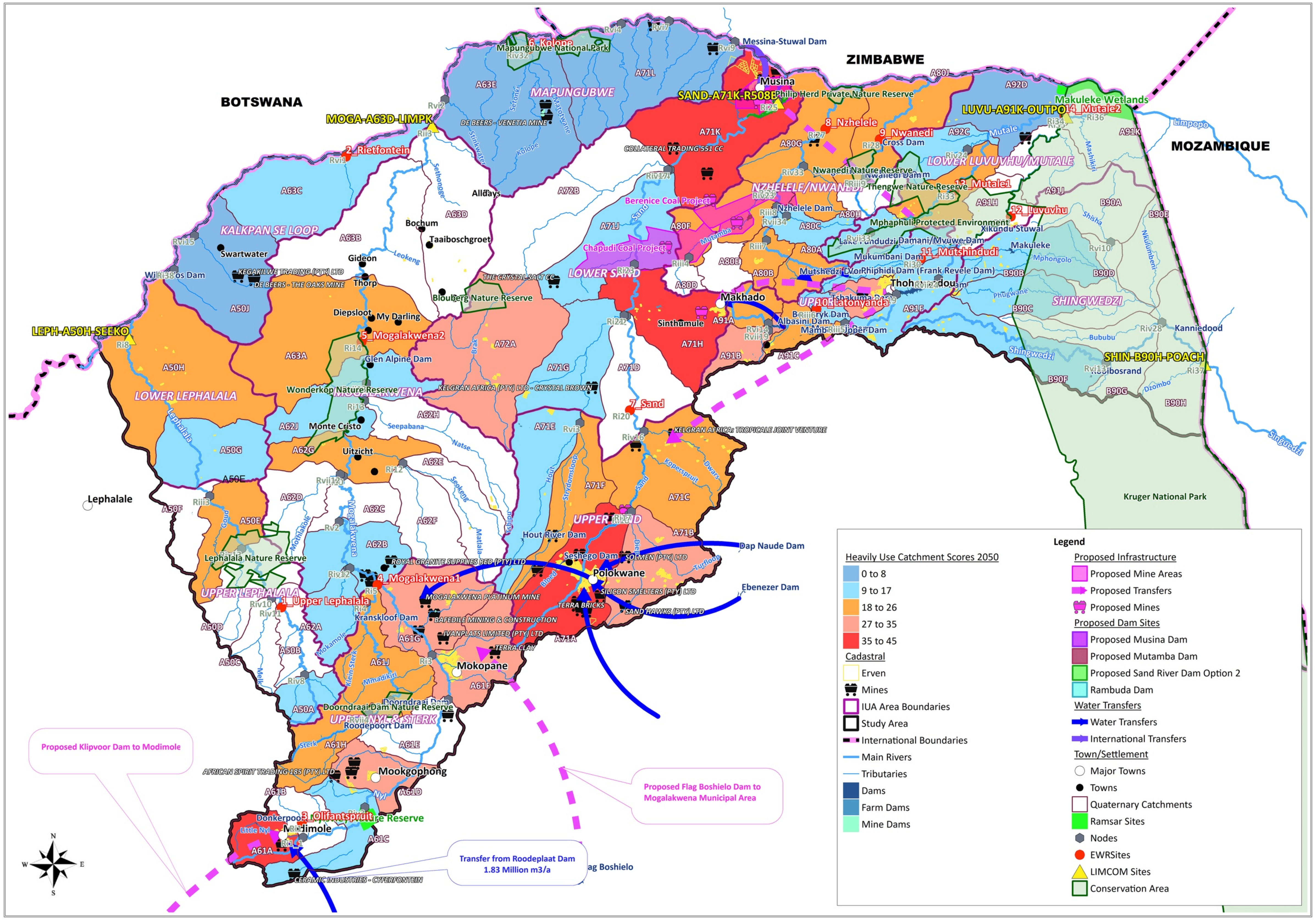


Figure 3-3. A map of the Development Scenario, showing the high priority development quaternary catchments for proposed future development options.

3.3.6 Scenario 5: Spatially-targeted conservation and development (STCD)

The fifth scenario is based on spatial considerations of priority objectives to achieve a blend of targeted ECs for all nodes ranging between BAS and ESBC. It is important to consider a spatially distributed solution, where different priorities can be recognised in different parts of the WMA, but with consideration for existing activities in the study area and ensuring a degree of compatibility that would not compromise these activities. For example, some areas are considered to be more ecologically or socially and culturally important and should be given a high ecological condition, e.g. BAS, while in other areas it is recognised that future development is important, and the ecological condition (EC) could be lower to allow for future growth in water demands. The STCD was created using the following rules:

- Increasing flows (by loading rule-based EWRs) in catchments upstream of EWR sites to try and meet the RECs set at all the EWR sites;
- Increasing flows in catchments with a high and very high ecological priority (see Figure 3-4) to avoid D category rivers;
- Where the Development Scenario results in a C or C/D category river, load rule-based EWRs to improve this up by at least half a category if possible; and
- Where Development Scenario results in flows that were higher than PES, then leave as is.

The ecological importance across the study area was assessed using a range of conservation-focused spatial layers from different sources, the data were aggregated to quaternary catchments, and each quaternary catchment given a score from 0 to 5 (with 1 being very low and 5 being very high priority), based on a set of criteria and assumptions (Table 3-3).

Table 3-3. Criteria and scoring assumptions used in the prioritisation

Criteria	Scoring		
1. The percentage of the quaternary catchment in a: a. Protected area (e.g., wildlife-based land-use). b. Critical Biodiversity Area (CBA1: Irreplaceable), CBA2 (Optimal for reaching biodiversity targets), Ecological Support Area 1 (ESA1: largely natural areas that support CBAs) and ESA2 (no longer natural but important ecologically). c. Strategic Water Source Area: Groundwater (SWSA-GW). d. Strategic Water Source Areas: Surface water (SWSA-SW).	**%**	**Score**	
	< 20	1	
	21 – 40	2	
	41 – 60	3	
	61-80	4	
	>81	5	
2. The number of high priority wetlands in a quaternary catchment (Wetland Assessment Volume 1 – Eco-status and Priority wetlands report).	**Number**	**Score**	
	0	0	
	1	4	
	>1	5	
3. The number of rivers that are fish sanctuaries for at least: a. One vulnerable or near threatened fish species. b. One critically endangered fish species.	**Number**	**Score**	
	0	0	0
	1	1	3
	2	2	4
	> 3	3	5
4. The number of rivers with a Present Ecological Status (PES) in an A category (DWS 2014).	**Number**	**Score**	
	0	0	
	1	3	
	2	4	
	> 3	5	
5. The number of rivers with a PES in a B category (DWS 2014).	**Number**	**Score**	
	0	0	
	1	1	
	2	2	

Criteria	Scoring	
	> 3	3
6. The number of rivers with a high Ecological Importance (EI) (DWS 2014).	**Number**	**Score**
	0	0
	1	1
	2	1.5
	3	2
	4	2.5
	5	3
	6	3.5
	7	4
	8	4.5
	>8	5
7. The number of rivers with a very high Ecological Importance (EI).	**Number**	**Score**
	0	0
	1	5
	>1	5
8. The number of rivers that are Freshwater Ecosystem Priority Areas (FEPA), Fish Support Areas (FSA), Phase 2 FEPA and Upstream Management Areas (UMA).	**Number**	**Score**
	0	0
	1	2
	2	3
	3	4
	>3	5

Each category contributed differently to the overall priority using the following weights:

Table 3-4. Categories and weightings used in the overall prioritisation.

Category	Weight	Relative weights
Protected areas	2.6	0.19
Critical Biodiversity Areas 1	1.0	0.07
Critical Biodiversity Areas 2	0.5	0.04
Ecological Support Areas 1	0.3	0.02
Ecological Support Areas 2	0.3	0.02
High priority wetlands	1.25	0.09
Surface Water Source Areas – groundwater	0.5	0.04
Surface Water Source Areas – surface water	0.5	0.04
Fish sanctuaries 1 (vulnerable/ near threatened)	0.4	0.03
Fish sanctuaries 2 (critically endangered)	1.0	0.07
Present Ecological Status A	0.8	0.06
Present Ecological Status B	0.5	0.04
Ecological Importance High	1.0	0.14
Ecological Importance Very High	0.7	0.05
Freshwater Ecosystem Priority Area	0.7	0.05
Fish Support Area	0.5	0.04
Phase 2 FEPA	0.3	0.02
Upstream Management Area	0.2	0.01
Sum	14.1	1

The ecological priority of the quaternary catchments is shown in Figure 3-4 that shows (from South to North and West to East):

- High priority (light blue) around the Lephalala Nature Reserve and moderate (green) in quaternary catchments up and downstream of this.
- High priority of the Nylsvlei River floodplain, moderate downstream of Nylsvlei and along the Sterk River, and high priority of the Nyl pans downstream of the Dorps River tributary.
- Moderate priority of the Brak River tributary catchments before they enter the moderate priority catchment of the Lower Sand River.
- Very high (dark blue) priority of the Mapungubwe National Park and high priority of the quaternary catchment A71L to the east, between Mapungubwe and the Lower Sand River.
- High priority of the lower Nzhelele, Ṅwanedi, Mutale, Luvuvhu and upper tributaries of the Shingwedzi Rivers, very high priority of the upper Mutale River, and very high priority of the Luvuvhu River floodplain and the lower Shingwedzi Rivers along the Limpopo River.

While the STCD scenario assumes some level of development, this is significantly reduced compared to the full development (DEV) scenario, with consideration also applied to the type of development activities planned for. Given that the provincial and local municipalities recognise the importance of biodiversity conservation and nature-based tourism in strategic planning documents and the role it plays in achieving sustainable development outcomes that are linked to national strategies such as those relating to the Biodiversity Economy and Green Economy, the STCD looks to ensure that these outcomes are not lost and that the development planned for aligns as best as possible with achieving sustainable development goals. As such, the level of development included in the STCD is reduced by around 50% compared to DEV. The STCD aims to align with South Africa's NDC commitment to achieving a 31% reduction in greenhouse gas emissions levels and a reduction in coal production.

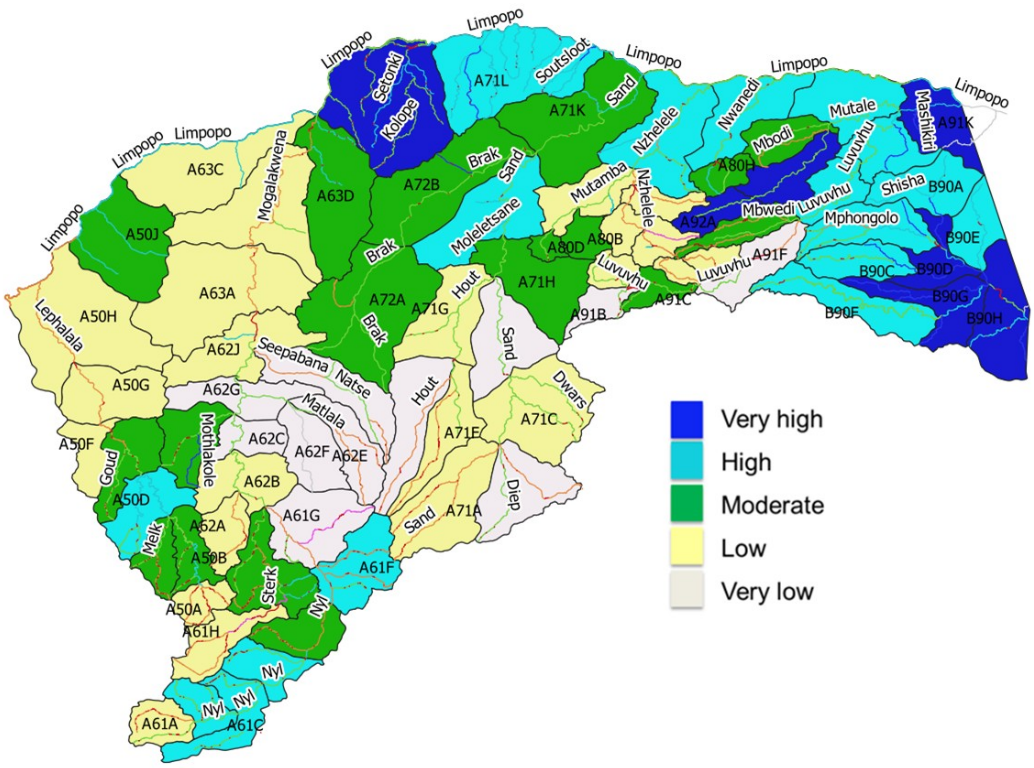


Figure 3-4. Ecological priority of quaternary catchments in the STCD scenario

Only scenario 4 (DEV) is a development-driven scenario, in that what happens to water resource condition is an outcome of the scenario. The remaining scenarios are ecologically-driven, in that the ecological decisions are set first, and then the level of development possible under the scenarios is determined based on the resulting constraints on water yield and water quality. This difference is illustrated in Figure 3-5.

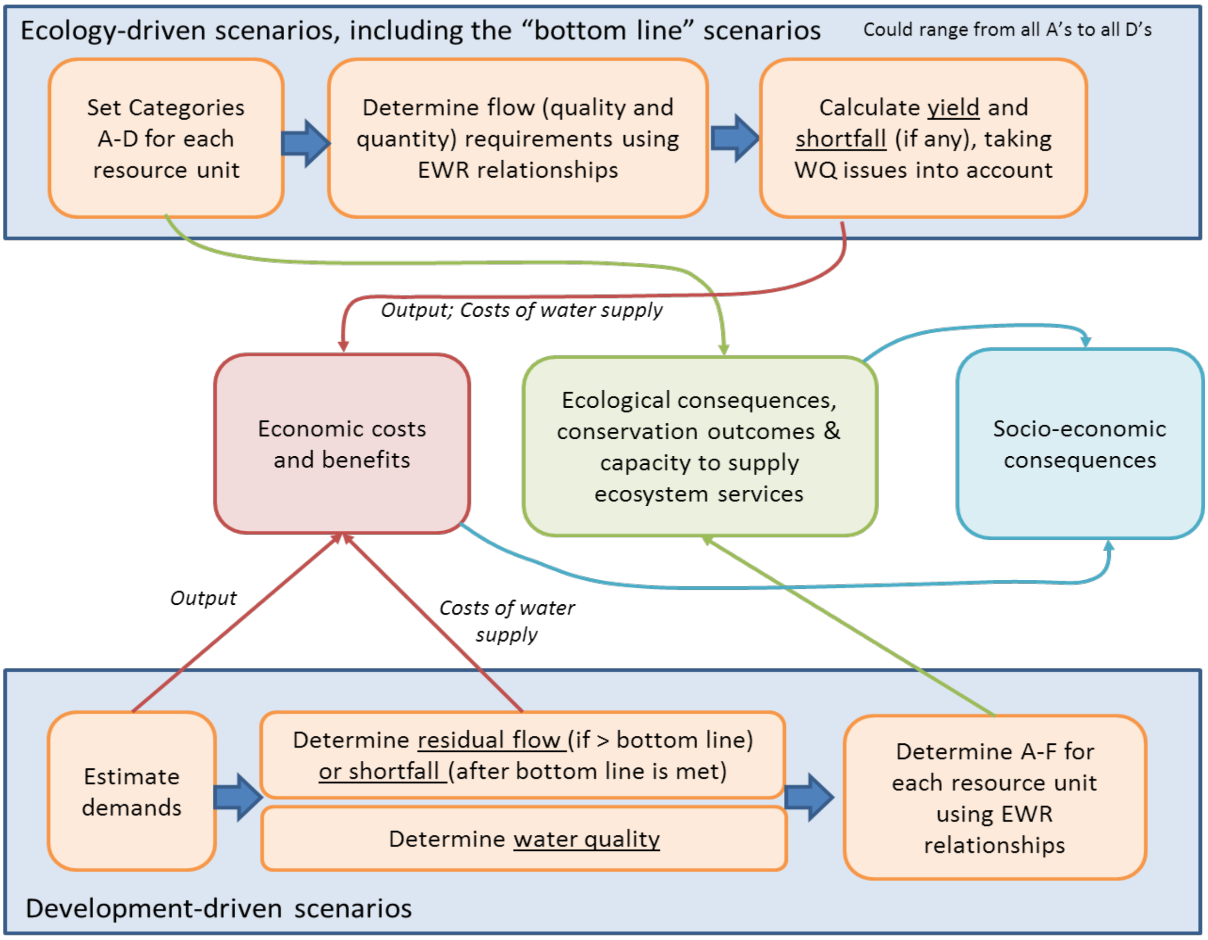


Figure 3-5. The technical process for assessment of the classification scenarios. Source: (DWS, 2017a).

3.4 Scenario assumptions

3.4.1 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 below).

3.4.2 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 or medium term (5-10 years) are very difficult because of unknown technological innovation etc. In this study a time horizon of 2025 to 2050 (25 years) was used.

3.4.3 Climate

All scenarios are presented under current rainfall conditions (based on water resources modelling using historical time series rainfall data).

3.4.4 Changes in water demand

Water demand projections were based on assumptions about population and economic growth. A low growth and medium growth scenario were used for the analysis. The demands under projected population growth and alternative economic growth assumptions were estimated for each IUA.

Current water use was described by IUA in the Status Quo Report. Future water requirements and growth projections were based on Census statistics, data collated from the latest reconciliation strategy reports and data sourced from the mining houses. 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 effects of afforestation, invasive alien plants, irrigation/wastewater treatment return flows and nett evaporation from water bodies are considered in the hydrological modelling.

For the domestic sector, the future water requirements were based on expected population growth rates using the historical population rate of growth for the 2001, 2011 and 2022 population census figures from Stats SA; and the average per capita consumption together with levels of service provision for six household income levels.

It is not expected that significant further allocations for irrigation will be made, except to meet transformation targets. Farmers typically expand their irrigation practices by becoming more efficient on-farm, and by planting higher-value crops. Therefore, it was assumed that, because of the limited availability of water in the Limpopo WMA, water requirements for the irrigation sector would be allowed to increase to its allocation. Once the water allocation was reached, no further growth in the water requirements was assumed and the allocation was capped.

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. The water requirements for planned mining and industrial development were sourced from the various mining houses.

3.4.5 Options for meeting water supply shortfall

Based on the difference between system yield using current infrastructure and projected demand, the shortfall in meeting demands was estimated (after meeting the Reserve), which was then translated into costs of increasing water supply to the level required in 2050 (Figure 3-6).

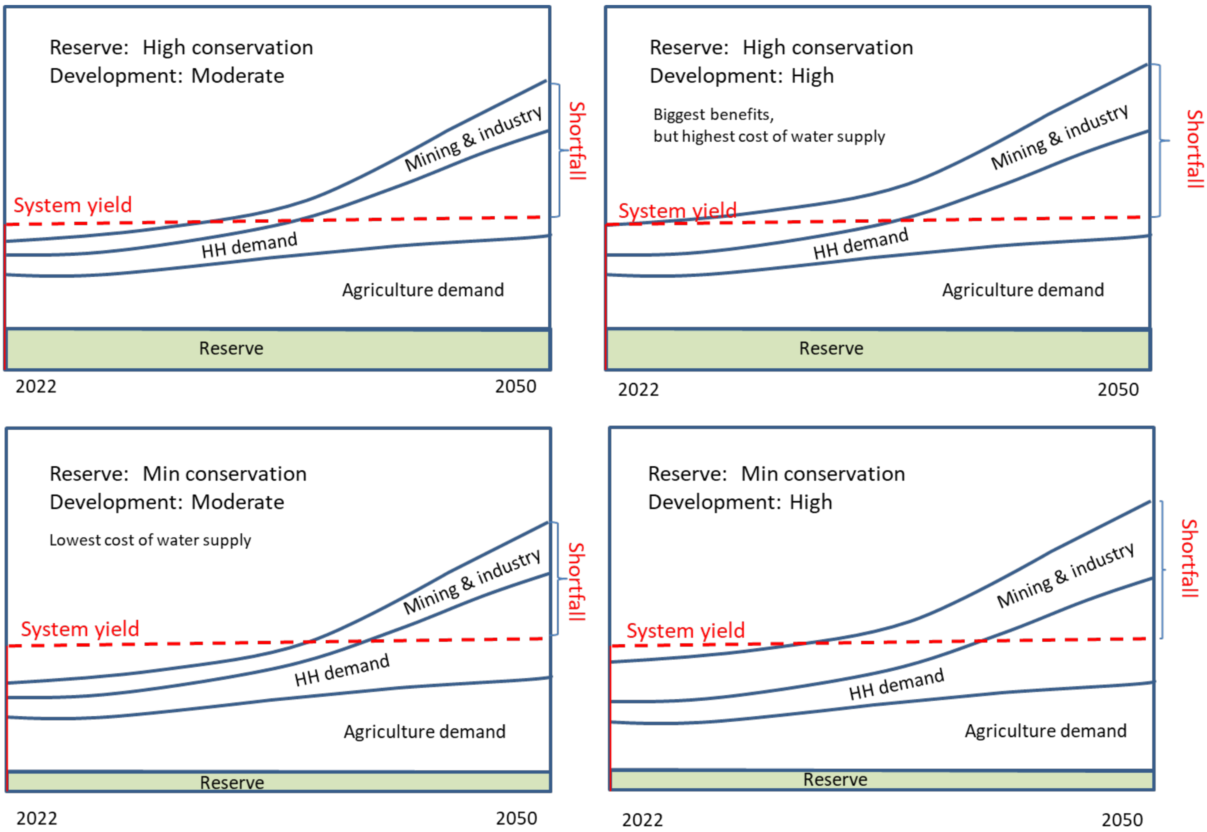


Figure 3-6. Simplified examples of classification scenarios.

Under the Reconciliation Strategy Studies for the Limpopo WMA North, the Luvuvhu and Letaba Water Supply System (DWA, 2015; 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 interventions included 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 (Lephalala, Sand, Mogalakwena and Nzhelele) 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 Lephalala 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 industrial activity is expected which will increase urban water demands. In the Sand catchment major developments such as the Musina-Makhado Special Economic Zone (MMSEZ) are expected to go ahead which will increase mining and industrial water requirements significantly, in an already highly water stressed catchment. 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, 2015).

For this analysis, a water balance which is a comparison of the future water requirements with the available water resources was generated for each IUA. These are described and shown in chapter 4.

A list of potential intervention options was then 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. These options are shown in Table 3-5.

Table 3-5. Potential development options identified to meet future demands.

IUA	Potential development option	Description
Upper Nyl & Sterk	Water transfer	Klipvoor Dam to the Upper Nyl
	Water transfer	Flag Boshielo Dam to Mogalakwena Municipality
Mogalakwena	Groundwater	
Upper Sand	Water transfer	Nandoni Dam to Polokwane
Lower Sand	Dam	Musina Dam (no pumped scheme)
	Dam	Musina Dam off channel storage
	Dam	Sand River Dam
	Water transfer	From Beit Bridge Zimbabwe
Nzhelele/Ṅwanedi	Dam	Mutamba River Dam
	Water conservation + demand management	Refurbishment of irrigation canals
Upper and Lower Luvuvhu/Mutale	Dam	Paswane Dam
	Dam	Tswera Dam
	Dam	Rambuda Dam
	Dam	Thengwe Dam

3.5 Approach taken in evaluating the flow scenarios, and the management options available to address these flows.

Three scenarios were evaluated to determine the implications on the water use sectors in each IUA. The average flows required to meet the ecological category at each node were evaluated and the node in the channel driving the flows was first identified. This was used to determine the additional average flow required either through curtailment of the water requirements at 2050 development levels, or through implementation of management options. To mitigate the impact on water users, different management options were identified and evaluated to determine how much water can be made up without curtailment of the water use sectors which could have a negative effect on the economic growth and development in the IUA. The management options that were evaluated include but are not limited to the following:

- Water Conservation and Water Demand Management (WC/WDM) - The water requirements projections are based on the current operating practices and water use efficiency levels. There is potential to reduce the water losses and to improve the water use efficiency levels. Given the national average water losses of 37%, there is potential to reduce the water losses by 20%. This has been used to reduce the future water requirements projections in the domestic sector. This would mean the water saved is available for the EWR from the existing water resource infrastructure.
- Removal of Invasive Alien Plants (IAPs) - One of the issues with most catchments, particularly in the headwaters is IAPs which reduce streamflow. The removal of IAPs will improve streamflow and contribute positively to the EWR.
- Return Flows – The wastewater from the domestic and irrigation sectors are returned to the rivers downstream of their use. Although irrigation agriculture is not increasing, water for domestic and industrial use is projected to increase and their increasing return flows will contribute toward the additional flows required where these are downstream of discharge points.

Where the above management options cannot make up the additional flows required to improve the EC at the key node, curtailment would then be required. This was determined using the priority classification as presented in Table 3-6. The table shows how the low assurance water use for the water users is curtailed first until the additional water required is met. Each of the IUAs were evaluated to determine the extent of curtailment that would be required to achieve the ecological objectives of the alternative scenarios.

The priority classification can also be referred to as a set of guidelines on how to implement water restrictions within a water supply system. The user categories that were decided on were domestic/urban, mining and industry, irrigation, EWR and losses. The user categories were each split into five different levels of assurance of supply as indicated Table 3-6. In this way a portion of the demand for a specific user category (for instance Domestic/Urban) can be supplied at a high level of assurance (e.g. domestic consumption), while the remaining portion of the demand can be supplied at a lower level of assurance (e.g. garden watering).

It is important to note that the priority classification for the different dams on the rivers of the Limpopo WMA are available. However, the priority classification below has been developed specifically for the environmental assessment.

Table 3-6: Water user category and priority classification assumed for the EWR in the Limpopo Catchments.

Category /Water User	Priority Classification					
	Low 90% Assurance (1 in 10 years)	Medium Low 95% Assurance (1 in 20 years)	Medium 98% Assurance (1 in 50 years)	High 99% Assurance (1 in 100 years)	Very High (99.5% Assurance) (1 in 200 years)	
Domestic & Urban	15%	20%	25%	30%	10%	
Mining, Industries & Power Generation	5%	20%	20%	35%	20%	
Irrigation	30%	30%	15%	15%	10%	
Return Flows	25%	25%	20%	20%	10%	
Curtailment Level	**0**	**1**	**2**	**3**	**4**	**5**

3.6 Ecological consequences: Ecosystems and ecosystem services

3.6.1 River flow and river health

Changes in river flow (volume in Million Cubic Meters, MCM) and ecological condition are modelled in a spreadsheet called the 'Balancing Tool'[2] (hereafter called the Tool). The purpose of the Tool is to determine the effect of changes in flow on the ecological condition of the river at various points (the river nodes). In the tool BHN allowances were treated as abstractions and all results reported include BHN demands.

In the Tool, the average monthly flows for Natural and Current (present day) are routed from one node to the next in a downstream direction. The nodes are located at points of ecological or hydrological relevance through the system. It is set up so that if flows are changed at a node, the associated monthly flows are routed to the next node (and so on down the river). Each node has an associated Present Ecological Status (PES). The Ecological Condition resulting from a change in flow is reported at each node.

The Tool also reports "surpluses" and "deficits" in flow at each node, specified annually and monthly, relative to current day flows (PES flow scenario). If the chosen flows upstream or at a node do not provide the required flows at a node, the deficit or surplus can be reported and / or the flows can be changed until the requirement is met.

The main inputs in the Tool and those used to construct the scenarios are:

- The location of each node geographically in the study area relative to the other nodes, up and downstream respectively. These are listed in a downstream direction in the Tool, and equations link upstream nodes and their flows to those downstream.
- The ecological condition (PES) of each node.

[2] Also called the 'Basin Configuration Tool' due to its function of assisting with the compilation of configurations of node ECs.

- The water quality condition (PES) of each node.
- The Naturalized monthly flow time series (volumes in million cubic meters, MCM).
- Current day monthly flow time series (volumes in Mm^3).
- Monthly Reserves (rule-based Ecological Water Requirements) flow time series (volumes in Mm^3) for certain ecological categories, calculated using the Revised Desktop Model (explained in the Ecological Base Configuration Scenario Report).

At each node, the Tool calculates and reports the cumulative average monthly flows. The Present Day (PES) and Naturalised flows are the references against which other flows can be compared.

The links between flow and ecological condition were programmed into the tool based on a number of standard assumptions common to EWR flow studies in general, including:

- The ecological condition or health of a system is designated an Ecological Condition (EC) from A to F (Kleynhans 1996, Table 3-7).
- Flows were also grouped into Flow States (FSs) from A to F. The FSs are based on annual percentages of Naturalised flow. There were four different sets of rules which applied to different rivers based on the hydrological index and perenniality of the reach.

Table 3-7. Definitions of the ecological categories (Kleynhans and Louw 2007)

ECOLOGICAL CATEGORY	GENERIC DESCRIPTION OF ECOLOGICAL CONDITIONS	SCORE (%)
A	Unmodified/natural. Close to natural or close to predevelopment conditions within the natural variability of the system drivers: hydrology, physico-chemical and geomorphology. The habitat template and biological components can be considered close to natural or to pre-development conditions. The resilience of the system has not been compromised.	>92-100
A/B	The system and its components are in a close to natural condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a B category.	>88-≤92
B	Largely natural with few modifications. A small change in the attributes of natural habitats and biota may have taken place in terms of frequencies of occurrence and abundance. Ecosystem functions and resilience are essentially unchanged.	>82-≤88
B/C	Close to largely natural most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a C category.	>78-≤82
C	Moderately modified. Loss and change of natural habitat and biota have occurred in terms of frequencies of occurrence and abundance. Basic ecosystem functions are still predominantly unchanged. The resilience of the system to recover from human impacts has not been lost and it is ability to recover to a moderately modified condition following disturbance has been maintained.	>62-≤78
C/D	The system is in a close to moderately modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a D category.	>58-≤62
D	Largely modified. A large change or loss of natural habitat, biota and basic ecosystem functions have occurred. The resilience of the system to sustain this category has not been compromised and the ability to deliver Ecosystem Services has been maintained.	>42-≤58

ECOLOGICAL CATEGORY	GENERIC DESCRIPTION OF ECOLOGICAL CONDITIONS	SCORE (%)
D/E	The system is in a close to largely modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of an E category. The resilience of the system is often under severe stress and may be lost permanently if adverse impacts continue.	>38-≤42
E	Seriously modified. The change in the natural habitat template, biota and basic ecosystem functions are extensive. Only resilient biota may survive, and it is highly likely that invasive and problem (pest) species may dominate. The resilience of the system is severely compromised as is the capacity to provide Ecosystem Services. However, geomorphological conditions are largely intact but extensive restoration may be required to improve the system's hydrology and physico-chemical conditions.	>22-≤38
E/F		>18-≤22
F	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete change of the natural habitat template, biota, and basic ecosystem functions. Ecosystem Services have largely been lost This is likely to include severe catchment changes as well as hydrological, physico-chemical, and geomorphological changes. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible. Restoration of the system to a synthetic but sustainable condition acceptable for human purposes and to limit downstream impacts is the only option.	<18

Table 3-8. An example of the rules used to determine Flow State from seasonal percentages of natural flows

Rule no	Rule conditions (seasonal flows as a % of naturalised)			Resulting Flow State
1	90 < seasonal flow <105			A
2	78.9 < seasonal flow < 90	or	105 < seasonal flow < 150	A/B
3	71.7 < seasonal flow < 78.9	or	150 < seasonal flow < 200	B
4	63.9 < seasonal flow < 71.7	or	200 < seasonal flow < 260	B/C
5	56 < seasonal flow < 63.9	or	260 < seasonal flow < 335	C
6	47 < seasonal flow < 56	or	335 < seasonal flow < 450	C/D
7	37 < seasonal flow < 47	or	450 < seasonal flow < 800	D
8	27 < seasonal flow < 37	or	800 < seasonal flow < 1200	D/E
9	17 < seasonal flow < 27	or	1200 < seasonal flow< 2000	E
10	7 < seasonal flow < 17	or	2000 < seasonal flow < 3000	E/F
11	seasonal flow < 7	or	3000 < seasonal flow <4500	F

The tool was used to create the two ecologically-based scenarios and the spatially-targeted scenario. This was done on an ad-hoc basis by changing flows at particular nodes to explore the importance of flow contributions from different tributaries and the feasibility of obtaining particular Ecological Conditions (EC), etc. by specifying rule-based EWRs at various nodes. The changed flows are routed downstream and the resulting ECs shown, as well as other information (e.g. percentage of Natural, deficit or surplus, etc.).

The starting point for the ESBC scenario were the current day flows (PES flow scenario). The flows at the nodes were adjusted (by loading rule-based EWRs) to reduce flow relative to PES. Where this was possible the outcome was a deterioration in ecological condition to a maximum of a D category, the lowest ecological condition acceptable from a river management perspective. This scenario is designed to result in a surplus of water and basin-wide maximally degraded river ecological conditions.

The Biodiversity Economy (high conservation) scenario was also created starting with the current day flows (PES) and by loading rule-based EWRs to increase flow relative to PES (2022) where this was possible.

The modelled hydrology for the Development Focus scenario was loaded into the Tool and the outcomes on flow, relative to PES and Natural flows compared, and the expected ecological conditions reported. A summary of the developments loaded into the Development Focus scenario is given in Section 3.3.5.

The Spatially Targeted Conservation Development (STCD) Scenario was created from the Development (DEV) scenario, making the following adjustments:

- Increasing flows (by loading rule-based EWRs) in catchments upstream of EWR sites to try and meet the RECs set.
- Increasing flows in high and very high priority catchments (see Figure 3-4) so there are no D category rivers.
- Where the Development Scenario results in a C or C/D ecological category adjust flow to improve this up by at least half a category if possible.
- Where the Development Scenario resulted in flows that were higher than PES (2022) these were left as is.

In the tables of results from the tool, colouring is used to guide description and highlight changes. The ECs are coloured according to the colours specified by DWS (Table 3-7). The outcomes of changes in flow for river condition and water quality were integrated into an overall condition score for the river, by giving the water quality score a weight of 33% toward the final score.

3.6.2 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.

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 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 effect on any of the users.
- **Acceptable**: water that is fit for most use, but the most sensitive users or crops might be slightly affected.
- **Tolerable**: water quality that is moderately fit for use but certain outcomes 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 (irrigation) water use, recreation, and aquatic ecosystem requirements. The evaluation of scenarios 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 have an effect 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 model that was used to assess the flow scenarios in the study, has not been configured to simulate water quality.

Therefore, a qualitative assessment of the water quality outcomes for each scenario was performed based on an examination of the relationship between key water quality parameters and flow at water quality sampling sites where flow data was 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). This information was then fed into the socio-economic analysis by combining EC scores with water quality ratings to achieve an overall health score which was used to estimate changes in ecosystem goods and services and overall biodiversity scores which combined health and importance of river and wetland resources.

3.6.3 Wetland health

The methodology for assessing changes in wetland health under each of the scenarios was conducted at different levels and with differing degrees of confidence / precision. At the broadest (IUA) scale, qualitative assessments based on expert opinion in terms of changes in surface and groundwater usage formed the basis of the assessment for wetlands in general. However, distinction was made between different hydrogeomorphic (HGM) wetland types as these generally respond differently or are affected differently to scenarios. For example, depressional and unchanneled valley bottom wetlands are usually more robust to flow scenarios than riverine or floodplain wetlands. Where possible wetland HGMs were aligned to applicable river nodes and the associated changes in volume (from present day – PES) used to make interpretations. Wetland condition (PES) was assigned generally using the wetland condition data field in the National wetland map 5 (Van Deventer *et al.*, 2018).

