CONJUNCTIVE WATER USE GUIDELINE

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CONJUNCTIVE WATER USE GUIDELINE

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

This Guidance document forms part of a series of guidelines developed as part of the Danish and South African Strategic Water Sector Cooperation.

It is recognised that groundwater can play a significant role in decreasing the pressure placed on water supply due to unplanned fast urban growth outpacing economic, social and institutional interventions. Water planners are forced to explore developing and maintaining a combination of water supply sources to ensure water security and reduce the impacts of extreme climatic conditions such as drought.

Groundwater can be developed conjunctively with surface and other measures, such as reducing non-revenue water to support the growing demand for clean water in South Africa. A solid knowledge base provides the foundation for conjunctive water use. This guidance document adds to the knowledge by promoting the emergence of groundwater as a significant contributor towards water security and resilience. Municipalities can benefit from the guideline as a resource to guide decisions rooted in providing net social benefits through coordinated institutional involvement and well-informed processes for selecting options for conjunctive water use.

AIMS

The following were the aims of the project:

1. To provide an overview of conjunctive water use within selected municipalities
2. To provide an overview of perceptions of decisions makers on conjunctive water use (interviews)
3. To provide a high-level water use options analysis process with particular emphasis on groundwater supply
4. To provide a high-level cost-benefit analysis process relating to socio-economic limitations, access and availability to supply sources
5. To add to capacity building through stakeholder consultations/training through the guideline

OVERVIEW OF CONJUNCTIVE WATER USE

Conjunctive water use is defined as the coordinated use of surface water and groundwater to maintain a continuous water supply of a region over a long term. Conjunctive water use has the potential to reduce the influence of unpredictable rainfall patterns on water supply availability and reliability. It is considered one of the effective methods of meeting increasing demands from different sectors of society for water supply.

As a water-stressed country, South Africa has been operating under water supply deficit conditions, which means the water demand exceeds the available resources. To deal with the water security challenges, a great deal of focus has been on developing surface water resources. The current projects in their planned implementation phase focus on surface water infrastructure and inter-catchment transfers, with relatively few projects incorporating groundwater development. Despite these measures, a deficit is still predicted, which suggests the growing demands on water supply need a different approach to water management. Intentional conjunctive water use is being proposed to build the country's water supply resilience against extreme weather conditions.

The challenge associated with conjunctive water use in the country is the existing bias towards surface water development, and groundwater use is regarded as an emergency response to drought conditions. Conjunctive water use promotes the planned use of groundwater to sustain supply through different climatic conditions. This is not an innovative approach since over 50 percent of settlements in the country have groundwater as part of their water supply. Although groundwater is supplying a significant portion of rural settlements in South Africa, municipalities still approach its use for water supply with scepticism and resistance. It is often cited that the resource is unreliable.

Conjunctive water use has gained global attention in many parts of the world, where the consensus has been that it has the potential to meet the increasing demands of competing water users and ease the challenge of over-allocated surface water. However, South Africa's municipalities have not intentionally shifted their perception of groundwater to invest in resource development. Even with the lack of investment, groundwater is still an important water source. Through the conjunctive use of surface water and groundwater, South Africa's water needs can be met while reducing expenditure on more expensive structures that are likely inappropriate for the environment. When managed well, groundwater can be more reliable and potable with minimal treatment than surface water.

OPTIONS ANALYSIS

An options analysis is one of the requirements of the National Treasury project appraisal process. This non-linear process should be used to confirm whether a detailed investigation is needed to support the project business case. An initial list of projects is developed based on the project objectives, from which a shortlist is created based on defined criteria. The water supply project appraisal process should consider all potential options for the target area regardless of perceived feasibility to guard against biased perceptions against water sources, in particular, the development of groundwater. The Department of Water and Sanitation has a number of assessments that it conducts for water supply projects that are also aligned with the requirements outlined in the National Treasury guidelines. These assessments include:

- **Water Requirements Assessment** – should be completed with a long-term objective of creating a sustainable and resilient water supply system. During the assessment, the population trends and baseline and forecast of water consumption are estimated, considering whether the project will be implemented at a regional or local scale. The status quo of the existing supply system, including the infrastructure and utility service areas, should be noted. This can be used to determine to what extent conjunctive use of the surface and groundwater can be supported without significant interventions.
- **Water Resource Yield Modelling** – the project objectives and strategy should be used to guide the resource modelling. The modelling process must reflect the interlinked nature of groundwater and surface water resources which will require the collaboration of a multidisciplinary team. Different strategies can be simulated to find the optimal ratios and temporal scales for using the different water sources. Four strategies are highlighted, drought cycling, seasonal cycling, initial intensive exploitations and mixed strategy. The assumptions and limitations of the modelling process must be noted.
- **Technical Analysis** – the current analysis is skewed towards surface water developed, which means there is an opportunity to encourage conjunctive water use during the analysis. This assessment has multiple components, including developing conceptual layout options, designing the distribution system, developing an operations and maintenance strategy and action

plans, financing strategy and implementation plan. Each one of the components offers an opportunity to consider how surface and groundwater can be used conjunctively to create a sustainable and resilient water supply.

- **Environmental Impact Assessment** – it is likely that a proposed conjunctive water use project will trigger the need to complete an Environmental Impact Assessment. The assessment requirements will be based on the design and scope, which must be relatively well-defined before initiating the EIA. The first step may be to complete a scoping report before the final project is selected from the list of options since the outcomes can influence the feasibility of the proposed project. The assessment must highlight sensitive ecosystems that may be impacted, regulatory requirements and specialist studies needed before implementing the proposed project.
- **Socio-economic Impact Assessment** – the intentional implementation of conjunctive use has the potential to impact communities and the economy in the target area. The benefits may manifest in how water is used for domestic activities and through changes in industrial and agricultural activities. However, these benefits should not be assumed as a given. A socio-economic impact assessment is needed to identify negative social and economic effects that could arise from the project. This assessment should also ensure that the project is aligned with government policies and gain the appropriate local cultural context.
- **Regulatory Due Diligence** – it is very likely that regulatory requirements will be triggered for any conjunctive water use project. The key legal considerations and legislations, such as the Water Services Act and zoning and town planning requirements, need to be noted.

COST BENEFIT ANALYSIS

A Cost Benefit Analysis (CBA) is one of many analyses that can be applied as point of a project appraisal. An analysis is used to determine a proposed project's net social benefits to society. In so doing, it can assist decision-makers regarding the value provided to society should the project be implemented. Although sufficient literature points to the benefits of conjunctive water use, a CBA is a valuable tool that can support a project's implementation by illustrating the costs and benefits involved. These benefits and costs are generally presented in monetary value as the Net Present Value of a project. The assumption is that the final NPV reflects the impacts on individuals or groups that benefit directly or indirectly from a project.

The steps involved in the process of completing the CBA include the following:

- **Defining the objectives and scope** – to ensure that the context within which the project is being analysed is understood and that the appropriate solutions and recommendations are made. This step outlines the motivation behind implementing the project and the boundaries within which these considerations are made.
- **Defining the base case and alternative options** – this step is used to define the status quo (base case) if the proposed project is not implemented and outline the proposed alternative projects that can meet the stated objectives. Ideally, an options analysis should have been completed to assist with defining the different alternatives.
- **Identifying costs and benefits** – although costs and benefits are generally difficult to identify and quantify, they are used to evaluate the suitability of the projects to ensure net social benefits. Different methods can be used to identify the costs and benefits, considering whether these impacts are experienced directly or indirectly by primary markets or secondary markets within local, national or international boundaries.
- **Quantifying the impacts** – a number of approaches can be used to value the identified costs and benefits; however, the outcome should be presented in monetary value. This figure generally indicates the present value with the future cost and benefits discounted. The opportunity costs of a resource or service can be evaluated, or the willingness to pay concept can be used to determine value.
- **Discounting of the project costs and benefits** – this step considers that the value of cost and benefits today differs from those gained in the future. Furthermore, it acknowledges that not all gains can be presented in monetary value. Therefore, discount rates must be applied to present the costs and benefits in present value.
- **Conducting a sensitivity analysis** – while discounting accounts for discrepancies due to the different impacts of the timelines, the sensitivity analysis is completed to test the impact of assumptions made and key input on project outcomes. It is an opportunity to test the CBA premise under different conditions.
- **Determining acceptability of risk** – it is accepted that in projecting scenarios into the future, risk and uncertainty are added to the project

outcomes. The risk assessment process is designed to identify risks, and where applicable, the project's sensitivity to the risk is tested. This step can assist decision makers with determining the acceptability of risk associated with a project and evaluate trade-offs between net higher benefits vs net higher risks.

- **Reporting** – the outcome should be captured in a report documenting the different aspects of the analysis. The final evaluation is important, since it captures the social benefits gained from a project through the calculated NPV, with a positive NPV indicating net positive social benefits that society gains from implementing the project.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS & ABBREVIATIONS

AMD	Acid Mine Drainage
CBA	Cost Benefit Analysis
CWC	Central Water Commission
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
GIS	Geographic Information System
IWRP	Integrated Water Resource Planning
MAR	Managed Aquifer Recharge
NPV	Net Present Value
NWRS	National Water Resource Strategy
O&M	Operation and Maintenance
sw	Surface Water
SWSA	South Africa's Strategic Water Source Areas
WCWDM	Water Conservation and Water Demand Management
WMA	Water Management Area
WSA	Water Service Authority
WSP	Water Service Provider

GLOSSARY

Base Case Scenario – The state of the project without implementing the proposed project or activity, which includes the minimum interventions or improvements that would have naturally occurred

Conjunctive Water Use – Coordinated/planned use of surface and groundwater to optimise water supply in a region over the long term

Cost Benefit Analysis – A project evaluation method used to assist decision-making regarding the value provided to society by a project

Managed Aquifer Recharge. – The intentional storing and treatment of water using aquifers. MAR is differentiated from unintentional recharge from leaking canals, water infrastructure and irrigation

Options Analysis – A non-linear process used to confirm whether a detailed investigation should be completed to support the project business case and cost-benefit analysis.

Recharge – Infiltrating water that reaches the water table, expressed as volume per time unit

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

This guidance document forms part of the Danish and South African Strategic Water Sector Cooperation – long-term bilateral cooperation contributing to the South African water sector through knowledge sharing of practical experiences by industry experts.

As surface water resources become increasingly over-allocated, municipalities and water utilities can benefit from revising their water use mix options, including tapping into the available groundwater potential. Still, groundwater is often only used as an emergency water supply during droughts. According to the National Groundwater Strategy (DWS, 2016), water supply in Provinces such as Limpopo and the North West is predominantly from groundwater. The resource only accounts for 13 per cent of the total national water supply (Reimann *et al*., 2012).

Water resource managers are faced with managing water resources in the context of a high rate of urbanisation which places a strain on water infrastructure, poses a risk to human and environmental health, and contributes to disparate socio-economic development and access to water. These challenges are, to an extent, linked to a failure in the governance of water management institutions. As South African towns and cities face challenges of unplanned urban growth outpacing economic, social and institutional interventions, they need to develop and maintain diversified water resource schemes to guard against water insecurity and extreme climatic (drought) conditions (Dos Santos *et al*., 2017). Consequently, South Africa can benefit from emphasis on implementing conjunctive water resource management, the benefits of which are (SADC-GMI, 2019):

- Diversification of the water supply mix
- Improved water supply security and security of water sources (prevention of over-exploitation, preparedness for extreme weather events)
- Larger net water supply yield (efficient use of both water resources)
- Reduced environmental impact (prevents/limits over-exploitation of groundwater and surface water, waterlogging and salinisation)

Conjunctive water use supports a resilient water supply and security. The concept of resilience here refers to coping and recovering from stresses and shocks. Resilience system analysis is increasingly applied to water governance to understand socio-ecological systems' ability to recover from imposed shocks such as extreme weather events. Several measures support the increasing development of groundwater for resilience, such as conjunctive water resource management, managed aquifer recharge (MAR), and groundwater reuse and recycling. Therefore, the proposed guidelines on conjunctive water use contribute to resilience building, emphasising groundwater use.

Conjunctive water use is aligned with the Department of Water Sanitation's strategy to meet water demand in the country. In 2015, the then-minister of the DWS highlighted the need to improve the water mix by incorporating additional water sources to supplement the country's current reliance on surface water (DWS, 2017). To increase supply assurance and reduce pressure on existing sources, multiple water sources and demand management are viewed as the best options (Gnawali *et al*., 2019; Zhang et al., 2018).