At the onset of the wetland component for this study it was understood that there are too many wetlands to assess in detail and a process of prioritisation was therefore necessary to determine a small set of high priority wetlands for field verification and to improve confidence in further assessments. The prioritisation led to 11 high priority wetlands / wetland complexes that were assessed in the field to update their respective PES scores and categories (Luvuvhu Floodplain (Makuleke), Nyl River Floodplain, Wonderkrater, Nyl Pans, Maloutswa Floodplain, Kolope Wetlands, Lake Fundudzi, Mutale Wetlands, Mokamole wetlands (tributary of the Mogalakwena), Malahlapanga and Bububu wetlands (tributary of the Shingwedzi)). Two of these wetlands (both Ramsar sites: the Nyl and Luvuvhu floodplains) were selected for more detailed analysis and modelling to determine flow requirements. This process also allowed for the assessment of additional flow-related scenarios. Investigations of the EWRs for floodplain wetlands required a model to predict the extent and duration of flooding on the floodplains, and an understanding of how this related to vegetation and other biotic patterns. Thus, the bulk of the effort in the Nyl and Luvuvhu River floodplain EWR assessments was focussed on developing these two sets of information.

Accordingly, the approach adopted for the EWR assessments, which also served to assess flow-related scenarios, was to:

- create vegetation maps and groundtruth the mapped plant communities.
- focus on developing a reliable and efficient hydrodynamic model to predict the extent and duration of flooding on the floodplains using daily timeseries.
- review the literature on key biota and undertake an EcoStatus assessment based on existing information and field verification.
- populate a DRIFT model for each floodplain that represents a sound understanding of the hydro-ecological functioning, including vegetative and faunal indicators of flow.
- evaluate the ecological outcome of a future development or other scenarios as appropriate.

The resulting assessment facilitates high confidence of ecological response and altered condition to flow regimes (some of which are scenarios), and is based on:

- the hydrodynamic models underpinning the assessments.
- vegetation mapping with ground-truthing.
- extensive information on flow/flood relationships for river and floodplain organisms used to populate the DRIFT models.

The methodology, process and results have been outlined in detail in the Wetland EWR report Vol 2 of this study.

3.6.4 Groundwater

The approach for assessing effects on groundwater condition (stress levels) was largely based on the variation of groundwater abstraction under the different scenarios. The Groundwater Resource Directed Measures (GRDM) classification system for groundwater comprise of a ranking approach by applying the stress index (SI) principle. The stress index provides a measure of the groundwater balance in a groundwater unit (in this case, the quaternary catchment), indicating the fraction of how much of the groundwater recharge [volume] is used, i.e. (i) the amount required for BHN (25 l /c /d), (ii) the volume of groundwater supporting the base flow (i.e. the baseflow requirement of the quaternary catchment), and (iii) the actual groundwater use /abstraction. When the SI is =1> 1.00, all the recharged groundwater is "allocated ". SI classification system is an indicator of the groundwater use and is shown in Table 3-9.

Table 3-9. GRDM SI classification system.

Index	Description
< 0.20 (20 %)	Low
0.20 (20 %) - 0.40 (40 %)	Moderate
0.40 (40 %) - 0.65 (65%)	Moderate to High
0.65 (65 %) - 0.95 (95%)	High
> 0.95 (95 %)	Critical

The presented outcome of the scenarios includes qualitative statements based on expert opinion in terms of effects from groundwater usage on baseflow as well as the potential for further groundwater development. A description of how the groundwater component was incorporated for the scenario analysis is provided in Table 3-10. For the future scenarios consideration was given to reduced recharge (available groundwater) values due to climate change and increasing rainfall variability.

Table 3-10. Description of scenarios applied to groundwater

#	Scenario	Abbreviation	Description
1	Maintain Present Ecological Status	PES	Current groundwater index (i.e., groundwater contribution to baseflow, BHN and current groundwater abstraction)
2	Ecological Bottom Line	ESBC	Current groundwater uses plus allocable groundwater abstraction, while considering exploitation potential.
3	Biodiversity Economy	BE	Current groundwater uses while over-exploited catchments were reduced to a SI of below 95%.
4	Unconstrained Development	DEV	Current groundwater uses plus additional exploitation of groundwater (i.e., groundwater contribution to baseflow, BHN and current groundwater abstraction + additional groundwater potential) SI of 50% to 65% depends on areas with low to moderate to groundwater potential.
5	Spatially-targeted Conservation and Development	STCD	Similar to DEV but with consideration given to high ecological priority areas. As such groundwater development in these IUAs are limited to a SI of 25% or up to 65% with limited priority catchments.

3.6.5 Ecosystem Goods, Services and Attributes (EGSAs)

Potential changes in Ecological Condition were estimated based on assumed relationships between ecosystem health and capacity to supply provisioning, regulating and cultural services, and the value of these services. The main types of ecosystem services considered are summarised in Table 3-11, along with the flow-related characteristics that are the main drivers of these values.

Table 3-11. Main ecosystem services provided by rivers and wetlands of the study area, and the main variables related to river and wetland condition 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	Overall health Freshwater fish abundance Wetland plant abundance
	Instream water use	Instream water used by households for basic human needs and for irrigation of small home gardens.	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
Attributes (Cultural services)	Nature-based tourism value	A river or wetland's contribution to recreation/tourism appeal of a location	Overall health Water quality

3.7 Assessing socio-economic consequences

3.7.1 Sectors considered

The following sectors, as the main water users in the study area or EGSA user sectors, were considered in estimating socio-economic consequences of different scenarios:

- Urban and domestic household use;
- Industry and mining;
- Irrigation agriculture; and
- Eco-tourism.

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. This hierarchy was considered when estimating economic consequences under the scenarios when meeting shortfalls.

3.7.2 Economic indicators

The economic outcomes are described in terms of (1) value added to the economy (= contribution to GDP) and (2) costs saved or incurred in terms of water supply and water treatment.

It should be noted that the economic indicators selected do not always provide the full picture of the 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 outcomes 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) were used to estimate value added to GDP as a proportion of the gross output value of production. The costs incurred (or saved) in terms of water supply and water treatment were calculated based on the change in water available for use under each scenario, as a possible effect is a decrease in land use as water is curtailed to different water use sectors. The economic outcome for the scenarios was provided where water was curtailed using estimates of the productivity of water by sector (e.g., value per m^3 of water) and economic multipliers from the SAM for how this would affect value added in the economy and household income.

3.7.3 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. In this study we have incorporated changes in ecosystem services into both the economic and social analysis since ecosystem services can have an effect on both.

The social outcomes for water allocation will come from changes in household income, 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 are 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), as is the case for the Venda people who live in the study area and have a strong spiritual and cultural connection to the rivers and wetlands. Changes in these benefits are described qualitatively 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.

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. Changes in the capacity of these ecosystems to deliver these resources would have an effect on those households. These outcomes are estimated in terms of value, based on the estimated changes in for example the harvested populations derived from the ecological models. For those households depending on river water, changes in the quantity and quality of dry season flows are important. This effect is quantified in the modelling of surface flows as part of the Basic Human Needs consideration. The cultural and spiritual appreciation of the rivers and wetlands is captured through a non-monetary variable that recognises 'sense of place' in the scenario evaluation.

3.8 Overall evaluation of scenarios

The ecosystem characteristics and the water available for abstraction form the basis for evaluating and estimating the consequences of each scenario. Figure 3-7 shows the three key variables (biodiversity, economy, society) that are being evaluated. The consequences for each of these variables 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 or catchments are more important than others and secondly that the variables listed in Figure 3-7 may differ in their relative importance.

Each scenario is scored based on the 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 outcomes can be assessed.

This study expresses 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 variables are described in terms of state, e.g., % of targets met; health score out of 100, while socio-economic variables will be described in terms of gains in household income, gains or losses in value added or costs saved or incurred.

In order to rank the scenarios, the scores and values for each of the variables were normalised. Score normalisation is a process where attribute values are scaled to the same interval (between 0 and 1), ensuring equal importance in the data. This allows for combining scores across variables for overall ranking of the scenarios. The scores of the variables are combined using weightings. In this case, biodiversity was given a weighting of 0.5 and the variables of economy and society were weighted as 0.25 each. It was deemed appropriate to give a higher weighting to biodiversity because of the important intangible elements associated with biodiversity that are not being captured through this process. These weightings can be "toggled" as part of a sensitivity analysis to demonstrate how the final scores and ranking of scenarios might change under different assumptions.

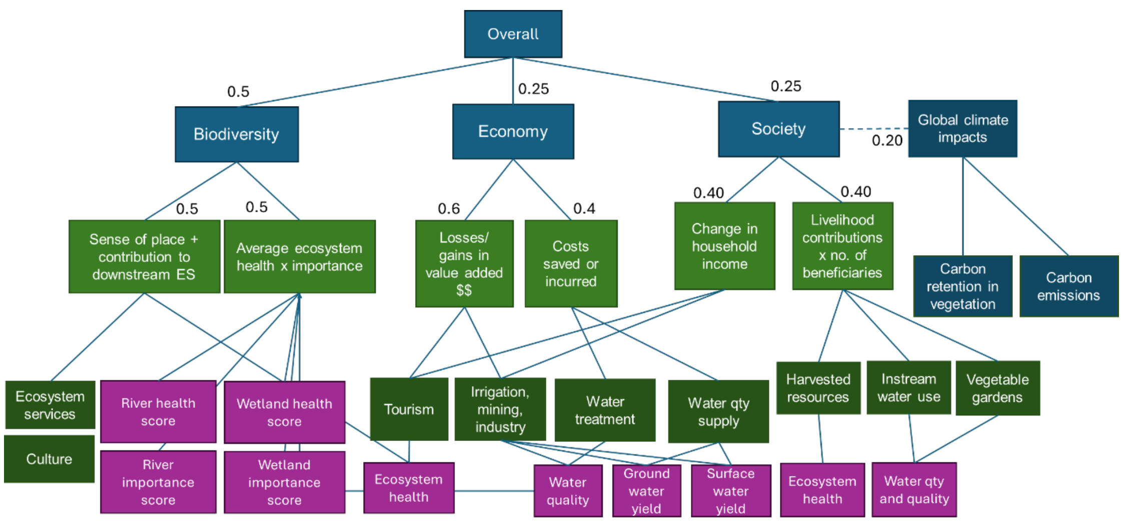


Figure 3-7. Variables and inputs into the multi-criteria analysis used to rank the scenarios.

4 IMPLICATIONS FOR SURFACE AND GROUNDWATER RESOURCES

4.1 Current water requirements

The average annual volume of surface water supplied to user categories to meet current water requirements are 470 million m^3/a. Two thirds of water is used for irrigation agriculture, which is highest in the Lower Sand and Mogalakwena IUAs. Domestic users account for 27% and mining and industry 4%. This is summarised per IUA in Table 4-1. Note that the Kalpan se Loop IUA was not included in the assessment of water use/requirements as it was deemed that there were no significant water users abstracting water in the IUA. For the Mapungubwe IUA, the area is mostly under conservation but there are some mining activities which receive water from the Sand River Catchment, and this is where the demand has been included in the assessment.

Table 4-1. Current water requirements per IUA in million m^3/a.

IUA	Total	Irrigation agriculture	Domestic	Livestock	Mining and industry
Upper Lephalala	33.82	28.61	2.82	2.39	0
Lower Lephalala	17.4	14.3	3.1	0	0
Upper Nyl & Sterk	25.87	4.97	10.3	0	10.6
Mogalakwena	62.78	55.98	3.3	3.5	0
Upper Sand	58.99	12.89	41	0	5.1
Lower Sand	125.91	113.91	7.5	0	4.5
Nzhelele/Ṅwanedi	42.91	34.41	8	0	0.5
Upper Luvuvhu	83.36	41.76	41.6	0	0
Lower Luvuvhu/Mutale	7.43	6.83	0.6	0	0
Shingwedzi	11.70	4.20	7.5	0	0
Total	**470.17**	**317.86**	**125.72**	**5.89**	**20.7**
		68%	27%	1%	4%

4.2 Existing water use and water supply

The water users in the Upper Lephalala IUA are dependent on private farm dams in the case of irrigation agriculture while the domestic users are dependent on groundwater. In the Lower Lephalala IUA irrigation agriculture is dependent on private farm dams as well as run-of-river abstraction. The level of assurance of supply for irrigation is low. The farm dams are located mainly in the tributaries of the Lephalala River. There is also pumping from the main river to local farm dams for use as and when required by irrigators. For the domestic users, the main sources of water supply are groundwater as well as run-of-river abstraction. There are no major dams in the Upper or Lower Lephalala IUAs.

Table 4-2 presents a summary of available water for use in the Upper Nyl & Sterk IUA and Mogalakwena IUA. There are two main dams in the Upper Nyl & Sterk IUA namely Donkerpoort and Doorndraai Dams. These are multi-purpose dams to meet water demands by the domestic and industrial sectors as well as for irrigation agriculture. Groundwater is also used to meet the current domestic water requirements. Additionally, Magalies Water transfers water from Roodeplaat Dam to augment the local water resources of the Upper Nyl & Sterk IUA. There is treated effluent from Seshego in the Sand River catchment to meet the water requirements for the mining activities in the IUA. The total yield available was determined to be 33.51 million m^3/a.

The only dam in the Mogalakwena IUA is Glen Alpine Dam which is for irrigation agriculture purposes. There are major groundwater aquifers where water is currently being abstracted to supplement the Glen

Alpine Dam for irrigation agriculture. There is also groundwater abstraction to meet the domestic water requirements. The total water available was determined to be 62.69 million m^3/a (Table 4-2).

Table 4-2: A summary of available water for use in the Upper Nyl & Sterk IUA and Mogalakwena IUA.

Available water for use	Historical Firm Yield (million m^3/a)
Donkerpoort Dam	3.65
Doorndraai Dam	9.64
Water Transfer - Roodeplaat Dam	9.96
Groundwater	1.35
Mogalakwena Transfer	8.90
Total Upper Nyl & Sterk	**33.51**
Glen Alpine Dam	7.09
Groundwater - Irrigation	50.00
Groundwater - Domestic	5.60
Total Mogalakwena	**62.69**

Table 4-3 presents a summary of the available water supply in the Upper and Lower Sand IUAs. There are three main dams in the Upper Sand IUA namely Seshego, Houtriver and Molepo Dams. These are dams to meet water use for the domestic and industrial sectors. Groundwater is also used to meet the current domestic water requirements. Additionally, Lepelle North Water transfers water from Dap Naude, and Ebenezer Dams to augment the local water resources of the Upper Sand IUA. There is also a water transfer from Olifantspoort to augment the local water resources. The total water resources available in the Upper Sand IUA is estimated at 64.74 million m^3/a.

Table 4-3: A summary of available water for use in the Upper and Lower Sand IUAs.

Available water for use	Historical Firm Yield (million m^3/a)
Seshego Dam	0.58
Ebenezer Transfer	17.03
Dap Naude Transfer	6.57
Olifantspoort Transfer	19.50
Groundwater	2.45
Houtriver Dam	1.42
Molepo Dam	2.19
Groundwater - Irrigation	15.00
Total Upper Sand	**64.74**
Limpopo River Alluvial Aquifer	7.50
Albasini Dam	4.91
Groundwater - Sinthumile	5.00
Nandoni Bulk Pipeline	10.00
Groundwater - Rural communities	2.45
Return Flows - Polokwane	26.50
Groundwater - Irrigation	85.00
Total Lower Sand	**141.36**

There are no dams in the Lower Sand Catchment as irrigation agriculture is dependent on return flows from the wastewater treatment works from the City of Polokwane while the domestic sector is dependent on local groundwater sources, the Limpopo aquifer in the case of Musina town and transfers of water from Albasini Dam in the case of Makhado (Table 4-3). In addition to the Albasini Dam, the Nandoni bulk pipeline provides additional water resources to Makhado town which is in the Lower Sand IUA. The total water available was determined to be 141.36 million m^3/a.

Table 4-4 presents a summary of water supply for use in the Nzhelele/Ṅwanedi IUA. There are several dams in the IUA which are multi-purpose dams supplying both irrigation water and domestic water. These are dams to meet water use for both the domestic and industrial sectors. Groundwater is also used to meet the current domestic water requirements. It is important to note that all these dams ae located in the two catchments (Nzhelele and Ṅwanedi). Currently there are no environmental releases except for compensation releases. The total water resources available is estimated at 43.4 million m^3/a.

Table 4-4: A summary of available water for use in the Nzhelele/Ṅwanedi IUA.

Available water for use	Historical Firm Yield (million m^3/a)
Nzhelele Dam	23.92
Cross Dam	3.50
Luphephe Dam	9.17
Ṅwanedi Dam	1.62
Mutshedzi Dam	2.69
Groundwater - Irrigation	2.50
Total Nzhelele/Ṅwanedi	**43.40**

Table 4-5 presents a summary of the available water for use in the Upper Luvuvhu and Lower Luvuvhu/Mutale IUAs. There are several dams in the Upper Luvuvhu IUA which are multi-purpose dams supplying both irrigation water and domestic water, with Nandoni Dam being the largest. The total water resources available in the Upper Luvuvhu IUA is estimated at 101.1 million m^3/a.

There are no major dams in the Lower Luvuvhu/Mutale IUA. Lake Fundudzi, which is a natural freshwater lake, is the only major water body in the IUA and is not used as a source of water supply. Water is released from Nandoni Dam in the Upper Luvuvhu to supply the domestic water requirements in the Lower Luvuvhu. There is some use of groundwater to meet the current domestic water requirements. This is likely to be the main source of water supply in the future together with the proposed Rambuda Dam in the Mutale Catchment. The total water resources available in the Upper Luvuvhu/Mutale IUA is estimated at 8.00 million m^3/a (Table 4-5).

Table 4-6 presents a summary of available water for use in the Shingwedzi IUA. There are no major dams in the Shingwedzi catchments. Water in this IUA is provided by the Vhembe District Municipality (VDM) from dams outside of the IUA, such as Nandoni, Vondo, and Makuleke. The total water resources available in the Shingwedzi IUA is estimated at 11.5 million m^3/a.

Table 4-5: A summary of available water for use in the Upper Luvuvhu and Lower Luvuvhu/Mutale IUAs.

Available water for use	Historical Firm Yield (million m^3/a)
Nandoni Dam	70.00
Vondo Dam	21.90
Damani Dam	5.30
Albasini Dam	3.90
Total Upper Luvuvhu	**101.10**
Nandoni Dam	6.50
Groundwater - Domestic	1.50
Total Lower Luvuvhu/Mutale	**8.00**

Table 4-6: A summary of available water for use in the Shingwedzi IUA.

Available water for use	Historical Firm Yield (million m^3/a)
Makuleke Dam	6.50
Nandoni Dam	2.50
Groundwater - Domestic	2.50
Total Shingwedzi	**11.50**

4.3 Future water requirements and water balances

Total 2050 water requirements as per planned development are estimated to be 739 million m^3/a. This shows that into the future, water use for irrigation agriculture as a percentage of total use will decline and mining and industry use will increase to be just under 20% of total use. Domestic use is also expected to increase to be 35% of the total expected use.

Table 4-7. Future 2050 water requirements per IUA in million m^3/a.

IUA	Total	Irrigation agriculture	Domestic	Livestock	Mining and industry
Upper Lephalala	36.06	29.33	4.34	2.39	
Lower Lephalala	21.45	14.66	6.79		
Upper Nyl & Sterk	43.78	5.09	22.41		16.28
Mogalakwena	66.2	57.39	5.22	3.59	
Upper Sand	129.09	16.09	89.35		23.65
Lower Sand	230.24	116.79	18.45		95.00
Nzhelele/Ṅwanedi	54.48	38.00	14.44		2.04
Upper Luvuvhu	129.76	46.19	83.57		
Lower Luvuvhu/Mutale	8.43	7.50	0.93		
Shingwedzi	19.71	4.65	15.06		
Total	**739.20**	**335.69**	**260.56**	**5.98**	**136.97**
		45%	35%	1%	19%

Future total water requirements are estimated to increase by 57% compared to current requirements (Table 4-8). The large proportional increases in the Upper and Lower Sand, Upper Luvuvhu and Upper

Nyl & Sterk IUAs are related to the high growth projected for mining and industrial activities in these IUAs, particularly the planned MMSEZ in the Sand River catchment.

Table 4-8. IUA-based consolidation of current and future water requirements (million m^3/a)

IUA	Current surface water requirements (million m^3/a)	Future total water requirements (million m^3/a)	Percentage increase
Upper Lephalala	33.82	36.06	7%
Lower Lephalala	17.4	21.45	23%
Upper Nyl & Sterk	25.87	43.78	69%
Mogalakwena	62.78	66.2	5%
Upper Sand	58.99	129.09	119%
Lower Sand	125.91	230.24	83%
Nzhelele/Ṅwanedi	42.91	54.48	27%
Upper Luvuvhu	83.36	129.76	56%
Lower Luvuvhu/Mutale	7.43	8.43	13%
Shingwedzi	11.70	19.71	68%
Total	**470.17**	**739.20**	**57%**

4.3.1 Upper and Lower Lephalala IUAs

The future water requirements of the Upper and Lower Lephalala IUAs are driven by growth in the population of the area. Due to the limited local water resources available to meet any increase in irrigation agriculture, it has been assumed that the water requirements for irrigation agriculture will remain the same over the planning period until 2050. An increase in the area under irrigation would be due to increased irrigation efficiency. The water requirements for irrigation agriculture in the Upper Lephalala IUA is expected to be capped at 29.33 million m^3/a, and in the Lower Lephalala IUA at 14.66 million m^3/a.

The domestic water requirements are however envisaged to grow over the planning period at an annual rate of growth of 1.45% per annum for a median growth scenario, from 2.82 million m^3/a to approximately 4.34 million m^3/a in the Upper Lephalala IUA and at an annual rate of growth of 2.65% per annum, from 3.10 million m^3/a to approximately 6.79 million m^3/a in the Lower Lephalala IUA.

Figure 4-1 presents a comparison of the future water requirements with the available water resources in the Upper Lephalala IUA. The water requirement projections are likely to exceed the available water resources by 2026/27 hydrological year.

Figure 4-2 presents a comparison of the future water requirements with the available water resources in the Lower Lephalala IUA. The water requirement projections are likely to exceed the available water resources. If no additional water is made available, there will be increased water restrictions in the domestic water users with increasing lower level of service provision.

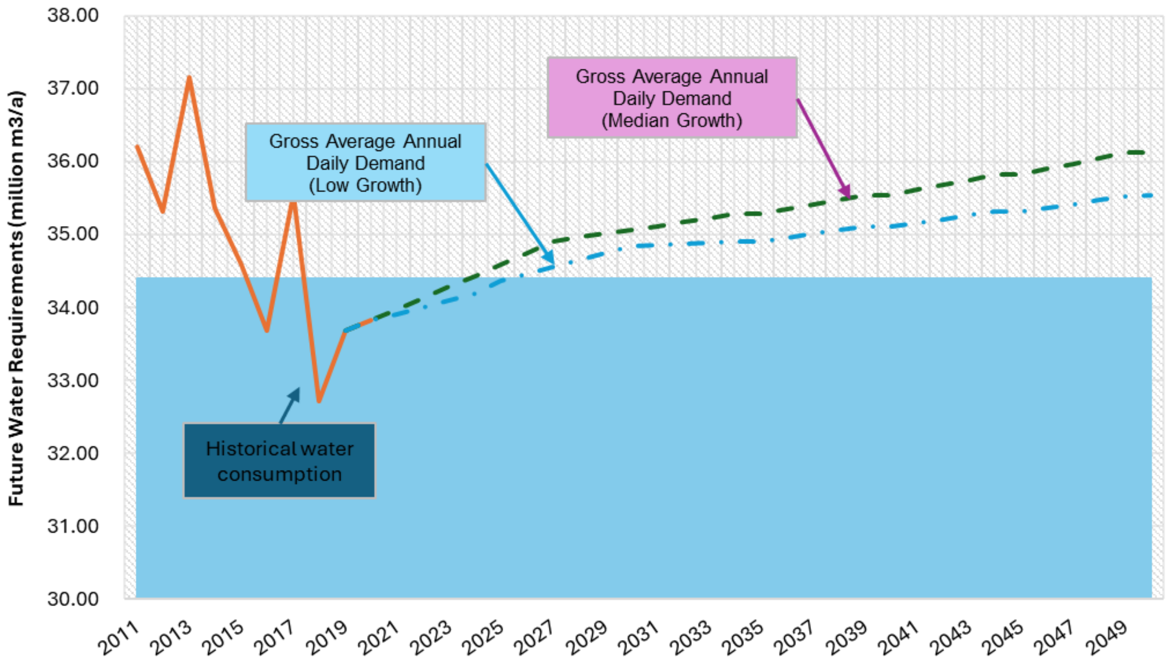


Figure 4-1: Comparison of the future water requirements and available water resources in the Upper Lephalala IUA.

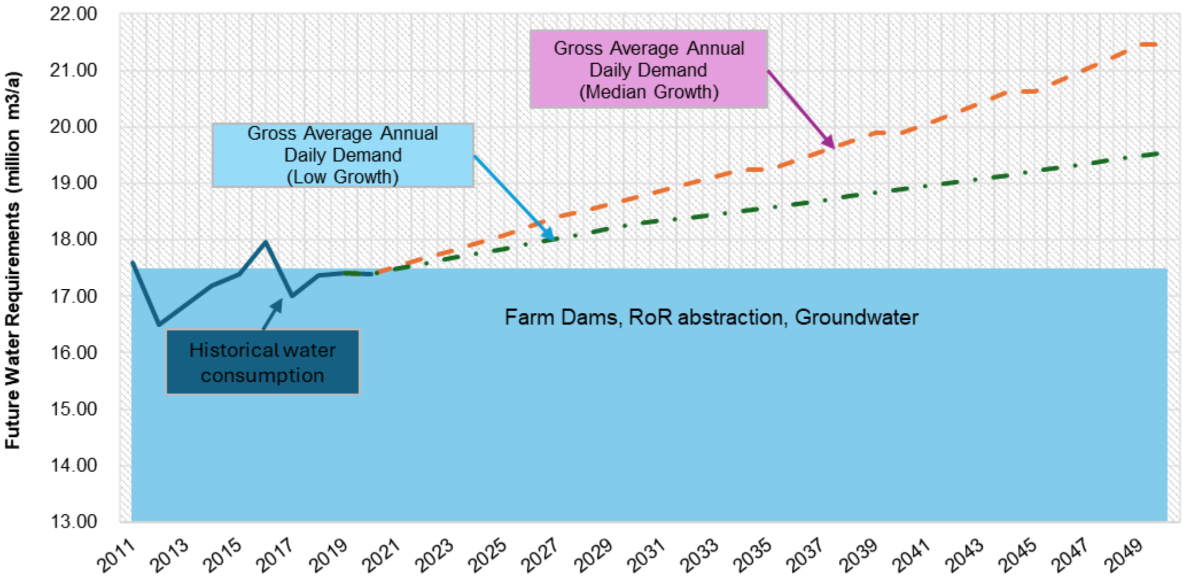


Figure 4-2: Comparison of the future water requirements and available water resources in the Lower Lephalala IUA.

4.3.2 Upper Nyl & Sterk IUA

The future water requirements of the Upper Nyl & Sterk IUA are driven by growth in the population of the area. Due to the limited local water resources available to meet any increase in irrigation agriculture, it has been assumed that the water requirements for irrigation agriculture will remain the same over the planning period until 2050. An increase in the area under irrigation would be due to increased irrigation efficiency. The water requirements for irrigation agriculture in the Upper Nyl & Sterk IUA is expected to be capped at 5.09 million m^3/a. The domestic water requirements including water requirements for the mining activities are however expected to grow over the planning period. For the domestic sector the water requirement is expected to grow at an annual rate of growth of 2.24% per annum from 10.26 million m^3/a to approximately 22.41 million m^3/a. Water requirements for the mining activities are expected to grow from 10.64 million m^3/a to 16.28 million m^3/a at an annual average rate of growth of 1.43% per year.

Figure 4-3 presents a comparison of the future water requirements with the available water resources in the Upper Nyl & Sterk IUA. As presented in the figure below, the water requirements projections are likely to exceed the available water resources by 2030 hydrological year.

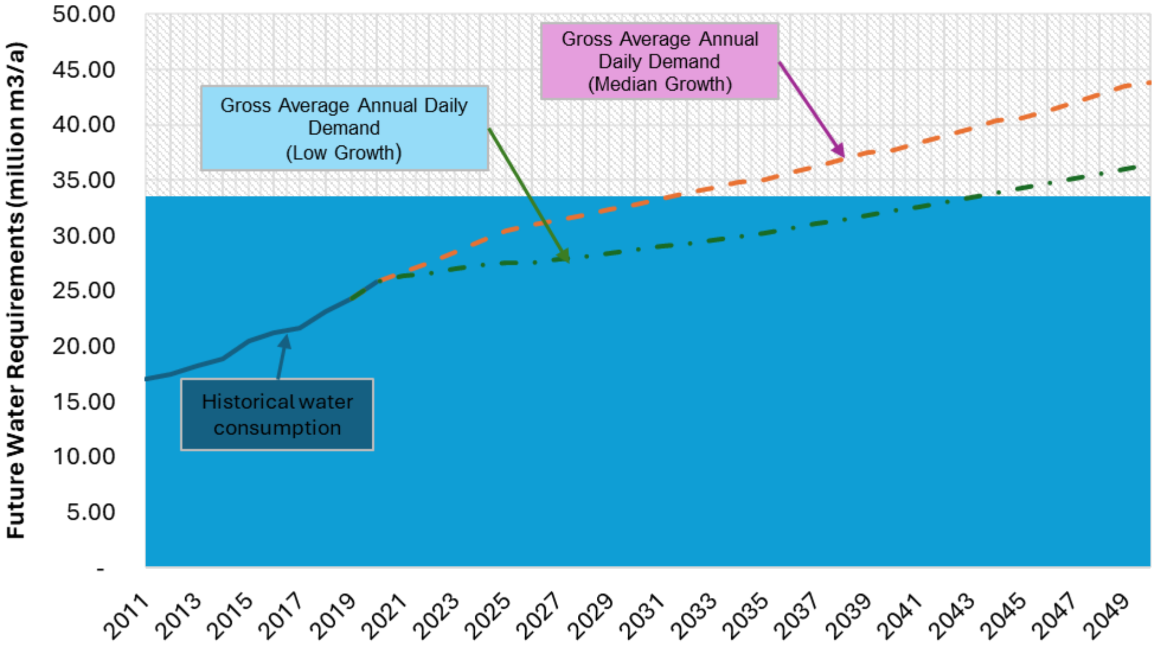


Figure 4-3: Comparison of the future water requirements and available water resources in the Upper Nyl & Sterk IUA

4.3.3 Mogalakwena IUA

The future water requirements of the Mogalakwena IUA are driven by growth in the population of the area. Due to the limited local water resources available to meet any increase in irrigation agriculture, it has been assumed that the water requirements for irrigation agriculture will remain the same over the planning period until 2050. An increase in the area under irrigation would be due to increased irrigation efficiency. The water requirements for irrigation agriculture in the Mogalakwena IUA is expected to be capped at 57.39 million m^3/a. Water requirements for livestock farming was also capped at 3.59 million m^3/a. The domestic water requirements are however expected to grow over the planning period at an annual rate of growth of 1.50% per annum from 3.34 million m^3/a to approximately 5.22 million m^3/a. There are no major mining activities currently proposed for the Mogalakwena IUA.

Figure 4-4 presents a comparison of the future water requirements with the available water resources in the Mogalakwena IUA. As presented in the figure below, the water requirements projections currently exceeding the available water resources at the level of assurance of supply. It may be an indication of the restrictions being imposed on the Glen Alpine Dam of 100% with irrigators depended on groundwater mainly. If no additional water is made available, there will be increased water restrictions on the domestic water users with increasing lower level of service provision.

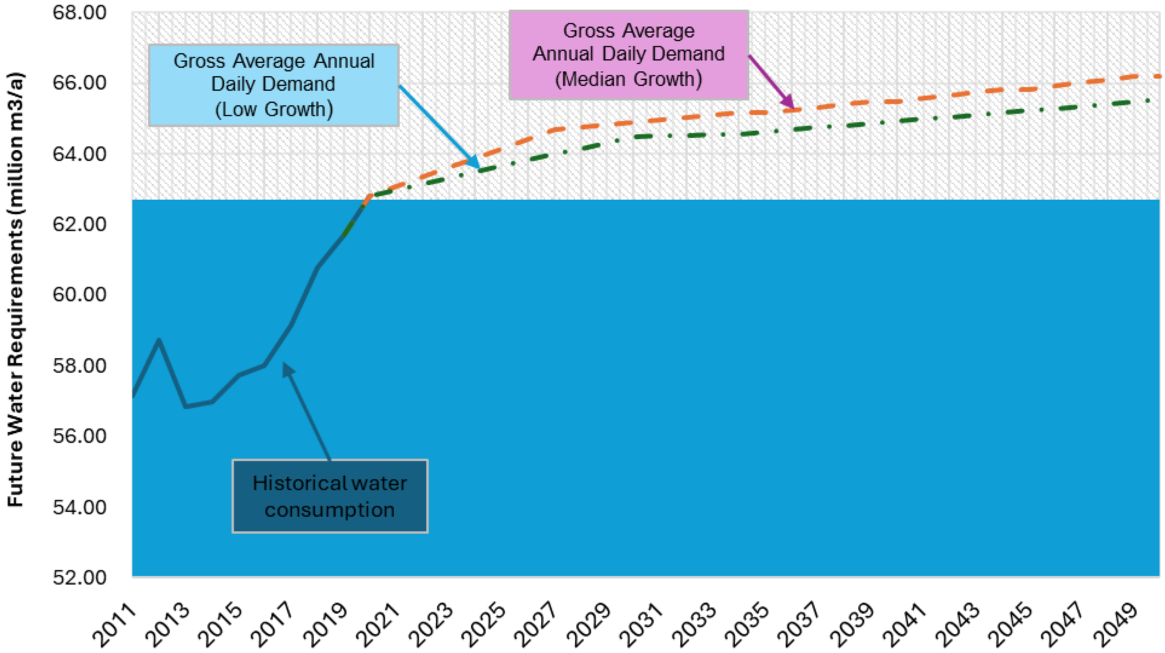


Figure 4-4: Comparison of the future water requirements and available water resources in the Mogalakwena IUA.

4.3.4 Upper Sand IUA

The future water requirements of the Upper Sand IUA are driven by growth in the population of the area particularly in the city of Polokwane and surrounds. Due to the limited local surface water resources available to meet any increase in irrigation agriculture, it has been assumed that the water requirements for irrigation agriculture will increase only slightly over the planning period until 2050, and are expected to be capped at 16.09 million m^3/a.

The domestic water requirements including water requirements for the mining activities are however expected to grow over the planning period. For the domestic sector the water requirement is expected to grow at an annual rate of growth of 3.0% per annum for a median growth scenario, from 40.99 million m^3/a to approximately 89.35 million m^3/a. Water requirements for mining and industrial activities taking place in the Upper Sand IUA is expected to grow at an annual rate of growth of 4.96% per year from 5.10 million m^3/a to 23.65 million m^3/a by 2050.

Figure 4-5 presents a comparison of the future water requirements with the available water resources in the Upper Sand IUA. As presented in the figure below, the water requirements projections are likely to exceed the available water resources by 2030 hydrological year.

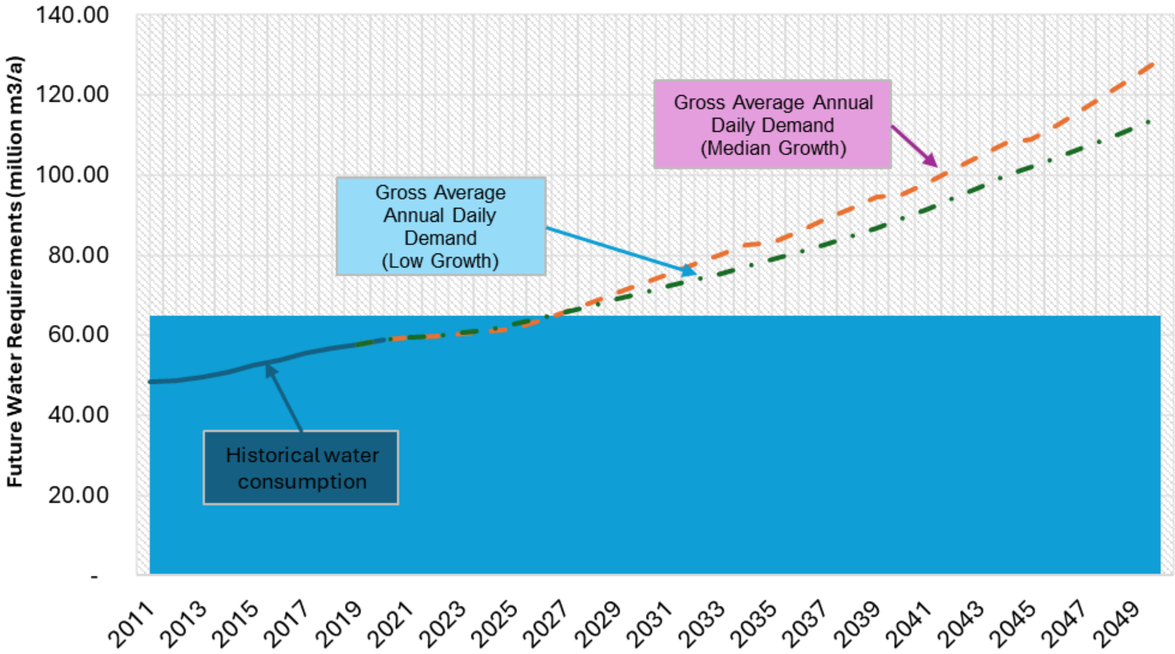


Figure 4-5: Comparison of the future water requirements and available water resources in the Upper Sand IUA.

4.3.5 Lower Sand IUA

Due to the limited local water resources available to meet any increase in irrigation agriculture, it has been assumed that the water requirements for irrigation agriculture will remain the same over the planning period until 2050. Any increase in the area under irrigation would be due to increased irrigation efficiency. The water requirements for irrigation agriculture in the Lower Sand IUA is expected to be capped at 116.79 million m^3/a. This includes water requirements for livestock farming in the area.

The future water requirements of the Lower Sand IUA are expected to be driven by growth in the population of the area due to the Musina-Makhado Special Economic Zone (MMSEZ). The growth in industries in both the Musina and Makhado sites will have a significant bearing on the water requirements for the Lower Sand IUA. The domestic water requirements are expected to grow over the planning period at an annual rate of growth of 2.1% per annum for a median growth scenario, from 7.51 million m^3/a to approximately 18.45 million m^3/a by 2050.

Water requirements for the industries and existing mining activities is expected to increase significantly if the MMSEZ is successfully implemented as the proposed power station and major industries will require cooling water and water for production over the period. This is expected to increase from 6.59 million m^3/a to 95.0 million m^3/a at an annual rate of growth of 10.5% per year over the planning period.

Figure 4-6 presents a comparison of the future water requirements with the available water resources in the Lower Sand IUA. As presented in the figure below, the water requirements projections are expected to exceed the available water resources at the required level of assurance of supply for the different water use sectors. It may be an indication of the restrictions being imposed on the Albasini Dam for the irrigators. The assurance of water supply for the irrigation agriculture has decreased because of the limited water resources and over-abstraction of groundwater. If no additional water is made available, there will be increased water restrictions on the domestic water users with increasing lower level of service provision.

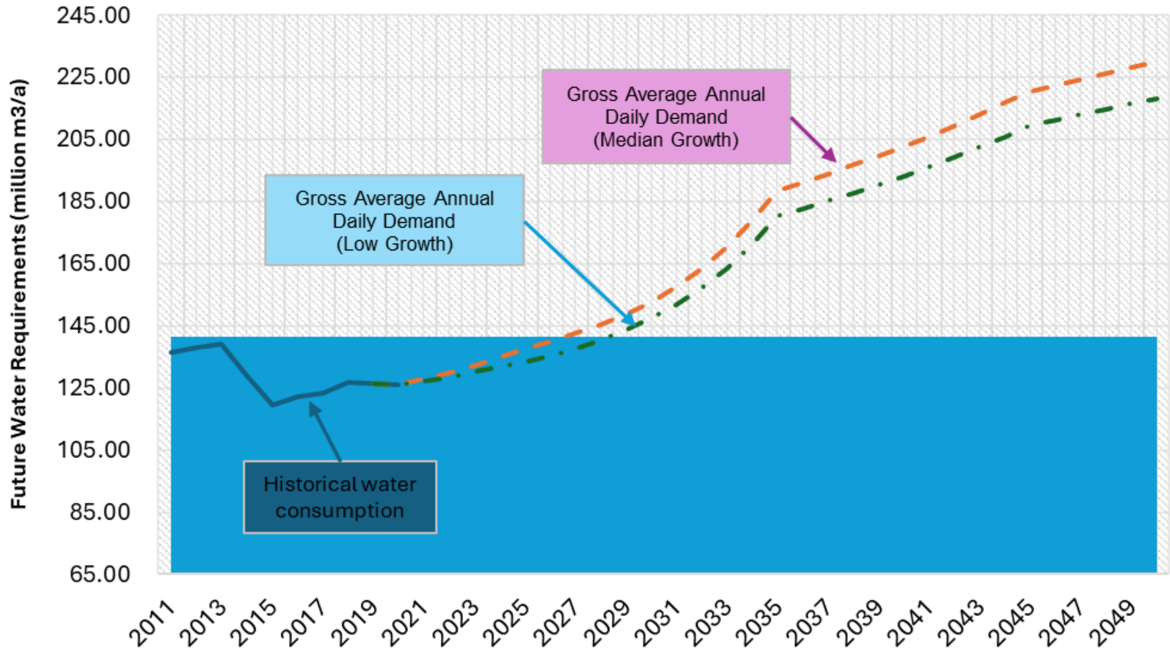


Figure 4-6: Comparison of the future water requirements and available water resources in the Lower Sand IUA

4.3.6 Nzhelele/Ṅwaneḓi IUA

The future water requirements of the Nzhelele/Ṅwaneḓi IUA are driven by the potential development of coal mines as well as growth in the population of the area. Due to the limited local surface water resources available to meet any increase in irrigation agriculture, it has been assumed that the water requirements for irrigation agriculture will remain the same over the planning period until 2050. Any increase in the area under irrigation will be attributed to increased irrigation efficiency. The water requirements for irrigation agriculture in the Nzhelele/Ṅwaneḓi IUA is expected to be capped at 38 million m^3/a. Most of the irrigation agriculture is taking place in the Nzhelele Irrigation District, which is located downstream of Nzhelele Dam, the main water supply for the irrigators.

The domestic water requirements including water requirements for the mining activities are however expected to grow over the planning period. For the domestic sector the water requirement is expected to grow at an annual rate of growth of 1.87% per annum for a median growth scenario, from 8.02 million m^3/a to approximately 14.44 million m^3/a. Water requirements for mining and industrial activities taking place in the Mutamba River, a tributary of the Nzhelele River catchment is expected to grow at an annual rate of growth of 5.6% per year from 0.5 million m^3/a to 2.04 million m^3/a by 2050 as additional coal mines are opened in the upper catchments. The coal field extends into the Lower Sand IUA.

Figure 4-7 presents a comparison of the future water requirements with the available water resources in the Nzhelele/Ṅwaneḓi IUA. As presented in the figure below, the water requirements projections are likely to exceed the available water resources by 2030 hydrological year.

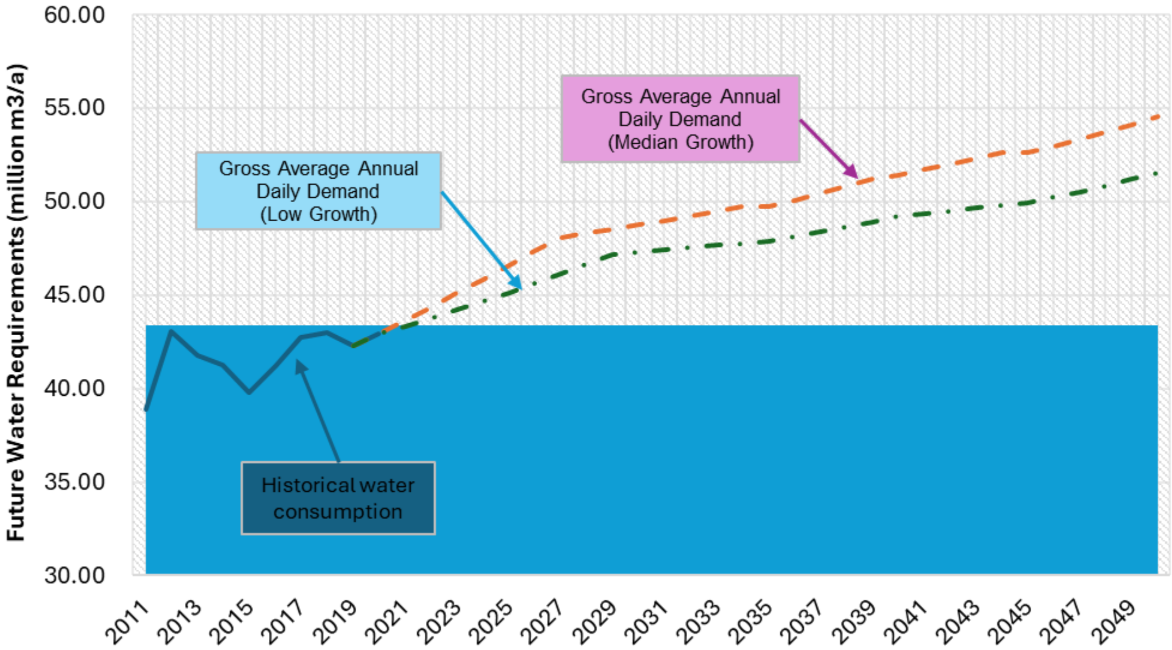


Figure 4-7: Comparison of the future water requirements and available water resources in the Nzhelele/Ṅwanedi IUA

4.3.7 Upper Luvuvhu IUA

Due to the limited local surface water resources available to meet any increase in irrigation agriculture, it has been assumed that the water requirements for irrigation agriculture will increase slightly over the planning period until 2050 in the Upper Luvuvhu IUA. The water requirements for irrigation agriculture in the Luvuvhu and downstream of Nandoni Dam is expected to be capped at 46.19 million m^3/a. Most of the irrigation agriculture is taking place in the Luvuvhu Irrigation District, which is located downstream of Albasini Dam, the main water supply for the irrigators. For the domestic sector the water requirement is expected to grow at an annual rate of growth of 2.35% per annum for a median growth scenario, from 41.63 million m^3/a to approximately 83.57 million m^3/a.

Figure 4-8 presents a comparison of the future water requirements with the available water resources in the Upper Luvuvhu IUA. As presented in the figure below, the water requirements projections are likely to exceed the available water resources by 2032 hydrological year.

4.3.8 Lower Luvuvhu/Mutale IUA

The future water requirements of the Lower Luvuvhu/Mutale IUA are driven by growth in the population of the area. Water requirements for irrigation agriculture, which is dependent on run of river abstraction from the Mutale River for the Mukambani Tea Estate, has been assumed that it will remain the same over the planning period until 2050. Any increase in the area under irrigation will be attributed to increased irrigation efficiency. The water requirements for irrigation agriculture downstream of Nandoni Dam is expected to be capped at 7.5 million m^3/a. The domestic water requirements are however expected to grow over the planning period. For the domestic sector the water requirement is expected to grow at an annual rate of growth of 1.35% per annum for a median growth scenario, from 0.62 million m^3/a to approximately 0.93 million m^3/a.

Figure 4-9 presents a comparison of the future water requirements with the available water resources in the Lower Luvuvhu and Mutale IUA. As presented in the figure below, the water requirements projections are likely to exceed the available water resources by 2026 hydrological year.

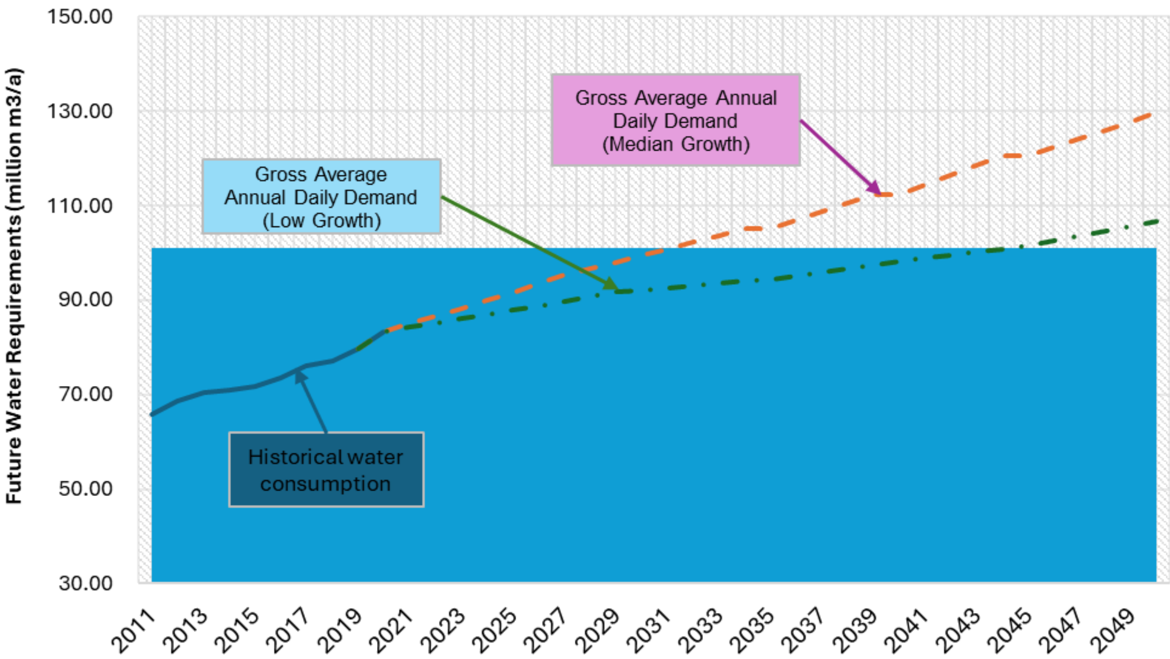


Figure 4-8: Comparison of the future water requirements and available water resources in the Upper Luvuvhu IUA.

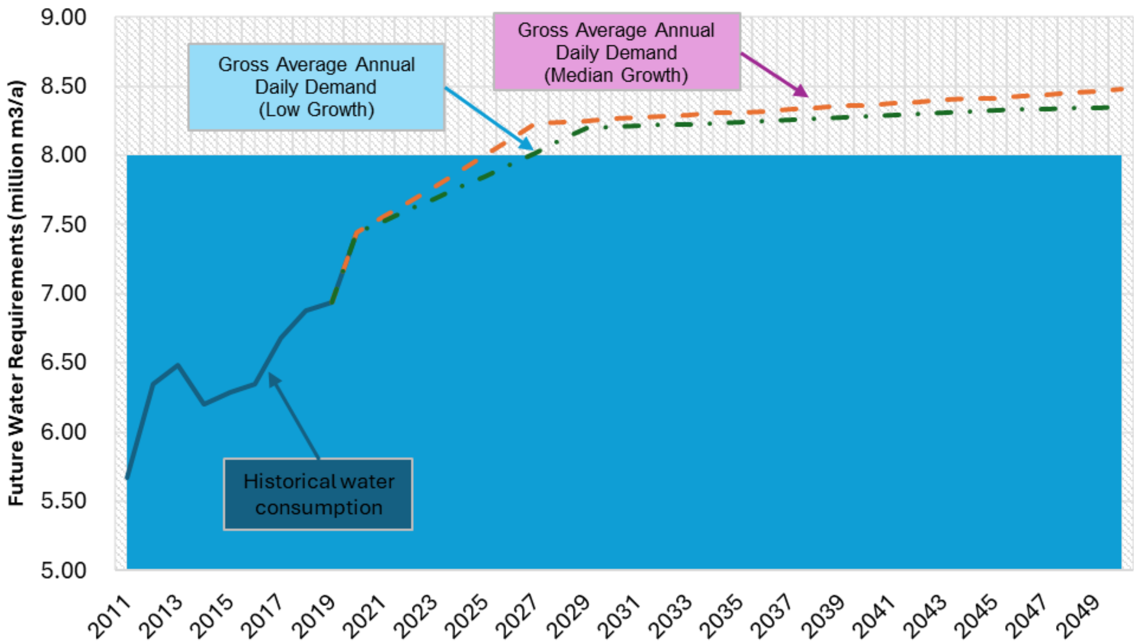


Figure 4-9: Comparison of the future water requirements and available water resources in the Lower Luvuvhu/Mutale IUA.

4.3.9 Shingwedzi IUA

The future water requirements of the Shingwedzi IUA are driven by growth in the population of the area. There is some irrigation agriculture taking place at a relatively small scale which is expected to increase slightly over the planning period from 4.2 to 4.7 million m^3/a. The domestic water requirements are expected to grow over the planning period at an annual rate of growth of 2.35% per annum for a median growth scenario, from 7.5 million m^3/a to approximately 15.06 million m^3/a.

Figure 4-10 presents a comparison of the future water requirements with the available water resources in the Shingwedzi IUA. As presented in the figure below, the water requirements projections are currently exceeding the available water resources at the level of assurance of supply for the domestic sector of 1 in 50 years risk of failure.

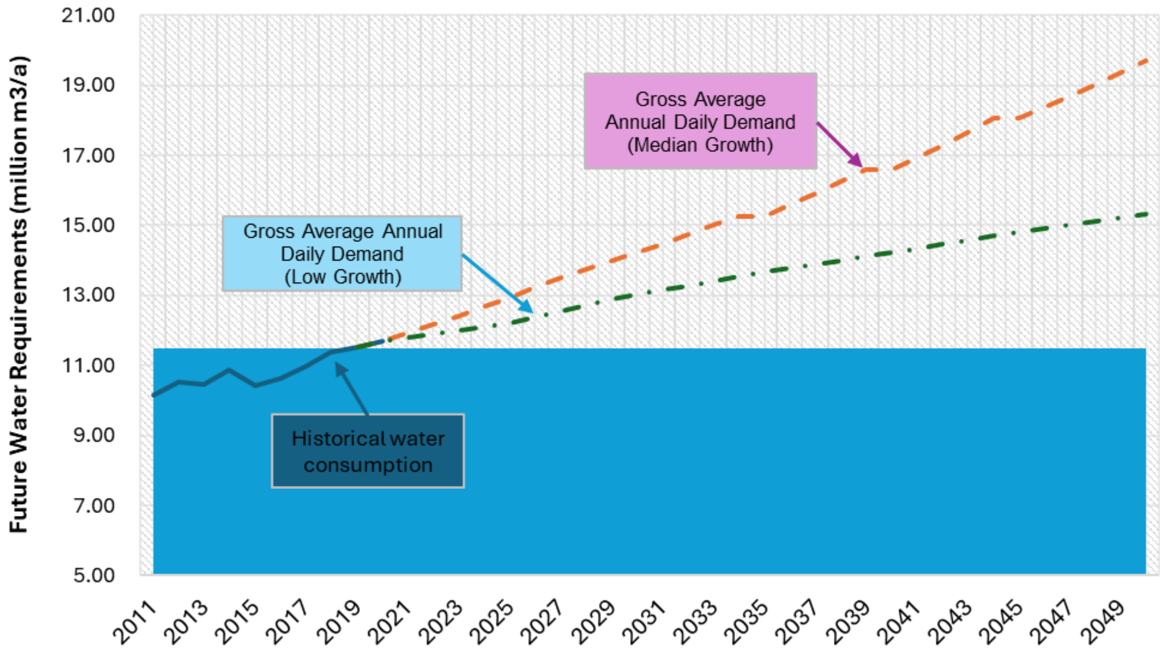


Figure 4-10: Comparison of the future water requirements and available water resources in the Shingwedzi IUA.

4.4 Potential development options and capital infrastructure requirements

A summary of the potential development options and the capital investment requirements needed to meet the future water requirements are shown in Table 4-9. These represent the potential development options that are currently being considered for the study area but are at different stages of technical and financial feasibility. The capital investment requirements for the proposed water supply infrastructure are significant. The total capital investment required for each development option was calculated and an updated Unit Reference Value (URV – Rm/^{3}) calculated for each option. This was done using discount rates of 6%, 8% and 10%. Here the URV using an 8% discount rate is presented. These URV's were used to estimate the cost of supplying the additional water needed for meeting future demands (domestic/urban, irrigation agriculture, mining and industry) and/or for meeting EWR requirements under the alternative scenarios. These potential development options are discussed briefly for each IUA below.

No major development options were identified for the Lephalala Catchment. The future water requirements in both the Upper and Lower Lephalala IUAs are expected to be met by the development of groundwater to meet the growing domestic water requirements including any increasing levels of water service provision.

Table 4-9: Potential development options and the capital investment requirements needed to meet the future water requirements.

IUA	Development Option	Name	Additional water that could be supplied (Mm^3/a)	Total Capital Investment R million	URV @8% (R/m^3)
Upper Nyl & Sterk	Water transfer	Klipvoor Dam - Upper Nyl	6.9	2,238.0	12.2
	Water transfer	Flag Boshielo to Mogalakwena Municipality	3.4	527.5	5.7
Mogalakwena	Groundwater		3.5	87.1	0.8
Upper Sand	Water transfer	Nandoni Dam to Polokwane	64.4	9,795.4	5.7
Lower Sand	Dam	Musina Dam (no pumped scheme)	13.0	2,600.0	7.5
	Dam	Musina Dam off channel storage	44.0	11,440.0	9.7
	Dam	Sand River Dam	223.0	44,154.0	11.8
	Water transfer	From Beit Bridge Zim	15.0	2,970.0	11.8
Nzhelele / Ṅwanedi IUA	Dam	Mutamba River	2.1	556.5	9.9
	Water conservation + demand management	Refurbishment of irrigation canals	6.2	1,050.5	6.3
Upper and Lower Luvuvhu/Mutale IUA	Dam	Paswane Dam	43.0	4,515.0	3.0
	Dam	Tswera Dam	53.0	5,512.0	3.4
	Dam	Rambuda Dam	16.7	3,907.8	13.9
	Dam	Thengwe Dam	51.0	5,559.0	4.1

There are some potential development options that were identified for the Mogalakwena Catchment particularly to meet the growing domestic and industrial water requirements in the Upper Nyl & Sterk River. The future water requirements for domestic water use in the Mogalakwena IUA is expected to be met by the development of groundwater. Two potential water transfers into the Upper Nyl & Sterk River were identified to meet growth of the domestic, industrial and mining water requirements in the area. These include the following:

1. Development of a water transfer scheme from Klipvoor Dam to Modimole to meet the additional 10.28 million m^3/a, for the domestic, industrial and mining activities. This includes construction

of a 78 km bulk pipeline from the dam to Modimolle and upgrading of the existing water treatment works and related bulk distribution networks.

2. Transfer of water from Flag Boshielo Dam. This will include construction of a bulk pipeline to Mookgopong and surrounding mines.

There are no plans for the development of local water resources in the Upper Nyl & Sterk IUA. However, there will be additional groundwater development that is likely to take place in the IUA.

There are several potential development options that were identified for the Sand River Catchment particularly to meet the growing domestic and industrial water requirements in the Upper Sand as well as the Lower Sand IUA. This will be supplemented by the development of groundwater resources to meet the future water requirements in the rural communities and small towns located in the Sand River catchment. One potential water transfer into the Upper Sand IUA was identified to meet growth of the domestic, industrial and mining water requirements in the area. This includes construction of a bulk water supply pipeline from the existing Nandoni Dam to the Polokwane urban development complex and surrounds.

With the development of the MMSEZ in Musina (known as Site 1) which has been gazetted and in Makhado (known as Site 2) which has not been gazetted, the following potential development options have been identified. These include the following:

1. Construction of dams in the Lower Sand Catchment near Musina Dam. The first option will be without pumping from the Limpopo River to augment the limited water resources of the Sand River upstream with the confluence of the Limpopo River.
2. The second option is to construct a weir in the Limpopo River and pump the excess flood waters in the proposed Musina Dam. The pumped storage scheme will improve the yield of the dam from 13 million m^3/a to 57 million m^3/a.
3. Construction of a dam in the Sand River upstream of the proposed Musina Dam. This will have a historical firm yield (HFY) of 223 million m^3/a. There are however issues with the lifecycle of the dam due to high sedimentation rates in the Sand River catchment.
4. Construction of dam in the Mutale River to meet the local water requirements as well as to augment the water requirements of the MMSEZ in Musina depending on the useful life of the proposed Musina Dam.
5. A bilateral agreement between South Africa and Zimbabwe to transfer water from the Beitbridge Water Treatment Works to Musina of an amount of 15 million m^3/a.

There are not many potential development options that were identified for the Nzhelele/Ṅwaneḓi Catchment. The potential development option(s) focus on meeting the water requirements for the proposed coal mines in the area. The future water requirements for the domestic water are envisaged to be met by the development of the groundwater resources in the catchments. There are no major towns in the IUA. There are mainly rural communities and small towns located in the Nzhelele and Ṅwaneḓi River catchment. A potential development and a demand management option was identified to meet future water requirements for the proposed development of coal mines in the Upper Nzhelele River catchment. These include the following:

1. Construction of dam in the Mutamba River, a tributary of the Nzhelele near Musina Dam. This will have a storage capacity of 5.27 million m^3 and a history firm yield (HFY) of 2.10 million m^3/a.

This is an option for meeting the water requirements for cooling of pumps and dust suppression, etc.

2. From a demand management perspective, there is significant transmission water losses from the irrigation canals supplying irrigators in the Nzhelele Irrigation District. The water management plan undertaken for the scheme determined that the avoidable losses were 6.24 million m^3/a in 2012 financial year. Refurbishment of the irrigation canals will save the avoidable losses that can be made available for the water requirements of the mining and industrial sectors in the Nzhelele catchment.

In the Luvuvhu and Mutale River Catchments there is the proposed development of the Rambuda Dam in the Upper Mutale River which is planned to meet the local future water requirements as well as for transfer of water to site 1 of the MMSEZ as discussed in the Lower Sand IUA. There are four other potential dams that can be developed in the Lower Luvuvhu and Mutale catchments:

1. Luvuvhu Catchment – one potential dam site was identified:
    a. Paswane Dam on the Mutshindudi River, a tributary of the Luvuvhu River. The proposed dam will have a yield of 55 million m3/a at 1 in 50 years risk of failure.
2. Mutale Catchment – two potential dam sites were identified in addition to the Rambuda Dam that was discussed in the Lower Sand catchment. The other two potential dam sites include the following:
    a. Tswera Dam on the Mutale River. The proposed dam will have a yield of 62.1 million m^3/a at 1 in 50 years risk of failure.
    b. Thengwe Dam in the Lower Mutale River. The proposed dam is to meet any water requirements for mining activities in the area. It will have a historical firm yield of 51 million m^3/a.

It is important to note that not all the dams can be developed. The final decision will depend on the future water requirements, the technical and financial viability of each proposed option.

There are no potential water resource development options that were identified for development in the Shingwedzi Catchment. The development options identified in the Luvuvhu and Mutale will provide the additional water needed to meet the future water requirements in the Shingwedzi catchment. This will be mainly for domestic and industrial water use sectors.

4.5 Approach taken in evaluating the flow scenarios, and the management options available to address these flows.

The results and assumptions made for each of the scenarios at the different nodes of the IUAs are discussed in the following sections.

4.5.1 Changes in flow and management options in the Upper and Lower Lephalala IUA

In the Upper Lephalala IUA, the flows for the STCD scenario were the same as for the development scenario. However, for the BE scenario an average increase in flow of 1.38 million m^3/a is required to meet the EC for the river reach at the node. Because the nodes in the Upper Lephalala are sequential to the nodes in the Lower Lephalala, the node driving the additional water was determined to be node Ri8, in the A50H quaternary catchment. For the STCD and BE scenarios the additional water required to improve the EC was provided.

Table 4-10 presents a summary of the additional average flows required at node Ri8 and the water that can be made up from implementing the management options which include reducing the water losses, and the increasing return flows upstream of the node.

As presented in Table 4-10, the management options will make up a total of 3.73 million m^3/a as less run of river abstraction is made upstream and the increased discharge from the wastewater treatment works (WWTW) upstream of the node. It is however important to note that the quality of the effluent discharge has generally been very poor. The adjusted flows can be met with the recommended management options.

Table 4-10. Summary of the additional flows and management options in the Upper & Lower Lephalala Catchment (units in million m^3/a).

IUA	Management Options			Average Additional Flows		
	WC/WDM	Removal of IAPs	Return Flows Upstream of Key Node	Total	STCD	BE
Upper Lephalala	0.52			0.52		
Lower Lephalala	0.82		2.39	3.21	0.89	1.04
Sub-Total Savings	**1.34**	**-**	**2.39**	**3.73**		

4.5.2 Changes in flow and management options in the Upper Nyl & Sterk and Mogalakwena IUA

In the Upper Nyl and Sterk, there are two river reaches that were evaluated, namely the Sterk River and the Nyl River before it confluences with the Mogalakwena River. In the Sterk River, two key nodes were identified. These were the Rvii4 upstream of Doorndraai Dam and Ri4 just upstream of the confluence with the Mogalakwena River. In the case of the Upper Nyl, node Riii1 was determined to be the critical node based on the additional/increased flows required to improve the ecological categories of these river reaches.

The increased flows were compared with the potential management options that can free up water in the Sterk River as well as the Upper Nyl River. Table 4-11 presents a summary of the water that can be freed up from implementing WC/WDM intervention in Modimolle and surrounds as well as the increased return flows that will be returned to the Upper Nyl River upstream of the key nodes. The total volume that can be made up of 10.58 million m^3/a is comparable to the increased flows required to improve the EC for both the STCD as well as the BE scenario. This is even more than the adjusted increased flows as indicated in Table 4-11.

Table 4-11: Summary of the Additional Flows and Management Options in the Upper Nyl & Sterk and Mogalakwena IUA (units in million m^3/a).

IUA	Driver Node(s)	Management Options			Average Additional Flows	
		WC/WDM	Return Flows Upstream of Key Node	Total	STCD	BE
Upper Nyl & Sterk	Sterk River - Rvii4			-	4.59	4.59
	Sterk River - Ri4			-	1.84	5.09
	Upper Nyl- Riii1	2.69	7.89	10.58	0.72	0.07
Mogalakwena	Mogalakwena - Rii3	7.94	23.30	31.25	2.87	3.96

For the Mogalakwena River, the key node is in the lower Mogalakwena just before its confluence with the Limpopo River. This is node Rii3. The additional water required for STCD and BE scenario was provided to be 16.06 million m^3/a, and 24.38 million m^3/a respectively. The water that can be freed up from implementing WC/WDM interventions, as well as increased return flows from the WWTW was estimated to 31.25 million m^3/a. This is comparable to the increased flows required to achieve both the STCD and the BE scenario. The adjusted flows will provide a conservative approach if the water that can be freed up cannot be achieved.

4.5.3 Changes in flow and management options in the Upper and Lower Sand IUA

There are two IUAs in the Sand River catchment. In the Upper Sand, the development scenario will require an interbasin transfer (IBT) from a neighbouring catchment. This will result in increased return flows from the WWTWs in the Upper Sand catchment. The increased flows into the river reaches is not required to improve the EC of the Upper Sand catchment.

Table 4-12 below illustrates that for the STCD scenario no additional water is required while for the BE scenario approximately 28.06 million m^3/a needs to be taken out of the return flows. The increased return flows will also flow into the Lower Sand catchment with further increases taking place as the return flows from Makhado are discharged into the A71H quaternary catchment. The adjusted water that is required to be taken out through water reuse is presented in Table 4-12.

In order to address the excess return flows, it is recommended that a water reuse scheme is developed by Polokwane Local Municipality. The scheme is estimated to have a capacity of 20.07 million m^3/a, or a 55 Ml/d reuse plant (see Table 4-12 below). There is also potential to develop another water reuse scheme in Makhado. These two water reuse schemes could address the problem of excess flow and potentially the water quality issues currently being experienced by water users in the Sand River catchment.

Table 4-12: Summary of the Additional Flows and Management Options in the Upper and Lower Sand IUA (units in million m^3/a).

IUA	Driver Node(s)	Management Options				Average Additional Flows	
		WC/WDM	Return Flows Upstream of Key Node	Water Reuse Scheme Option	Total	STCD	BE
Upper Sand	Sand River - Ri16	10.72	31.45	20.07	42.17	-11.38	-24.00
Lower Sand	Sand River - Ri22					-11.38	- 22.75
	Sand River - Ri25	2.21	6.50		8.71	-0.91	1.80
Sub-Total Savings		**12.94**	**37.95**	**20.07**	**50.88**		

4.5.4 Changes in flow and management options in the Nzhelele and Nwanedi IUA

In the Nzhelele/Nwanedi IUA there are two river reaches that were evaluated, namely the Nzhelele River and the Nwanedi River before they confluence with the Limpopo River. In the Nzhelele River, two key nodes were identified. These were the Ri26 immediately downstream of the confluence of Mutamba and Nzhelele Rivers and Ri27 which is downstream before the confluence with the Limpopo River. The increased flows required to improve the ecological category at the nodes are presented in Table 4-13 below. In the Nzhelele River there is potential to reduce the water losses on the irrigation scheme by refurbishing the canal infrastructure and implementing WC/WDM in the domestic sector. The growth in water requirements for the domestic sector will increase the return flows as provided in the table.

For the STCD scenario, the increased flow required can be achieved if the refurbishment of the irrigation canals is undertaken. Without it, the increased flows for the STCD cannot be met. However, when these are adjusted the recommended management options will provide the water needed over the planning period.

For the BE scenario, the flows are much higher on the two nodes in the Nzhelele River. Even with the refurbishment of the irrigation canals undertaken the make-up water from these management options cannot meet the additional flows. However, when the flows for the BE scenario are adjusted, the recommended management options will provide the make-up water over the planning period to achieve the flow related objectives of the BE scenario.

The increased flows at node Ri 28 on the Nwanedi River would increase the make-up water required by 3.77 million m^3/a for the STCD and 10.16 million m3/a for the BE scenario. However, the adjusted increased flows together with the adjusted increased flows for Nzhelele can be met with the recommended management options

Table 4-13. Summary of the Additional Flows and Management Options in the Nzhelele and Nwanedi IUA (units in million m³/a).

IUA	Driver Node(s)	Management Options			Average Additional Flows	
		WC/WDM	Return Flows Upstream of Key Node	Total	STCD	BE
Nzhelele	Nzhelele River - Ri26	1.73		1.73	1.64	3.51
	Nzhelele River - Ri27	6.20	5.08	11.28	1.61	7.51
Nwanedi	Nwanedi River - Ri28			-	1.91	3.99
	Sand River - Ri25					
Sub-Total Savings		**7.93**	**5.08**	**13.01**		

4.5.5 Changes in flow and management options in the Luvuvhu and Mutale IUA

In the Luvuvhu and Mutale IUA there are two river reaches that were evaluated, namely the Luvuvhu River, split into Upper and Lower Luvuvhu River and the Mutale River before they confluence with the Luvuvhu River. In the Upper Luvuvhu River mainstem, the key node identified was the Rvii24 immediately downstream of the Nandoni Dam. The requirements for the different scenarios can be managed by making releases from Nandoni Dam. However, this will need to be modelled as there is significant transfers from the dam and the increased flows as presented in Table 4-14 may have a significant effect on the available yield for these transfers. The other node is on the tributary of the Upper Luvuvhu River, node Ri30. The increased flows cannot be met by releases as there are no developments in the tributary.