The perception of municipal planners has limited groundwater use within municipalities. However, there have been ongoing efforts to showcase the significance of groundwater resources through studies initiated by institutions like the Water Research Commission (WRC) and the more recent global campaign in 2022, "Groundwater: Making the invisible visible", championed by UN-Water.

Even with the negative perception, groundwater remains a strategic and vital resource for some municipalities in South Africa. An opportunity exists to diversify water resources. Numerous groundwater management strategies and guidelines exist:

- National Water Resource Strategy (DWAF, 2004, 2013)
- Framework for a National Groundwater Strategy (DWAF, 2007a)
- Guidelines for Catchment Management Strategies Towards Equity, Sustainability and Efficiency (DWAF, 2007b)
- Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa (DWAF, 2008)
- Groundwater Strategy (DWS, 2010; 2016)
- Regional groundwater plans

These strategies and plans are available in South Africa, but the practical challenges associated with the implementation appear to be a significant hurdle for sustainable conjunctive water use. In the "Strategic Overview of the Water Sector in South Africa" report (DWA 2013), the following challenges to sustainable service delivery for the water sector were defined:

- There is no surplus water in South Africa. Available water resources are at their limit, and climate change worsens the situation
- Due to water scarcity, all pollutants and effluent streams increasingly need to be treated to higher standards before being discharged
- A study of 905 towns (excluding Metros and large cities) found that 28 per cent have inadequate water resources
- Water must be distributed over large areas and rugged terrain at a high cost to service the remaining needs
- Waste Water Treatment Works are generally in poor condition, and many are at overcapacity, which increases the environmental health risk
- Municipal water consumption per capita is unacceptably high
- There is a lack of water demand management and poor water use efficiency
- There is a lack of capacity, particularly technical capacity, within Water Service Authorities (WSA) and especially regarding infrastructure asset management, with the result that infrastructure fails and service delivery suffers
- Many municipalities cannot provide sustainable services or run a successful WS business because of a lack of capacity and skills

1.2 PROJECT AIMS

Based on the terms of reference (ToR), the project aims are summarised as follows:

The following were the aims of the project:

1. To provide an overview of conjunctive water use within selected municipalities
2. To provide an overview of perceptions of decisions makers on conjunctive water use
3. To provide a high-level water use options analysis process with particular emphasis on groundwater supply

4. To provide a high-level cost-benefit analysis process relating to socio-economic limitations, access and availability to supply sources
5. To add to capacity building through stakeholder consultations/training through the guideline

1.3 SCOPE AND LIMITATIONS

This guidance document focuses on municipalities' conjunctive water use for domestic water supply. As a result, we have drafted the document to provide broad directions that can be tailored to the specific municipalities' needs when implementing conjunctive water use. The guideline is intended to assist with shifting groundwater use by municipalities from an ad-hoc, emergency implementation approach to one that is intentional and able to support supply-demand rates during different seasons.

Although key considerations, steps involved and practical examples for completing an Optional Analysis and Cost Benefit Analysis, these should be viewed as basic requirements for which different institutions involved in the project appraisal process may have additional requirements that must be met.

Conjunctive water use in this document refers to the combined use of groundwater and surface, including managed aquifer recharge. Other water sources, such as desalination, reclaimed water and rainfall harvesting, are briefly discussed. This should not be confused with Integrated Water Resource Management (IWRM), which promotes synchronised developments and management of water, land, and related resources to maximise the resulting economic and social well-being equitably while maintaining the sustainability of important ecosystems (GWP, 2000).

The water sector in South Africa faces several challenges, amongst which is the assurance of water supply for domestic water use. One of the significant challenges is non-revenue water, estimated in 2012 to account for at least 37 percent of municipal water consumption (Mckenzie *et al.,* 2012; Bhagwan *et al*., 2014). Non-revenue water refers to the difference between the amount of water put into the distribution system and the amount of water billed to consumers" (Mckenzie *et al.,* 2012; Donnefeld *et al.,* 2018). According to Donnefeld *et al.* (2018), leakages occur due to poor operations and maintenance, water meter manipulations or other forms of theft, and authorised consumption that is not billed, including water use for emergencies such as firefighting. Operations and maintenance (O&M) related losses were estimated to make the larger percentage (70 percent) of water losses. Compared to other water-stressed countries like Australia, South Africa's non-revenue water is relatively high (Mckenzie *et al.,* 2018). If South Africa could reduce non-revenue water along the same margins as Australia's 10 percent, it would equate to approximately 75 percent of total withdrawal by industry in 2017. This indicates that while conjunctive water use can be used to optimise water supply in the country, more will still need to be done to achieve water security in the country.

Furthermore, it is recognised that water conservation and demand management play a significant role in the water management strategy of the country. It is considered one of the most important features of ensuring stability in the water sector (Bhagwan *et al*., 2014; Donnefeld *et al.,* 2018). While this is noted, it does not form part of the scope of this guidance document

CHAPTER 2: OVERVIEW OF CONJUNCTIVE WATER USE

2.1 WHAT IS CONJUNCTIVE WATER USE

Conjunctive water use refers to the coordinated/planned use of surface and groundwater to optimise water supply in a region over the long term. Kayhomayoon *et al.* (2022) defined conjunctive water use as a strategy to connect, combine and synchronise the use of surface and groundwater to sustain demands on water supply systems. The Water Education Foundation differentiates between active and passive conjunctive water use. Active conjunctive use is the direct injection of surface water into aquifers as part of groundwater banking, while passive conjunctive water use is defined as the use of surface water during wet years and reliance on groundwater during the dry years. Sahuquillo (2021), on the other hand, differentiated between two types of conjunctive use, one where there is an artificial recharge of groundwater which cannot be used directly, and the other is alternate conjunctive use where wet periods are dominated by the use of surface water and groundwater use dominate dry periods. A key feature of conjunctive us is that the objective is to maximise available aquifer storage to buffer erratic stream/river flow rates and vulnerability to drought conditions (Foster *et al.*, 2010). This key characteristic makes conjunctive water use appealing, particularly for semi-arid countries like South Africa, for mitigation of climate change impacts.

Using groundwater and surface water conjunctively, water supply availability and reliability can be improved by reducing reliance on unpredictable rainfall. Moreover, it is an effective method of meeting the increasing water demands from different sectors. By actively implementing conjunctive use, South Africa can build resilience against droughts by planning to abstract water stored in the aquifer during wet periods in the dry seasons. This is a similar strategy proposed by the Sacramento Groundwater Authority (SGA) to maintain water supplies and build a resilient water supply sector in their region (See Box 1).

The environmental impacts, of course, need to be taken into consideration. According to Foster *et al*. (2010), some elements should be managed to optimise water user benefits whilst minimising the risk to the environment, such as:

- The balance needed between local recharge and groundwater use
- Impact of surface water abstraction during low river flow periods
- Delaying groundwater abstraction until river flow periods are high
- Hydraulic interconnection between aquifer and surface water

Municipalities in South Africa, like the City of Cape Town and the City of Tshwane, already use a mix of water sources to ensure supply for domestic use. However, the common operational strategy is to preferentially depend on surface water while flow levels are enough for downstream effluent assimilation and dilution and to maintain the ecological reserve. Groundwater use is often limited to extended drought conditions when river flows and dam levels are low. This approach puts unnecessary pressure on both water resources since one source is not likely to have the capacity to substitute for the other completely. Instead, understanding the balance and conditions to alternate between or simultaneously use the two sources is needed.

BOX 1: SACRAMENTO GROUNDWATER AUTHORITY GROUNDWATER BANKING CONJUCTIVE WATER USE

The Sacramento Community in California, United Stated has a history of prolonged droughts. Surface water accounts for 60 percent of water supply and groundwater accounts for the remaining 20 percent. The region has multiple water service providers who use a combination of surface water and groundwater. Different suppliers rely exclusively on groundwater and others surface water while some use a combination of both sources.

Due to increasing pressure to dedicate more water to the ecosystem, declining groundwater levels and growing threats to water quality, a Water Forum Action Plan was put forward after substantial stakeholder participation. The program aims to prevent future water shortages, avoid environmental degradation, groundwater contamination as well as reduce threats to groundwater reliability and limits to economic growth.

The program, which was endorsed by environmental, public and political stakeholders, proposes the “banking” and “exchange” process of water resources. Groundwater abstraction will be reduced during the wet years and water levels allowed to recover via natural recharge which is what they refer to as “banking”. Additional banking of water would also take place through direct recharge (MAR). During dry periods, reliance on surface water would be reduced and water would be sourced predominantly from groundwater.

The Sacramento Groundwater Authority (SGA) which has the authority for managing the regions groundwater resources will facilitate the program. Contractual agreements needed to implement the conjunctive use would be managed through SGA. This approach would also provide potential partners with legal and political assurance needed to enter into long-term agreements.

Conjunctive water use is not a new and innovative water management strategy. It is a common practice in the agricultural sector. Studies on conjunctive water use are often within the context of crop irrigation. Foster *et al*. (2010) highlighted that this could often be encountered as a "piecemeal engineering coping strategy" to sustain water supply outside agriculture. That often means, when implemented, the groundwater component is incorporated independently of existing water supply systems on an ad-hoc basis to support a new settlement/suburb. For the older areas connected to the existing water supply system, surface water is imported from a distance source to limit dependency on groundwater abstraction due to perceptions of reliability and vulnerability to pollution.

Kayhomayoon *et al.* (2022) mentioned that several researchers had investigated the use of water resources conjunctively to inform water management strategies for regions facing water scarcity. The consensus is that conjunctive use has the potential to meet the increasing water demands of competing water users and ease the challenges of surface water shortages (Zhang, 2015). The following benefit of conjunctive water use was noted by Foster et al. (2010):

- Greater water supply security can be realised by taking advantage of groundwater storage available in aquifers.
- The net water yield is larger than if there was dependence on only one source.
- Better irrigation scheme management and overall supply as groundwater can be deployed to compensate for surface resource shortfalls at critical times.
- Minimised environmental impacts through mitigating land groundwater depletion, waterlogging, salinisation and excessive river flow depletion.

The benefits of augmenting surface water with groundwater have not intentionally shifted South Africa's municipality’s perceptions to invest in groundwater supply development. Investments in the water supply have predominantly been in surface infrastructure. Southern Africa has experienced severe drought but has had few national projects linked to groundwater (Cobbing and Hiller, 2019). The explicit connection between strategic groundwater investments and regions that experience recurrent droughts is minimal (Cobbing and Hiller, 2019). Even with the lack of investment, groundwater remains a vital resource, especially for countries with little surface water. Although the volume of stored water can vary from tens of times the annual recharge for a small aquifer to thousands of times in a large aquifer, the available storage provided by small changes in the hydraulic head can exceed the available or economically feasible storage in dams. By conjunctively using groundwater and surface water, the water needs of South Africa can be met whilst avoiding more expensive structures that are likely inappropriate for the environment (Sahuquillo, 2021). When managed well, groundwater can be more reliable and potable with minimal treatment than surface water.

Kayhomayoon *et al*. (2022) provide a case study where model simulation was used to determine how conjunctively using surface water and groundwater would impact the water supply. Their simulation showed that the groundwater level decline could also be controlled by relying on both groundwater and surface water whilst maintaining the reservoir water level to a certain extent. However, there are limitations to how well the system can function since it can require coordinated institutional efforts. Issues often arise where urban growth drives the simultaneous unplanned use of groundwater and surface water. Consequently, growing cities often do not fully grasp the extent to which their conjunctive water use is unplanned, assuming it has been recognised. Foster et al. (2010) suggested that unplanned conjunctive use can thrive in environments where cities or settlements:

- Were originally supplied from traditional groundwater sources
- Close to surface water courses

Additional sources are added when these sources become insufficient due to increasing demand and competing water users. A common occurrence is borehole installation by private and commercial users as a “coping strategy” to deal with utility costs and increase the reliability of (potable) water supply for their properties. These effects mean there is no optimisation of resources due to the unplanned nature, especially for regions where utility water supply is derived mainly from surface water resources (Foster *et al*., 2010). The dangers of unplanned and unregulated groundwater use are that it can result in groundwater mining. This can have knock-on effects, such as increased installation costs when the resource is intentionally being developed. In coastal aquifers, depletion can lead to induced saline groundwater encroachment, impacting water quality and usability.

There are examples of cities that were intentional about implementing conjunctive water use. An example is Lima, Peru, where conjunctive use of water related to source development and engineering of the main water distribution allows cities to be supplied from various sources at different times. What commonly hinders municipalities from the full development of conjunctive water supply (Foster *et al*., 2010):

- The separate management of surface water and groundwater can fail to identify engineering opportunities for planned conjunctive use (groundwater and surface water belonging to different divisions).
- Lack of data on the extent of private borehole installations and the risks associated with private abstractions for domestic use.
- Lack of information and communication about conjunctive use’s benefits at different stakeholder levels.

  - A bias from water planners and engineers to seek out only operationally simple setups such as traditionally preferred surface water sources and treatment works. Robust conjunctive use options may add operational complexity, the benefits of which may not be fully appreciated. This reinforces rigid perceptions and adds to the resistance towards change, a narrow focus on surface water development.
- Political and institutional constraints prevent water service providers from proposing new wellfields with good yields and water quality in favourable locations outside the municipal jurisdictions. The challenges of dealing with long-standing entitlements within social groups, reinforced rigid perceptions and resistance towards change can lead to a narrow focus on surface water development.

While the groundwater community works to change misperceptions about groundwater, alternative water sources could be considered in conjunctive water use, such as rain water harvesting, desalination and water reuse. These options have been exploited in countries such as Israel, the United States and Australia, where water is very scarce. Foster *et al*. (2010) suggest that developing countries might not have the administrative and technological investments to implement such measures. This is not necessarily true for the South African context.

2.1.1 Managed Aquifer Recharge

Managed aquifer recharge (MAR) is an extension of conjunctive water use. Incorporating MAR into conjunctive use can take different forms, including groundwater banking and protection against salt water intrusion. According to Scanlon *et al.* (2016), MAR differs from conjunctive use in that instead of substituting surface water for groundwater; surface water is used to recharge the aquifer artificially. MAR is defined as the intentional storing and treatment of water using aquifers which are differentiated from unintentional recharge from leaking canals, water infrastructure and irrigations. Scanlon *et al.* (2016) suggest that the ideal areas to implement MAR are along alluvial plains with large rivers linked to major aquifers where different recharge approaches, such as a) spreading basins, b) vadose dry boreholes and c) direct recharge using boreholes can be used.

Recharge or natural recharge occurs when rainfall infiltrates the unsaturated zone to reach the water table. The aquifer water balance determines the resulting groundwater level change. If groundwater discharge, usually to streams or springs, does not exceed recharge, then groundwater levels will increase. MAR increases the potential for groundwater levels to increase; existing MAR schemes in South Africa are listed below in Table 1

Table 1 : Active MAR schemes in Southern Africa (Braune and Israel, 2021)

Scheme name	**Aquifer type**	**Water source**	**Recharge method**	**Recharge capacity (Mm^3/year)**	**Status**
Cape Flats	Sand	Treated waste water and storm water	Infiltration basin	-	Pilot scale
Atlantis	Sand	Urban storm water & treated waste water	Infiltration basin	2.7	In operation
Sedgefield	Sand	Treated waste water	Dune infiltration	0.5	Desk study
South Africa and wider	Alluvium	Ephemeral river flood water	Sand dams feeding deeper aquifer	small	In operation
Omdel (Namibia)	Alluvium	Ephemeral river flood water	Dam to hold back flood water – releases to d/s aquifer	7.9	In operation
Langebaan	Cenozoic sediments	River water and treated wastewater.	Borehole injection	14	Initial injection tests
Windhoek (Namibia)	Fractured quartzite	Surface water impoundments	Borehole injection	12	In operation
Kharkams	Fractured gneiss	Ephemeral spring	Borehole injection	0.005	In operation
Plettenberg Bay	Fractured quartz-arenites	River runoff	Borehole injection	0.8	Pre-feasibility

2.2 THE NEED FOR CONJUNCTIVE WATER USE

South Africa generally relies heavily on surface water for its domestic water supply. Over the years, drought conditions and increasing demand for water have resulted in the available surface water resources being predominantly allocated. Over allocation of surface water resources that results in reduced flow introduces other risk factors such as reduced ecosystem resilience and decline in dilution and assimilation capacity. This increases the likelihood of exposure to waterborne diseases. This is especially true for the western portions of the country that are characterised by desert to semi-desert conditions compared to the sub-humid conditions along the eastern coastal areas. The low average annual rainfall of 490 mm (Maitre *et al*., 2018) compared to the global average of 990 mm characterises South Africa as a water-scarce country. Both groundwater and surface water resources are unevenly distributed due to climatic and geographical conditions. The country has limited renewable water sources, with only 8.6 percent conversion of rainfall into usable run-off (Molobela and Sinha, 2011). According to Molobela and Sinha (2011), this is one of the lowest conversion percentages globally.

Over the years, the country has made significant strides in providing basic water and sanitation to a large portion of the previously excluded population. It is among the few African countries that have made significant progress under the Sustainable Development Goal (SDG) 6, which aims to "ensure availability and sustainable management of water sanitation for all". The water legislation in the country promotes equity and sustainable management and exploitation of the country's resources; however, more still needs to be done to create a resilient water sector. Water is among the most mismanaged resources in developing countries despite its importance for food and ecosystem security (Molobela and Sinha, 2011).

The 2015 drought in South Africa marked the lowest annual rainfall total since 1904, when the South African Weather Service was established (Donnenfeld *et al.*, 2018; Odoulami *et al*., 2020). This was after three consecutive years of below-average rainfall. Donnenfeld *et al*. (2018) suggest that these droughts did not cause water scarcity but highlighted the vulnerabilities in the South African water system. With climate change now influencing the availability of water resources and likely to have further and even more severe impacts, South African municipalities must be actively implementing a mix of water sources for their water supply.

Climate change prediction points to increased temperature and evapotranspiration, a decrease in precipitation, and extreme and prolonged droughts. These conditions can exacerbate the declining trend of water resources, further aggravating water scarcity challenges, particularly for regions with semi-arid and arid conditions (Zhang, 2015). The Climate projections for Southern Africa indicate that the region is likely to experience a decline in the average precipitation level, with the southwestern portion of South Africa anticipated to be at risk of severe droughts (Donnenfeld *et al.*, 2018; Odoulami *et al*., 2020). A 2005 study by Milly et al. (2005) suggested that southern Africa would experience a decrease in the run-off in the range of 10 to 30 percent. For most southern African countries, a decrease between 1- and 30 percent is very significant and would likely put more strain on an already strained water sector. Therefore, countries like South Africa can benefit from effective management strategies for decision-making to mitigate the potential effects of climate change on water security.

Droughts (extreme weather events) cannot be prevented, but the effects they leave behind can be reduced through the efficient management of water systems. South Africa has focused mainly on increasing the surface water infrastructure projects (e.g. new dams) and inter-catchment water transfers to manage water security challenges. But these approaches are, according to Mutamba (2019), not enough to deal with the growing demands on water supply even if implemented on time and to scale. A combination of strategies and implementable plans that consider multiple sources and demand management is needed to ensure that water resources do not become a limiting factor for the country's development.

Groundwater resources in Sub-Saharan Africa are generally underutilised. A study by Cobbing and Hiller (2019) stated that groundwater is still significantly underutilised in 41 of the 43 countries with estimated renewable groundwater resources in Sub-Saharan Africa. Groundwater in South Africa is viewed as a strategic resource with a potential yield as surface water. However, approximately 85 percent of groundwater is underutilised (Donnenfeld, 2018).

Although groundwater is supplying a significant portion of rural settlements in South Africa, groundwater as a source of water supply within Municipalities is still met with scepticism and resistance. Cobbing *et al.* (2014) quoted the mayors of 24 district municipalities who stated that "borehole water is not preferred and is not reliable". But studies (Ravenscroft *et al*., 2004; Cobbing *et al*., 2014; Cobbing and Hiller, 2019) have shown that perceived unreliability is not due to aquifer characteristics but rather due to the management of operation and maintenance requirements.

Therefore, there is great potential for municipalities to implement conjunctive water use within their water service areas.

CHAPTER 3: WATER SOURCES

The country's climate varies from desert and semi-desert in the west to sub-humid along the eastern coastal area, with an average rainfall of about 450 mm per year. This is well below the world average of about 860 mm per year, while evaporation is comparatively high. Most of the economically available yield from surface water resources has been fully developed and used, and opportunities for developing new and there are few economic dams. (DWS, 2017)

South Africa’s strategic water source areas (SWSAs) can be divided into two groups: surface water source areas (SWSA-sw) and groundwater source areas (SWSA-gw). Groundwater and surface water are interwoven as groundwater discharges provide much of the river flow and sustain all perennial rivers during the dry season
Le Maitre *et al.* (2018).

The 2018 study by Le Maitre *et al*. (2018) identified 22 SWSA-sw and 37 SWSA-gw that are considered to be strategically important at the national level for water and economic security in South Africa. They include portions of the SWSA-sw, which extend into Lesotho and Swaziland. The transboundary SWSA-sw that includes Lesotho is critically important for the Gauteng metropolitan region, with the largest population and economy in southern Africa.

The total area for SWSA-gw is around 104 000 km^2, and 24% of this area delineated as SWSA-gw overlaps with the updated areas delineated for SWSA-sw. Considering the total area of South Africa delineated as a SWSA, SWSA-gw (without overlaps) accounts for 39%, surface water (without overlaps) account for 49%, with the overlaps contributing 12%. This study only defined SWSA-gw within South Africa as suitable data were lacking for Swaziland and Lesotho.

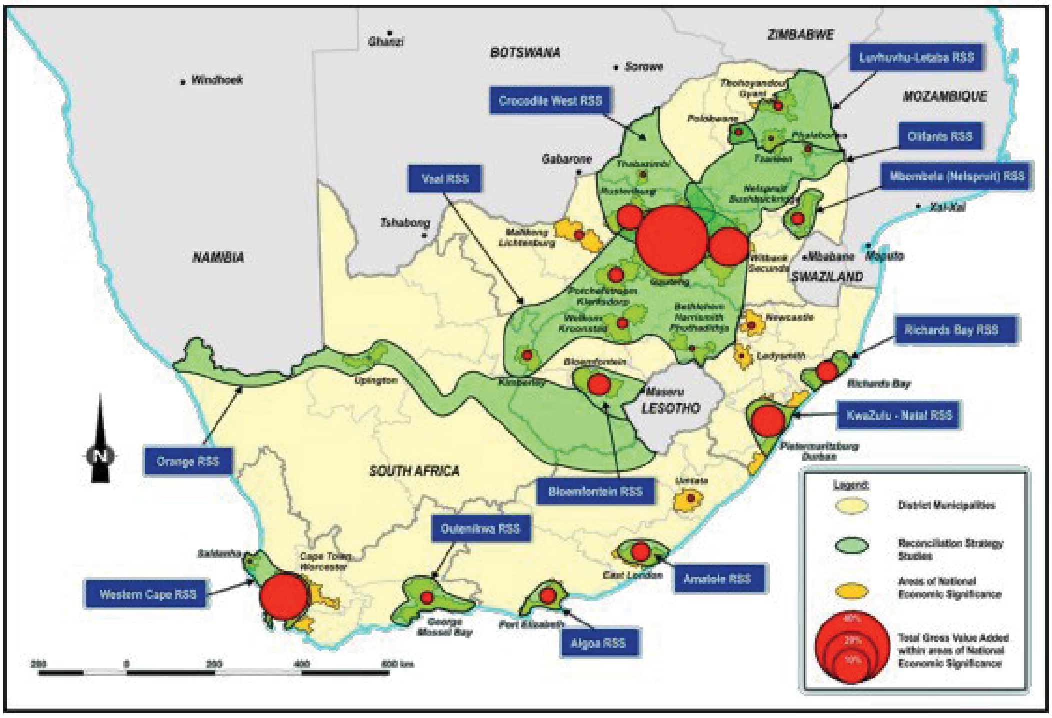

Figure 1: Key Water Resources System (NSWR 2021)

South Africa has several major urban centres and economic development nodes. Most of these centres use a substantial percentage of water from the SWSAs, surface or groundwater. In many cases, the water from the SWSAs reaches these centres from quite large distances via a range of water transfer schemes.

Based on data from 2019, the National State of Water Report for 2021 states that there are large water systems where water requirements exceed the water available. These are discussed further in this chapter. Therefore, it is within these areas where conjunctive use with groundwater should be, if not considered already.