In the Lower Luvuvhu mainstem, the node just before the confluence of the Mutale was considered the critical node, node Ri35. In the Mutale River the node just before the confluence with the Luvuvhu River was considered critical. This is node Ri34.

The increased flows required to improve the ecological category at the nodes in the Luvuvhu and Mutale Rivers are presented in Table 4-14 below for the STCD and BE scenarios. In the Upper Luvuvhu there is potential to reduce the water losses on the irrigation scheme by refurbishing the canal infrastructure and implementing WC/WDM in the domestic sector. The growth in water requirements for the domestic sector will increase the return flows as provided in the table.

For the STCD scenario, the increased flows required in the Upper Luvuvhu River cannot be achieved with the water loss reduction and increased return flows. However, when these are adjusted the recommended management options will provide the make-up water over the planning period.

For the BE scenario, the flows required in the Upper Luvuvhu are much higher. The savings from WC/WDM and the increased return flows will not make-up the water required to meet the BE additional flows. However, when the flows for the BE scenario are adjusted, the recommended management options will provide the make-up water over the planning period to achieve the flow related objectives of the BE scenario.

Table 4-14: Summary of the Additional Flows and Management Options in the Luvuvhu and Mutale IUA (units in million m³/a).

IUA	Driver Node(s)	Management Options			Average Additional Flows	
		WC/WDM	Return Flows Upstream of Key Node	Total	STCD	BE
Upper Luvuvhu	Luvuvhu River - Rvii24	10.03	29.42	39.44	20.83	20.83
	Mutshindudi River - Ri30			-	0.00	0.60
Lower Luvuvhu	Lower Luvuvhu River - Ri35	0.11	0.33		18.14	52.20
Mutale	Mutale River -Ri34			-	2.35	19.58
Sub-Total Savings		**10.14**	**29.74**	**39.44**		

For the STCD scenario, the increased flows required in the Lower Luvuvhu cannot be achieved with the water loss reduction and increased return flows. The additional water can be achieved through releases from Nandoni Dam which will effect the available yield of transfers. However, when these additional flows are adjusted the recommended management options will provide the water over the planning period. This is because of the incremental flows from the Upper Luvuvhu River reach.

For the BE scenario, the flows required in the Lower Luvuvhu are much higher. The savings from WC/WDM and the increased return flows will not make-up the water required to meet the BE additional flows. However, when the flows are adjusted, the recommended management options will provide 76% of the make-up water over the planning period to achieve the flow related objectives of the BE scenario. The additional water will need to be released from the Nandoni Dam.

For the STCD scenario, the increased flows required in the Mutale River can only be achieved by incremental runoff from tributary inflows as there are no major developments for which WC/WDM and increased return flows can be undertaken. For the BE scenario, the flows required in the Mutale River are much higher. The tributary flows will contribute to the incremental flows.

5 IMPLICATIONS FOR ECOSYSTEMS AND ECOSYSTEM HEALTH

In presenting the results of the scenarios in Table 3-1, the IUAs have been grouped together where this makes sense, for example, because of flow links between them. For example, the two IUAs describing the Lephalala catchment are described together rather than individually. The results of the scenario analysis are presented for each IUA or group of IUAs. The scenario descriptions for surface water focus on changes in streamflow and water quality and the resulting changes in river ecological condition for each scenario as well as river linked wetlands. Condition is scored relative to the natural condition, with A being closest to natural and F being the lowest possible score. In some instances, and for certain IUAs, mention is also made of wetlands, conservation areas of importance or certain socio-economic factors, as appropriate. The ecological condition at the river nodes (Sections 5.1.1 - 5.8.1) is a combined score that shows how the ecological condition of the river is predicted to change in response to changes in flow and water quality. The changes in water quality are explained in Sections 5.1.3 - 5.8.3. The monthly flow volumes at each river reach for each scenario are shown graphically in Appendix 1.

5.1 Upper and Lower Lephalala IUAs

There are five nodes in the Upper Lephalala IUA and one node in the Lower Lephalala IUA. The predicted ecological condition as a result of changes in flow and water quality (see Table 5.4) at each node under each scenario is shown with the annual volume (in MCM) in Table 5.1.

Table 5.1. Annual volume (MCM), and river condition (A to F) at each node for all scenarios for the Upper and Lower Lephalala IUAs.

		Nat	PES		ESBC		DEV		STCD		BE	
Node	**River**	**Vol**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**
Upper Lephalala IUA												
Riv8	Lephalala	32.56	22.92	B	16.97	C	20.02	B/C	20.02	B/C	22.92	B
Riv11	Lephalala	67.63	56.15	C	45.69	C	53.15	C	53.15	C	56.06	C
Riv10	Melk	14.86	12.42	C	9.77	C	12.22	C	12.22	C	12.22	C
Riv13	Boklandspruit	13.27	12.83	B	7.80	C/D	12.83	B	12.83	B	12.83	B
Riii3	Lephalala	122.93	96.35	D	90.37	D	93.08	D	93.08	D	95.99	D
Lower Lephalala IUA												
Ri8	Lephalala	139.46	95.62	C	98.64	C	91.89	C	97.21	C	98.14	C

5.1.1 Rivers

River flows were reduced by 9.1% relative to current flows under the ESBC scenario (Figure 5.1) and the river health of two reaches was predicted to deteriorate from B category to C and C/D category (Figure 5.2). Flows under the BE scenario were higher by 0.6% and the river health predicted to be the same as the PES scenario. The DEV scenario reduced flow by 4.4%, which cause one reach to drop from a B to a B/C category. River health was the same for the STCD as the DEV scenario but there was less of a change in flow overall – it reduced by only 2.6%.

The STCD scenario targeted the REC of a B/C category at Riv11 (EWR site 1_Lephalala), but it was not possible to improve the PES of a C category by increasing flow alone because the issues at the site are non-flow related. The management recommendations to achieve the REC require clearing exotic vegetation and re-stocking indigenous fish.

The REC of a C category at Ri8 (LIMCOM site LEPH-A50H-SEEKO) was met by the PES, ESBC, DEV and STCD scenarios. The EWRs set at this site must be met at its confluence with the Limpopo River, *i.e.* must flow into the Limpopo River.

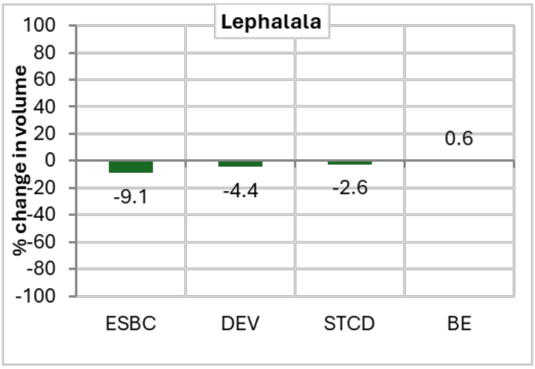


Figure 5.1. The percentage change in water volume from the PES (2022) scenario in the Upper and Lower Lephalala IUAs.

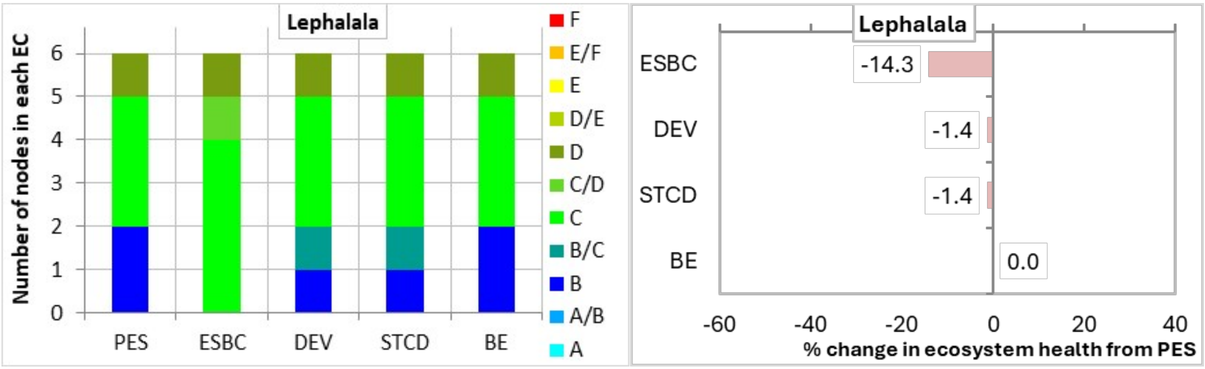


Figure 5.2. The number of nodes in each EC per scenario for the Upper and Lower Lephalala IUAs and the consequent % change in river health from PES.

5.1.2 Wetlands

The Lephalala Catchment (Upper and Lower Lephalala IUAs) have 941 ha of wetlands, which represents 1.2% of all the wetlands in the study area. The majority of these (62%) are depressional wetlands, mostly in the Lower Lephalala catchment, some of which were noted as important wetland clusters in the NFEPA data. Most of these depressional wetlands are considered to be in good condition, mostly A, B or A/B according to the wetland condition data field in the National Wetland Map 5 (Van Deventer *et al.*, 2018). Channelled and unchanneled valley bottom wetlands comprise 12% and 21% respectively of wetlands, mostly in the Upper Lephalala catchment and the National Spatial Biodiversity Assessment (Driver *et al.*, 2005) noted the Lephalala wetlands, mostly riverine wetlands comprising permanent rivers and streams, including waterfalls. Most of these wetlands either have poor condition (D/E/F) according to the wetland condition data field in the National Wetland Map 5 (Van Deventer *et al.*, 2018) or are unassessed. None of the wetlands in the Upper or Lower Lephalala catchment were highlighted as priority wetlands in this study. In terms of response of these various wetlands to different scenarios, generalised and qualitative statements have been applied to different hydrogeomorphic (HGM) types with reference to the node Ri8 for the Lower Lephalala and node Riii3 for the Upper Lephalala (Table 5-2). Generally, depressional wetlands are unaffected by scenarios as they are mostly not directly connected to the river channel, and the same for unchanneled valley bottom wetlands as these are either in headwater areas or tributaries and are less influenced by changes in flow under the scenarios.

Table 5-2. Annual volume (MCM), and river / wetland HGM condition (A to F), generalised for wetlands using applicable nodes, and representing all scenarios for the Upper and Lower Lephalala IUAs.

Ref Node	River / Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Upper Lephalala IUA												
Riii3	Lephalala	122.9	96.3	D	90.4	D	95.9	D	93.1	D	93.1	D
	Riverine			D		D		D		D		D
	Channelled valley bottom			D		D		D		D		D
	Unchanneled valley bottom			D		D		D		D		D
Lower Lephalala IUA												
Ri8	Lephalala	139.5	95.6	C	98.6	C	98.14	C	91.9	C	97.2	C
	Depressional			B		B		B		B		B

5.1.3 Water Quality

Water quality in the upper third of the Lephalala River was very good and in an Ideal category for all the constituents assessed. Occasional (< 5% of the time) elevated Orthophosphate concentrations were observed in an Acceptable category. In the lower reaches at sampling point A5H008Q01 (Ga-Seleka Village Bossche Diesch 53 LQ R572 Bridge) (A50H quaternary) water quality was Ideal for the parameters assessed although elevated Orthophosphate concentrations were observed from time to time that fell within Acceptable (75th percentile) or Unacceptable (95th percentile) categories. This could be due to agricultural return flows, domestic wastewater discharges and/or runoff from villages near the lower Lephalala River. A summary of the likely water quality outcomes for the different scenarios in the Upper and Lower Lephalala IUAs, are presented in Table 5-3.

Table 5-3. Likely water quality outcomes in the Upper and Lower Lephalala IUA

Scenario	Likely water quality outcomes
PES	Under the PES scenario with 79% allocation of natural, the overall water quality was in a B water quality category.
ESBC	With a moderate increase in allocation of 88% of natural, it was estimated that the overall river will probably remain in a B water quality category as there are no major point sources of pollution that affects quality in the river.
BE	With a slight decrease in allocation of 75% of natural, it was estimated that the overall river would probably remain in a B water quality category as there are no major point sources of pollution that affects quality in the river.
DEV	With a moderate increase in allocation of 88% of natural, it is estimated that the overall river will probably remain in a B water quality category as there are no major point sources of pollution that affects quality in the river.
STCD	With a moderate increase in allocation of 85% of natural, it is estimated that the overall river will probably remain in a B water quality category as there are no major point sources of pollution that affects quality in the river.

Table 5.4. Changes in water quality condition at the Upper and Lower Lephalala IUAs

IUA	Quat	Node	River	WQ EWR	PES	DEV	STCD	BE
Upper Lephalala IUA								
Lephalala	A50A	Riv8	Lephalala		B	B	B	B
Lephalala	A50B	Riv11	Lephalala	B	B	B	B	B
Lephalala	A50C	Riv10	Melk		B	B	B	B
Lephalala	A50D	Riv13	Boklandspruit		B	B	B	B
Lephalala	A50E	Riii3	Lephalala		B	B	B	B
Lower Lephalala IUA								
Lephalala	A50H	Ri8	Lephalala		B	B	B	B

5.1.4 Groundwater

The change in the groundwater balance under the alternative scenarios is presented in Table 5-5. The groundwater abstraction index was increased by 21.2% for the ESBC scenario. Due to the limited groundwater use no change was applied to the BE scenario. Further development of groundwater in the IUA was reflected by a classification index increase of 24.6% for the DEV scenario. At these abstraction rates potential reduction of baseflows may occur along the perennial rivers and in the upper catchment with higher probability of baseflow.

Table 5-5. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Upper and Lower Lephalala IUAs.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	32.23	34.44%		Low groundwater use
ESBC	52.08	55.66%	21.21%	Groundwater development within perennial systems (upper Lephalala) may effect baseflow
BE	32.23	34.44%	0.00%	
DEV	55.23	59.02%	24.58%	Low groundwater potential may limit groundwater development; groundwater development within perennial systems (upper Lephalala) may effect baseflow
STCD	40.93	43.74%	9.30%	Moderate/High priority areas largely in upper Lephalala.

5.1.5 EGSA

The total value of EGSA in the Upper and Lower Lephalala IUAs is some R170.7 million per year. Large parts of the Lephalala catchment are conservation areas and as such nature-based tourism is very important, particularly in the upper catchment where there are several nature reserves and private game reserves. This catchment holds approximately 6% of the riparian carbon stocks and is thus also important in terms of carbon retention and as a buffer against global climate change. This catchment is less important in terms of natural resource use and instream water use for basic human needs. The value of EGSA remains largely the same under the ESBC, DEV and STCD scenarios and increases by 14% under the BE scenario – largely due to the increases in tourism and carbon retention associated with improved river health under this scenario. Under the STCD scenario, the value of EGSA increases by 4% compared to current day. It declines by 4% under the DEV and ESBC scenarios.

5.2 Kalpan se Loop IUA

There are three river nodes in the Kalpan se Loop IUA. The predicted ecological condition as a result of changes in flow and water quality (Table 5.9) at each node under each scenario is shown with the annual volume (in MCM) in Table 5.6.

Table 5.6. Annual volume (MCM), and river condition (A to F) at each node for all scenarios for the Kalpan se Loop IUA.

		Nat	PES		ESBC		DEV		STCD		BE	
Node	River	Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Ri38	A63C Trib 1	2.08	1.37	B	0.59	D	1.37	B	1.38	B	1.38	B
Rvi15	A63C Trib 2	1.64	1.08	B	0.47	D	1.08	B	1.09	B	1.09	B
Rvi1	Rietfontein	0.19	0.13	B/C	0.08	D	0.13	B/C	0.14	B/C	0.14	B/C

5.2.1 Rivers

The ESBC scenario reduces flow by 56.0% (Figure 5.3) and is predicted to reduce the river health of two rivers from a B and B/C to a D category (Figure 5.4). There are no opportunities for increased water supply and no developments planned in this IUA so BE, DEV and STCD return the same river health as PES. The STCD scenario targeted and achieved the REC of a B/C category at Rvi1 (EWR site 2_Rietfontein).

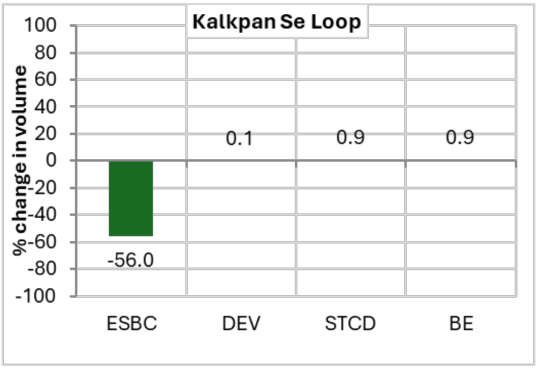


Figure 5.3. The percentage change in volume from the PES (2022) scenario in the Kalpan se Loop IUA.

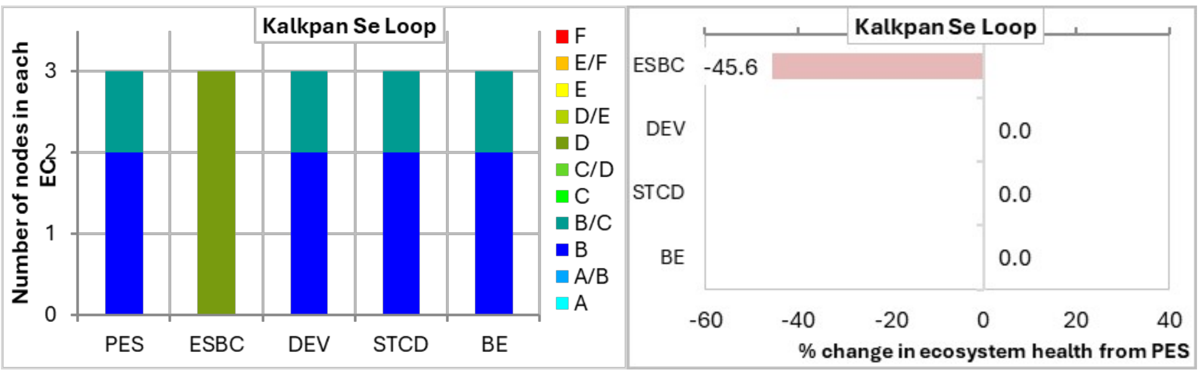


Figure 5.4. The number of nodes in each EC per scenario for the Kalpan se Loop IUA and the consequent % change in river health from PES.

5.2.2 Wetlands

The wetlands in the Kalkpan se Loop IUA are either riverine or depressional and are either unassessed for condition, or are in good condition (A, B or AB) according to the wetland condition data field in the National Wetland Map 5 (Van Deventer *et al.*, 2018). None of the wetlands in the Kalkpan se Loop IUA were highlighted as priority wetlands in this study. In terms of response of these various wetlands to different scenarios, generalised and qualitative statements have been applied to different HGM types with reference to the node Rvi1 for the IUA (Table 5-7). Generally, depressional wetlands are unaffected by scenarios as they are mostly not directly connected to the river channel, while riverine wetlands respond in similar ways to the river they are associated with, in this case node Rvi1 as a reference for riverine wetlands.

Table 5-7. Annual volume (MCM), and river / wetland HGM condition (A to F), generalised for wetlands using applicable nodes, and representing all scenarios for the Kalpan se Loop IUA.

Ref node	River/Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Rvi1	Rietfontein	0.19	0.13	B/C	0.08	D	0.14	B/C	0.13	B/C	0.14	B/C
	Riverine			B		C		B		B		B
	Depressional wetlands			B		B		B		B		B

5.2.3 Groundwater

The change in the groundwater balance according to the different scenarios is presented in Table 5-8. The groundwater abstraction index was increased by 13.9% for the ESBC scenario. Due to the limited groundwater use no change was applied to the BE scenario. No further development of groundwater in the IUA was assessed for the DEV scenario.

Table 5-8. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Kalpan se Loop IUA.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	5.97	32.29%		Low groundwater use
ESBC	8.54	46.19%	13.90%	Potential for additional abstraction with limited effect on the groundwater system.
BE	5.97	32.29%	0.00%	
DEV	5.97	32.29%	0.00%	
STCD	5.97	32.29%	0.00%	

5.2.4 Water quality

Only one perennial stream in this IUA that is fed from a spring with naturally high salinity water. Water quality status will probably remain unchanged under the different scenarios due to dry nature of the IUA and the lack of any significant change in water demand.

Table 5.9. Changes in water quality condition in the Kalk pan se Loop IUA

IUA	Quat	Node	River	WQ EWR	PES	DEV	STCD	BE
Kalkpan Se Loop	A50J	Ri38	A63C Trib 1		B/C	B/C	B/C	B/C
Kalkpan Se Loop	A50J	Rvi15	A63C Trib 2		B/C	B/C	B/C	B/C
Kalkpan Se Loop	A63C	Rvi1	Rietfontein	B/C	B/C	B/C	B/C	B/C

5.2.5 EGSA

The value of EGSA in this IUA is relatively small compared to other IUAs in the study area, amounting to R71.2 million per year. Nature-based tourism associated with private game reserves is the most important ecosystem service here. The value of EGSA declines significantly under the ESBC scenario compared to PES (-41%) and declines by 3% under DEV, highlighting the importance of maintaining river health and functioning. Under the STCD scenario values increase by 2% and by 11% under the BE scenario.

5.3 Upper Nyl and Sterk and Mogalakwena IUAs

There are nine river nodes in the Upper Nyl and Sterk IUA and ten river nodes in the Mogalakwena IUA. The predicted ecological condition as a result of changes in flow and water quality (Table 5.13) at each node under each scenario is shown with the annual volume (in MCM) in Table 5.10.

Table 5.10. Annual volume (MCM), and river condition (A to F) at each node for all scenarios for the Upper Nyl and Sterk and Mogalakwena IUAs.

		Nat	PES		ESBC		DEV		STCD		BE	
Node	**River**	**Vol**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**
Upper Nyl and Sterk IUA												
Rvii4	Sterk	35.56	22.08	E	28.77	D	22.08	E	26.67	D	26.67	D
Rv1	Sterk	39.60	12.12	E	18.81	D	7.69	E	14.62	D/E	17.82	D
Ri4	Sterk	58.17	22.84	C	23.05	C	18.59	C/D	20.43	C	23.63	C
Ri1	Olifantspruit	8.11	7.61	C	7.51	C	7.61	C	7.61	C	7.61	C
Ri1-1	Nyl	23.80	21.40	C	19.80	C	19.03	C	19.03	C	19.94	C
Riv3	Nyl	23.44	21.52	C	19.83	C	21.42	C	21.42	C	22.33	B/C
Riii1	Nyl	32.70	24.15	D	22.45	D	23.88	D	24.60	C/D	25.50	C/D
Ri3	Mogalakwena	52.78	36.84	D	35.14	D	43.66	C/D	44.97	C/D	45.88	C
Ri5	Mogalakwena	133.27	77.19	C	75.70	C	79.63	C	82.03	C	86.14	C
Mogalakwena IUA												
Riv12	Mogalakwena	136.05	79.56	C	78.07	C	82.00	C	84.40	C	86.86	C
Ri6	Mokamole	15.01	12.53	D	7.26	E	12.53	D	12.53	D	12.53	D
Rv2	Mogalakwena	161.14	100.54	C	85.52	C/D	102.72	C	105.12	B/C	107.58	B/C
Rvii12	Klein Mogolakwena	5.04	3.93	C	2.81	C/D	3.93	C	3.93	C	3.93	C
Ri10	Mogalakwena	165.59	103.42	C	87.88	C/D	105.47	C	107.87	B/C	110.33	B/C
Ri12	Matlalane	9.65	8.14	C	4.99	D	8.14	C	8.14	C	8.14	C
Ri13	Seepabana	4.71	4.09	D	4.09	D	4.09	D	4.09	D	4.09	D
Rvii13	Mogalakwena	190.98	124.72	C	103.27	D	126.78	C	129.17	C	131.64	C
Ri14	Mogalakwena	193.27	113.64	C	92.19	C/D	112.72	C	116.93	C	117.58	C
Rii3	Mogalakwena	205.52	119.73	C	92.61	C/D	118.46	C	121.92	C	123.32	C

5.3.1 Rivers

Upper Nyl and Sterk IUA

The ESBC scenario results in a slight increase in flow (Figure 5.5) because EWRs were supplied at two reaches currently in an unacceptably low E condition to raise them both to a predicted D category (Figure 5.6). A 12.1% increase in flow under the BE scenario is predicted to improve the river health of four of the nine reaches from two Es to Ds, a C to a B/C, and two Ds to a C and C/D respectively. The DEV scenario decreased flow by 0.9%, and decreased one reach from C to C/D, and increased one from D to C/D with an overall decrease in overall health. The STCD increases flow by 5.9% and predicts an improvement in river health of four reaches from two Es to a D and D/E category, and two Ds to C/Ds.

The STCD scenario targeted the REC of a B/C category at Ri1 (EWR site 3_Olifantspruit) but it was not possible to improve the PES of a C category by increasing flow alone because the issues at the site are non-flow related. The management recommendations to achieve the REC require clearing exotic vegetation and curtailing future further water use to support inflows into the Nyl River for the Nyl River Floodplain. On the other hand, the STCD scenario targeted and maintained the REC of a C category at Ri5 (EWR site 4_Mogalakwena1).

Mogalakwena IUA

The ESBC scenario reduces flow by 16.6% (Figure 5.5) and is predicted to reduce the river health of seven C category reaches down to C/D and D categories, and one D category reach to an E (Figure 5.6). A small improvement in flow of 5.4% under the BE scenario is predicted to improve the condition of two reaches from a C to a B/C category. There are no developments planned in the Mogalakwena IUA so the DEV scenario did not change river health. STCD scenario results in a 3.6% and predicts the same outcome as the BE scenario.

The STCD scenario targeted and maintained the RECs of a C category at Ri14 (EWR site 5_Mogalakwena2) and the LIMCOM site MOGA-A63D-LIMPK, (node Rii3). The EWRs set at the LIMCOM site must be met at its confluence with the Limpopo River *i.e.* must flow into the Limpopo River.

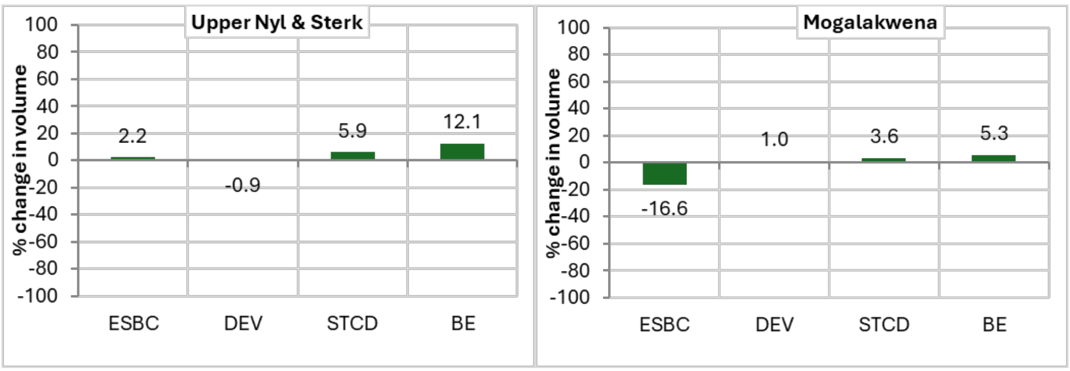


Figure 5.5. The percentage change in volume from the PES (2022) scenario in the Upper Nyl and Sterk IUA and Mogalakwena IUA.

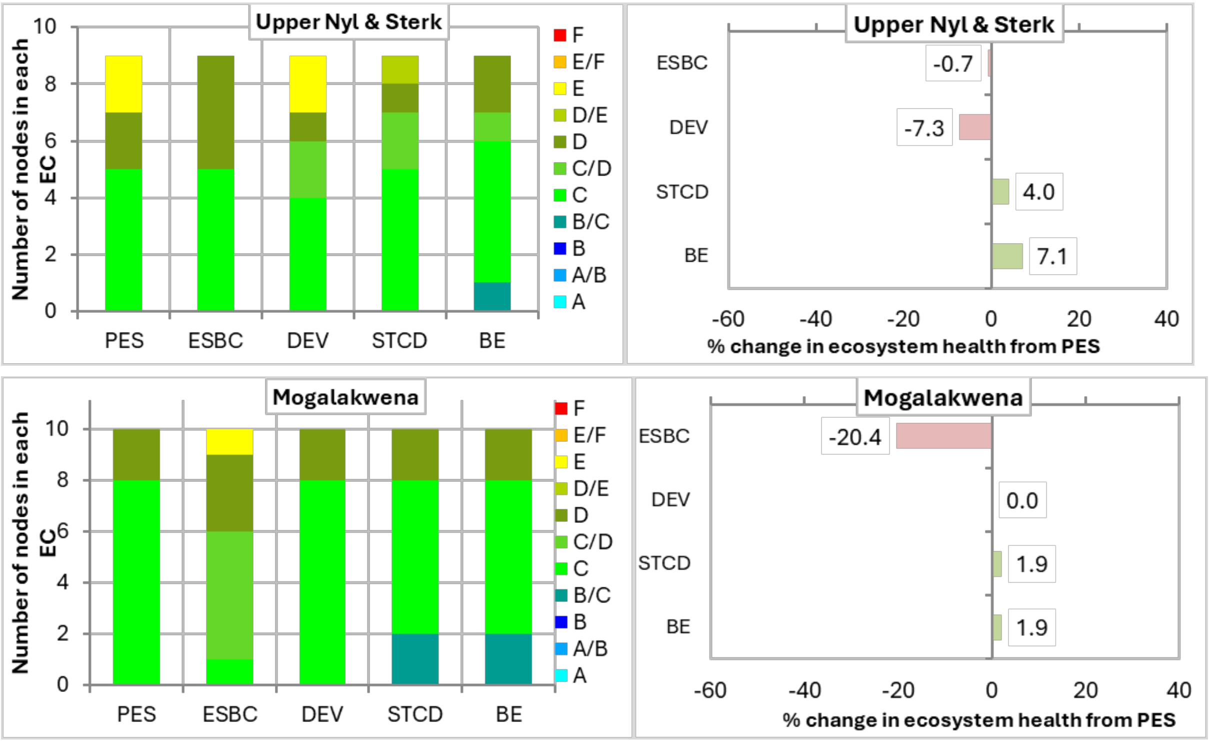


Figure 5.6. The number of nodes in each EC per scenario for the Upper Nyl and Sterk IUA (top) and Mogalakwena IUA (bottom) and the consequent change in health relative to PES.

5.3.2 Wetlands

The Mogalakwena Catchment has a total 24 727 ha of wetlands, which is 32.1% of all the wetlands in the study area, more than any other sub-catchment. The majority of these (77%) are floodplain wetlands, dominated by the Nyl floodplains associated with the Nylsvley Ramsar site. Channelled valley bottom (7% of wetlands in the sub-catchment) and unchanneled (8%) wetlands dominate the central region of the sub-catchment. The Nyl and Sterk IUA is characterised by the dominance of floodplain wetlands, notably with 86% of wetland extent being floodplain, the bulk of which is the Nyl floodplain, which includes the Nylsvley Nature Reserve Ramsar site. The Nyl floodplain, Wonderkrater and the Nyl pans were highlighted as priority wetlands and received more detailed studies (refer to Wetland Ecostatus report Vol1, this study), and a flow requirement was determined for the Nyl floodplain (refer to Wetland EWR report Vol 2, this study) along with scenario evaluation using a combination of a hydrodynamic model and DRIFT. The nodes that align best for the scenario evaluation are Riv3 and Riii1 for the Nyl floodplain and Ri3 for the Nyl pans, with no applicable node for Wonderkrater (Table 5-11).

The Mogalakwena IUA is dominated by several wetland HGMs, with riverine comprising 39% of wetlands, unchanneled valley bottoms 22% and channelled valley bottoms 14%, all of which are mostly in the upper reaches of the IUA and align best with river nodes Ri10, Ri12 and Rvii12. The Makamole wetlands, a tributary of the Mogalakwena River, were highlighted as high priority and align to river node Ri6. Depressional wetlands comprise 20% of wetland area and are mostly scattered in the east and west portions of the IUA and don't align to river nodes. Generally, depressional wetlands are unaffected by scenarios as they are mostly not directly connected to the river channel, while riverine and channelled valley bottom wetlands respond in similar ways to the river they are associated with.

Table 5-11. Annual volume (MCM), and river / wetland HGM condition (A to F), generalised for wetlands using applicable nodes, and representing all scenarios for the Upper Nyl and Sterk and Mogalakwena IUAs.

Ref node	River/ Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Upper Nyl and Sterk IUA												
Riv3	Nyl	23.44	21.55	C	19.83	C	22.3	B/C	21.42	C	21.42	C
	Nyl floodplain			C		C/D		B/C		C		C
Riii1	Nyl	32.70	24.18	D	22.45	D	25.50	C/D	23.88	D	24.60	C/D
	Woderkrater			B/C		B/C		B/C		B/C		B/C
Ri3	Mogalakwena	52.78	36.8	D	35.14	D	45.88	C	43.66	C/D	44.97	C/D
	Nyl Pans			D		D		C		C/D		C/D
Mogalakwena IUA												
Ri6	Mokamole	15.01	12.55	D	7.26	E	12.53	D	12.53	D	12.53	D
	Mokamole wetlands			B/C		C/D		B/C		B/C		B/C
Rvii12	Klein Mogalakwena	5.04	3.9	C	2.81	C/D	3.93	C	3.93	C	3.93	C
Ri10	Mogalakwena	165.6	103.4	C	87.88	C/D	110.33	B/C	105.5	C	107.87	B/C
Ri12	Matlalane	9.65	8.1	C	4.99	D	8.14	C	8.14	C	8.14	C
	Riverine			C		D		C		C		C
	Channelled valley bottom			C		C/D		C		C		C
	Unchanneled valley bottom			B/C		B/C		B/C		B/C		B/C
	Depressional			B		B		B		B		B

5.3.3 Water Quality

The drivers of water quality in this catchment are the towns of Modimolle, Dimune, Nylsvley, Mokopane and Mookgophong all of which have the challenges of poor performing wastewater treatment works (WWTWs). Furthermore, there are large platinum mines in the upper and middle catchment with nitrate problems from blasting as well as seasonal elevated turbidity levels from runoff from mining activities. Glen Alpine Dam is used for commercial agriculture of potatoes and tomatoes. Salinity in the upper Mogalakwena catchment (A61A) is in an Ideal category for most of the constituents evaluated. The median orthophosphate concentrations are in an Ideal category, but slightly elevated concentrations (Acceptable category) are measured from time to time. Water quality in the A61F catchment, in and around Mokopane, is poor with elevated salts, unionised ammonia, and phosphate concentrations in the Unacceptable category. High sulphate concentrations are also recorded in the Dorps River in Mokopane. This could be due to runoff from the industrial area upstream of the sampling point. Water quality in the Pholotsi River downstream of the Mogalakwena platinum mines is poor with high salts, high phosphates and high sulphate concentrations, all in an Unacceptable category. Water quality in the lower Mogalakwena River upstream of the Limpopo confluence is mostly in an Acceptable category due to slightly elevated salts, pH values and some elevated phosphate concentrations. Water quality in the upper Sterk River is probably in a D water quality category due to intensive irrigation agriculture and possible runoff of agrochemicals.

A summary of the likely water quality outcomes for the different scenarios in the Upper Nyl, Sterk and Mogalakwena IUAs, are presented in Table 5.12 and Table 5.13.