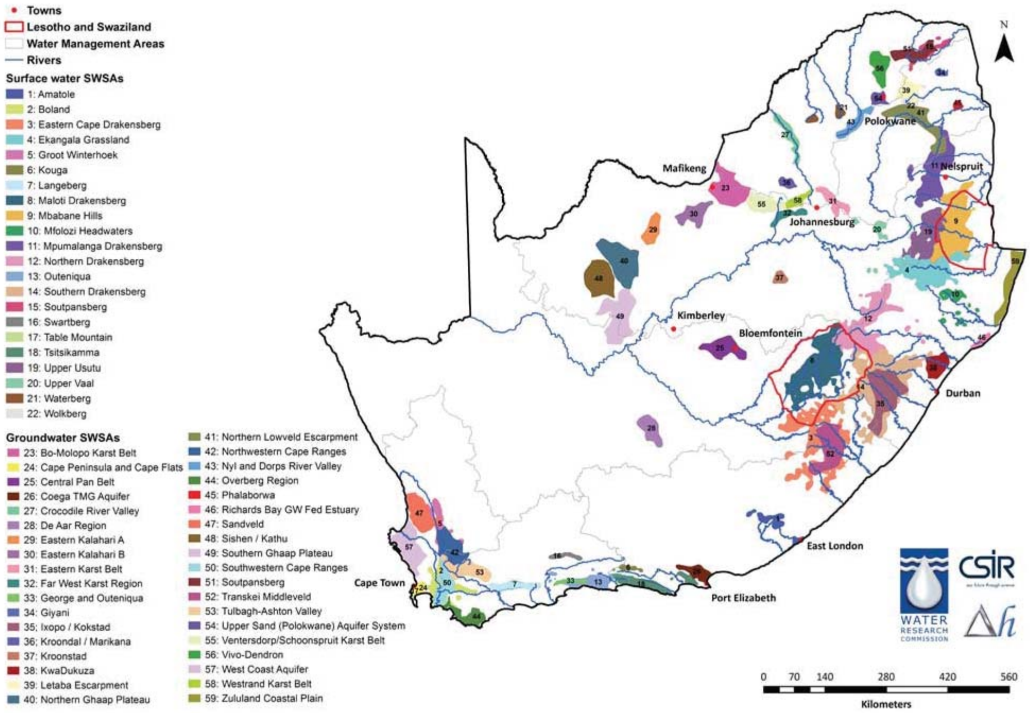

Figure 2: South Africa's Surface and Ground-water SWSAs

3.1 SURFACE WATER

Although South Africa made huge dam investments and complicated water transfer schemes during the 20th century to secure its water supplies, the country faces significant water security challenges. More than 98% of the reliably available surface water is already used, demand outstrips supply in most catchments, and there are severe and growing water quality problems. Le Maitre *et al*. (2018) stated that because of the growing population, there is a failure to proactively adapt to water-scarce conditions and a lack of protection measures against the degradation of water resources.

The total area of the national SWSA-sw in the region is 124 075 km^2 (10% of the region) and provides a Mean Annual Recharge (MAR) of 24 954 million m^3 (50% of the total). With the addition of the sub-nationally important Pondoland Coast and Zululand Coast SWSA-sw, they cover about 148 478 km^2 (12% of the area) and provide a MAR of 29 354 million m^3 (59% of the total) (Table 2). If the contributions of the SWSA-sw within Lesotho and Swaziland are excluded, the updated SWSA-sw now cover about 96 129 km^2 (8% of the area) and provides a MAR of 19 379 million m^3 (39% of the national volume). The most significant volume of MAR is generated by the Southern Drakensberg (9% of national and transboundary MAR), followed by the Eastern Cape Drakensberg and the Boland, but the Boland has the highest MAR per ha followed by Table Mountain and the Northern Drakensberg. The areas of the SWSA-sw within Lesotho and Swaziland are 18 570 and 9 376 km^2, respectively. The total MAR for Lesotho is about 4 445 million m^{3,} and the portions of the SWSAs that fall within Lesotho (Eastern Cape, Southern, Northern and Maloti Drakensberg, totalling 61% of Lesotho's area) generate about 3 522 million m^3 or 79% of that county's MAR. In the case of Swaziland, the total MAR is about 2 465 million m^{3,} and the portions of the SWSAs within this country (Enkangala Drakensberg, Mbabane Hills, Upper Usutu, totalling 54% of the country's area) generate 2 053 million m^3 or 83% of the total MAR. These SWSA-sw generate a MAR of about 3 522 million m^3, about 79% of its total MAR. In total, 27 913 km^2 of the SWSA-sw fall within these two countries and account for about 5 575 million m^3/a or about 11% of the three countries' MAR.

Table 2: Summary of the updated surface water SWSAs for South Africa only with the estimated pre-development MAR (total and per unit area volume) and their extent (Le Maitre, 2018)

Name	MAR (million m3)	Percent of national MAR	MAR (m3 per ha)	Area (km^2)
Amatole	333	0.67	1662	2 001
Boland	2 182	4.41	3588	6 083
Eastern Cape Drakensberg	2 673	5.40	1671	15 997
Enkangala Drakensberg	1 412	2.85	1646	8 582
Groot Winterhoek	1 002	2.02	1931	5 191
Kouga	77	0.16	1262	613
Langeberg	343	0.69	1989	1722
Maloti Drakensberg	2232	4.51	1859	12 003
Mbabane Hills	2237	4.52	2234	10 015
Mfolozi Headwaters	277	0.56	1438	1 925
Mpumalanga Drakensberg	1 929	3.90	2304	8 374
Northern Drakensberg	2 448	4.94	2376	10 302
Outeniqua	580	1.17	1929	3 005
Southern Drakensberg	4 317	8.72	2135	20 225
Soutpansberg	532	1.07	2267	2 345
Swartberg	96	0.19	1239	775
Table Mountain	127	0.26	2730	465
Tsitsikamma	708	1.43	2203	3 213
Upper Usutu	722	1.46	1166	6 191
Upper Vaal	122	0.25	872	1 401

Waterberg	99	0.20	957	1 033
Wolkberg	506	1.02	1937	2 614
Total	24 954	50.39	2011	124 075
South Africa	49 520		391	1 267 814

22 nationally strategic SWSA-sw provide 50.4% of the river flows and occupy 9.8% of South Africa, Lesotho and Swaziland. In simple terms: 50% of the water is from 10% of the area. They also sustain water-supply systems for more than 50% of the population, supply cities and towns that generate more than 64% of national economic activity and supply about 70% of the water used for irrigation.

Based on data from 2019, the National State of Water Report for 2021 states that there are significant water systems where water requirements exceed water available; these are:

- Outeniqua in WC (-6 M m³/year)
- Amathole in EC (-11 M m³/year)
- Olifants in Limpopo (-33 M m³/year)
- Orange in NC, FS, EC (-147 M m³/year)
- Mngeni – KZN (-62 M m³/year)

The objective of the reconciliation strategy within a water supply system is to reconcile or find a balance between the current and future water requirements by implementing appropriate intervention measures to increase the available water, conserve water through water conservation and demand management measures, as well as improve the water quality in the river systems.

The Department of Water and Sanitation has recently completed the reconciliation strategies for the Integrated Vaal River System, Mbombela water supply system, Algoa water supply system, and the Richards Bay water supply system. The interventions in these areas have been based on the recommended reconciliation options.

3.1.1 The Integrated Vaal River System Reconciliation Strategy

The Vaal Catchment consists of the Upper, Middle, and Lower Vaal River Water Management Areas (WMAs). Due to numerous inter-basin transfers that link the major Vaal WMA with other WMAs, the reconciliation planning is done in the context of the integrated Vaal River System, which includes portions of the Komati, Usuthu, Thukela, and Senqu River (located in Lesotho) catchments. Significant water transfers also occur to water users in Olifants and Crocodile (West) River Catchments, of which most are dependent on water resources of the Integrated Vaal River System. The main users of the IVRS water resources are bulk industrial users (Eskom and Sasol), urban users (Rand Water and Sedibeng water), and irrigators (predominantly the Vaalharts Scheme).

The following options are recommended:

- Water Conservation and Demand Management – Water loss reduction to reduce water requirement growth.
- Removal of unlawful irrigation – Finalize Verification and Validation of lawful water use.
- Reuse – Carry out a Regional Reuse investigation. Implement reuse where feasible
- Lesotho Highlands Water Project Phase 2 – Implement project, and finalise completion of Polihali Dam and other associated infrastructure construction.
- Yield Replacement: Orange River – Finalise feasibility to determine a suitable option (Noordoewer/Vioolsdrift, Verbeeldingskraal). Implement a project to construct the scheme

The status of the implementation of some of the interventions is summarized in Table 3.

Table 3:Status of implementation of the intervention plans

Intervention Summary of implementation progress	
WCWDM	Limited progress made, some successes of Rand Water Project 1600, Impacts not yet seen on water balance, greater attention required, Municipalities to improve the commitment of financial resources
Removal of unlawful irrigation	Initially, some progress was made – successfully removing 80 million m^3 of unlawful irrigation. Recent years have seen a slowdown – validation and verification completion delaying further implementation. Northern Cape continued with efforts, and Free State and Gauteng committed to restarting the process. Target to remove an additional 75 million m^3.
Reuse of treated effluent and other discharges	Short Term AMD solution implemented. Long-term AMD solution requires further investigation. CoT reuse plans slowed down

	due to budget constraints. Overall regional reuse feasibility investigation is required. Ongoing links to Crocodile (West) Reconciliation Strategy implementation plans.
New infrastructure construction	Implementation of LHWP Phase 2 has been delayed till the earliest date of April 2027 for delivery. The yield replacement dam in Orange River Feasibility Study started but is still to be completed before the best option is determined. The earliest data for yield replacement is set for 2028.

3.1.2 Mbombela Reconciliation Strategy

The major water requirements within the Mbombela Water Supply System are for irrigation, making up 54% of the total Crocodile and Sabie catchment requirements. Sugarcane is the predominant crop in these two catchments. Cross-border flows for the Crocodile and Sabie Rivers have a minimum requirement of 37 million m^3/annum, according to the IncoMaputo Water Use Agreement, to cross the border from South Africa into Mozambique.

The Crocodile system provides water to several users along the stretch of the river and downstream of the main dam for the system – Kwena Dam. The yield of the Crocodile River System is influenced directly by the abstraction volumes and location of the water users within the system. The main water resource infrastructure in the Sabie River is the Inyaka Dam which supplies the Sabie and Sand catchments via the Bushbuckridge Transfer Pipeline.

Options for reconciliation and or intervention measures for the **Crocodile System** include:

- WCWDM
- Removal of Invasive Alien Plants
- Surrender Irrigation allocations
- Strict restriction rules on low-priority users
- Releases from the Ngodwana Dam

Reconciliation options and or intervention measures for the **Sabie System** include:

- WCWDM
- Removal of Invasive Alien Plants
- **Development of groundwater**

- Additional return flows from treated effluent

3.1.3 Algoa Reconciliation Strategy

The Algoa Water Supply System (WSS) currently comprises three major dams in the west, several smaller dams, a spring near NMBM, and an inter-basin transfer scheme from the Orange River via the Fish and Sunday Rivers to the east. Five water user categories included domestic/industrial, Gamtoos irrigation, other irrigation, environmental, and losses.

Urban water use from the Algoa Water Supply System is more than 60% of the total use of the system and is expected to increase. Water use within the Kouga Municipality is 10.0 million m^3/a (27.3 Mℓ/d), with an estimated bulk water requirement of 13.0 million m^3/a (35.5 Mℓ/d). Of this, 5.85 million m^3/a was supplied from the Algoa WSS in 2016/17. The Municipality plans to develop a long-term Water Provision Master Plan to upgrade and rehabilitate bulk infrastructure. In the future, groundwater from the Humansdorp area will be used by Kouga LM. There is a possibility of the supply of additional Orange River water to the NMBM instead of more water from the Kromme River subsystem to the Kouga LM and the proposed power plant.

The following interventions are recommended:

1. **Further allocation of Orange River water to NMBM**
   The concept of the further phasing of the NCLLS (post Phase 4) of transferred Orange River water has been added, termed Phase 5. The assumed yield of the Nooitgedagt Phase 5 Scheme has been assumed to be 18.25 million m^3/a (50 Mℓ/d). Conveyance to NMBM could be by either of the two-bulk supply (high-level and low-level) pipelines. Should the capacity of these pipelines be exceeded (assuming that supply cannot be boosted), a different bulk supply pipeline would be required.
2. **Groundwater supply**
   The yields of the Coega Fault, Moregrove Fault, and Jeffreys Arch aquifers have been revised, while in some areas, the original yield estimates have not been changed. The long-term yield of the eight potential groundwater interventions has been updated from 29.5 million m^3/a to 36.0 million m^3/a.
3. **Large seawater desalination scheme**
   A potential large seawater desalination scheme, with a capacity of 87.6 million m^3/a (240 Mℓ/d), has been added as a potential intervention to

consider for implementation should the allocation of transferred Orange River water be revoked.

3.2 GROUNDWATER

The 57 SWSA-gw cover about 11% of South Africa, with 37 being nationally strategic (Le Maitre *et al.*, 2018). The SWSA-gw supplies 32% of the settlements that get more than half of their supply from groundwater (and house 4% of the national population). They supply 44% of the groundwater for agriculture and 32% of the groundwater used for industrial purposes in South Africa. Groundwater is also the main water source for a further 268 settlements in South Africa (Le Maitre *et al.*, 2018).

The average contribution to national recharge of each of the 37 SWSA-gw is relatively small, varying from less than 0.01% to more than 2.3% (Le Maitre *et al*., 2018). The greatest recharge volume was for the Ixopo/Kokstad SWSA-gw, the Southwestern Cape Ranges, the Transkei Middleveld, and the Northern Lowveld Escarpment (Figure 2).

Figure 3 illustrates the groundwater use by the water management area. The Vaal utilizes the most reported groundwater use by water management area with 24%. The Berg-Olifants, Breede-Gouritz, and Inkomati-Usuthu report the least groundwater utilized, with all reporting 3%.

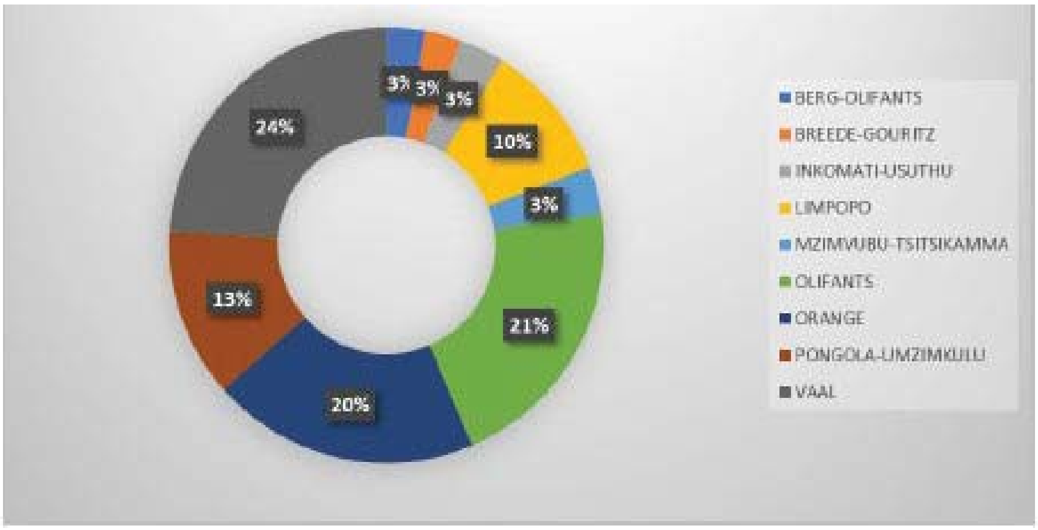

Figure 3: Groundwater Utilisation per Water Management Area (WARMS Report – 29 November 2022)

Table 4: Summary of the SWSA-gw for South Africa with the estimated recharge, and relative contribution to national recharge

Name	Recharge (million m^3/a)	Area (km^2)	National recharge (%)
Bo-Molopo Karst Belt	5268	144.8	0.4%
Cape Peninsula and Cape Flats	599	59.5	0.2%
Central Pan Belt	3368	53.6	0.2%
Coega TMG Aquifer	1682	32.3	0.1%
Crocodile River Valley	2163	38.9	0.1%
De Aar Region	2475	32.5	0.1%
Eastern Kalahari A	2010	26.4	0.1%
Eastern Kalahari B	2656	37.8	0.1%
Eastern Karst Belt	1984	108.1	0.3%
Far West Karst Region	1382	65.8	0.2%
George and Outeniqua	727	95.8	0.3%
Giyani	438	5.3	0.0%
Ixopo/Kokstad	7150	792.2	2.3%
Kroondal/Marikana	795	24.4	0.1%
Kroonstad	799	11.7	0.0%
KwaDukuza	2352	177.0	0.5%
Letaba Escarpment	2151	165.5	0.5%
Northern Ghaap Plateau	6274	82.6	0.2%
Northern Lowveld Escarpment	5168	457.6	1.3%
Northwestern Cape Ranges	3638	287.7	0.8%
Nyl and Dorps River Valley	2036	57.5	0.2%
Overberg Region	2261	71.6	0.2%

Phalaborwa	433	3.9	0.0%
Richards Bay GW Fed Estuary	606	91.5	0.3%
Sandveld	4010	85.9	0.2%
Sishen/Kathu	4827	40.9	0.1%
Southern Ghaap Plateau	6542	67.6	0.2%
Southwestern Cape Ranges	2749	629.5	1.8%
Soutpansberg	2573	247.2	0.7%
Transkei Middleveld	5607	555.0	1.6%
Tulbagh-Ashton Valley	3560	184.3	0.5%
Upper Sand (Polokwane) Aquifer System	966	16.5	0.0%
Ventersdorp/Schoonspruit Karst Belt	2875	114.8	0.3%
Vivo-Dendron	2555	14.5	0.0%
West Coast Aquifer	4586	106.2	0.3%
Westrand Karst Belt	1090	63.3	0.2%
Zululand Coastal Plain	3305	347.2	1.0%

Table 5: Groundwater contribution to current or future water supply at 26 areas of national economic significance (Le Maitre *et al*., 2018)

Area	Current % Groundwater supplied	Current Aquifer	Future groundwater use, aquifer	References for delineation of current groundwater resource unit, and potential future supply
Cape Town, Worcester	2%	TMG Albion springs (Cape Peninsula) & Atlantis	Yes; Cape Flats aquifer, TMG aquifer in Southwestern Cape Fold Belt, increased abstraction at Atlantis	(CCT, 2015, 2012; Delta-h, 2016; DWS, 2016a; H Seyler et al., 2016)
Saldanha	11%	Langebaan Road Aquifer System	Yes; Langebaan Road Aquifer System, Elandsfontein Aquifer System	(DWAF, 2007a; H. Seyler et al., 2016)
George, Mossel Bay	0% (backup/drought relief only)	Local TMG aquifer	Yes; Peninsula aquifer north of Georgetown	(DWS, 2014a)
Port Elizabeth	2%	Uitenhage springs	Yes: Coega TMG aquifer	(Groundwater Africa, 2012)
Richards Bay	<6%	Supply source is (GW fed) lakes and transfers from	No increased groundwater supply planned	(DWS, 2015a, 2015b) Delineation of lake

Area	Current % Groundwater supplied	Current Aquifer	Future groundwater use, aquifer	References for delineation of current groundwater resource unit, and potential future supply
		river systems. The lakes receive 6% of their yield from groundwater.		groundwater catchment based on geology, topography and surface water drainage.
Welkom, Kroonstad	None	n/a	Yes; Kroonstad groundwater local to Kroonstad	(DWA, 2012a) All Towns strategy
Gauteng (Tshwane)	6%*	Pretoria Springs (Dolomite)	No	(DWA, 2009a, 2009b; DWAF, 2009)
Mafikeng	71%	Grootfontein spring (Dolomite): Molopo Grootfontein Compartment	Yes; increased use of same aquifer	(DWA, 2009b), DWS All Towns strategy
Lichtenburg	>50%**	Lichtenberg dolomites compartment/NW Dolomites	Yes; increased use of same aquifer	(DWA, 2009b), & based on information in DWS All Towns strategy
Thabazimbi	34%	Alluvial aquifer around Crocodile River	No	Based on information in DWS All Towns strategy
Rustenburg	No	n/a	Yes; groundwater local to Rustenburg	DWS All Towns strategy
Phalaborwa	No	n/a	Yes; groundwater local to Phalaborwa	DWS All Towns strategy
Polokwane	>11%***	Basement aquifer local to Polokwane	Yes; increased use of same aquifer	Assumed based on information in DWS All Towns strategy
Tzaneen	No	n/a	Yes; groundwater local to Tzaneen	Assumed based on information in DWS All Towns strategy
Gyani	26%	Basement aquifer local to Gyani	Yes; increased use of same aquifer	Assumed based on information in DWS All Towns strategy

* Percent reflects use in Tshwane Metropolitan municipality, groundwater is not currently a supply source in other parts of Gauteng Johannesburg or Ekurhuleni Metropolitan Municipalities (excluding treated AMD, Section 6.3.4)
**No yield information is contained within the Lichtenburg All Towns strategy, however >50% can safely be assumed based on the supply make up to surrounding towns in the Ghaap Plateau
*** Groundwater yield in the Polokwane All Towns strategy was listed as a minimum yield, hence this translates as >11%.

CHAPTER 4: OPTION ANALYSIS

One highlighted challenge in groundwater resource development is the resolution of data available for project appraisal. A relatively significant amount of capital is needed before a return on investment in the water supply is realised when dealing with groundwater schemes. Consequently, this also impacts stakeholder perceptions of whether the funds are well spent. Moreover, the O&M for groundwater tends to be generally higher than surface water. However, Cobbing *et al*. (2014) found that a shortage of funding for water infrastructure at the municipal level was not usually a constraint. Although it is noted that the are discrepancies between funding for capital projects compared to ongoing O&M. Cobbing *et al*. (2014) argued that shortage of funds was not a driving factor of water supply backlogs in the country. Instead, a review showed that the National Treasury credited delays in project registrations, lack of project management units and capacity, and limited multi-year budgeting to underspending on projects. The National Treasury has project appraisal requirements, including completing an options analysis throughout the different project stages.

An options analysis should be conducted to assess all the feasible options to achieve the required identified needs and objectives. This non-linear process should be used to confirm whether a detailed investigation should be completed to support the project business case and cost-benefit analysis. The options analysis process should document the process/criteria used to select the options. The shortlisted options must be accompanied by financial, economic, environmental and social impact analyses to support the selection of the final project to be implemented. According to the National Treasury Capital Planning Guideline (2017), an options analysis should:

- have a defined base case scenario
- ensure that all feasible options are evaluated
- have a list of selected options that are economically viable
- select a final project that provides the best return on investment
- consider the factors that are critical for the success of the project

A number of factors must be considered when evaluating conjunctive water use options. Different assumptions for the identified options must be tested before exclusion from the shortlist. The sections below highlight the critical factors, like the distribution system, that must be incorporated into the options analysis. These are the same factors considered by DWS (Figure 4)

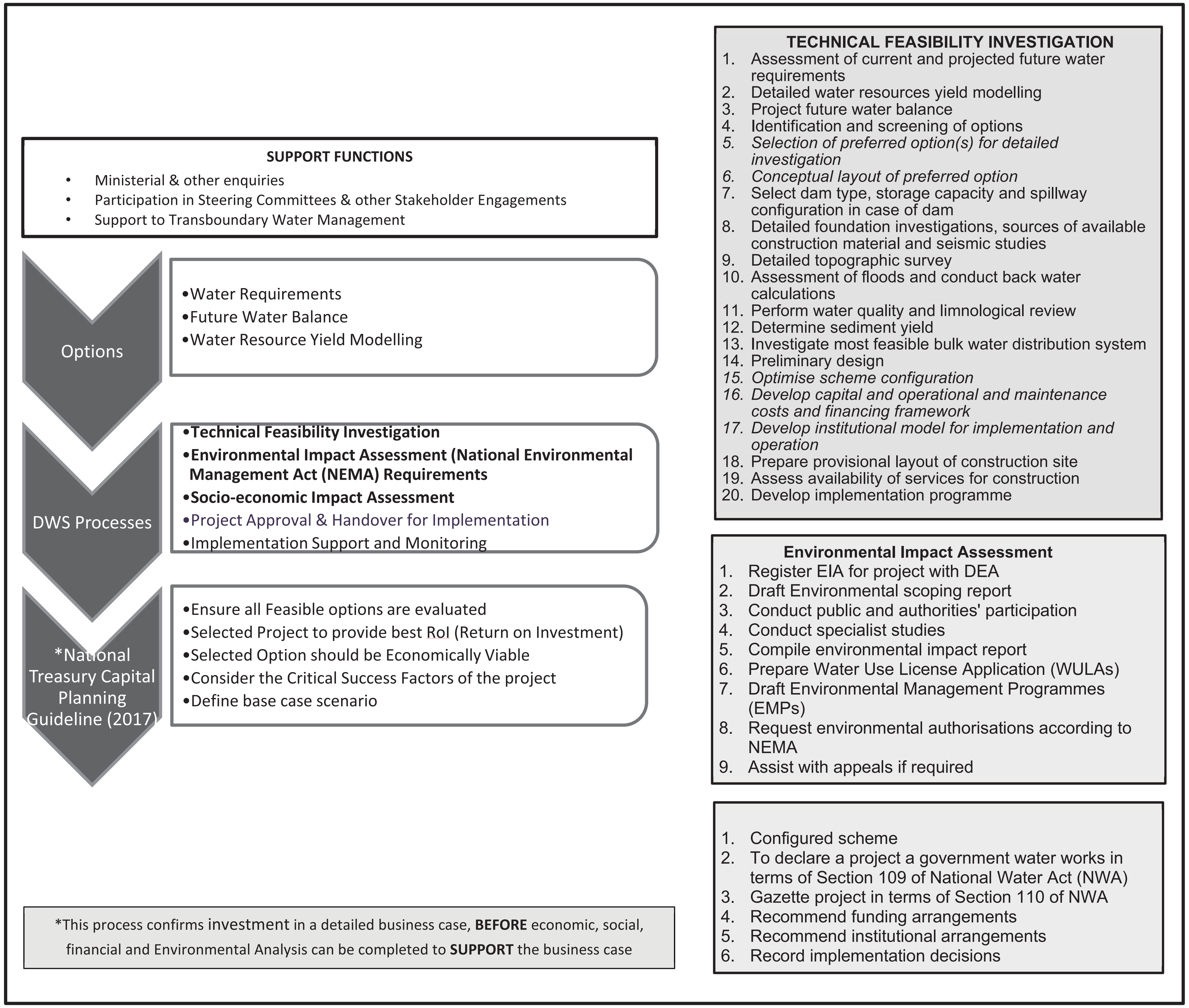

Figure 4: Project selection and appraisal process followed by the Department of Water and Sanitation (modified from DWS, 2016)