Table 5.12. Likely water quality outcomes in the Upper Nyl, Sterk and Mogalakwena IUAs

Scenario	Likely water quality outcomes
PES	With a 57% allocation of natural, an overall C water quality category due to poor functioning WWTW, and mining in the middle Mogalakwena catchment.
ESBC	Overall high C water quality category with an increase in allocation of 95% of natural due to less dilution of urban (WWTW) and industrial wastewater.
BE	Overall C water quality category, largely the same as the PES scenario with 56% of natural runoff allocated.
DEV	Overall C/D water quality category with an increase in allocation of 97% of natural due to less dilution of urban (WWTW) industrial, and mining wastewater.
STCD	Overall C/D water quality category, slightly poorer than the PES scenario with 58% of natural runoff allocated.

Table 5.13. Changes in water quality condition in the Upper Nyl, Sterk and Mogalakwena IUAs

IUA	Quat	Node	River	WQ EWR	PES	DEV	STCD	BE
Upper Nile and Sterk IUA								
Upper Nyl & Sterk	A61H	Rvii4	Sterk		D	D	D	D
Upper Nyl & Sterk	A61H	Rv1	Sterk		D	D	D	D
Upper Nyl & Sterk	A61J	Ri4	Sterk		B	B	B	B
Upper Nyl & Sterk	A61B	Ri1	Olifantspruit	B	B	B	B	B
Upper Nyl & Sterk	A61A	Ri1-1	Nyl		B	B	B	B
Upper Nyl & Sterk	A61C	Riv3	Nyl		B	B/C	B/C	B/C
Upper Nyl & Sterk	A61E	Riii1	Nyl		C	D	D	C/D
Upper Nyl & Sterk	A61F	Ri3	Mogalakwena		C	D	D	C/D
Upper Nyl & Sterk	A61G	Ri5	Mogalakwena	C	C	D	C/D	C/D
Mogalakwena IUA								
Mogalakwena	A62B	Riv12	Mogalakwena		C	C/D	C/D	C/D
Mogalakwena	A62A	Ri6	Mokamole		C	C	C	C
Mogalakwena	A62B	Rv2	Mogalakwena		C	C/D	C/D	C/D
Mogalakwena	A62D	Rvii12	Klein Mogolakwena		B	B	B	B
Mogalakwena	A62C	Ri10	Mogalakwena		C	C	C	C
Mogalakwena	A62F	Ri12	Matlalane		C/D	C/D	C/D	C/D
Mogalakwena	A62H	Ri13	Seepabana		C	C	C	C
Mogalakwena	A62J	Rvii13	Mogalakwena		C	C	C	C
Mogalakwena	A63A	Ri14	Mogalakwena	B/C	B/C	C	C	C
Mogalakwena	A63D	Rii3	Mogalakwena		C	C	C	C

5.3.4 Groundwater

The change in the groundwater balance according to the different scenarios is presented in Table 5-14 for the Upper Nyl & Sterk IUA. The groundwater abstraction index was increased by 3.5% for the ESBC scenario. Due to the existing low to moderate groundwater use no change was applied to the BE scenario. Further development of groundwater in the IUA was reflected by a classification index increase of 4.1% for the DEV scenario.

The change in the groundwater balance according to the different scenarios is presented in Table 5-15 for the Mogalakwena IUA. The groundwater abstraction index was increased by 13.5% for the ESBC scenario. For the BE scenario a reduction of 1.0% reflects a single modified high groundwater use quaternary catchment. Overall, the groundwater use is regarded as underutilised (with low to moderate groundwater use). Further development of groundwater in the IUA was reflected by a classification index increase of 7.2% for the DEV scenario.

Table 5-14. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Upper Nyl and Sterk IUA.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	63.22	52.28%		Low to Moderate groundwater use
ESBC	67.41	55.74%	3.46%	Groundwater development within perennial systems may effect baseflow
BE	63.22	52.28%	0.00%	Existing use low to moderate
DEV	71.92	59.47%	7.19%	Groundwater potential for development; groundwater development within perennial systems may effect baseflow
STCD	68.22	56.41%	4.13%	High priority areas limit large groundwater development under this scenario

Table 5-15. The percentage change in the groundwater balance from the base scenario (i.e., PES) scenario in the Mogalakwena IUA.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	79.33	44.72%		Low to Moderate groundwater use
ESBC	103.32	58.24%	13.52%	Potential for additional abstraction with limited effect on the groundwater system
BE	77.63	43.76%	-0.96%	
DEV	116.33	65.58%	20.86%	Potential for groundwater development; groundwater development within perennial systems (upper Mogalakwena) may effect baseflow.
STCD	91.33	51.48%	6.76%	Largely low priority areas

5.3.5 EGSA

The total value of EGSA in the Upper Nyl & Sterk IUA is R445 million and in the Mogalakwena is R193 million per year. In the Upper Nyl & Sterk IUA, nature-based tourism and carbon retention are the most important ecosystem services provided by the rivers and wetlands, largely associated with the Nylsvley Nature Reserve. In this IUA, instream water use, and resource harvesting are relatively small. Overall, the EGSA value declines by 31% under the DEV scenario and increases by 72% under the BE scenario compared to the PES. This is the result of projected tourism growth under the BE scenario and the high value associated with carbon storage. In the Mogalakwena IUA, instream water use, and resource harvesting are more important and are essential for maintaining livelihoods in this part of the WMA. Similar changes are seen under the scenarios here with a large decrease under the ESBC of 27% and an increase under the BE of 48% and STCD of 6%.

5.4 Mapungubwe IUA

There are five river nodes in the Mapungubwe IUA. The predicted ecological condition as a result of changes in flow and water quality (Table 5.19) at each node under each scenario is shown with the annual volume (in MCM) in Table 5.16.

Table 5.16. Annual volume (MCM), and river condition (A to F) at each node for all scenarios for the Mapungubwe IUA.

		Nat	PES		ESBC		DEV		STCD		BE	
Node	**River**	**Vol**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**
Rvi2	Stinkwater	0.24	0.07	C	0.00	E	0.07	C	0.11	B	0.11	B
Riv32	Kolope	2.06	1.00	C	0.98	C	1.00	C	1.04	C	1.14	B/C
Rvi4	Kongoloop	3.14	1.87	C	1.34	D	1.87	C	1.91	C	1.91	C
Rvi7	A71L Trib 4	0.20	0.07	C	0.00	E	0.07	C	0.11	B	0.11	B
Rvi9	Soutsloot	1.10	0.62	A	0.17	C/D	0.62	A	0.64	A	0.64	A

5.4.1 Rivers

The ESBC scenario reduces flow by 31.7% (Figure 5.7) and is predicted to reduce river health from four Cs and an A to two Es, a D and a C/D category (Figure 5.8). The two Es result in zero flows because of deductions made for BHN. There is 7.3% more flow under the BE scenario which is predicted to improve river health of the three Cs to two Bs and a B/C category. The STCD increases flow by 4.5% and is predicted to improve the health of two rivers from C to B category.

The STCD is predicted to maintain the PES at Riv32 (EWR site 6_Kolope) and it is not possible to meet the REC of a B/C category from changes in flow alone. The predictions are that management to curb further bank instability (gabion dams) and to monitor the re-establishment of riparian vegetation will help to achieve the REC.

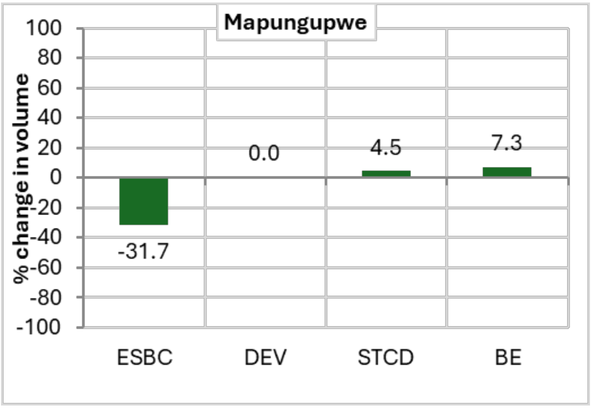


Figure 5.7. The percentage change in volume from the PES (2022) scenario in the Mapungubwe IUA.

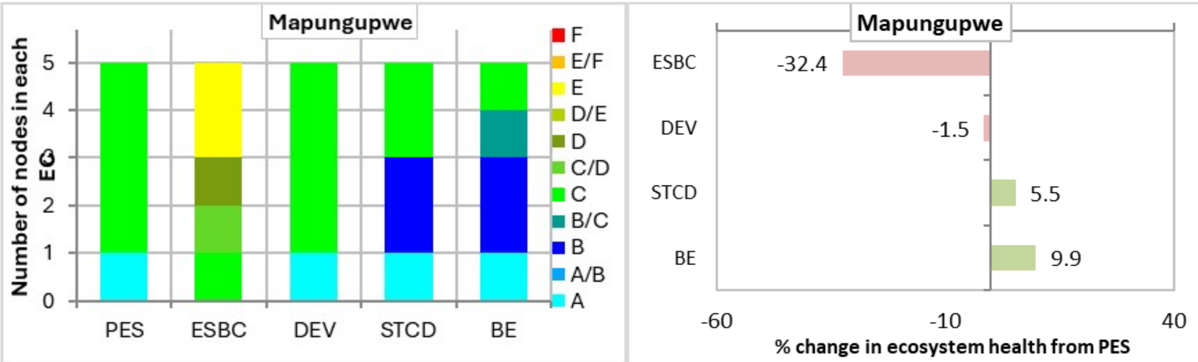


Figure 5.8. The number of nodes in each EC per scenario for the Mapungubwe IUA and the consequent change in health relative to PES

5.4.2 Wetlands

The wetlands in the Mapungubwe IUA are dominated by riverine, mostly seasonal wetlands (87% of wetland extent) with about 5% floodplain wetlands associated with the Limpopo and Maloutswa rivers. Most of the wetlands remain unassessed for PES but several were highlighted as priority wetlands: Kolope riverine wetlands including Leeupan (river node Riv32), Maloutswa floodplain (river node Rviii1) and the Mapungubwe wetlands (floodplains along the Limpopo; river node Rviii1). Generally, riverine and channelled valley bottom wetlands respond in similar ways to the river they are associated with, while floodplain wetlands will respond to altered flood regimes as noted by changes in volume (Table 5-17).

Table 5-17. Annual volume (MCM), and river / wetland HGM condition (A to F), generalised for wetlands using applicable nodes, and representing all scenarios for the Mapungubwe IUA.

Ref node	River/ Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Riv32	Kolope	2.06	1.00	C	0.98	C	1.14	B/C	1.00	C	1.04	C
	Riverine			A/B		A/B		A/B		A/B		A/B
	Maloutswa floodplain			C		C		B/C		C		C
	Mapungubwe wetlands			C		C		B/C		C		C

5.4.3 Water Quality

There are no sampling points in the Mapungubwe IUA catchment, so the water quality was assessed qualitatively based on generalised relationships. The water quality is estimated to be in a B/C category. Water quality in the Kolope River would be characteristic of a nonperennial stream with high fluctuations in quality. Salinity would fluctuate widely as accumulated salts are washed off the catchment, pools start forming when flows stop, and salinity increase as water evaporate from the pools leaving behind the salts. These are natural processes, but it is aggravated by degradation of the catchment. A summary of the likely water quality outcomes for the different scenarios in the Mapungubwe IUAs, are presented in Table 5-18 and Table 5.19.

Table 5-18. Likely water quality outcomes in the Mapungubwe IUA

Scenario	Likely water quality outcomes
PES	Overall B/C water quality category due to nonperennial nature of the rivers. Wide fluctuations in water quality as described above.
ESBC	Overall C water quality category due to interception of runoff.
BE	Overall C water quality category if no runoff is intercepted.
DEV	Overall C water quality category
STCD	Overall C water quality category, similar water allocation situation as PES scenario.

Table 5.19. Changes in water quality condition in the Mapungubwe IUA

IUA	Quat	Node	River	WQ EWR	PES	DEV	STCD	BE
Mapungupwe	A63E	Rvi2	Stinkwater		C	C	C	C
Mapungupwe	A63E	Riv32	Kolope	B/C	B/C	C	C	C
Mapungupwe	A71L	Rvi4	Kongoloop		B/C	C	C	C
Mapungupwe	A71L	Rvi7	A71L Trib 4		C	C	C	C
Mapungupwe	A71L	Rvi9	Soutsloot		C	C	C	C

5.4.4 Groundwater

The change in the groundwater balance according to the different scenarios is presented in Table 5-20. The groundwater abstraction index was not increased for the ESBC scenario, due to the high (to critical) groundwater use along the Limpopo River. For the BE scenario a reduction of 9.7 % reflects the lowering of the groundwater index from critical to high (i.e., <95%). This scenario should result in a positive outcome for the groundwater dependant ecosystems (GDE) along the Limpopo River. No further development of groundwater in the IUA was assessed for the DEV scenario.

Table 5-20. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Mapungubwe IUA.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	23.68	101.67%		Hight to critical groundwater use
ESBC	23.68	101.67%	0.00%	
BE	21.41	91.93%	-9.74%	Reduction from critical to high groundwater index may result in positive outcome to GDEs along the Limpopo River
DEV	23.68	101.67%	0.00%	
STCD	23.68	101.67%	0.00%	High priority area

5.4.5 EGSA

The total value of EGSA in the Mapungubwe IUA is some R211 million per year. This IUA is important for nature-based tourism and holds approximately 4% of the riparian carbon. This catchment is less important in terms of natural resource use and instream water use. The value of EGSA declines by some 40% under the ESBC scenario and 14% under DEV, increased by 10% under the STCD and by 60% under the BE scenario – due to significant growth in tourism and carbon storage opportunities under this scenario.

5.5 Upper and Lower Sand IUAs

There are five river nodes in the Upper Sand IUA and six in the Lower Sand IUA. The predicted ecological condition as a result of changes in flow and water quality (Table 5.24) at each node for each scenario is shown in Table 5.21.

Table 5.21. Annual volume (MCM), and river condition (A to F) at each node for all scenarios for the Upper and Lower Sand IUAs.

		Nat	PES		ESBC		DEV		STCD		BE	
Node	**River**	**Vol**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**
Upper Sand IUA												
Rvi3	Hout	6.92	2.88	C	2.79	C	2.88	C	2.88	C	2.99	C
Ri21	Hout	11.70	5.59	C	4.87	C/D	4.85	C/D	5.48	C/D	5.59	C
Ri16	Sand	11.05	12.97	D	12.97	D	41.17	D/E	29.79	D/E	17.17	D
Ri17	Diep	7.83	5.96	D	5.02	E	5.96	D	5.96	D	6.08	D
Riv16	Dwars	2.43	1.38	C	1.00	D	1.38	C	1.38	C	1.49	C
Lower Sand IUA												
Ri20	Sand	27.45	23.04	C	21.91	C/D	51.25	C/D	39.86	C	27.51	B/C
Ri22	Sand	31.59	23.64	C	23.25	C/D	51.78	C	40.40	B/C	29.15	B/C
Ri23	Sand	52.35	36.00	C	32.41	C/D	35.99	C	34.72	C	37.10	C
Ri24	Sand	62.54	44.88	C	36.71	C/D	44.88	C	44.60	C	46.26	C
Riv17	Brak	13.55	12.13	C	8.23	D	12.13	C	12.13	C	12.13	C
Ri25	Sand	85.32	63.15	C	47.17	C/D	63.15	C	62.87	C	65.07	C

5.5.1 Rivers

Upper Sand

Flow is reduced by 7.4% under the ESBC scenario (Figure 5.9) and is predicted to reduce the health of three reaches from Cs to a C/D and D category, and from a D to and E (Figure 5.10). The BE scenario increases flow by 15.8% and maintains the PES of all nodes. There is a large 95.4% increase in flow under the DEV scenario and the prediction is that this will decrease the ecological condition at two nodes from Cs to a C/D and a D/E category, largely due to the poor quality of effluent water from WWTW that could be released into the river (47.17 MCM at Ri16). The STCD returns the same result of a D/E category at nodes Ri16 even though the volume is lower (29.79 MCM). A reduction in the volume of the effluent water to 17.17 MCM at Ri16 under the BE scenario is predicted to maintain the PES of a D category at this node.

The upper Sand River is a sand bed river that receives poor water quality effluent from WWTWs (Polokwane, Seshego). Continuing these poor quality releases is detrimental to the river. There are plans to increase the volumes released: 50% - 70% of this is to supply irrigators downstream (mostly in A71C) and the remainder to flow further downstream to be abstracted in A71H to meet some of the needs for the MMSEZ development. The large increases in flow in the dry season will considerably change the flow regime from a nearly non-perennial system to perennial. Besides this, the water is expected to be of very poor quality. Better management of the WWTW and treatment of the water currently being released into the upper Sand is needed before further increased return flows into the Sand should be considered. If increased return flows into the upper Sand River are permitted, sufficient care needs to be taken ensure that the water entering the river is treated and tested to comply with effluent standards.

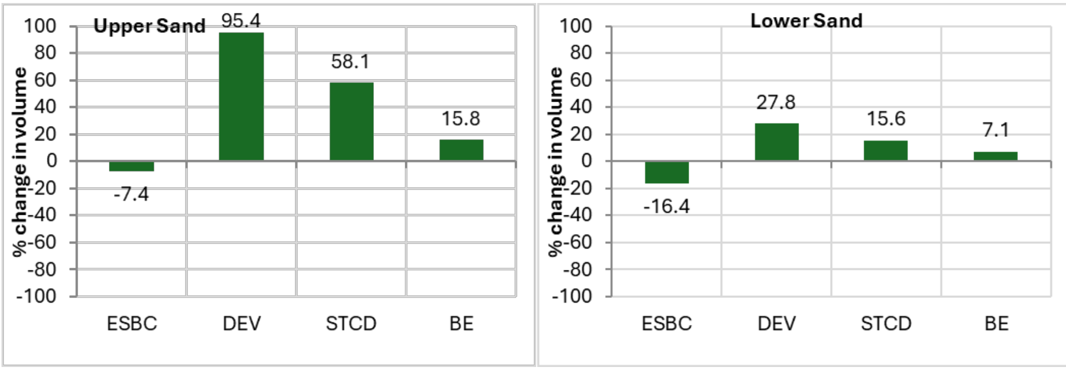


Figure 5.9. The percentage change in volume from the PES (2022) scenario in the Upper Sand and Lower Sand IUAs.

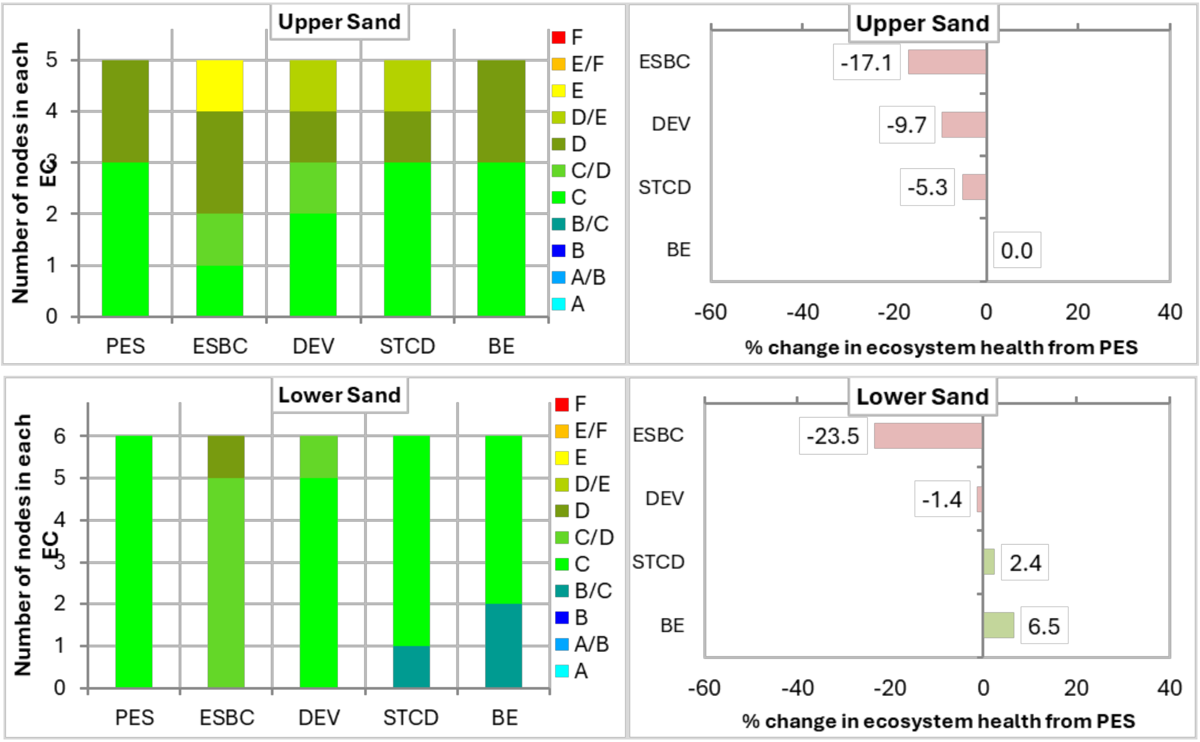


Figure 5.10. The number of nodes in each EC per scenario for the Upper Sand IUA (top) and Lower Sand IUA (bottom) and the consequent change in health relative to PES.

Lower Sand

Flow in the Lower Sand Flow is reduced by 16.4% under the ESBC scenario (Figure 5.9) and the predictions are that five reaches will drop from a C to a C/D category and one from a C to a D category (Figure 5.10). Under the BE scenario flow are increased by 7.1% and two of the C category reaches are predicted to improve to a B/C category in response. Flows are increased by 27.8% under the DEV scenario which is predicted to drop the EWR site Ri20 from its PES of a C to a C/D category, again because of poor water quality.

The increases in volume at Ri20 are reduced under the STCD scenario that targets and maintains the REC of a C category at Ri20 (EWR site 7_Sand) and at Ri25 (LIMCOM site Sand-A71K-R508B). The LIMCOM site is located in the inundation area of the Sand River Dam, but the corresponding node Ri25 is situated upstream of the tail end of the reservoir and will not be inundated. The EWRs set at Ri20 must be met at the Limpopo River, i.e. must flow into the Limpopo River. This means that the dams planned to be built on the Sand at is junction with the Limpopo must be built with release structures to release the EWRs into the Limpopo River.

5.5.2 Wetlands

The Sand River Catchment has 8474 ha of wetlands, which is 11% of all the wetlands in the study area. These are dominated by unchanneled valley bottom wetlands (82% of wetlands in the sub-catchment), the bulk of which occur along the Hout River in quaternary A71E, which is largely modified, including the riparian and wetland condition and continuity (DWS, 2014). Depressional wetlands, mostly in the central region of the sub-catchment comprise 9% of all wetlands. Riverine wetlands are mostly in the upper Sand IUA and associated with river nodes Ri16, Ri17, Ri20 and Riv16, while unchanneled valley bottoms are associated with river node Ri21 (Table 5-22). No high priority wetlands were identified in the Upper or Lower Sand IUAs. Generally, depressional wetlands are unaffected by scenarios as they are mostly not directly connected to the river channel, while riverine wetlands respond in similar ways to the river they are associated with, in this case node Rvi1 as a reference for riverine wetlands.

Table 5-22. Annual volume (MCM), and river/wetland HGM condition (A-F), generalised for wetlands using applicable nodes, representing all scenarios for the Upper & Lower Sand IUAs.

Ref node	River/Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Upper Sand IUA												
Ri21	Hout	11.7	5.6	C	4.87	C/D	5.59	C	4.85	C/D	5.48	C
	Unchanneled valley bottom			D		D		D		D		D
Ri16	Sand	11.05	13.1	D	12.9	D	17.2	D	41.2	D/E	29.8	D/E
Ri17	Diep	7.83	6.0	D	5.02	E	6.08	D	5.96	D	5.96	D
Riv16	Dwars	2.43	1.4	C	1.00	D	1.49	C	1.38	C	1.38	C
	Riverine			D		D		C/D		C/D		C/D
Lower Sand IUA												
Ri20	Sand	27.5	23.0	C	21.9	C/D	27.5	B/C	51.3	C/D	39.8	C
	Riverine			D		D		C		D		C
	Depressional			B/C		B/C		B/C		B/C		B/C

5.5.3 Water Quality

In general, water quality in the A7 catchment is effected by effluent from poorly managed WWTWs in the area. There are also many areas of sand and aggregate mining, brick making factories and one silica mine and factory. There are also intensive pivot points irrigation activities near the rivers which probably contribute to elevated nutrient levels. The water quality sampling points in the A71A catchment are located on the Sand River and Bloedrivier within the urban areas of Polokwane and Seshego. Their water quality therefore reflects the effects of urban runoff, agricultural return flows upstream of Polokwane, and perhaps the Witkop Silica Mine. At many of these sampling points high salts were recorded, high phosphate concentrations and elevated pH values, often in Unacceptable categories.

High unionised ammonia concentrations were also recorded in the Sand and Bloedrivier. These are characteristic of poorly treated domestic wastewater dominating flow in the rivers. The lower reaches of the Sand River are very poorly monitored with most sampling points located downstream of WWTW discharges. A summary of the likely water quality outcomes for the different scenarios in the Upper and Lower Sand IUAs, are presented in Table 5-23 and Table 5.24.

Table 5-23. Likely water quality outcomes in the Upper and Lower Sand IUAs

Scenario	Likely water quality outcomes
PES	Overall D water quality category due to overall over-allocation of water, water imported into catchment to make up deficits, and wastewater discharges dominating flows in the Sand and Bloed rivers.
ESBC	Overall F category in the upper reaches due to a large increase in domestic wastewater return flows dominating flows in the Sand and Bloed rivers downstream of Polokwane region.
BE	Overall D category maintained due to overall over-allocation of water, water imported into the catchment to make up deficits, and wastewater discharges dominating flows in the Sand and Bloed rivers. Similar allocation as PES scenario.
DEV	Overall D/E water quality category in the upper reaches due to large increase in poor quality domestic wastewater return flows. Overall D/E water quality category in the lower reaches due to planned mining and industrial developments, possible acid mine drainage effects, and increase in industrial effluents.
STCD	Overall D/E water quality category in the upper reaches due to a large increase in domestic wastewater return flows. Overall D water quality category in the lower reaches due to smaller implementation of planned mining and industrial developments, possible acid mine drainage effects, and moderate increase in industrial effluents.

Table 5.24. Changes in water quality condition in the Upper and Lower Sand IUA

IUA	Quat	Node	River	WQ EWR	PES	DEV	STCD	BE
Upper Sand IUA								
Upper Sand	A71A	Rvi3	**Hout**		D	D	D	D
Upper Sand	A71B	Ri21	**Hout**		D	D	D	D
Upper Sand	A71C	Ri16	Sand		D	E	D/E	D
Upper Sand	A71C	Ri17	Diep		D	D/E	D/E	D
Upper Sand	A71F	Riv16	Dwars		D	D	D	D
Lower Sand IUA								
Lower Sand	A71D	Ri20	Sand	D	D	E	D/E	D
Lower Sand	A71G	Ri22	Sand		D	E	D/E	D
Lower Sand	A71H	Ri23	Sand		C	C	C	C
Lower Sand	A71J	Ri24	Sand		C	D	C	C
Lower Sand	A72B	Riv17	Brak		B	B	B	B
Lower Sand	A71K	Ri25	Sand		C	D	C	C

5.5.4 Groundwater

The change in the groundwater balance according to the different scenarios is presented in Table 5-25. A groundwater abstraction index increase of 2.6% was applied for the ESBC scenario. Most of the Upper and Lower Sand River catchment is heavily dependent on groundwater and the current use is classed as hight (to critical) for many quaternary catchments. In the Upper Sand natural groundwater-surface water interaction has been modified by the artificial recharge of treated sewage effluent that is continuously being discharged from the municipal sewage treatment works into the Sand River. Due to low probability of baseflow in the Lower Sand the high use of groundwater has not resulted in any measurable changes in the baseflow. For the BE scenario an index reduction of 23.1% reflects the lowering of the groundwater index from critical to high (i.e., <95%). This should result in a positive outcome on the groundwater system (e.g., groundwater levels) more specifically during the drought cycles. No further development of groundwater in the IUA was assessed for the DEV and STCD scenarios.

Table 5-25. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Upper and Lower Sand IUAs.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	185.99	109.45%		High to critical groundwater use (Large areas dependent on groundwater)
ESBC	190.41	112.05%	2.60%	Limited potential for additional abstraction without impacting on the groundwater levels (especially during droughts)
BE	146.78	86.37%	-23.08%	Reduction to high groundwater class may result in positive outcome on groundwater levels during drought cycles
DEV	185.99	109.45%	0.00%	
STCD	185.99	109.45%	0.00%	High existing groundwater use

5.5.5 EGSA

The total value of EGSA in the Upper Sand IUA is R270 million and in the Lower Sand IUA is R332 million per year. In the Upper Sand IUA, harvested resources, instream water use, and nature-based tourism are the most important ecosystem services provided by the rivers and wetlands in this IUA. Overall, the EGSA value declines by 55% under the ESBC scenario and by 54% under the DEV scenario with increases under the BE scenario of 40% and under the STCD of 10% when compared to the PES. These large declines under the ESBC and DEV scenarios, which are associated with declining river and wetland condition under these scenarios, would have significant negative outcomes for societal wellbeing.

In the Lower Sand IUA, instream water use, carbon retention and nature-based tourism are also important. Similar changes are seen under the scenarios here with a decrease under the ESBC and DEV of between 45% and 54%. Under the STCD and BE these values could increase by between 10% and 54% as a result of improvements in river and wetland condition.

Such severe declines in river condition could result in significant negative outcomes for biodiversity and ecosystem services in an area where local people are highly dependent on these resources and the natural ecosystems that they support. In addition to the losses in the ecosystem services considered here, there are other negative externalities that have not been accounted for in the analysis, including impacts on human health and happiness.

5.6 Nzhelele/Ṅwanedi IUA

There are 11 river nodes in the Nzhelele/Ṅwaneḓi IUA. The predicted ecological condition as a result of changes in flow and water quality (Table 5.29) at each node under each scenario is shown with the annual volume (in MCM) in Table 5.26.

Table 5.26. Annual volume (MCM), and river condition (A to F) at each node for all scenarios for the Nzhelele/Ṅwaneḓi IUA.

		Nat	PES		ESBC		DEV		STCD		BE	
Node	**River**	**Vol**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**
Riii4	Mutamba	7.14	6.96	C	4.01	D	6.96	C	6.96	C	6.96	C
Riv23	Mutamba	18.61	20.97	C	11.33	D	14.26	C	16.04	C	16.84	C
Riii7	Nzhelele	14.81	13.63	D	11.85	D	13.63	D	13.63	D	13.63	D
Rvii34	Mufungudi	6.68	5.95	D	5.32	D	5.95	D	5.95	D	5.95	D
Riii8	Nzhelele	76.26	56.44	D	43.46	D	53.68	D	53.68	D	54.75	D
Ri26	Nzhelele	94.92	60.87	C	55.33	C	54.44	C	56.08	C	57.95	C
Riv33	Tshishiru	1.27	0.68	C/D	0.47	D	0.68	C/D	0.71	C	0.71	C
Ri27	Nzhelele	99.73	59.30	C	49.72	C/D	53.27	C/D	54.88	C	60.78	C
Riii9	Nwanedi	21.85	17.87	B	8.48	D	14.31	B/C	15.35	B/C	16.74	B
Riii10	Luphephe	10.17	8.04	C	4.71	D	10.47	B	10.47	B	10.47	B
Ri28	Nwanedi	33.47	26.49	C	15.35	D	21.07	C/D	22.98	C	25.06	C

5.6.1 Rivers

Flows are reduced by 24.2% under the ESBC scenario (Figure 5.11) and this is predicted to degrade four of the reaches down from C to D, one from a C to a C/D, another from a C/D to a D and yet another from a B to a D category (Figure 5.12). A slight reduction in flow of 2.7% under the BE scenario is predicted to maintain PES conditions, with slight increase in flow at Node Riv33 (Tshishiru River) making an improvement to a C category. Flows are reduced by 10.3% under the DEV scenario which is predicted to degrade the condition of the two EWR sites at node Ri27 (EWR site 8_Nzhelele) and Ri28 (EWR site 9_Ṅwaneḓi) from a C category down to a C/D, while a slight increase in flow along the Luphephe River improves the health from a C to a B category. Reduced flow on the upper Ṅwaneḓi reduces the river health from a B to a B/C category.

The STCD scenario targeted and is predicted to maintain the RECs of a C category at Ri27 (EWR site 8_Nzhelele) and Ri28 (EWR Site 9_ Ṅwaneḓi). There are further management recommendations to ensure that the perenniality of the Nzhelele River is restored by ensuring flows are released from the dams upstream of the EWR site that currently reduce dry season flows to zero.

The EWR requirements (*viz.* perennial flows all year) for these two rivers, set at EWR sites 8_Nzhelele and 9_Ṅwaneḓi, must be met at their confluences with the Limpopo River *i.e.* must flow into the Limpopo River.

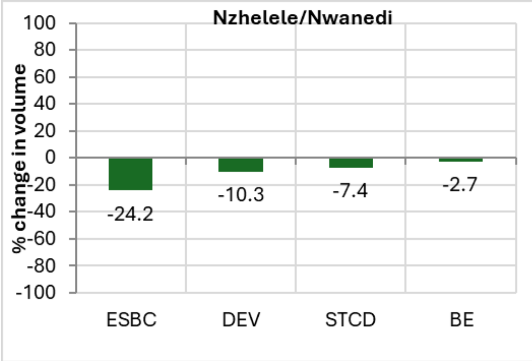


Figure 5.11. The percentage change in volume from the PES (2022) scenario in the Nzhelele/Ṅwaneḓi IUA.

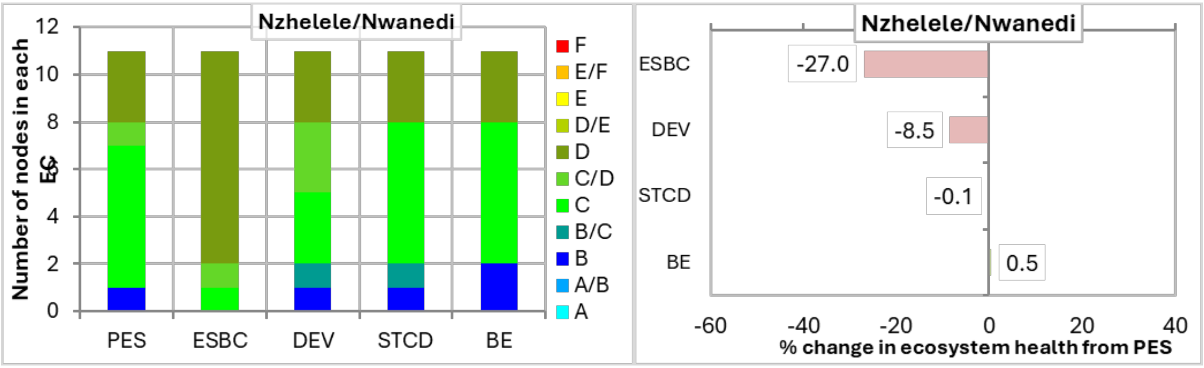


Figure 5.12. The number of nodes in each EC per scenario for the Nzhelele/Ṅwaneḓi IUA and the consequent change in health relative to PES.

5.6.2 Wetlands

The Nzhelele and Ṅwaneḓi catchments contain 3639 ha of wetlands, which is 4.7% of all the wetlands in the study area, the majority of which are unchanneled valley bottom (51%), but also riverine (20%) and channelled valley bottom wetlands (21%). The largest of these occur in the upper reaches of the Nzhelele River which is heavily impacted by human settlements and consequently has a poor ecological status (PES is C or E in PES-EI-ES data). The main impacts are denudation of vegetation and subsequent bank erosion. No high priority wetlands were noted in the Nzhelele/Ṅwaneḓi IUA and wetlands were generally aligned to appropriate river nodes: riverine (Riii9, Riii10), channelled valley bottoms (Ri26, Ri27), unchanneled valley bottoms (Riii7) and no association for depressional wetlands (Table 5-27). Generally, riverine wetlands respond in similar ways to the river they are associated with, and to some extent channelled valley bottom wetlands.