4.1 WATER REQUIREMENTS ASSESSMENT

The water supply requirements assessment should be used to define the extent and urgency with which the project needs to be implemented. Ideally, when conducting the feasibility assessment to implement conjunctive water use, it should be completed with a long-term objective of providing a sustainable and resilient water supply and not solely as an emergency strategy.

Since an options analysis will demonstrate how the selected project will meet the water demand, baseline water consumption and forecasts should be determined. An analysis of the existing supply capacity, baseline population data, and projections should accompany this. Projections should consider whether the project will be implemented at a country, city, or even suburb and village level to ensure the appropriate (growth) calculations are applied.

Water demand could increase, decline or remain the same into the future. Factors that influence water supply and demand of water, like market changes, should be noted and accounted for in the demand forecast. Uncertainty-associated projections due to potential changes in markets/industry that can influence population trends should be documented and analysed. Additionally, constraints and variables such as changing water quality or technological developments that can influence water supply efficiencies should also be noted.

Water availability and access differ between regions and municipalities. Even within municipalities, access and water availability can differ due to challenges such as infrastructure discrepancies between informal settlements and formal settlements. Consequently, the status quo of the water supply in the targeted project area should be understood, and the challenges identified to support a case to implement additional measures.

Identifying different utility service areas is important for estimating the target areas' future population and water needs. The assessment should distinguish the different water users in the target area, i.e. agricultural, industrial, domestic public water users (municipal customers) or domestic self-supply users. Additionally, details of the quality of water the users need should be documented, as this information can be used to design and test the feasibility of different combinations of conjunctive use during the resource modelling stage.

4.1.1 Define the Objective

Perceptions about water resources must not create resistance to the feasibility of implementing different options. While capital costs and the required system changes may appear to be significant hurdles, these should be weight against the main project objectives and potential long-term benefits. Objectives driving the need to explore conjunctive water use can differ between regions and municipalities. The objectives can be the following (CWC, 1995):

- To increase the total supply of water throughout the year
- To formalise conjunctive water use, particularly in areas where private use of groundwater is significant
- To provide demand-based flexibility in water supply by flattening the peaks of surface water use and groundwater abstraction
- To reduce evaporation losses from surface water dams
- To manage water quality by blending water from multiple sources of different qualities.
- To reduce capital costs as well as O&M costs associated with distance to water sources
- To maintain a river’s baseflow and extend the flow period by constructing structures such as gabions and levees to support induced recharge
- To prevent groundwater over-exploitation through MAR and planned development/use of minor streams.

4.2 WATER RESOURCE YIELD MODELLING

Implementing conjunctive water use is to derive more significant benefit from the collective use of the water sources than if they were developed separately. Resource modelling should consider the overall strategy required to achieve resilient supply in alignment with the project-specific objectives. The process should be cognisant of the surface and groundwater's connection, unique storage capacity, and interdependent system dynamics.

Although surface and groundwater tend to be treated as separate systems, it should be noted in the modelling process that surface and groundwater regimes are often linked, particularly for rivers and streams with baseflow sustained by groundwater (gaining river systems).

During water resource modelling, a combination of different water supply sources should be explored based on the region or the project area’s identified sources with a comparative and reasonable assurance of supply for all sources. Simulations can be completed for different temporal scales from monthly to seasonal or annual and decades according to the project goals and scope. This can be aligned with the following conjunctive strategies highlighted by Pulido *et al*. (2003):

- **Drought cycling strategy (annual to decadal time-frame)** – considers the climate-driven interannual variability in water availability and demands over the years to decades. This strategy aims to create supply stability by exploiting surface water in the wetter years, while groundwater abstraction is planned to make up for shortfalls during drought periods. Excess surface water is used to recharge aquifers to ensure reliable supply during an extreme drought without expanding or adding structures such as dams. The approach assumes institutional capacity and infrastructure delivers surface water effectively, allowing easy groundwater substitution over long periods.
- **Seasonal cycling strategy** – considers seasonal variability in water availability and demands that occur within a year. Like drought cycling, surface water use dominates during the wet months, excess water is used for MAR, while groundwater use dominates during the drier months. This strategy aims to dampen the difference in supply and demand peaks through groundwater storage.
- **Initial intensive exploitation** – implemented based on the development stage of an area where financial and institutional resources for large-scale systems are limited. This approach focuses on the intensive use of one water source to support regional development. Excessive use of the resources or drawdown in the case of groundwater abstraction is a trade-off for economic, infrastructure and institutional development. It is intended to support a phased approach to large-scale infrastructure development
- **Mixed strategy** – a combination of different strategies is implemented. For example, drought and seasonal strategies are implemented, allowing conjunctive water use to be managed over different temporal scales.

The water resource model should be set up together with the water resource planning model to simulate inflows/abstraction rates, supply-demand and future storage capacity trends. The resource yield model should be calibrated using historical data. The basis of the data used for simulations, like population data and simulation periods, should be documented and the data validated. The limitations associated with the data used for the modelling process should be noted, and recommendations to close the gaps should be provided. These recommendations should be used to plan for data collection and monitoring to improve confidence in the model outputs and reduce the uncertainty associated with input parameters.

The frequency at which the model is to be run should be defined such that the model can be used to advise management decisions regarding the ability of the sources to meet the anticipated peak period demands at the required assurance of supply. The process should be used as a leading indicator to prompt management action where there is a risk of supply shortfalls for the selected strategies. Additionally, the outputs should be used to confirm the potential for conjunctive water sources to meet project objectives in alignment with the relevant institutional policies.

One of the major assumptions made with modelling relates to climatic conditions. These assumptions should be subjected to a sensitivity analysis as climate change influences are anticipated to impact climate and weather patterns. A qualitative evaluation of the impact of changing temperatures, prolonged dry periods and late start of wet seasons predicted yields compared to the water requirements should be completed.

A number of factors will guide the decision to develop groundwater resources for water supply. For use as a long-term solution for access to water of adequate quantity and quality, the following can be should be noted:

- Determine the baseline groundwater balance for the target aquifer, highlighting significant data gaps that need to be addressed before further analysis can be completed. A qualified hydrogeologist should be engaged to calculate the groundwater balance. Additionally, the hydrogeologist may need to consult with a hydrologist and hydrometeorologist to provide inputs into the assessment. An initial groundwater balance may be sufficient during the evaluation of the screening of the long list options that are to be reduced to a shortlist for further feasibility assessment.
- The area that is to be developed for wellfield installation must be delineated. The delineation of the site should be based on an understanding of the conceptualised groundwater regime. Areas where the groundwater divide differs from the surface water catchments, should be noted. This includes aquifer systems that fall into multiple water management areas, which may affect the institutional management or the project. Factors that may result in the exclusion from the shortlist options, such as depth to groundwater, potential yield, proximity to pollution sources and risk of subsidence, should be noted.
- Efforts should be made, through a hydrocensus if necessary, to understand the extent of groundwater use in the area. An evaluation of the current groundwater use will indicate the actual yield vs perceived yield, assist with determining the available yield for the yield and highlight the different water users competing for the resource. Such data is invaluable for determining the

maximum permissible volumes for abstraction and putting in measures to avoid unintentional groundwater mining and drying up of boreholes.

- Aquifers characterised by brackish or slightly saline water should not be immediately disqualified for assessment. There are multiple sites in the country (e.g. eMalahleni, Mossel Bay and Plettenberg) where reverse osmosis technology was used to treat water for consumption. Mixing water of better quality before the desalination process can reduce O&M costs of running a desalination plant and increase the recovery rate.
- The objective of the project must guide groundwater yield modelling. During the screening of the long list options, multiple groundwater scheme setups, i.e. single large-scale wellfield or multiple small wellfields, can be explored to determine the most feasible layout from a water yield perspective. Evaluating the different scheme layouts early in the process will benefit the financial, economic and environmental assessments that need to be completed. The benefit from the available yield from multiple segregated wellfields might outweigh the O&M costs and complexity of managing a setup compared to a single wellfield.
- There are tools to assist with simulating and optimising multiple configurations for water supply schemes. A multiple objective algorithm tool as a decision-making support tool to determine the optimal resource allocation and timing and reduce the risk of conflict between competing water users.

4.3 OPTION LONGLIST TO SHORTLIST

The initial long list should consider all options regardless of their perceived feasibility. This process will assist with making sure that all possible options are considered. Different combinations of surface and groundwater development projects should be assessed. The list should indicate whether groundwater abstraction will occur or whether a combination of abstraction and MAR is being considered. The assessment should be completed for individual projects within the conjunctive water use program to assess feasibility.

It should be noted that some of the proposed options may need a pilot study before shortlisting. For groundwater sources, initial capital investment may be required to allow for field studies which may include borehole drilling and pumping tests to improve the confidence level of the assurance of yield from the targeted aquifer(s). For such cases, a detailed desktop study and hydrocensus should be used to collect as much of the existing data as possible to support further investment into the option.

The list should be accompanied by a qualitative description of the advantages and disadvantages, including a preliminary calculation of the costs and benefits of the areas relative to the objectives.

The scheme configuration should consider the main goal of conjunctive water use, which is to improve supply assurance through the seasonal alternation of sources, increasing storage capacity, reducing abstraction from certain sources, etc.

The list is to be used to select a few preferred options to be assessed in detail. The selected option is to be evaluated separately using the points described in the sections below. This information can then be used to complete financial and economic analyses.

In developing the list of options, the differences in temporal and spatial distribution, development stage, management needs and costs should be considered for the selection criteria. Identifying, collecting and considering data associated with the proposed scheme configuration is necessary to assess conjunctive water use projects. The components needed for the target area's water budget must be documented as part of the key steps defining available options. This will be necessary to estimate the timing, availability, quality and quantity of water for conjunctive use. For example, the following should be noted for the proposed options:

- Location of the identified sources, initial estimation of economic and financial costs, and water user requirements that are being addressed.
- Whether the aquifer is confined or unconfined, preference may be given to confined aquifers as they are less vulnerable to pollution and reduce the likelihood of water loss of injected water.
- Aquifer properties include transmissivity, depth to the aquifer, water quality and the type of geology that characterises the aquifer. Dolomitic aquifers may require a different management strategy compared to sand aquifers. Water quality can limit the feasibility of MAR or the amount of water that can be abstracted without negatively impacting water quality. However, a difference in water quality should not be viewed negatively as the option to blend waters of different quality or treatment may be available.
- Flow characteristics between the aquifer and nearby streams should be noted. The flow dynamics must be understood to improve/manage water supply and control externalities such as risks of aquifer contamination and stream depletion. The water quality and hydraulic gradient between connected groundwater and surface water systems may need to be managed through variable abstraction rates and MAR.

- The relationship between water allocation, water demand and distribution system should be noted. This includes taking note of the profile of different water users. Where the water resources cannot meet demand or proposed options are likely to infringe on existing water users, there is a risk of conflict.
- The different output levels needed for the implementation schedule should be noted. This requires that the initial details of the scheme's scale, design, location, technology, construction, operation and maintenance are considered.
- The scheme configuration will impact administrative and institutional processes, water pricing and legal procedures. South Africa has institutional processes that may overlap, which creates the risk of project failure.

It should be noted that the factors that will influence the proposed options are not independent. The evaluation process should be used to balance these factors while aiming to optimise the allocation of water resources. The selection criteria, including the assumptions, confidence level of models used and inputs, must be documented to form part of the project appraisal support documentation.

4.4 TECHNICAL ANALYSIS

The technical analysis should assess the components needed to ensure sustainable conjunctive water management. These encompass understanding the surface and groundwater interactions, responses to intervention and characteristics, appropriate water quality, and level monitoring.

Along with the technical consideration, the social and environmental impacts must be factored into the project option analysis process. This means the project must balance the need to meet water demands with maintaining healthy and resilient ecosystems and society.

Furthermore, the options selection process must consider the institutional arrangement and systems needed to ensure environmental integrity is maintained and regulatory compliance can be enforced. Defining the institutional context within which the project is to be implemented can highlight inherent institutional limitations and opportunities for providing long-term system maintenance, operations management and legal accountability critical for sustainable supply.

Although the surface and groundwater generally differ in their perceived availability, management requirements and development costs, their conjunctive use and management have the potential to provide the opportunity to gain maximum benefit from both resources. These differences should not be viewed as limitations that result in immediate disqualification from options lists.

4.4.1 Conceptual Layout of Options

A combination of layouts can be implemented depending on the objectives regarding water user requirements, water quality, O&M constraints and infrastructure capacity and availability. Since South Africa has been especially reliant on surface water, the existing infrastructure is likely favourable towards further development and management of surface water. The challenges associated with incorporating additional sources into the existing infrastructure should be weight against the need to create sustainable and resilient water supply schemes.

Space-dependent layouts should consider seasonal demands that will impact the assurance of supply and capital costs. A better option is to design layouts considering a supply scheme's seasonal and spatial requirements. The rotation of sources based on the selected conjunctive water use objective can be integrated into the layout to manage to change demands and hydrometrical conditions.

Therefore, the design of the layouts should be informed by the water resource yield modelling and vice versa. That is, the feasibility of a proposed layout is dependent on a number of factors that need to be considered, among which include:

- The spatial extension of the scheme – a decision regarding whether multiple wellfields are to be installed or a single large-scale wellfield will be installed needs to be made. This decision can be influenced by the number and characteristics of the aquifers in the area, the interconnection between the aquifer and stream, the distance of sources from water users, infrastructure requirements, whether MAR is to be implemented, etc.
- Where MAR is being considered, the required size of the MAR facilities should be estimated based on the approximated infiltration rates and quantity of water to be used for recharge. This can be used to simulate the required extent of the facilities for planning which must be refined to allow for contingencies like periodic maintenance. An indication must be provided regarding the number of recharge facilities to be installed, taking note that multiple facilities provide flexibility in case of breakdowns.
- Additionally, constraints brought on by the initial capital investment and O&M needed to maintain multiple or single sites will influence the final decision. These influences need to be documented in a manner that will illustrate the rationale for selecting specific options.

- Infrastructure – the status quo of the existing distribution and its capacity should be confirmed before modifications or new infrastructure are planned. Alignment regarding leveraging existing infrastructure, wellfield capacity and the potential to implement MAR should be confirmed, including whether this will take the form of passive or active recharge. Infrastructure layout and sizing should consider the influence on the capital investment and economic impacts of a phased installation design and design that allows for future expansion.
- Water user requirements – in some regions, an opportunity to differentiate water users according to water quality requirements may exist. Such information can be used to assess the feasibility of designing water supply schemes based on user requirements to optimise the use of known sources. This could create an opportunity to reduce the pressure on over-allocated drinking water sources by catering to user requirements, especially during dry periods. The process may have to consider the need to reallocate water resources and the resulting consequences based on the proposed layout.
- Coordination of operations – as mentioned, conjunctive water use will need coordinated efforts to manage the operations to gain full benefits as envisioned. Therefore, the conceptual layout should indicate how the different facilities and components of the water supply scheme will be integrated from the construction phase through to the operation and maintenance phase.

Ultimately, the conceptual layout should clarify whether the existing distribution system can be leveraged or whether a separate distribution system would be more practical. The number of scheme and how they are to be integrated and managed from an O&M perspective and at an institutional level should be noted.

4.4.2 Distribution System

The conceptual layout should form the basis of the initial design of the distribution system. At this stage, a decision should have been made regarding the project components, such as whether multiple wellfields or a single large-scale field will be installed, locations and type of MAR, and whether new infrastructure will be needed or existing infrastructure will be used.

The distribution system should be informed by:

- Operation and maintenance needed to coordinate the use of the different water sources. Whether groundwater and surface water will be mixed in different ratios or rotated according to seasonal changes should be understood and incorporated in the detailed design of the system.

- Inherent system limitations in the existing distribution system. This should be used to evaluate the feasibility of integrating multiple sources into the system and identify the potential challenges or opportunities of a new infrastructure configuration.
- Opportunities to reduce water losses. In addition to water demand and conservation initiatives, there is an opportunity to explore the reduction of non-beneficial water losses from, e.g. evaporation by moving water between storage facilities (from surface dams to groundwater storage).
- Water quality requirements for the different users. Water users must be allocated water based on their specific needs. Where practical, water users should be differentiated according to water quality and quantity to design a distribution system that caters to their specific needs.
- Knowledge of the location and design of the existing facilities and infrastructure. An inventory of the existing infrastructure within the target area should be documented to identify opportunities to optimise the use of these facilities. The facilities that are to be identified include but are not limited to existing pipelines, storage reservoirs, and boreholes that could be used for abstraction or active recharge. Further structures such as roads, irrigation pivots, powerlines, and human settlements/buildings should be highlighted as these areas would not be suitable for establishing MAR sites.
- A geographic information system project should be initiated to facilitate mapping and data management of the different water service areas impacted or influenced by the project. This information can also be used to calculate and depict the anticipated growth rates and demand changes which can be a significant aspect for services that cross municipal or city and water management area boundaries.

Complex surface and groundwater problems can stimulate the need to develop new approaches, as seen in California (Pulido *et al*., 2003). Regions with an extensive water infrastructure network, water rights and institutional support are likely to offer the best opportunities for conjunctive water use and management. The approaches used in California focused predominantly on integrating storage and transmission infrastructure to create efficient and flexible allocation and conservation of water. This also allowed more beneficiaries to be incorporated into the system and avoid conflicts. Additional advantages are the improved supply during peak demands without the expansion of the infrastructure and the potential to bring in a phased investment approach to adapt to gradual increases in water demands.

4.4.3 Operation and Maintenance

The risk of not formalising conjunctive use is that O&M will be implemented without the required knowledge to achieve success. To guard against failure, managers should be appointed and trained locally where conditions and special needs are well-known and understood. Although O&M is often viewed as the Water Service Authority and Water Service Provider's responsibility, at a local level, relevant stakeholders can also get involved to ensure the effectiveness of implemented actions.

O&M strategy can take the form of passive or active management, each with a range of limitations regarding infrastructure management, design and water use. Passive water management lacks system-level decision-making processes. This management style may leverage or permanently alter the operation and facilities to support incidental recharge or incorporate fixed facilities and policies to support conjunctive use operations. The designs of canals, reservoirs and streams are used to increase recharge by installing weirs and expanding infiltration areas without frequent management. The pricing structure is also used to encourage users to opt for groundwater during dry periods and surface water during wet periods. Consequently, encouraging alternating use of water sources.

In comparison, active management includes planned construction of facilities and active operation of existing infrastructure to take advantage of opportunities presented by integrated use and management of available water sources. Canals, reservoirs and streams are used to actively recharge groundwater so that the quantity and timing of infiltration are enhanced, and boreholes close to stream aquifers are used to induce recharge. The decision to divert surface water is determined by selecting a season during which water can be sustainably diverted for the required period. The duration of the season can impact the O&M costs and other resources, with a longer season generally expected to require more resources.

Abstraction and recharge operations are managed in such a way that they are coordinated to maintain aquifer water quality and levels. Run-off from the wet periods is diverted to a network of channels to highly permeable areas delineated for groundwater replenishment. Similarly, groundwater can be pumped directly into a stream as part of an active management strategy to meet stream flow needs at specific times and duration. On the other hand, passive management may rely on groundwater return flows to the stream, which is often used as a long-term strategy.

Whichever strategy is employed, it must be aligned with the project objectives. Furthermore, the O&M needed to ensure the successful continuation of the water supply must be considered.

O&M is critical to ensure the sustainable continuation of conjunctive water use. Several factors have been cited as leading to the deterioration of water supply systems, particularly groundwater schemes. These include (de Lange *et al*., 2019):

- Lack of finance, equipment, material, and inadequate data on Operation &Maintenance
- Inappropriate system design; and inadequate Workmanship
- The multiplicity of agencies and overlapping responsibilities.
- Inadequate operating staff
- Illegal tapping of water
- Inadequate training of personnel.
- The lesser attraction of maintenance jobs in career planning.
- Lack of performance evaluation and regular monitoring.
- Inadequate emphasis on preventive maintenance
- Lack of O&M manual.
- O& M manual.
- Lack of real-time field information

Therefore, the abovementioned must be addressed during the options analysis to ensure they are well incorporated into the final option's design, planning, implementation and management. For each of the options under consideration, the following must be detailed to allow for an objective assessment of the most feasible option to meet the set objectives:

- An effective maintenance plan is needed to guard against failure, especially failure driven by bias against groundwater use. The appropriate planning, design and implementation of O&M are necessary to ensure that the facilities are operated efficiently and effectively to provide a reliable water supply of adequate quality and quantity at a suitable pressure for all water users.

- A strategy covering the O&M plan, details of the necessary personnel (skills requirements), equipment and tools, GIS maps of the water system, monitoring, auditing and reporting system, and document control system for historical records is a necessity.

- Although the surface and groundwater components of conjunctive use need different O&M approaches, an integrated plan for the entire water supply scheme should be developed. The plan should detail the protocols, procedures, monitoring, and inspection intervals. These should highlight when and how water sources are incorporated into the water supply system, including the relevant internal and external stakeholders that should be consulted throughout the processes.

- The skills and training requirements to maintain the longevity of the O&M operations should be determined for each option. The necessary upskilling, training and human resource management should be documented. The management and O&M personnel to sustain an efficient operation needed, including the level of skills and experience, should be highlighted as this will also influence the financial, economic and CBA analysis.

- O&M, the selected option, is likely to be impacted by access to spares, tools and miscellaneous maintenance supplies and the frequency at which these resources are needed. Accessibility and frequency at which these resources will be needed, including inventory management, should be noted.

- A critical component of O&M that can easily be overlooked is the monitoring and management of records. The data collected from monitoring and maintenance activities provide essential feedback regarding the performance of an operation. Consideration must be made with respect to the level of monitoring needed for each option and the systems that must be in place to guard against bypassing protocols, procedures and lack of interest in managing specific components of the conjunctive water use operations.

The negative perception is cited regularly (de Lange *et al*., 2019; Murray, 2007; Cobbing *et al.,* 20014) as a leading reason for failed incorporation of groundwater into water supply schemes.

4.4.3.1 Operation and Management Protocols

The approach and intensity of O&M required to maintain groundwater resources compared to surface water differ. These differences need to be factored into the project planning process as they influence O&M and, therefore, the likelihood of success or failure of the scheme in the long term.

Implementing the required protocols to optimise borehole pumping rates and prevent aquifer over-exploitation and contamination will influence the final O&M requirements. The frequency and type of monitoring activities (e.g. compliance monitoring and early warning monitoring) that will be needed should be noted for the detailed project appraisal stage.

Since different institutions may be involved throughout the project stages, a plan should be in place regarding how monitoring activities (O&M) will be integrated between different institutional levels and directorates. It must be noted that close cooperation between different institutions will be needed for seamless operations.

The management and analysis of the collected data should also be factored into the planning and design process to ensure the protection and management of the resources and facilities.

4.4.4 Infrastructure Projects Financing

The National Treasury has several guidelines for public infrastructure projects, including the Infrastructure Planning and Appraisal Guideline (2022), which outlines the requirements at the different project stages for successful project fund approval.

Since the financial analysis of the project can significantly influence the decision to implement a project, thorough consideration regarding the water supply scheme configuration and planning is needed. While small multiple-wellfields may appear to be more favourable from a distribution network perspective, the costs of developing multiple segregated wellfields compared to a single large wellfield could render the project financially impractical. Therefore, an iterative process is recommended to balance and optimise the different aspects of the project appraisal process.