Table 5-27. Annual volume (MCM), and river / wetland HGM condition (A to F), generalised for wetlands using applicable nodes, and representing all scenarios for the Nzhelele/Ṅwanedi IUA.

Ref node	River/Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Riii7	Nzhelele	14.81	13.6	D	11.9	D	13.6	D	13.6	D	13.6	D
	Unchanneled valley bottom			C/D		D		C/D		C/D		C/D
Ri26	Nzhelele	94.92	60.9	C	55.3	C	57.95	C	54.4	C	56.08	C
Ri27	Nzhelele	99.73	59.3	C	49.7	C/D	60.8	C	53.3	C/D	54.8	C
	Channelled valley bottom			C/D		D		C/D		D		C/D
Riii9	Ṅwanedi	21.85	17.9	B	8.48	D	16.74	B	14.31	B/C	15.35	B/C
Riii10	Luphephe	10.17	8.08	C	4.71	D	10.47	B	10.47	B	10.47	B
	Riverine			C		D		B		B/C		B/C

5.6.3 Water Quality

Water quality in the Mutshedzi River (A80A) is in an Ideal category except some elevated phosphates (Acceptable category). In the Tshitavha River water quality is in an Ideal category except for elevated phosphates (Acceptable category). These rivers are surrounded by villages and subsistence agriculture close to the river. Grey water runoff and agricultural seepage could account for the elevated nutrient concentrations in the rivers. In catchment A80B of the Nzhelele River, water quality is in a poorer state. Salts are elevated (Acceptable to Tolerable categories), elevated pH values occur (Unacceptable category) and elevated phosphate concentrations are recorded. Here the Nzhelele River is surrounded by villages and subsistence agriculture up to the edge of the river. Grey water runoff and agricultural seepage could account for the elevated salt and nutrient concentrations in the rivers. The water quality of the outflow from Nzhelele Dam is in an Ideal category except for slightly elevated pH values (Acceptable category). There are no further water quality sampling points on the Nzhelele River downstream of the Mutamba River confluence where any long-term data record exists. There are a number of citrus irrigation schemes near the river that receives irrigation water from Nzhelele Dam via a canal. Water quality outcomes in these reaches can be expected to be affected by return flows with elevated salts and agrochemicals. The catchment downstream of the two dams are poorly monitored up to confluence with the Limpopo River. A summary of the likely water quality outcomes for the different scenarios in the Nzhelele/Ṅwanedi IUA, are presented in Table 5-28 and Table 5.29.

Table 5-28. Likely water quality outcomes in the Nzhelele/Ṅwanedi IUA

Scenario	Likely water quality outcomes
PES	Overall C water quality category in the upper and lower reaches, overallocation of 123% of natural.
ESBC	Deterioration to D water quality category due to increased allocation of 156% of natural.
BE	Maintain overall C water quality category in the upper and lower reaches, overallocation of 140% of natural.
DEV	Deterioration to overall D water quality category due to increased allocation of 156% of natural.
STCD	Maintain overall C category in the lower reaches, overallocation of 152% of natural.

Table 5.29. Changes in water quality condition in the Nzhelele/Ṅwanedi IUA

IUA	Quat	Node	River	WQ EWR	PES	DEV	STCD	BE
Nzhelele/Nwanedi	A80D	Riii4	Mutamba		C	C	C	C
Nzhelele/Nwanedi	A80F	Riv23	Mutamba		B	D	C	C
Nzhelele/Nwanedi	A80B	Riii7	Nzhelele		D	D	D	D
Nzhelele/Nwanedi	A80C	Rvii34	Mufungudi		C	C	C	C
Nzhelele/Nwanedi	A80C	Riii8	Nzhelele		C	C	C	C
Nzhelele/Nwanedi	A80F	Ri26	Nzhelele		B	D	D	D
Nzhelele/Nwanedi	A80G	Riv33	Tshishiru		C	C	C	C
Nzhelele/Nwanedi	A80G	Ri27	Nzhelele	C	C	D	D	C/D
Nzhelele/Nwanedi	A80H	Riii9	Nwanedi		B	B/C	B	B
Nzhelele/Nwanedi	A80H	Riii10	Luphephe		B	B	B	B
Nzhelele/Nwanedi	A80J	Ri28	Nwanedi	C	C	C	C	C

5.6.4 Groundwater

The change in the groundwater balance according to the different scenarios is presented in Table 5-30. The groundwater abstraction index was increased by 17% for the ESBC scenario. Due to the existing low to moderate groundwater use no change was applied to the BE scenario. Overall, the groundwater use is regarded as underutilised. Further development of groundwater in the IUA was reflected by a classification index increase of 23.75% for the DEV scenario. The catchment has a moderate groundwater potential for further groundwater development. The probability of baseflow reduces down-gradient towards the northeast (i.e., the Lower Nzhelele and Ṅwanedi).

Table 5-30. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Nzhelele/Ṅwanedi IUA.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	42.22	43.61%		Low to Moderate groundwater use
ESBC	58.68	60.60%	16.99%	Potential for additional abstraction with limited impact on the groundwater system
BE	42.22	43.61%	0.00%	
DEV	65.22	67.37%	23.75%	Potential for groundwater development; groundwater development within the upper Nzhelele may impact on baseflow
STCD	49.22	50.84%	7.23%	High priority areas limit large groundwater development under this scenario

5.6.5 EGSA

The total value of EGSA in the Nzhelele/Ṅwanedi IUA is around R391 million per year, which is 10% of the total EGSA value in the WMA. Riparian carbon stocks account for 11% of the total value and nature-based tourism, instream water use, and harvested resources are also important, contributing to household incomes and wellbeing. This value declines by some 26% under the ESBC and DEV scenarios and increases by around 15% under the BE and 3% under the STCD scenarios, when compared to the PES. The losses under the ESBC and DEV scenarios are associated with significant declines in overall aquatic ecosystem health as a result of changes in the quantity and quality of water flows in this IUA. Similarly to the Upper and Lower Sand, the degradation of aquatic water resources could be devastating for the people that live and depend on these systems for their livelihoods and wellbeing.

5.7 Upper Luvuvhu and Lower Luvuvhu/Mutale IUAs

There are eight river nodes in the Upper Luvuvhu IUA and seven river nodes in the Lower Luvuvhu IUA. The predicted ecological condition as a result of changes in flow and water quality (Table 5.34) at each node under each scenario is shown with the annual volume (in MCM) in Table 5.31.

Table 5.31. Annual volume (MCM), and river condition (A to F) at each node for all scenarios for the Upper Luvuvhu and Lower Luvuvhu/Mutale IUAs.

		Nat	PES		ESBC		DEV		STCD		BE	
Node	**River**	**Vol**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**	**Vol**	**EC**
Upper Luvuvhu IUA												
Rvi14	Luvuvhu	22.60	8.17	C	4.62	D	8.17	C	8.17	C	8.17	C
Rvii19	Doringspruit	11.58	6.05	C	2.93	D	6.05	C	6.05	C	6.05	C
Riii5	Luvuvhu	75.34	21.24	C	14.59	C/D	21.24	C	27.81	B	31.14	B
Riii6	Latonyanda	23.55	18.20	C	10.57	D/E	18.20	C	18.20	C	18.20	C
Riv18	Dzindi	69.63	66.18	D	66.18	D	66.18	D	66.18	D	66.18	D
Riv19	Luvuvhu	172.98	97.36	C	62.18	D	97.36	C	103.93	C	107.26	C
Rvii24	Luvuvhu	247.68	137.56	D	133.13	D/E	104.67	E	144.53	D	152.02	D
Ri30	Mutshindudi	55.81	45.81	C	25.72	D/E	36.69	C/D	43.02	C	44.61	C
Lower Luvuvhu/Mutale IUA												
Ri32	Luvuvhu	398.53	246.94	C	177.62	D	193.21	C/D	231.47	C	269.86	B/C
Rvii33	Mutale	73.89	66.04	C	66.04	C	49.24	D	55.61	C	63.95	C
Ri33	Mutale	124.65	113.82	C	77.78	D/E	90.82	D	93.84	C	110.26	C
Riv24	Mbodi	4.49	4.31	D	4.31	D	4.31	D	4.31	D	4.31	D
Ri34	Mutale	154.95	143.28	C	89.85	D/E	119.28	C/D	121.63	C	138.86	C
Ri35	Luvuvhu	416.74	265.14	B	192.23	C	211.40	C	238.77	B	276.16	A
Ri36	Luvuvhu	573.18	409.91	C	297.82	D	332.17	C/D	379.15	C	398.32	C

5.7.1 Rivers

Upper Luvuvhu

A 20.1% reduction in flow under the ESBC scenario (Figure 5.13) is predicted to degrade the health of all six C category reaches down to three Ds, two D/Es, and one C/DD category (Figure 5.14). Under the BE scenario flows are 8.3% higher and are predicted to improve the condition of the upper Luvuvhu River at node Riii5 from a C to a B category. A reduction in flow of 10.5% under the DEV scenario is predicted to degrade the Luvuvhu River at node Rbii24 from a D to an E category, and the EWR site 11_Mutshindudi (node Ri30) down from a C to a C/D category. Both these predicted reductions in condition are reversed under the STCD scenario where there is a slight improvement in flow and the current day (PES) conditions are maintained.

The STCD scenario targeted and is predicted to maintain the RECs of a C category at Riii6 (EWR site 10_Latonyanda) and Ri30 (EWR Site 11_Mutshindudi). There are further management recommendations made to remove the exotic plants at EWR site 11_Mutshindudi.

Lower Luvuvhu

Flows are reduced by 27.5% under the ESBC scenario (Figure 5.13) and four C category reaches are predicted to drop, two to a D and the other two to a D/E category, along with one B category reach down from a B to a C category (Figure 5.14). Under the BE scenario flows are increased by 0.9% and this is predicted to improve the EWR site 12_Luvuvhu (node Ri32) from a C to a B/C, and the lower Luvuvhu River at node Ri35 from a B to an A category. A reduction in flow of 19.9% under the DEV scenario is predicted to lower the health of five C category rivers to three C/Ds and two Ds, and one B to a C category. The STCD scenario is expected to maintain the PES conditions of all river nodes in the lower Luvuvhu River.

The STCD scenario fails to achieve the REC of a B/C at EWR site 12_Luvuvhu (node Ri32). The further management recommendations are to better manage nutrients from WWTW, sand mining, and to clear the exotic plants. The STCD is predicted to maintain the REC of a C category at EWR sites 13_Mutale1 (node Ri33) and 14_Mutale2 (node Ri34), provided *Mimosa pigra* is cleared and managed.

The PES and REC of a C category at LIMCOM site LUVU-A91K-OUTP are expected to be maintained by the STCD scenario. The EWRs set at LIMCOM site LUVU-A91K-OUTPO (node Ri36) must be met at its confluence with the Limpopo River *viz.* must flow into the Limpopo River.

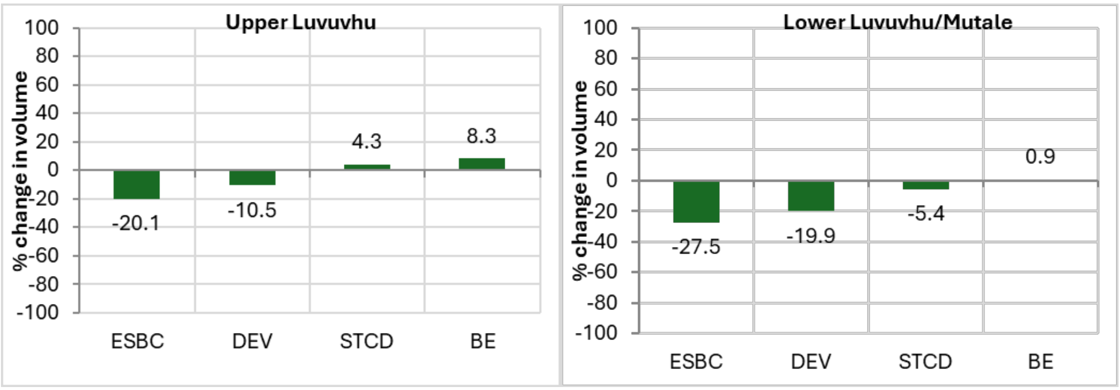
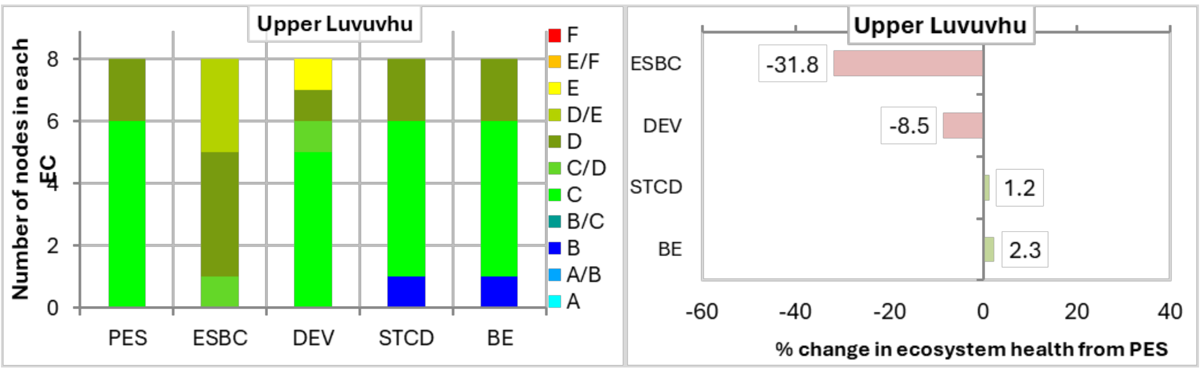


Figure 5.13. The percentage change in volume from the PES (2022) scenario in the Upper Luvuvhu IUA and Lower Luvuvhu/Mtale IUA.



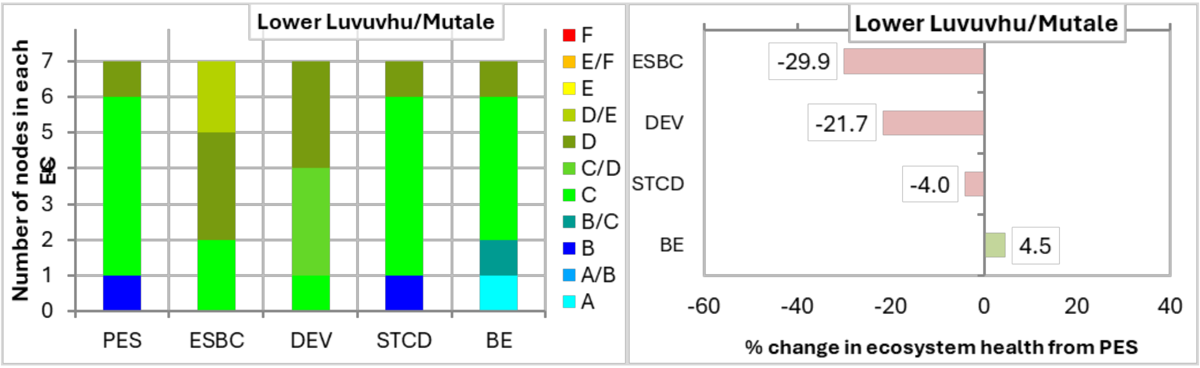


Figure 5.14. The number of nodes in each EC per scenario for the Upper Luvuvhu IUA (top) and Lower Luvuvhu/Mtale IUA (bottom) and the consequent change in health relative to PES.

5.7.2 Wetlands

The Luvuvhu and Mutale River catchments contain 13 146 ha of wetlands, which is 17.1% of all the wetlands in the study area. The majority of these are channelled valley bottom wetlands[3] (65%) but seep (15%) and unchanneled valley bottom wetlands (14%) also feature. On a quaternary catchment scale, A91K and A92B feature the bulk of the wetlands. The Makuleke Ramsar wetland which occurs in the Kruger National Park along the Luvuvhu River in A91K, while extensive seep and valley bottom wetlands occur in quaternary catchment A92B. The National Spatial Biodiversity Assessment (Driver *et al.*, 2005) noted the Banyini Pan, Makwadzi Pan, Spokonyolo Pan, Limpopo-Levubu wetlands, Fundudzi, the Mutale wetlands, Mathlaguza and Ximuweni, six thermal springs (Sagole, Natal Spa, Tshipala A, Magovani Hoof and Klopperfontein) and several other springs. The Luvuvhu floodplain (including pans on the Limpopo comprising the Makuleke Ramsar site), Lake Fundudzi and the Muyale wetlands (seeps, valley bottom wetlands, both channelled and unchanneled) were highlighted as priority wetlands and received more detailed studies (refer to Wetland Ecostatus report Vol1, this study), and a flow requirement was determined for the Luvuvhu floodplain (refer to Wetland EWR report Vol 2, this study) along with scenario evaluation using a combination of a hydrodynamic model and DRIFT.

The nodes that align best for the scenario evaluation are Ri34, Ri35 and Ri36 for the Luvuvhu floodplain and Ri33 for the Mutale wetlands, with no applicable node for Lake Fundudzi (Table 5-32). No priority wetlands were denoted in the Upper Luvuvhu IUA where rivers nodes Ri30 best align with riverine wetlands and Rvii24 with channelled valley bottom wetlands. Generally, riverine wetlands respond in similar ways to the river they are associated with, and to some extent channelled valley bottom wetlands.

[3] Note: The Luvuvhu floodplain is extensive and is denoted as a channelled valley bottom wetland in Map 5, while the more applicable HGM is floodplain.

Table 5-32. Annual volume (MCM), and river / wetland HGM condition (A to F), generalised for wetlands using applicable nodes, and representing all scenarios for the Upper Luvuvhu and Lower Luvuvhu/Mutale IUA.

Ref node	River/ Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Upper Luvuvhu IUA												
Rvii24	Luvuvhu	247.7	137.6	D	133.1	D/E	152.0	D	104.7	E	144.5	D
	Channelled valley bottom			C/D		D		C/D		D/E		C/D
Ri30	Mutshindudi	55.8	45.8	C	25.72	D/E	44.61	C	36.7	C/D	43.02	C
	Riverine wetlands			C		D/E		C		C/D		C/D
Lower Luvuvhu/Mutale IUA												
	Lake Fundudzi			B/C		D		B/C		C		B/C
Ri33	Mutale	124.7	113.8	C	77.8	D/E	110.3	C	90.8	D	110.2	C
	Mutale wetlands			C/D		D/E		C/D		D		C/D
Ri35	Luvuvhu	416.7	265.1	B	192.2	C	276.2	A	211.4	C	238.7	B
Ri36	Luvuvhu	573.2	409.9	C	297.8	D	398.3	C	332.2	C/D	395.6	C
	Luvuvhu floodplain			B/C		D		C		C/D		C

5.7.3 Water Quality

The water quality status of the Luvuvhu River is driven by intensive agriculture of sub-tropical fruits and afforestation in the upper catchment, urban sprawl of Thohoyandou in the middle catchment and the KNP in the lower end of the catchment. The unacceptable phosphate values that occur all the way into the KNP are as a result of the use of fertilizers for the intensive agriculture, to a lesser extent wastewater treatment plant effluent from Thohoyandou, and the lack of formal wastewater treatment for the dense urban sprawl outside the KNP. The water quality trends in the middle to lower Luvuvhu River indicate a deterioration of the phosphates, nitrates and ammonia levels. The Luvuvhu River is subject to ongoing research into the human health and fish impacts associated to the use of DDT for malaria control in the catchment. Water quality monitoring in the Mutale River catchment (A92A-D) is poor with most sampling points concentrated in the upper reaches of the A92A catchment. Water quality in the upper Mutale is in an Ideal category except for elevated phosphate concentrations (median Acceptable and 95th percentile in an Unacceptable category). In the Sambandou River at Tshitavha Village Bridge, a tributary of the middle Mutale River, all constituents assessed are in an Ideal category except for slightly elevated phosphate concentrations (Acceptable category). There are no further monitoring points on the Mutale River until you reach Sanari Village in the A92D catchment. In the Mutale River just upstream of the confluence with the Luvuvhu River, water quality is in ideal category and only slightly elevated phosphate concentrations are recorded in an Acceptable category. In the Luvuvhu River at Pafuri/Kruger National Park (A91K) water quality is in ideal category and only slightly elevated phosphate concentrations are recorded in an Acceptable category.

A summary of the likely water quality outcomes for the different scenarios in the Upper Luvuvhu and Lower Luvuvhu/Mutale IUAs, is presented in Table 5-33 and Table 5.34.

Table 5-33. Likely water quality outcomes in the Upper Luvuvhu and Lower Luvuvhu/Mutale IUAs

Scenario	Likely water quality outcomes
PES	Overall water quality category of C in the upper reaches due to high water allocation (98% of natural) and urban and agricultural runoff, WQ category of B in the lower reaches due to low water allocation (3%). In the lower Luvuvhu/Mutale IUA water quality is in a B category.
ESBC	Deterioration to water quality category of D in the upper reaches due to high water allocation (153% of natural) and less dilution of urban and agricultural runoff, WQ category of B in the lower reaches due to low water allocation (3%).
BE	Maintain water quality category of C in the upper reaches due to high water allocation (123% of natural) and urban and agricultural runoff, in the lower Luvuvhu/Mutale IUA the water quality is in a C category due to low water allocation (3%)..
DEV	Deterioration to an overall water quality category of C/D in the upper reaches due to high water allocation (153% of natural) and less dilution of urban and agricultural runoff, in the lower Luvuvhu/Mutale IUA the water quality is in a C category due to low water allocation (3%).
STCD	Maintain water quality category of C in the upper reaches due to high water allocation (144% of natural) and less dilution of urban and agricultural runoff, in the lower Luvuvhu/Mutale IUA the water quality is in a B/C category due to low water allocation (3%).

Table 5.34. Changes in water quality in the Upper Luvuvhu and Lower Luvuvhu/Mutale IUAs

IUA	Quat	Node	River	WQ EWR	PES	DEV	STCD	BE
Upper Luvuvhu IUA								
Upper Luvuvhu	A91A	Rvi14	Luvuvhu		C	C	C	C
Upper Luvuvhu	A91B	Rvii19	Doringspruit		C	C	C	C
Upper Luvuvhu	A91C	Riii5	Luvuvhu		D	D	C/D	C/D
Upper Luvuvhu	A91D	Riii6	Latonyanda	A/B	A/B	A/B	A/B	A/B
Upper Luvuvhu	A91E	Riv18	Dzindi		E	E	E	E
Upper Luvuvhu	A91F	Riv19	Luvuvhu		D	D	D	D
Upper Luvuvhu	A91F	Rvii24	Luvuvhu		B	C	B/C	B/C
Upper Luvuvhu	A91G	Ri30	Mutshindudi	B/C	B/C	C	C	B/C
Lower Luvuvhu/Mutale IUA								
Lower Luvuvhu/Mutale	A91H	Ri32	Luvuvhu	B	B	C	B/C	B
Lower Luvuvhu/Mutale	A92A	Rvii33	Mutale		B	C	B/C	B
Lower Luvuvhu/Mutale	A92B	Ri33	Mutale	B	B	C	B/C	B
Lower Luvuvhu/Mutale	A92C	Riv24	Mbodi		B	B	B	B
Lower Luvuvhu/Mutale	A92D	Ri34	Mutale	B	B	C	B/C	B
Lower Luvuvhu/Mutale	A91J	Ri35	Luvuvhu		B	C	B/C	B
Lower Luvuvhu/Mutale	A91K	Ri36	Luvuvhu		B	C	B/C	B

5.7.4 Groundwater

The change in the groundwater balance under the alternative scenarios for the Upper Luvuvhu is presented in Table 5-35. The groundwater abstraction index was increased by 8.5% for the ESBC scenario. For the BE scenario a reduction of 4.4% reflects the lowering of the groundwater index from critical to high (i.e., <95%). Further development of groundwater in the IUA was reflected by a classification index increase of 16.2% for the DEV scenario. The catchment has a moderate groundwater potential for groundwater development.

Table 5-35. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Upper Luvuvhu IUA.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	98.42	56.77%		Low to Moderate groundwater use
ESBC	113.10	65.23%	8.47%	Potential for additional abstraction with limited impact on the groundwater system (in low probability of baseflow catchments)
BE	90.84	52.40%	-4.37%	
DEV	126.42	72.92%	16.15%	Potential for groundwater development: groundwater development within the upper catchment may impact on baseflow via sub surface seepages and springs
STCD	111.42	64.27%	7.50%	Largely low priority areas

The change in the groundwater balance under the alternative scenarios for the Lower Luvuvhu is presented in Table 5-36. The groundwater abstraction index was increased by 19.1% for the ESBC scenario. Due to the existing low to moderate groundwater use no change was applied to the BE scenario. Further development of groundwater in the IUA was reflected by a classification index increase of 27.7% for the DEV scenario. The catchment has a low to moderate groundwater potential for further groundwater development.

Table 5-36. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Lower Luvuvhu/Mutale IUA.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	14.69	12.70%		Low groundwater use
ESBC	36.78	31.80%	19.10%	Potential for additional abstraction
BE	14.69	12.70%	0.00%	
DEV	46.69	40.37%	27.67%	Potential for groundwater development; but low to moderate groundwater potential
STCD	28.69	24.81%	12.11%	High priority areas limit large groundwater development under this scenario

5.7.5 EGSA

These two IUAs account for 30% of the total EGSA value in the WMA, amounting to some R718 million per year in the Upper Luvuvhu IUA and R535 million in the Lower Luvuvhu/Mutale IUA. These ecosystem goods and services play an important role here in terms of household wellbeing and livelihoods. In the Upper Luvuvhu IUA, instream water use and carbon retention account for the bulk of the value, with nature-based tourism also being of some importance. Riparian carbon stocks account for 24% of the total carbon value of the study area. Under the ESBC and DEV scenarios these values would decline by 23% when compared to PES and could increase by between 20% and 23% under the STCD and BE scenarios. In the Lower Luvuvhu/Mutale IUA, all the ecosystem goods and services are of importance, but particularly the value of harvested resources and nature-based tourism. This part of the study area is a high priority biodiversity area and buffers the Kruger National Park, and as such is critically important in terms of biodiversity conservation, providing strong opportunities for investment in the biodiversity sector through tourism. Under the ESBC and DEV scenarios, the overall value could decline by almost a third as a result of the changes in aquatic ecosystem health. Better management and protection of the aquatic resources would result in improved ecosystem health with positive outcomes for biodiversity and ecosystem services which are critically important to the people that live in this IUA.

5.8 Shingwedzi IUA

There are five river nodes in the Shingwedzi IUA. The predicted ecological condition as a result of changes in flow and water quality (Table 5.40) at each node under each scenario is shown with the annual volume (in MCM) in Table 5.37.

Table 5.37. Annual volume (MCM), and river condition (A to F) at each node for all scenarios for the Shingwedzi IUA.

		Nat	PES		ESBC		DEV		STCD		BE	
Node	River	Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Rvi10	Shisha	7.10	7.10	A	2.81	D	7.10	A	7.10	A	7.10	A
Riv28	Mphongolo	39.31	36.42	A	19.48	C	41.10	A	41.10	A	41.10	A
Rvi13	Shingwedzi	18.67	18.06	C	11.78	D	18.06	C	18.06	C	18.06	C
Riv27	Shingwedzi	33.80	33.05	A	19.10	C	33.05	A	33.05	A	33.05	A
Ri37	Shingwedzi	89.63	85.74	C	50.56	D	90.42	C	90.42	C	90.42	C

5.8.1 Rivers

There is a large reduction in flow of 42.5% under the ESBC scenario (Figure 5.15) that is predicted to reduce the health of all rivers from A and C categories down to Cs and Ds (Figure 5.16). There is a slight increase in flow under the DEV scenario that is not predicted to change river health. No adjustments were made to the STCD scenario, as further increases in flow would not improve river health. The slight improvement in flow under the STCD scenario is not expected to improve the PES of LIMCOM site SHIN-B90H-POACH (node Ri37) from a C to the REC of a B/C category.

The operation of the Shingwedzi River is through passive management as there is little opportunity to improve flow conditions through bulk water management. The previous LIMCOM surveys in 2012 and 2021 (E-flows for the Limpopo River Basin study, O'Brien *et al*., 2022) where this site was surveyed identified that the site vegetation state had remained relatively stable between B/C and B REC, whereas MIRAI had improved from D to B/C during this time. The following options should be considered that would stabilize over time and recover the prior aquatic habitat heterogeneity (Dr E Riddell, personal communication, 23 June 2025):

- Restore river connectivity for fish passage and hydraulic processes to mitigate excess sediment deposition. Notably the removal of Kanniedood Dam seems to have had a beneficial effect. This could be considered elsewhere, such as the Silvervis Dam.
- Improved rangeland management in the headwaters of the Shingwedzi catchment to reduce sedimentation down to the Kruger National Park and encourage stronger baseflows during the low flow period.
- Zinc was also identified as a heavy metal of concern in the Shingwedzi system, therefore effective implementation of Resource Quality Objectives at source will be important – notably at reactivated and small mining enterprises.

- Control of alien aquatic weeds

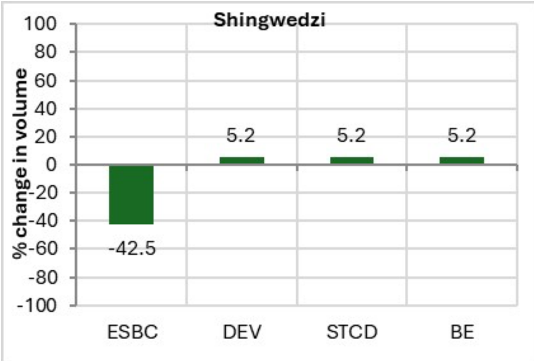


Figure 5.15. The percentage change in volume from the PES (2022) scenario in the Shingwedzi IUA.

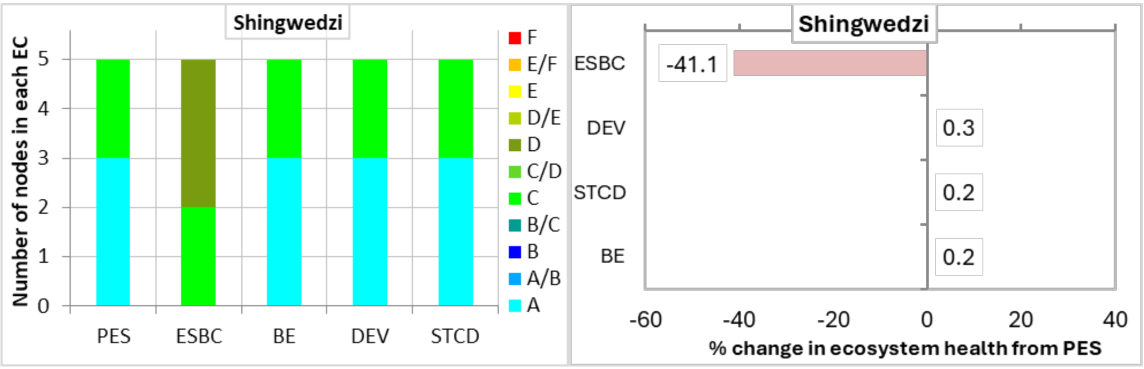


Figure 5.16. The number of nodes in each EC per scenario for the Shingwedzi IUA and the consequent change in health relative to PES.

5.8.2 Wetlands

The Shingwedzi Catchment contains 9233 ha of wetlands, which is 12% of all the wetlands in the study area. The majority of these are channelled (52%) and unchanneled (37%) valley bottom wetlands, many of which are in a good ecological condition since much of the catchment occurs in conservation areas such as the Kruger National Park and surrounding conservation properties. The National Spatial Biodiversity Assessment (Driver *et al.*, 2005) noted the Masokosa, Klawer, Mintomeni, Nwambiya, Magwitsi and Xirhamberhombe Pans, five thermal springs (Maritumbe, Malahlapanga, Malahlapanga B, Mafayini and Matiyavila act) and several other springs. The peat domes within Kruger National Park were highlighted as high priority (notably Malahlapanga and Mafayini) as well as extensive channelled valley bottom wetlands along the Bububu River, a tributary of the Shingwedzi River. Depressional wetlands, including pans and the peat domes were not affiliated with a river node, but channelled and unchanneled valley bottom wetlands were associated with river nodes Riv27 and Riv28 respectively (Table 5-38). Generally, riverine wetlands respond in similar ways to the river they are associated with, and to some extent channelled valley bottom wetlands.

Table 5-38. Annual volume (MCM), and river/wetland HGM condition (A to F), generalised for wetlands using applicable nodes, and representing all scenarios for the Shingwedzi IUA.

Ref node	River/Wetland HGM	Nat	Current		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Riv28	Mphongolo	39.31	36.43	A	19.48	C	41.10	A	41.10	A	41.10	A
	Unchanneled valley bottom			A		C		A		A		A
Rvi13	Shingwedzi	18.67	18.14	C	11.78	D	18.06	C	18.06	C	18.06	C
Riv27	Shingwedzi	33.80	33.13	A	19.10	C	33.05	A	33.05	A	33.05	A
	Bububu wetlands			A		B/C		A		A		A
	Peat domes (Malahlapanga)			B/C		B/C		B/C		B/C		B/C

5.8.3 Water Quality

The majority of the catchment of the Shingwedzi River falls within the KNP. Outside the land use is mainly subsistence agriculture and informal urban settlements. The unacceptable pH, phosphates and EC values are due to runoff from these land use practises that take place into the flood plain of the river. Fouche and Vlok (2010) undertook a comprehensive survey of the water quality condition on instream biota of the Shingwedzi River. It was found that water quality parameters frequently exceeded the threshold of potential concern values set by SANParks. The SASS scores were generally low, due mainly to organic pollution as a result of the lack of sanitation infrastructure in the catchment. Sources of pollution such as acid mine drainage from abandoned mines, inadequate sewerage infrastructure and habitat destruction due to siltation and sand mining were identified. Most villages in the catchment did not have formal sewage treatment facilities and their pit latrines could be considered to be the main source of organic pollution. In the larger towns, where WWTWs were present, they were inadequate to handle the existing sewage volumes and, in many cases, those systems were poorly maintained, with visible runoff into streams. Evidence of mining were found, likely caused by runoff from the abandoned Giants Reef mine. A summary of the likely water quality outcomes for the different scenarios in the Shingwedzi IUA, are presented in Table 5-39 and Table 5.40.

Table 5-39. Likely water quality outcomes in the Shingwedzi IUA

Scenario	Likely water quality outcomes
PES	Overall water quality category of B/C with a 20% allocation of natural runoff.
ESBC	Probably maintain the C water quality category if 40% of natural is allocated.
BE	Probably improvement to water quality category of B/C with a 20% allocation of natural runoff, due to improvements to wastewater infrastructure.
DEV	Probably deteriorate to an overall C water quality category if 40% of natural is allocated.
STCD	Probably deteriorate to an overall C water quality category if 40% of natural is allocated

Table 5.40. Changes in water quality in the Shingwedzi IUA

IUA	Quat	Node	River	WQ EWR	PES	DEV	STCD	BE

Shingwedzi	B90A	Rvi10	Shisha		A	A	A	A
Shingwedzi	B90H	Riv28	Mphongolo		B/C	C	C	C
Shingwedzi	B90F	Rvi13	Shingwedzi		C	C	C	C
Shingwedzi	B90G	Riv27	Shingwedzi		B	B	B	B
Shingwedzi	B90H	Ri37	Shingwedzi		B	B	B	B

5.8.4 Groundwater

The change in the groundwater balance under the alternative scenarios is presented in Table 5-41. The groundwater abstraction index was increased by 10.4% for the ESBC scenario. Due to the existing low to moderate groundwater use no change were applied to the BE scenario. Further development of groundwater in the IUA was reflected by a classification index increase of 10.6% for the DEV scenario. The catchment has a low to moderate groundwater potential for further groundwater development, while the IUA are largely within the KNP with no groundwater development plans.

Table 5-41. The percentage change in the groundwater balance from the base scenario (i.e., PES) in the Shingwedzi IUAs.

Scenario	Volume (MCM/A)	% Index Classification	% Change in Classification	Comment
PES	3.05	4.37%		Low to Moderate groundwater use
ESBC	7.27	10.43%	6.06%	Potential for additional abstraction with limited impact on the groundwater system; The catchment has a low probability of baseflow
BE	3.05	4.37%	0.00%	
DEV	10.55	15.14%	10.76%	Potential for groundwater development; but low to moderate groundwater potential
STCD	5.05	7.24%	2.87%	High priority areas limit large groundwater development under this scenario

5.8.5 EGSA

The total value of EGSA in this IUA is some R778 million per year which is 19% of the total EGSA value for the study area. About 36% of the overall nature-based tourism value is within this IUA and 14% of the riparian carbon retention value. The Kruger National Park attracts visitors to the broader area, resulting in visitor spend in and around these core conservation areas. These areas provide opportunities for investment in tourism, the revenue from which supports local communities and ensures the longevity of natural areas. Indeed, nature-based tourism can help to achieve economic development goals while promoting biodiversity conservation. Under the ESBC scenario, the overall EGSA values could decline by some 31%. However, under the STCD scenario where catchments with high ecological importance are prioritised, the value could increase by some 16% relative to the PES.

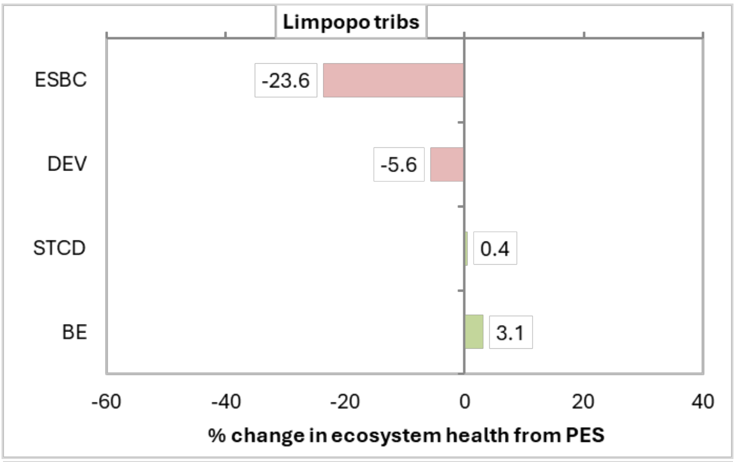
6 SUMMARY OF OVERALL OUTCOMES OF THE ALTERNATIVE SCENARIOS

A summary of the overall outcomes of the alternative scenarios for rivers, wetlands and groundwater are presented in this section as well as a summary of the overall effect on ecosystems goods, services and attributes (EGSA), water availability and additional water supply infrastructure, and overall socio-economic outcomes. These are then used to evaluate the overall outcomes of alternative scenarios.

6.1 Rivers

When considering the overall health of the Limpopo tributaries *viz.* the whole study area (Figure 6.1), it is predicted that there could be a large decrease in health for the ESBC scenario relative to PES (Figure 6.1a), and a smaller decrease under the DEV scenario. On the other hand, there is a small improvement in health under the BE scenario and a slight improvement under the STCD scenario, whereas there is a larger decrease under the ESBC versus the DEV scenarios. River health under the PES scenario is around 67.5% of natural (Figure 6.1b). The changes shown here do not consider whether the additional volume is available to support the predicted improved condition (e.g. in the BE scenario), nor whether the water made available for abstraction would be used by any development (e.g. the ESBC scenario), but rather provides "what-if" illustrations of what potential future paths could be.

(a)



(b)

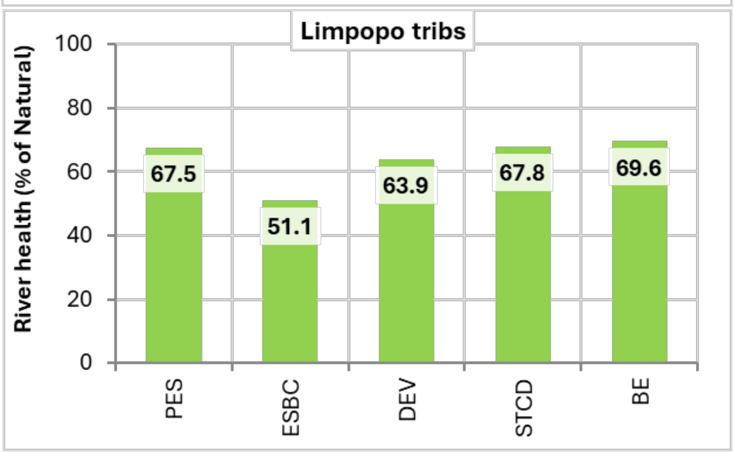


Figure 6.1. Percentage change in ecosystem health/integrity (a) from the PES (2022) scenario, and (b) relative to Natural for the Limpopo tributaries in secondary catchments A5 to A9 and B9.

A summary of the management recommendations for the EWR sites, and the success of the STCD scenario to meet the RECs are summarised:

- The STCD scenario targeted the REC of a B/C category at Riv11 (EWR site 1_Lephalala), but it was not possible to improve the PES of a C category by increasing flow alone because the issues at the site are non-flow related. The management recommendations to achieve the REC require clearing exotic vegetation and re-stocking indigenous fish.
- The REC of a C category at Ri8 (LIMCOM site LEPH-A50H-SEEKO) was met by the PES, ESBC, DEV and STCD scenarios. The EWRs set at this site must be met at its confluence with the Limpopo River, *i.e.* must flow into the Limpopo River.
- The STCD scenario targeted and achieved the REC of a B/C category at Rvi1 (EWR site 2_Rietfontein).
- The STCD scenario targeted the REC of a B/C category at Ri1 (EWR site 3_Olifantspruit) but it was not possible to improve the PES of a C category by increasing flow alone because the issues at the site are non-flow related. The management recommendations to achieve the REC require clearing exotic vegetation and curtailing future further water use to support inflows into the Nyl River for the Nyl River Floodplain. On the other hand, the STCD scenario targeted and maintained the REC of a C category at Ri5 (EWR site 4_Mogalakwena1).
- The STCD scenario targeted and maintained the RECs of a C category at Ri14 (EWR site 5_Mogalakwena2) and the LIMCOM site MOGA-A63D-LIMPK, (node Rii3). The EWRs set at the LIMCOM site must be met at its confluence with the Limpopo River *i.e.* must flow into the Limpopo River.
- The STCD is predicted to maintain the PES at Riv32 (EWR site 6_Kolope) and it is not possible to meet the REC of a B/C category from changes in flow alone. The predictions are that management to curb further bank instability (gabion dams) and to monitor the re-establishment of riparian vegetation will help to achieve the REC.
- The upper Sand River is a sand bed river that receives poor water quality effluent from WWTWs (Polokwane, Seshego). Continuing these poor quality releases is detrimental to the river. There are plans to increase the volumes released: 50% - 70% of this is to supply irrigators downstream (mostly in A71C) and the remainder to flow further downstream to be abstracted in A71H to meet some of the needs for the MMSEZ development. The large increases in flow in the dry season will considerably change the flow regime from a nearly non-perennial system to perennial. Besides this, the water is expected to be of very poor quality. Better management of the WWTW and treatment of the water currently being released into the upper Sand River is needed before further increased return flows into the Sand River should be considered. If increased return flows into the upper Sand River are permitted, sufficient care needs to be taken ensure that the water entering the river is treated and tested to comply with effluent standards.
- The increases in volume at Ri20 are reduced under the STCD scenario that targets and maintains the REC of a C category at Ri20 (EWR site 7_Sand) and at Ri25 (LIMCOM site Sand-A71K-R508B). The LIMCOM site is located in the inundation area of the Sand River Dam, but the corresponding node Ri25 is situated upstream of the tail end of the reservoir and will not be inundated. The EWRs set at Ri25 must be met at the Limpopo River, i.e. must flow into the Limpopo River. This means that the dams planned to be built on the Sand River at its junction with the Limpopo River must be built with release structures to release the EWRs into the Limpopo River.
- The STCD scenario targeted and is predicted to maintain the RECs of a C category at Ri27 (EWR site 8_Nzhelele) and Ri28 (EWR Site 9_ Ṅwanedi). There are further management

recommendations to ensure that the perenniality of the Nzhelele River is restored by ensuring flows are released from the dams upstream of the EWR site that currently reduce dry season flows to zero. The EWR requirements (*viz.* perennial flows all year) for these two rivers, set at EWR sites 8_Nzhelele and 9_Ṅwanedi, must be met at their confluences with the Limpopo River *i.e.* must flow into the Limpopo River.

- The STCD scenario targeted is predicted to maintain the RECs of a C category at Riii6 (EWR site 10_Latonyanda) and Ri30 (EWR Site 11_Mutshindudi). There are further management recommendations to remove the exotic plants at EWR site 11_Mutshindudi.
- The STCD scenario fails to achieve the REC of a B/C at EWR site 12_Luvuvhu (node Ri32). The further management recommendations are to better manage nutrients from WWTWs, reduce sand mining, and to clear invasive alien plants.
- The STCD is predicted to maintain the REC of a C category at EWR sites 13_Mutale1 (node Ri33) and 14_Mutale2 (node Ri34), provided *Mimosa pigra* is cleared and managed.
- The PES and REC of a C category at LIMCOM site LUVU-A91K-OUTP are expected to be maintained by the STCD scenario. The EWRs set at LIMCOM site LUVU-A91K-OUTPO (node Ri36) must be met at its confluence with the Limpopo River *viz.* must flow into the Limpopo River.
- The slight improvement in flow under the STCD scenario is not expected to improve the PES of LIMCOM site SHIN-B90H-POACH (node Ri37) from a C to the REC of a B/C category. The following actions are proposed to stabilise and recover the prior aquatic habitat heterogeneity over time: restore river connectivity for fish passage and hydraulic process to mitigate excess sediment deposition; improve rangeland management in the headwaters of the Shingwedzi system to reduce sedimentation down to the Kruger National Park and encourage stronger baseflows during the low flow period; effective implementation of RQOs at the source of heavy metal concern (zinc) from reactivated and small mining enterprises; and the control of alien aquatic weeds.

6.2 Water quality

When considering the overall water quality status of the Limpopo tributaries, there is predicted to be an overall deterioration in the water quality status for the ESBC scenario relative to the PES water quality status (Table 6-1). The same applies for the DEV scenario which would probably result in an even poorer water quality status than that of the ESBC scenario in some sub-catchments, in many cases at least one category poorer.

Table 6-1. The overall water quality rating in each IUA under each of the alternative scenarios.

IUA	PES	ESBC	BE	DEV	STCD
Upper and Lower Lephalala	B	B	B	B	B
Kalkpan se Loop	B/C	B/C	B/C	B/C	B/C
Upper Nyl & Sterk	C	C	C/D	C	C/D
Mogalakwena	C	C	C	C	C
Mapungubwe	B/C	C	C	C	C
Upper Sand	D	F	D	D/E	D/E
Lower Sand	C/D	F	D	D/E	D
Nzhelele/Ṅwanedi	C	D	C	D	C
Upper Luvuvhu	C	D	C	C/D	C
Lower Luvuvhu/Mutale	B	B	C	C	B/C
Shingwedzi	B/C	C	B/C	C	C

On the other hand, there is a relatively moderate improvement in the water quality status under the BE scenario and a small improvement under the STCD scenario which probably maintains the water quality within its present water quality category. These effects differ from catchment to catchment and are affected by local sources of pollution and operational challenges faced by domestic WWTWs. In many cases, the water quality category is weakly related to flow due to non-flow related causes of poor quality such as point and nonpoint sources of pollution in the catchments. An increase in flow as a result of interbasin transfers of water designated for domestic or industrial use, does not result in a better quality water since the water is returned to the catchment as WWTW effluent.

6.3 Wetlands

A summary of wetland / wetland complex PES in response to scenarios is shown in Table 6-2 for high priority wetlands as well as river node/s applicable to those wetlands (in each case listed above the wetland name). Overall combined wetland health for priority wetlands under each of the scenarios is shown in Figure 6-2. Wetland health is highest under the BE scenario, followed by the STCD scenario, and is lowest under the ESBC scenario. Wetland health under the ESBC and DEV scenarios declines to be below current PES condition.

Table 6-2. Annual volume (MCM), and river / wetland condition (A to F), aligned to applicable river nodes, and representing all scenarios for high priority wetlands

Ref node	River/ Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Upper Nyl and Sterk IUA												
Riv3	Nyl	23.44	21.55	C	19.83	C	22.3	B/C	21.42	C	21.42	C
	Nyl floodplain			C		C/D		B/C		C		C
Riii1	Nyl	32.70	24.18	D	22.45	D	25.50	C/D	23.88	D	24.60	C/D
	Woderkrater			B/C		B/C		B/C		B/C		B/C
Ri3	Mogalakwena	52.78	36.8	D	35.14	D	45.88	C	43.66	C/D	44.97	C/D
	Nyl Pans			D		D		C		C/D		C/D
Mogalakwena IUA												
Ri6	Mokamole	15.01	12.55	D	7.26	E	12.53	D	12.53	D	12.53	D
	Mokamole wetlands			B/C		C/D		B/C		B/C		B/C
Riv32	Kolope	2.06	1.00	C	0.98	C	1.14	B/C	1.00	C	1.04	C
Mapungubwe IUA												
	Riverine			A/B		A/B		A/B		A/B		A/B
	Maloutswa floodplain			C		C		B/C		C		C
	Mapungubwe wetlands			C		C		B/C		C		C
Lower Luvuvhu/Mutale IUA												
	Lake Fundudzi			B/C		D		B/C		C		B/C
Ri33	Mutale	124.7	113.8	C	77.8	D/E	110.3	C	90.8	D	110.2	C
	Mutale wetlands			C/D		D/E		C/D		D		C/D
Ri35	Luvuvhu	416.7	265.1	B	192.2	C	276.2	A	211.4	C	238.7	B
Ri36	Luvuvhu	573.2	409.9	C	297.8	D	398.3	C	332.2	C/D	395.6	C
	Luvuvhu floodplain			B/C		D		C		C/D		C

Ref node	River/ Wetland HGM	Nat	PES		ESBC		BE		DEV		STCD	
		Vol	Vol	EC	Vol	EC	Vol	EC	Vol	EC	Vol	EC
Shingwedzi IUA												
Rvi13	Shingwedzi	18.67	18.14	C	11.78	D	18.06	C	18.06	C	18.06	C
Riv27	Shingwedzi	33.80	33.13	A	19.10	C	33.05	A	33.05	A	33.05	A
	Bububu wetlands			A		B/C		A		A		A
	Peat domes (Malahlapanga)			B/C		B/C		B/C		B/C		B/C

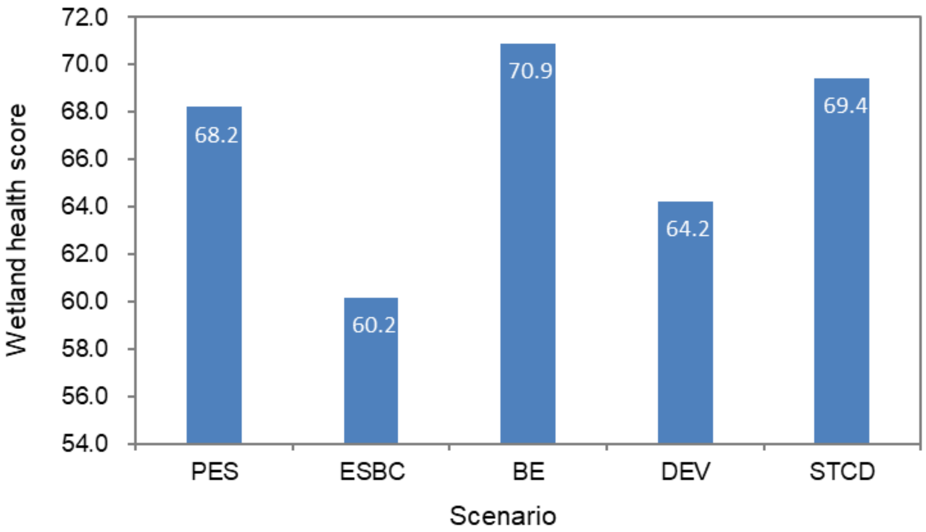


Figure 6-2. Overall combined wetland health score for priority wetlands under each scenario.

6.4 Groundwater

The overall percentage change in the groundwater stress index classification in each IUA for each scenario relative to the PES is shown in Table 6-3.

Table 6-3. The percentage change in the groundwater stress index (SI) classification under each scenario relative to the PES.

IUA	ESBC	BE	DEV	STCD	Comment
Upper and Lower Lephalala	36.17%	0.00%	40.61%	15.70%	Potential for additional abstraction/Low GW potential
Kalkpan se Loop	13.90%	0.00%	0.00%	0.00%	Potential for additional abstraction/No Development
Upper Nyl and Sterk	3.46%	0.00%	7.19%	4.13%	Moderate current GW use/High priority areas limit large groundwater development for STCD scenario
Mogalakwena	13.52%	-0.96%	20.86%	6.76%	Potential for additional abstraction with limited impact on the groundwater system
Mapungubwe	0.00%	-9.74%	0.00%	0.00%	High existing GW use; High priority area/Reduction from critical to high groundwater index may result in positive impact to GDEs along the Limpopo River
Upper and Lower Sand	2.60%	-23.08%	0.00%	0.00%	Reduction to high groundwater class (from critical) may result in positive impact on groundwater levels during drought cycles
Nzhelele/Ṅwanedi	16.99%	0.00%	23.75%	7.23%	High priority areas limit groundwater development for STCD scenario
Upper Luvuvhu	8.47%	-4.37%	16.15%	7.50%	Potential for additional abstraction with limited impact on the groundwater system (in low probability of baseflow catchments)/within the

IUA	ESBC	BE	DEV	STCD	Comment
					upper catchment, potential impact on baseflow via sub surface seepages and springs
Lower Luvuvhu/Mutale	19.10%	0.00%	27.67%	12.11%	High priority areas limit large groundwater development for STCD scenario/Low GW potential
Shingwedzi	6.06%	0.00%	10.76%	2.87%	High priority areas limit large groundwater development for STCD scenario/Low GW potential

6.5 Ecosystem goods, services and attributes

The overall value of ecosystem goods and services are expected to increase under the BE and STCD scenarios relative to the PES scenario, with positive outcomes on household livelihoods and overall wellbeing, and in terms of meeting national climate targets and contributing towards climate change mitigation and adaptation (Table 6-4). The estimates are considered to be conservative given that they do not account for all ecosystem services and do not include the intangible biodiversity values which are inherently difficult to measure. Many of the catchments, especially to the north-east, are recognised as being high priority biodiversity areas and play a very important role in attracting both international and domestic tourists to the region, contributing to economic growth by creating jobs and diversifying rural economies through investment in nature-based and cultural and heritage tourism. Furthermore, aquatic ecosystems play an important role in supporting the livelihoods of the rural populations living in these areas, many of which still do not have formal access to water supply. The degradation of these water resources would have a significant negative effect on human wellbeing and health, which has not been quantified here.

Table 6-4. The value of the ecosystem services (R millions/year) considered in the analysis and how these values might change under the alternative scenarios.

EGSA	PES	ESBC	BE	DEV	STCD
Nature-based tourism	1,253.0	636.8	2,971.4	664.2	1,599.9
Harvested resources	59.9	36.5	67.6	39.2	64.0
Instream water use	475.6	313.6	538.7	354.0	506.7
Carbon retention (riparian)	2,330.0	1,800.0	2,550.0	1,860.0	2,430.0
Total (R million)	**4,118.5**	**2,786.9**	**6,127.7**	**2,917.4**	**4,600.6**

Under the ESBC and DEV scenarios there would be significant loss in the overall EGSA value. Relative to a scenario where the PES is maintained, the value of ecosystem services would be 32% lower for the ESBC and 29% lower for the DEV scenario. This could have significant negative outcomes on the wellbeing of people who rely heavily on natural ecosystems for additional income, and for basic resources such as water, particularly those in rural areas who are already the most vulnerable. Furthermore, the degradation of water resources in the study area would likely result in significant negative outcomes downstream on the Limpopo River and into Mozambique. Under the DEV scenario which proposes a significant increase in mining and industrial activity, which is likely unsustainable, the degradation of biodiversity and loss in ecosystem services downstream as a result of deteriorating water quantity and quality is expected to be severe.

Investing in the protection and restoration of aquatic ecosystems is critical for water security in the long term, especially in an area that is already water stressed and where water resources are over allocated.

The long-term effects of aquatic ecosystem degradation include habitat disturbance, biodiversity loss, harmful algal blooms and other health impacts, all of which are incredibly difficult and costly to fully remedy and restore. Investing in ecological infrastructure (natural ecosystems that provide important services and save on built infrastructure costs) can have significant positive outcomes in terms of hydrological services and water security, particularly in water-scarce areas. Indeed, studies have now shown that undertaking restoration and conservation measures in catchment areas not only has a positive return on investment but can also be cost-effective in meeting water security goals (Webster et al. 2024). In the Luvuvhu-Letaba Water Supply System, it was estimated that the removal of IAPs could increase stream flow by 11.8 million m^3 by 2050, with the cost of removal being significantly lower than investing in built infrastructure to achieve the same water gains (see Webster et al. 2024). Furthermore, such activities can contribute towards employment as well as offer opportunities for stimulating the green economy.

6.6 Socio-economic consequences

The economic consequences of the scenarios were assessed in terms of the costs of water supply infrastructure and water supply management activities needed to meet increasing demands or EWRs as outlined in chapter 4 of the report, and in terms of contribution to GDP (value added) through increased output from water using sectors or water dependent sectors.

Total infrastructure costs to meet shortfalls as a result of increased water demands and EWR requirements, is highest under the ESBC and DEV scenarios (Table 6-5). This is because under the ESBC and DEV scenarios water demands into the future are significantly higher than under the other scenarios and this will require significant investment in water supply infrastructure to meet these demands. The cost of supplying future demands is highest in the Upper and Lower Sand IUAs and Nzhelele/Ṅwaneḓi IUA where higher levels of water intensive development have been proposed. It is important to note that these costs are based on proposed options which have not been fully assessed or finalised, and which fall beyond the scope of this study. The values presented here are indicative only and illustrate the likely order of magnitude difference in costs across the alternative scenarios based on the levels of development assumed under each.

Under the BE scenario, water supply costs are lower than the other scenarios, as this scenario only considers increases in domestic demand as a result of population growth and management interventions such as WC/WDM which would be needed in some IUAs to achieve the EWRs under this scenario. In the Upper Sand, a water reuse system was costed as a way to reduce transfers and return flows into the Sand Catchment and to improve water quality. These costs were applicable under both the STCD and BE scenarios. The overall water supply costs under the STCD scenario lie between the BE and DEV scenario due to the reduced demands associated with development under this scenario.

Table 6-5. Total water supply costs (R millions) to meet shortfalls under the scenarios in terms of increased demands and EWR requirements. This includes conservation and demand measures that are assumed to be implemented to meet any shortfalls.

IUA	PES	ESBC	BE	DEV	STCD
Upper and Lower Lephalala			0.24		
Upper Nyl & Sterk	88.33	630.16	88.33	630.16	88.33
Mogalakwena	1.57	89.86	1.57	89.86	1.57
Kalkpan se Loop			2.65		1.68
Upper Sand	6,151.38	10,192.86	1,224.14	10,192.86	1,224.14
Lower Sand	79.87	10,385.90	80.49	10,385.90	6,231.54

IUA	PES	ESBC	BE	DEV	STCD
Mapungubwe			1.50		4.18
Nzhelele/Ṅwanedi	46.97	670.70	46.97	670.70	46.97
Upper Luvuvhu	124.23	137.34	124.23	137.34	124.23
Lower Luvuvhu/Mutale	0.98	2.96	0.98	2.96	0.98
Shingwedzi	26.01	27.55	27.50	27.55	27.50
TOTAL R million	**6,519.34**	**22,137.34**	**1,598.62**	**22,137.34**	**7,751.13**

Value added to the economy is highest under the DEV scenario (for all other sectors held equal), which is associated with the significant gains in industrial and mining production, particularly in the Sand Catchment. However, the gains under this scenario are only slightly higher than under the STCD and BE scenarios which have sustained growth in nature-based tourism which is strongly linked to condition of aquatic ecosystems in the study area. Under the DEV scenario, losses in tourism value are expected to be significant, as shown by an assumed loss of eco-tourism across the broader area due to irreparable environmental degradation under this scenario. Intensive mining, such as open cast coal mining, could result in prolonged and irreversible environmental degradation as well as air pollution which would likely lead to the loss of nature-based tourism in the broader geographical landscape and lead to significant downstream biodiversity and ecosystem service losses.

Under the BE and STCD scenarios, the higher flow volumes needed to maintain EWRs resulted in the need for curtailment of irrigation and mining in some IUAs. This resulted in some losses to the overall contribution to GDP under each of these scenarios. It is important to note that the overall gains under the DEV scenario have a high level of uncertainty and risk attached to them as the level to which such development can be sustained into the future remains unknown given the current levels of water scarcity in the region and a likely drier future under climate change.

Table 6-6. Total value added to the economy (contribution to GDP, R millions) as a result of changes in outputs of water using sectors under each of the scenarios.

IUA	PES	ESBC	BE	DEV	STCD
Upper and Lower Lephalala	330.00	320.0	370.0	320.0	350.0
Upper Nyl & Sterk	1,080.00	1,170.0	1,490.0	1,250.0	1,290.0
Mogalakwena	450.00	420.0	530.0	420.0	490.0
Kalkpan se Loop	10.00	0.0	20.0	0.0	10.0
Upper Sand	1,440.00	3,670.0	1,660.0	3,670.0	2,950.0
Lower Sand	1,280.00	5,910.0	1,520.0	5,910.0	4,230.0
Mapungubwe	70.00	0.0	230.0	0.0	150.0
Nzhelele/Ṅwanedi	320.00	390.0	410.0	390.0	370.0
Upper Luvuvhu	310.00	320.0	320.0	320.0	290.0
Lower Luvuvhu/Mutale	210.00	50.0	610.0	50.0	310.0
Shingwedzi	440.00	30.0	1,390.0	30.0	650.0
TOTAL R million	**5,940.00**	**12,280.0**	**8,550.0**	**12,360.0**	**11,110.0**

In terms of household income, development of irrigation agriculture, mining and industry would have some positive outcome on household income under the DEV scenario. While household incomes will increase under the BE scenario, this will be slightly lower than under the DEV scenario given the lower levels of development across the whole study area under this scenario but higher than maintaining the PES due to the likely increase in household income associated with the investment in nature-based tourism and associated biodiversity economy activities. Household incomes under the STCD scenario will be higher than under the BE and DEV scenarios. This is due to the lower levels of development in the high priority ecological catchments compared to the DEV but still maintaining some development outside of the conservation areas and with increases in incomes associated with nature-based tourism.

Table 6-7. Changes in household incomes (R millions) as a result of changes in outputs of water using sectors under each of the scenarios.

IUA	PES	ESBC	BE	DEV	STCD
Upper and Lower Lephalala	30.00	30.00	30.00	30.00	30.00
Upper Nyl & Sterk	62.00	48.00	85.00	48.00	69.00
Mogalakwena	40.00	39.00	50.00	39.00	42.00
Kalkpan se Loop	0.50	-	1.00	-	0.55
Upper Sand	115.00	241.00	125.00	241.00	250.00
Lower Sand	100.00	337.00	110.00	337.00	347.00
Mapungubwe	6.00	-	13.00	-	7.00
Nzhelele/Ṅwanedi	27.00	30.00	31.00	30.00	28.00
Upper Luvuvhu	28.00	29.00	30.00	29.00	28.00
Lower Luvuvhu/Mutale	18.00	5.00	36.00	5.00	21.00
Shingwedzi	35.00	3.00	77.00	3.00	44.00
TOTAL R million	**462.00**	**762.00**	**588.00**	**762.00**	**867.00**

7 OVERALL ANALYSIS AND RECOMMENDATIONS

7.1 Multicriteria analysis

The multicriteria analysis involved scoring the scenarios based on the change in a range of ecological, economic and social criteria or indicators. Not all of these could be measured in comparable units such as money. The MCA approach allows for both monetary and non-monetary effects to be assessed. This was done through score normalisation whereby the attribute values were scaled to the same interval (between 0 and 1), ensuring equal importance in the data. A normalised score was generated for biodiversity (based on a wetland and river health and importance score; and a score relating to sense of place and maintenance of downstream ecosystem services), for economy (based on value added gains or losses to the economy and water supply costs), and for society (based on change in household income, ecosystem goods and services, and contributions to meeting climate commitments and mitigation of climate change).

To generate an overall score and ranking of scenarios, the variable scores are weighted. In this analysis, biodiversity was given a weighting of 0.5 and the variables of economy and society were weighted as 0.25 each. It was deemed appropriate to give a higher weighting to biodiversity because of the important intangible elements associated with biodiversity that are not being captured through the scenario process. However, a sensitivity analysis was also undertaken which explored the changes under different weightings. The final scores and ranking of scenarios are shown in Table 7-1 and Figure 7-1.

The results of the MCA indicate that the STCD scenario is ranked the highest followed by the BE scenario. Whilst there is some trade-off in terms of biodiversity under the STCD scenario (compared to the BE scenario), this is relatively small, and the overall economic and societal impacts are highest under this scenario. When the weightings of the variables are changed to be equal (i.e., 0.33 weighting across the three variables) the STCD scenario remains the highest ranked scenario (score 0.80), and this is followed by the BE scenario (0.75) and DEV scenario (0.45). The BE scenario scores higher than the ESBC and DEV scenarios for economy as it has very low water supply costs associated with it and the difference between water costs is much greater than the difference between value added to the economy across the scenarios.

Table 7-1. Overall scores and ranking of scenarios.

Variable	PES	ESBC	BE	DEV	STCD
Biodiversity	0.81	0.11	0.92	0.41	0.84
Economy	0.34	0.54	0.67	0.55	0.76
Society	0.36	0.38	0.65	0.40	0.83
Overall score and ranking	**0.58**	**0.28**	**0.79**	**0.44**	**0.82**

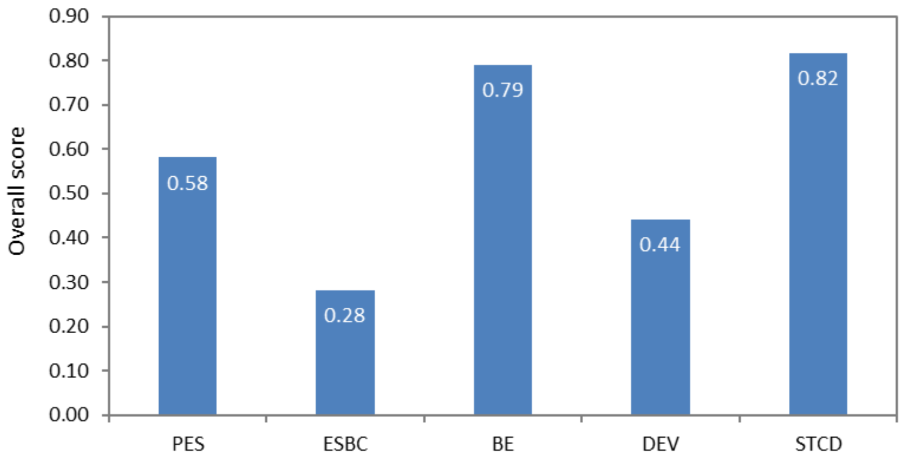


Figure 7-1. The overall score and ranking of scenarios from the MCA.

Figure 7-2 shows the normalised score across the three variables for each of the scenarios. This clearly illustrates the trade-offs involved. For example, under the BE scenario, a trade-off is made in terms of the economy and to some extent society through changes in household income, for higher biodiversity gains. Societal gains are highest under the STCD, and the economy and biodiversity scores are higher than under the DEV and ESBC scenarios which score poorly in terms of biodiversity as well as in terms of society.

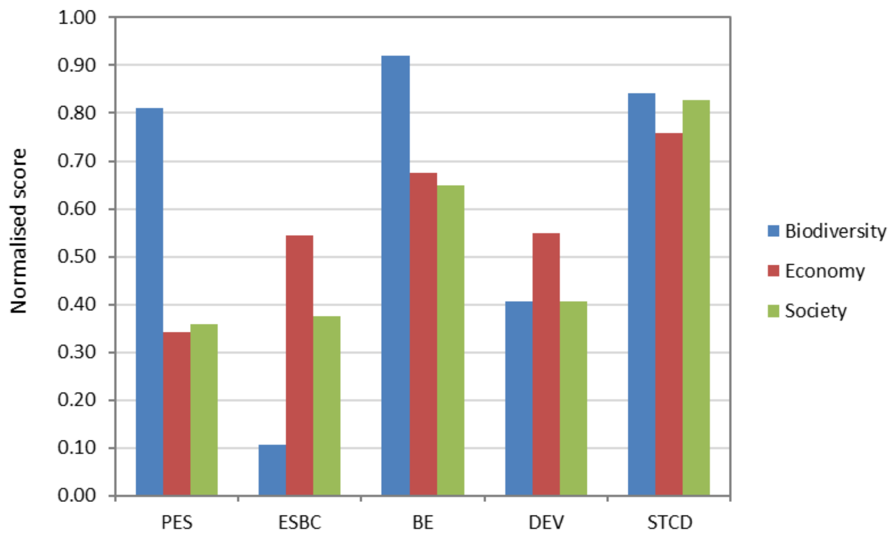


Figure 7-2. The normalised score for each of the variables (Biodiversity, Economy and Society) for each of the scenarios.

7.2 Proposed Water Resources Classes

Water resource classes (WRCs) were determined for each IUA based on the proportion of nodes falling within each of ecological categories. These are presented in Table 7-2 and for the STCD scenario are shown spatially in Figure 7-3. All scenarios are mostly in a Class II, except for the ESBC scenario, which is mostly Class III. The DEV scenario has three IUAs in a class III which is more than the STCD and BE scenarios which have one IUA in a Class III. The BE scenario has just one IUA (Upper Sand) in a Class

III and the highest number of IUAs in a Class I. The STCD scenario is the same as the BE scenario but with one less IUA in a Class I.

Table 7-2. Water resource classes for each IUA under each scenario

Variable	PES	ESBC	BE	DEV	STCD
Lephalala	II	II	II	II	II
Kalkpan Se Loop	I	III	I	I	I
Upper Nyl & Sterk	III	III	II	III	II
Mogalakwena	II	III	II	II	II
Mapungupwe	II	III	I	II	II
Upper Sand	III	III	III	III	III
Lower Sand	II	II	II	II	II
Nzhelele/Ṅwaneḓi	II	III	II	II	II
Upper Luvuvhu	II	III	II	II	II
Lower Luvuvhu/Mutale	II	III	II	III	II
Shingwedzi	II	III	II	II	II

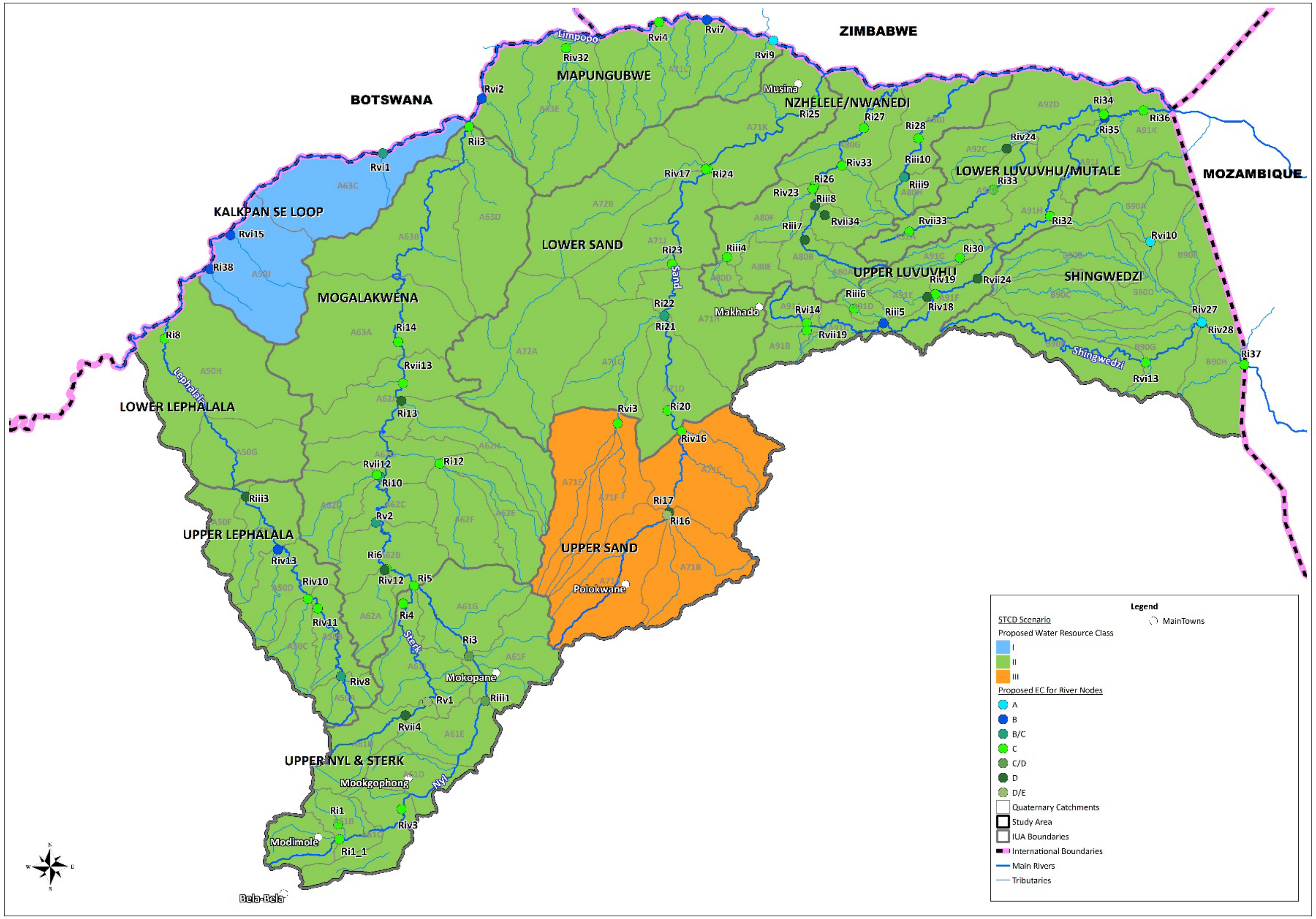


Figure 7-3. The proposed water resource classes for each IUA under the STCD scenario showing the proposed EC for each of the river nodes. Class I represents higher ECs and minimal use, Class II represents moderate use and Class III lower ECs with heavy use.

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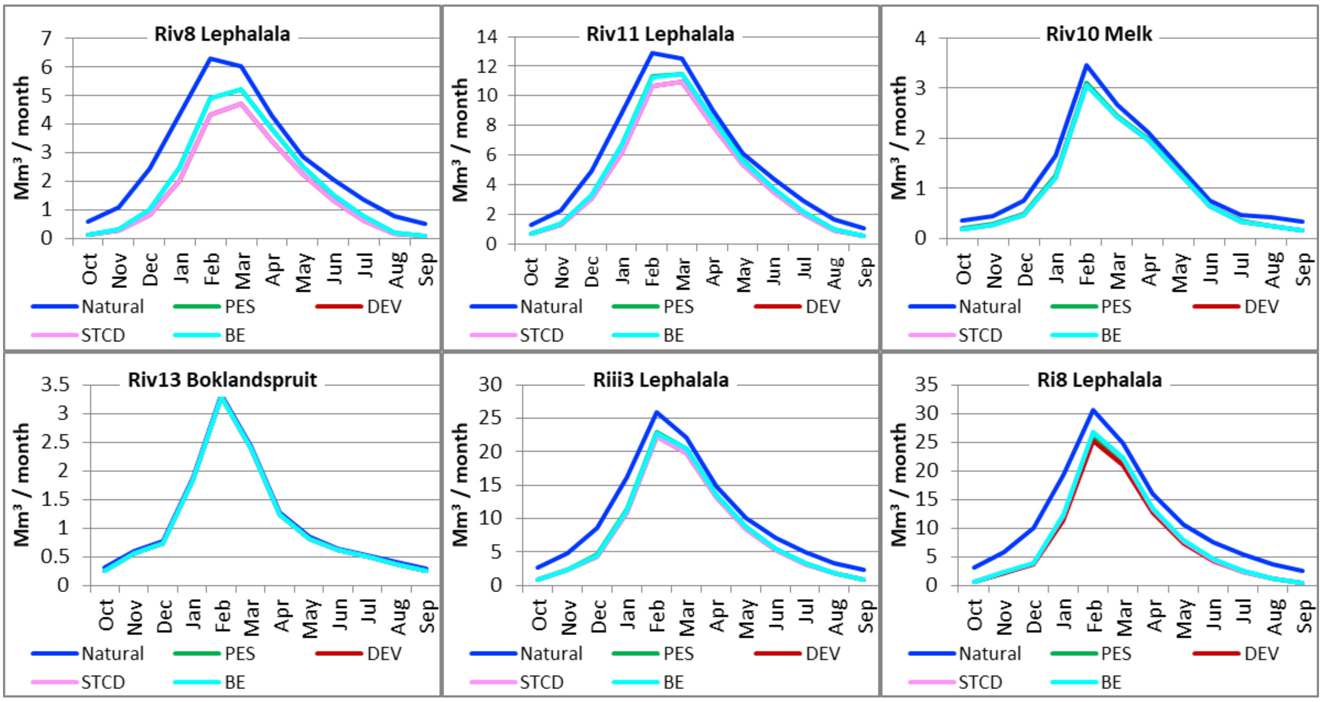
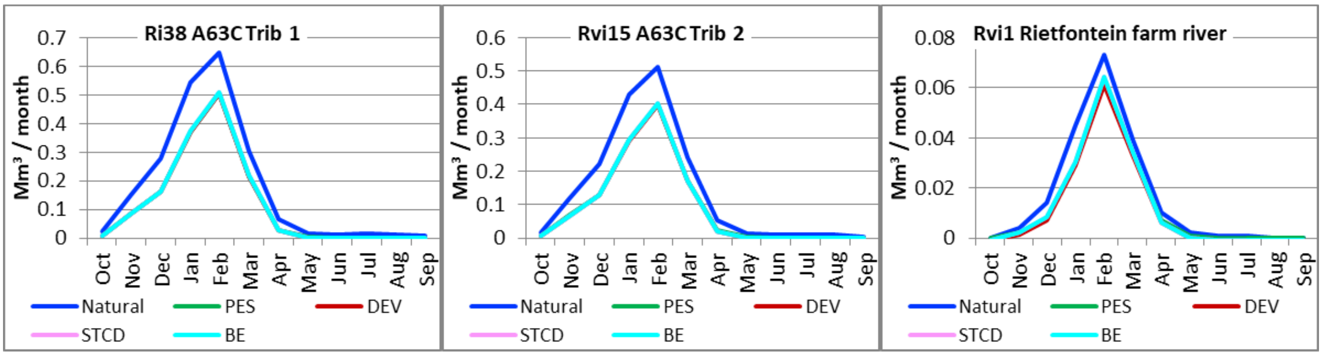
APPENDIX 1: MONTHLY FLOW VOLUMES PER RIVER NODE/REACH

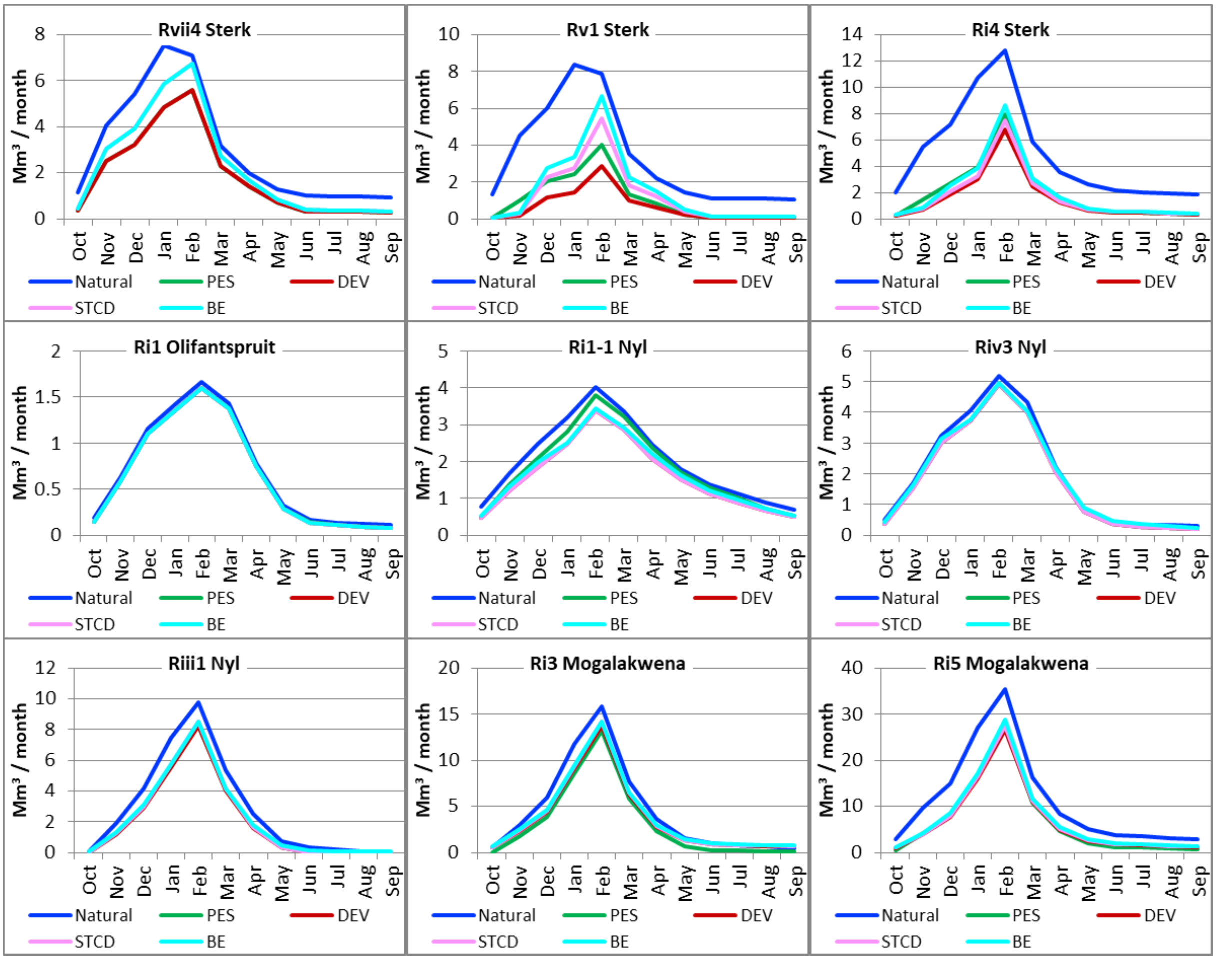
Upper and Lower Lephalala



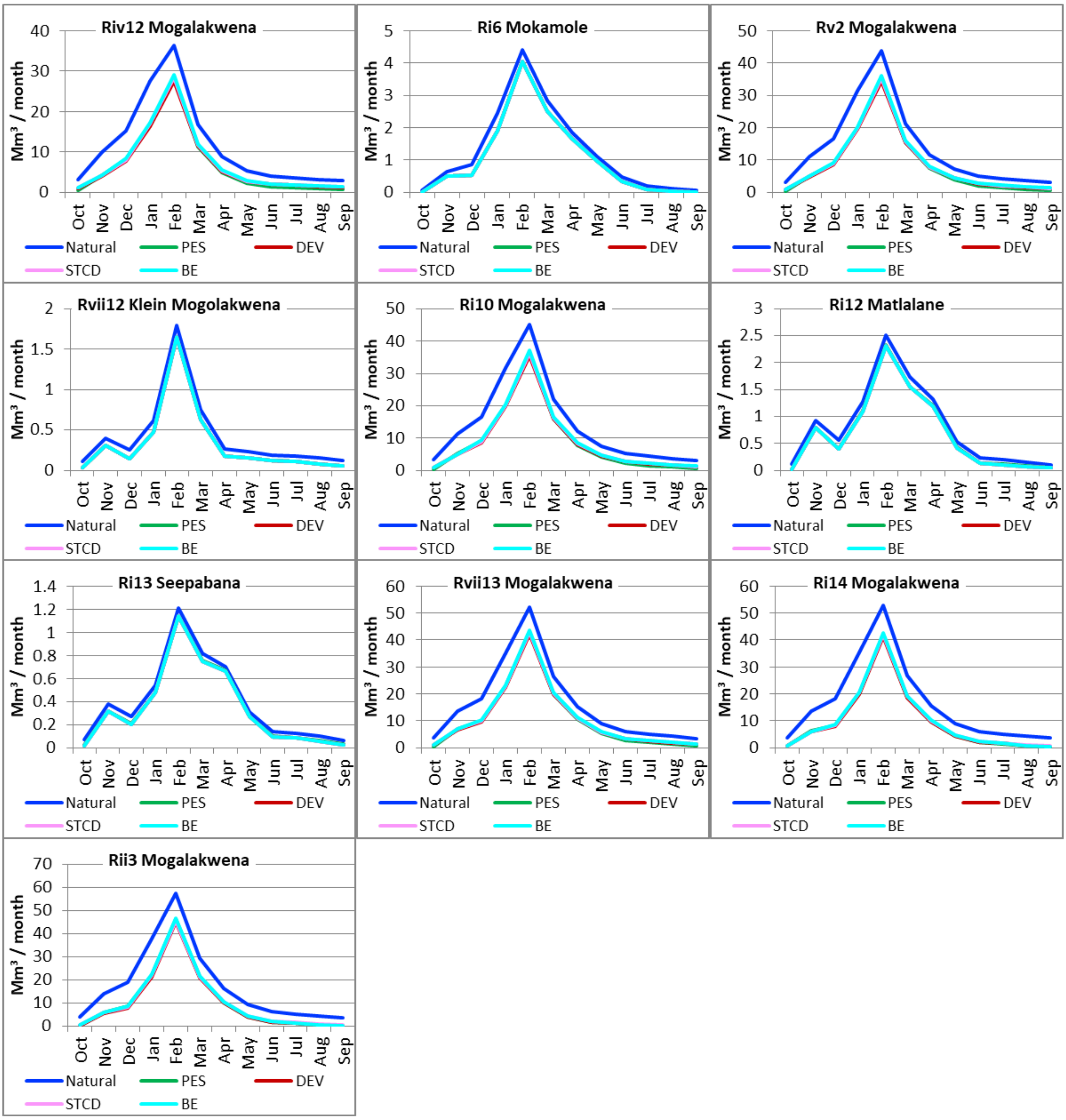
Kalkpan se Loop



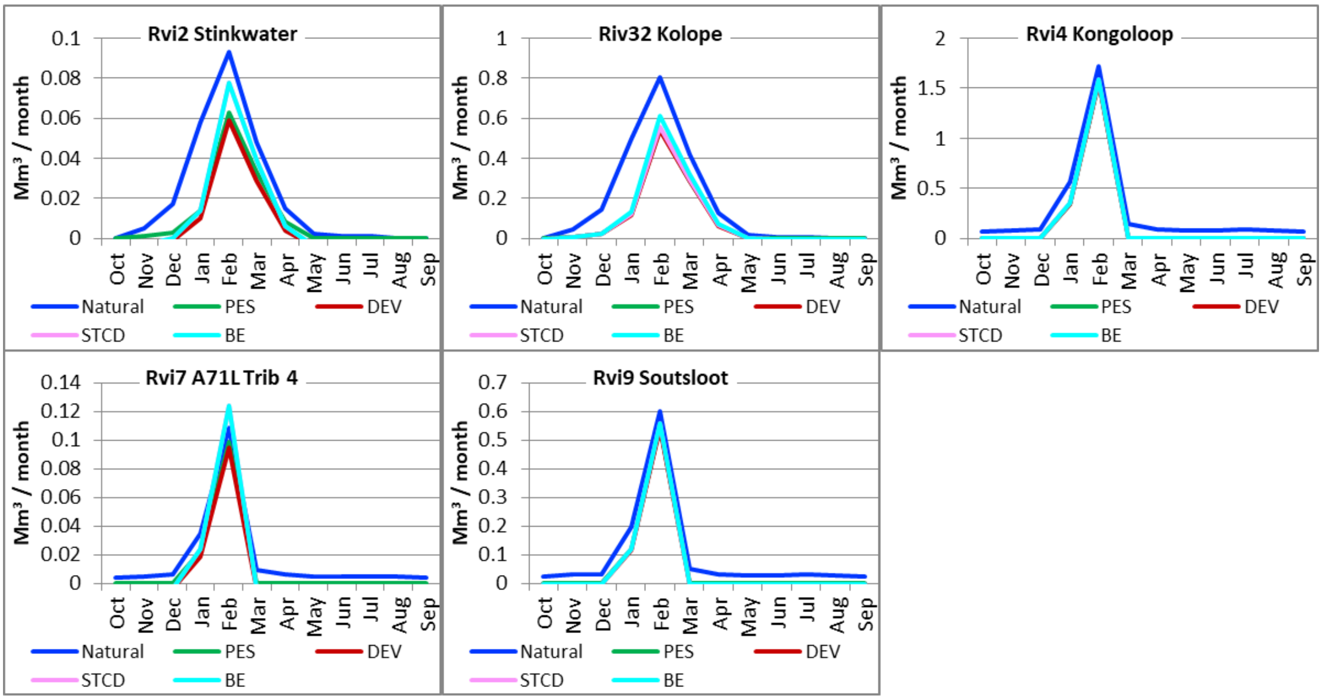
Upper Nyl and Sterk IUA



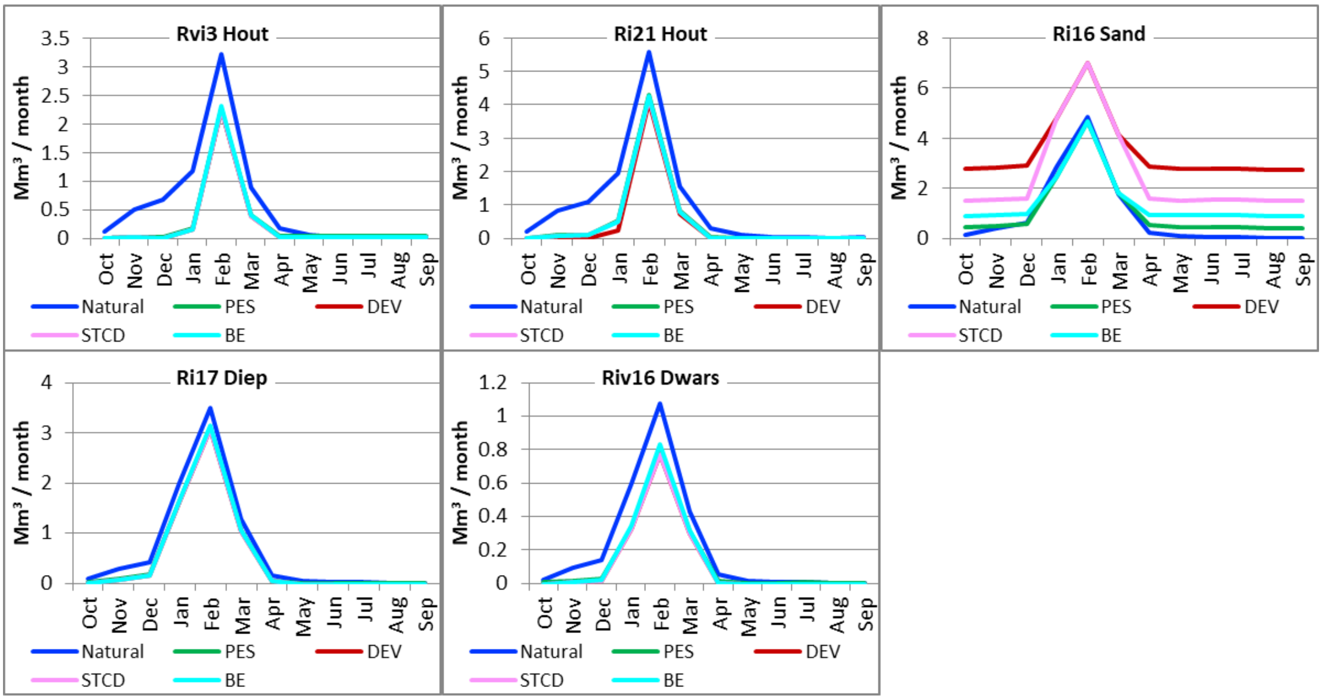
Mogalakwena IUA



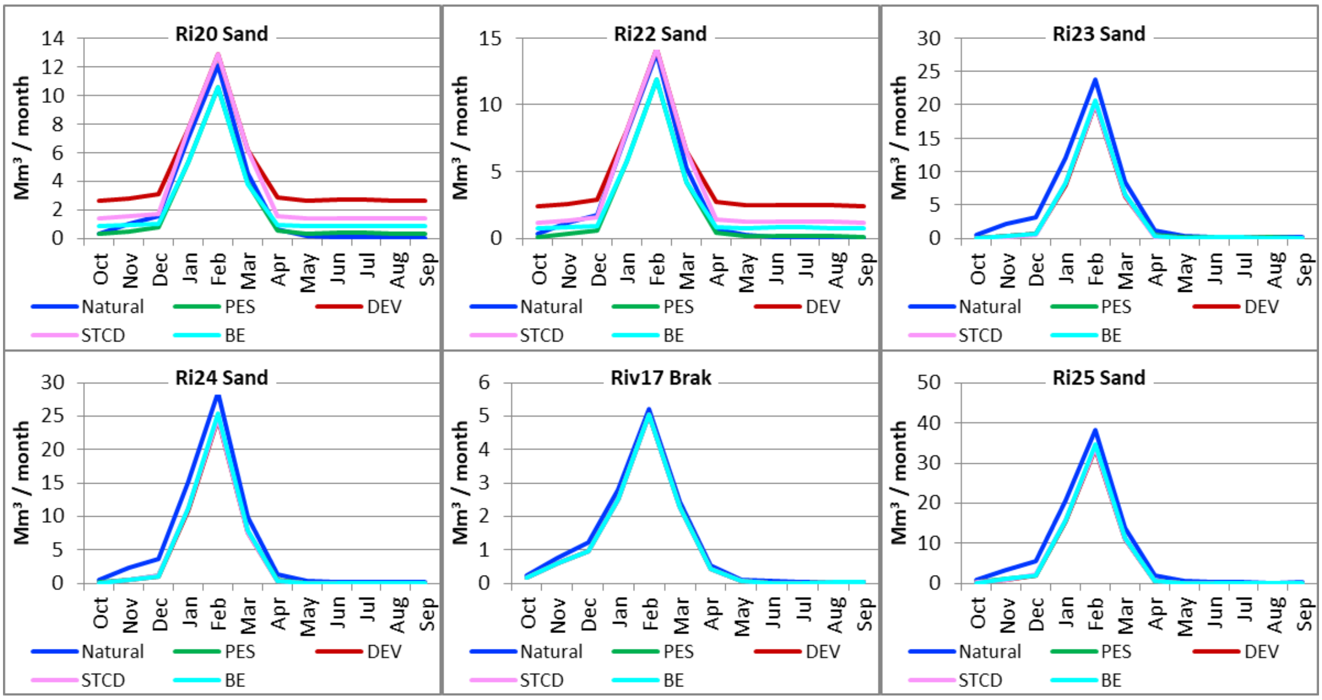
Mapungubwe IUA



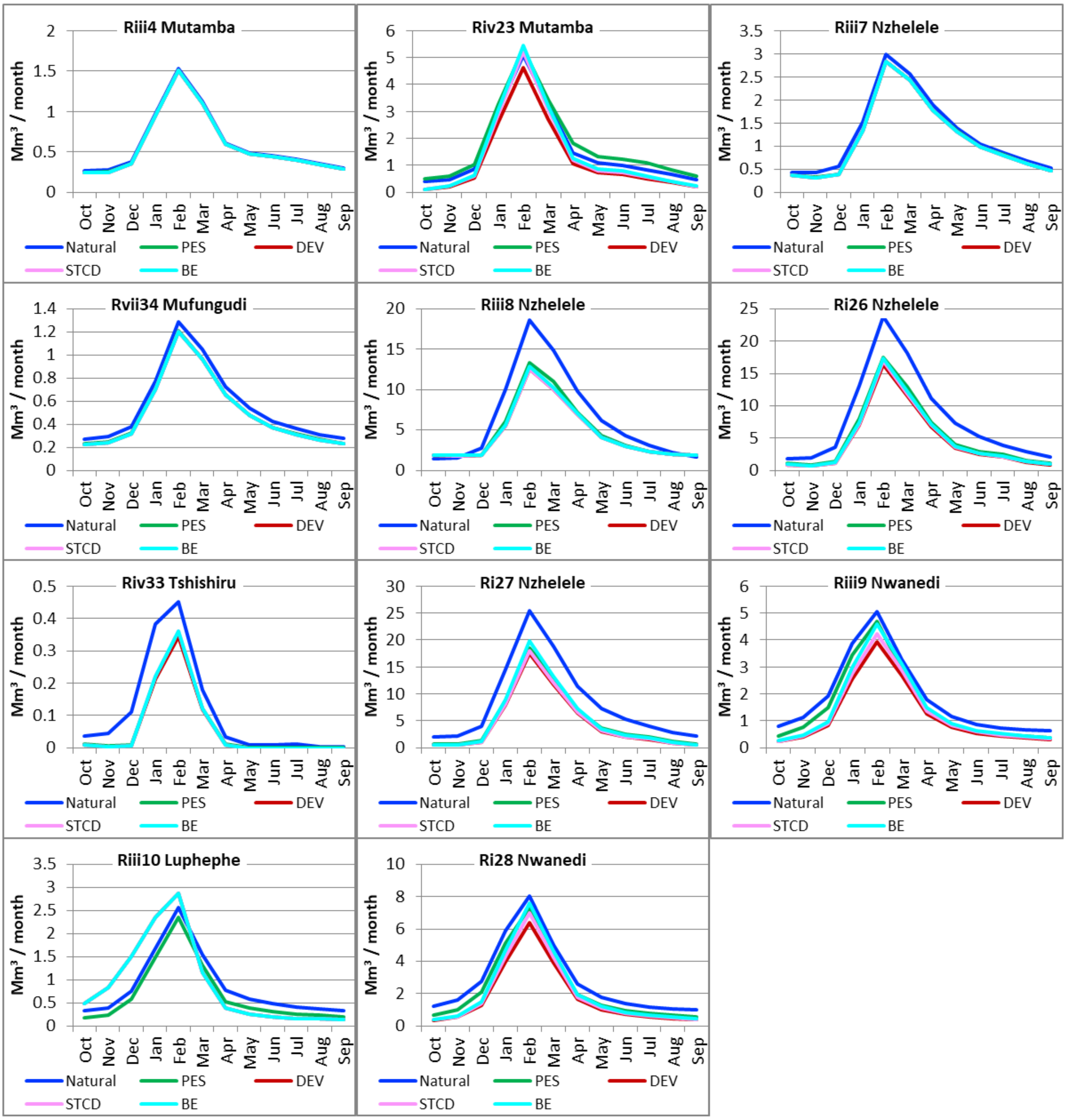
Upper Sand IUA



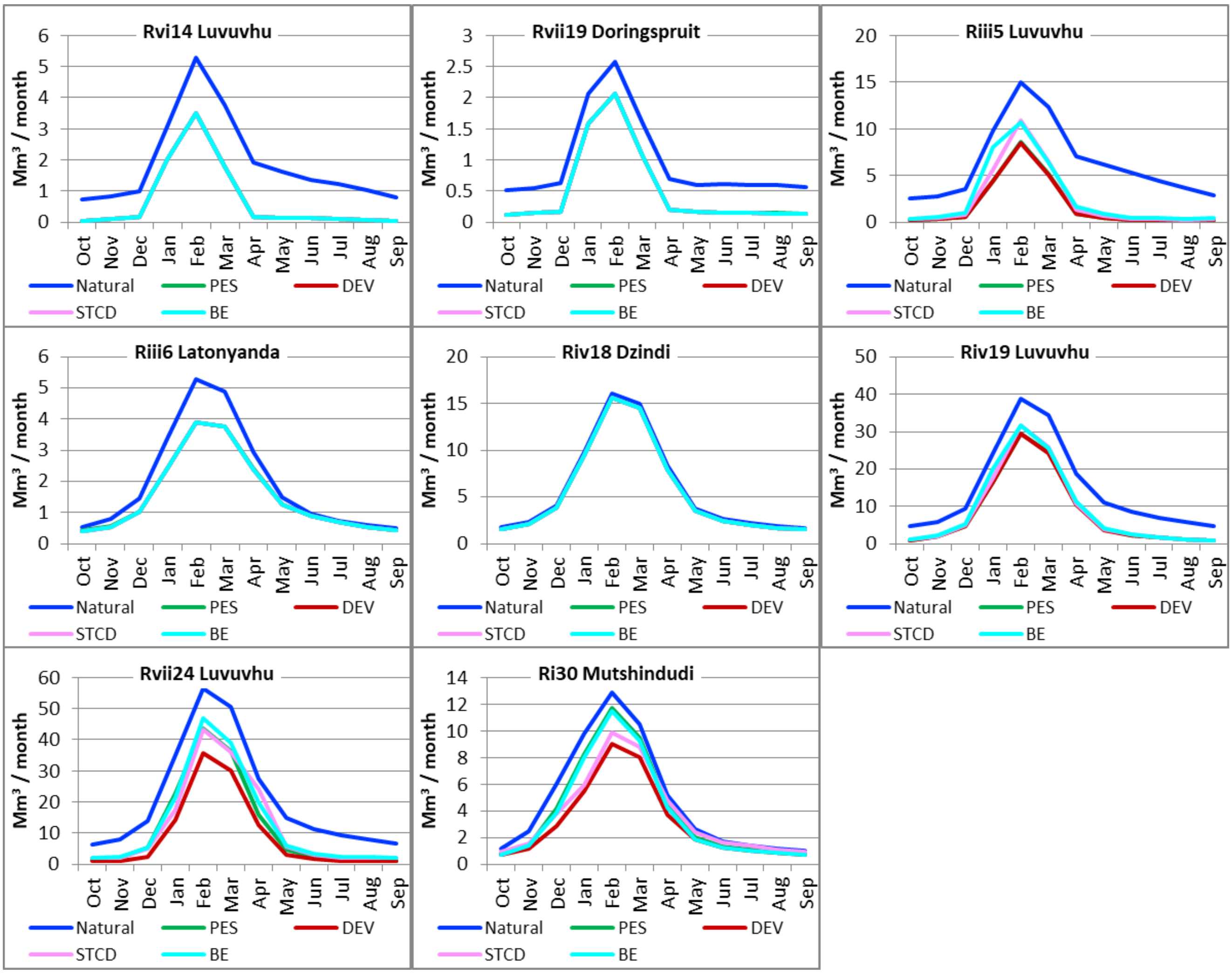
Lower Sand IUA



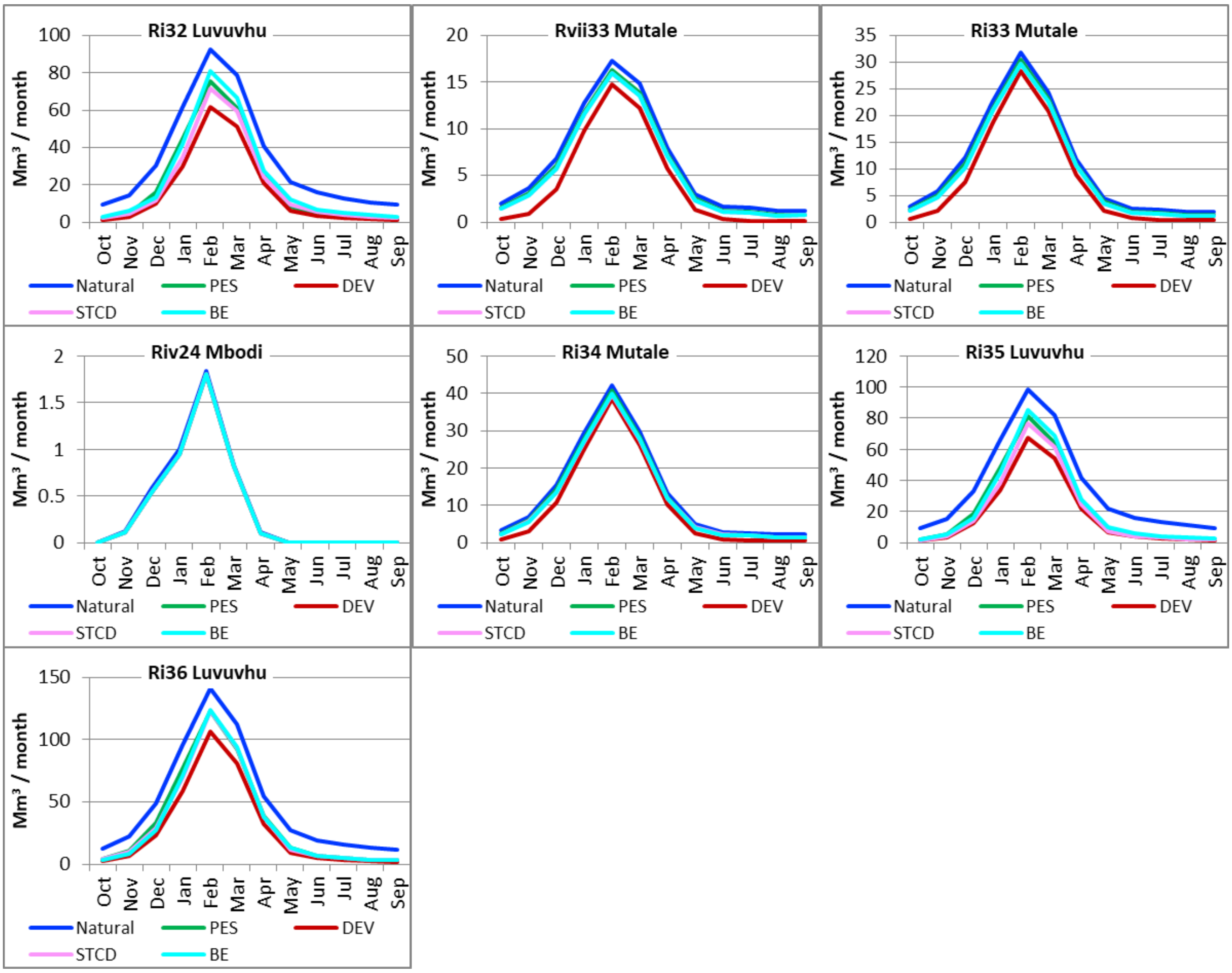
Nzhelele/Nwanedi IUA



Upper Luvuvhu IUA



Lower Luvuvhu IUA



Shingwedzi IUA