Costs can be managed by optimising through detailed desktop studies and well-planned intrusive studies/fieldwork that can later be used to motivate additional funds. The project team should consider whether, for example, the exploration boreholes used during the feasibility studies can be leveraged later in the project as production or monitoring boreholes. Additionally, scenario planning founded on sound assumptions can also be used as an effective means to keep costs within a restrictive budget. Where cost remains a significant limitation, consider whether the project costs can benefit from a phased approach. This approach also provides time to adapt to the complexities of managing the conjunctive use of surface and groundwater.

The project selection process needs to consider the source of capital investment and financing strategy during the O&M stage of the project. Most infrastructure projects rely on a mix of borrowing, tax revenue and tariffs. The approach for financing water services to non-poor or commercial customers will differ from those meeting low-income areas' basic needs. While tariffs can work well for water services to non-poor or commercial customers, a similar approach may not work in low incomes areas. However, a wide range of funding support mechanisms supports the provision of essential services. Cobbing *et al*., 2014 highlighted the following government funding mechanism:

- The Municipal Infrastructure Grant is a conditional grant to finance capital costs of basic services for low-income households.
- The Equitable Share – unconditional fund intended to support municipalities' recurrent costs
- Regional Bulk Infrastructure Grant – highly conditional grant to support bulk water and wastewater infrastructure, often for projects that straddle multiple municipal boundaries. DWS builds the bulk infrastructure for municipalities.
- The Accelerated Community Infrastructure Programme – funds are sourced from the DWS budget to achieve universal access to water and sanitation.
- Rural Household Infrastructure Grant – introduced in 2010/11 to support infrastructure development outside small towns in the priority districts.
- Urban Services Development Grants – incorporates funds previously allocated to the municipal infrastructure grant to finance the upgrade of informal settlements in metros.
- Municipal Water Infrastructure Grant – conditional grant for accelerating access to water using intermediate technologies to areas that remain unserved to date.

One of the significant concerns regarding groundwater resource development compared to surface water is the initial capital costs. However, National Treasury has indicated that delays in project registration, absence of project management units, inadequate capacity and interferences in the capital procurement process have been notable factors leading to underspending on water-related projects (Cobbing *et al.*, 2014). This suggests that if these pitfalls can be avoided, sufficient funds can be sourced to fund even the groundwater component to establish conjunctive water use.

4.4.5 Implementation Programme

4.4.5.1 Institutional Model for Implementation and Operation

Four main institutions are recognised to ensure access to water for the different sectors. The Department of Water and Sanitation (DWS) is predominantly responsible for ensuring that water resources management is beneficial to all, avoids environmental degradation, and ensures that water is allocated equitably. The Department has a number of Directorate, all with different responsibilities. One of these Directorates is the Integrated Water Resource Planning (IWRP) which has the mandate to develop comprehensive plans that guide the water sector initiatives and infrastructure development (Seago, 2016). the plans take into account the water needs of users and different interventions that can guarantee a reliable, efficient, sustainable and socially beneficial supply of water (Seago, 2016). Four chief directorates fall under the IWRP:

- National Water Resource Planning – responsible for developing strategies and procedures to reconcile water availability and needs to meet socio-economic development goals, including international obligations.
- Water Resource Planning Systems – responsible for assessing strategic water resource management challenges and developing operating rules, water quality, integrated hydrology planning and management decision support systems.
- Options Analysis – responsible for identifying and assessing projects to meet water requirements and the multidisciplinary project planning needed to implement the options, including drafting the applicable procedures and guidelines.
- Climate Change – responsible for developing appropriate climate change adaptation strategies and contributing to policies for the water sector.

Water Service Authorities (WSA) are municipalities responsible for ensuring water service provision, including rural councils. They are tasked with ensuring all water users within their jurisdiction have access to sustainable, cost-effective, efficient, and reasonably priced water supply. The WSA can select to act as a water service provider (WSP) or enter into a contract with a WSP. WSPs are public or private institutions that supply water services on behalf of WSAs within a specified area of jurisdiction. Their service provision performance, including legal compliance, is monitored through the WSA.

Water boards are primarily tasked with providing bulk water services to other water service institutions within specified regions. The boards can also take on secondary functions related to support services provided their primary function will not be jeopardised. Although water boards were initially formed to provide the infrastructure of regional significance to support economic growth, some boards that function in areas that lack financially feasible retail operations or areas of low economic activity operate under a social mandate. In effect, water boards are water service providers accountable to DWS.

Although institutional boundaries should be clear, this can be blurred since water and sanitation services are executed and managed concurrently at national, provincial and local government levels. Through legislation, the DWS is obligated to support local government and regulate all water services.

An additional institutional level that must be considered in water resource development is River Basin Organisations (RBOs). This is valid for catchments such as the Orange River basin and the Limpopo basin, whose boundaries straddle international boundaries. Projects under this scope should be cognisant of the policies, agreements and principles governing the relevant commission.

The institutional framework within which the conjunctive water use project is to be implemented is a key aspect of achieving an effectively and efficiently managed conjunctive water use scheme. It should be anticipated that the institutional complexity of implementing conjunctive water use could be greater than the complexity of the physical and operational logistics. Therefore, it is important that from the onset of the project appraisal process, there is engagement from relevant users and institutions to support the capacity to better coordinate local, regional or inter-regional management of the conjunctive use.

The appraisal process must consider the different levels of governance that can significantly impact the implementation and management of the water supply project. Uncertainty regarding accountability and responsibilities can contribute to the eventual failure of water service provision.

It should be clearly defined during the project evaluation which institutions will be accountable and responsible for O&M activities, for example. Lack of defined responsibilities for O&M has led to ineffective O&M and groundwater management as a result, risking the success of water services for rural communities.

Currently, surface water and groundwater are managed under different directorates. An intentional plan to integrate groundwater into the “mainstream” institutional governance systems/processes may be required. A level of transparency, accountability and participation throughout the different appraisal stages will likely be needed to reduce the risk of failure. The project appraisal process needs to consider whether the institutions that are going to manage the water supply scheme have the following:

- The appropriate mandate
- The required capacity and skill or can access make provision to access them
- Processes that will ensure accountability, transparency and reasonable risk allocation
- Existing policies and strategic management plans that support the coordinated use of multiple sources.
- Where applicable, the necessary bilateral or regional arrangements to manage a water supply system that straddles multiple boundaries.

Furthermore, the institutional model for implementation should be based on the knowledge of the surface water catchment and aquifer boundaries. While institutional boundaries are generally designed to coincide with surface water catchments, groundwater sources may cross these boundaries. As a result, stakeholder engagement may need to extend beyond the project's target area.

4.4.5.2 Procurement Strategy

The National Treasury requires a procurement strategy that meets the Framework for Infrastructure Delivery and Procumbent Management (FIDPM) to be developed early in the project stages. Multiple documents, such as the Public Finance Management Act and the Municipal Supply Chain Management Regulations, offer guidance on the aspects that must be covered in the procurement strategy.

Procurement Strategies for conjunctive water use will differ between, for example, rural areas and metropolitan cities. Tools and consumables that can influence the effectiveness and efficiency of the project O&M need to be accessible within a reasonable time. The strategy should identify the challenges associated with the location of the water sources and infrastructure and strategies that will be implemented to reduce the likelihood of failure.

4.5 ENVIRONMENTAL IMPACT ASSESSMENT

The scale of a conjunctive water use project is likely to trigger the need to complete an environmental impact assessment (EIA). This is necessary to obtain environmental, zoning and planning authorizations. Since the EIA process is project-based, the scope and boundaries of the project must be relatively well defined by the time the assessment process is initiated. The data and information from the conceptual layout and distribution system should be used to determine the type of EIA required and the authorisations needed before the project can be implemented.

An EIA has multiple phases according to the stage of the project and the level of detail needed to make decisions regarding authorisations. Since the options analysis is meant to determine whether a detailed business case is needed, the minimum requirement is to complete the EIA

Screening phase at this stage.

Based on the project design and battery limits, the screening phase should be used to determine the assessment level, i.e. basic of full EIA, that will be required. At this stage, sensitive ecosystems/sites that the project may impact should be identified, potentially fatal flaws, such as lack of relevant technical information, should be identified, and environmental authorisation processes triggered by the project activities.

It may also be necessary to complete a scoping report before the final project is selected since the outcomes from this phase can also influence conclusions made during the financial analysis. The scoping phase should be used to streamline key issues that apply to the project-specific activities. Consequently, the scope of the EIA for each option can be determined along with the specialist studies that must be completed. Furthermore, a public participation process may be required since the interested and affected parties' consultation will inform the scoping recommendations.

At the end of the options analysis, the following should be documented:

- Whether the project requires an EIA. If an EIA is needed, it should be clear which assessment process should be followed.
- Classification of environmentally sensitive environments.
- Needed permits, licenses and approvals before commencing with project activities.
- An estimation of time frames to complete the EIA and obtain all approvals and licenses
- Anticipated specialist studies, mitigation actions and displacement costs (if applicable).

4.6 SOCIO-ECONOMIC IMPACT

Historically, access to water has been a catalyst economic development of regions, and it remains essential for socio-economic development. Therefore, the implementation of conjunctive water use can be expected to impact communities in the target area and the economic activities surrounding them. According to Zhang *et al.* (2019), the social benefits of water resources show up in their domestic, industrial, agricultural and ecological use. In as much as access to water is a basic need, meeting the water needs of industrial and agricultural activities is also vital for social stability and ongoing economic development (Zhang *et al*., 2019).

It is important not to assume that since the project caters to the basic needs of society, the impacts will predominantly be positive. The socio-economic impact assessment should be conducted to identify unwanted social and economic effects, make recommendations, and provide mitigation options. The process should be designed so that the proposed project's future social and economic challenges can be forecasted, monitored and managed. Furthermore, public participation and incorporation of social values and priorities are fundamental when designing mitigation options or making changes to the project scope.

Therefore, the project options being assessed during the analysis must consider the socio-economic impacts of implementing the projects. Consider to what extent the proposed options can, for example, positively influence the local labour market and land values. The assessment should be conducted within the context of South Africa’s need to address socio-economic challenges, such as ensuring access and participation of Broad-Based Economic Empowerment and Small, Medium and Micro Enterprises in economic activities.

An initial impact assessment should be conducted to ensure that the proposed projects are aligned with relevant government policies and are appropriate solutions for the identified objectives. The government has provided socio-economic impact assessment guidelines as part of the “Integrated Environmental Management Information Series”. Some of the key elements highlighted in the guideline include:

- It identifies the project activities that are likely to cause impacts, including mitigation options. This includes documenting potential concerns of conflict and resolution processes. Coping strategies for impacts that cannot be prevented should also be documented.
  Potential risks that could fail the project should be noted along with the mitigation options.
- Documenting anticipated contributions towards skills development and capacity building in the surrounding community.
- Documenting the local cultural context as well as analysing the historical context. The I&APs must be identified, and their participation, including input into the project, must be facilitated and coordinated before the project is approved. The appropriate institutional and coordination arrangements should also be highlighted.

Ideally, the major social and economic groups that will be affected by the projects should be consulted through the project assessment and implementation

For a conjunctive water use project, the socio-economic impact assessment should illustrate how implementation will effectively address the challenges of adequate water at the required volumes and quality while minimising or preventing negative impacts on the community and existing economic activities. Additionally, it is necessary to highlight the socio-economic risks of reliance on a single source, especially where extreme climatic conditions are concerned.

4.7 REGULATORY DUE DILIGENCE

Legal, due diligence is needed to confirm all legal and regulatory mandates that must be adhered to before the project can be implemented and during the operational phase. A list of considerations has been provided in the Capital Planning Guideline. Key legal considerations during the options analysis stage that are specific to conjunctive water use include:

- The National Water Act (Act 36 of 1998) and associated regulations which are used to protect water resources and govern their use.
- Water Services Act (Act 108 of 1997) provides for the right to access water and ensures equitable, sustainable and efficient water supply services.
- Environmental Legislation such as National Environmental Management Act (NEMA, Act 107 of 1998) provides for environmental protection and sustainable use of resources.
- Local Government: Municipal Systems Act (Act 3 of 2000) which provides for the central processes for planning, managing performance, mobilising resources and partnerships that municipalities may engage to ensure service delivery.
- Heritage legislation
- Zoning and town planning requirements
- Site ownership and access approvals

The analysis should identify the risks and obligations that may influence the outcome of the anticipated benefits and costs. It is unavoidable that regulatory requirements will be triggered. The analysis should be sensitive to restrictions put in place through legislation to protect the environment or infringement on communities despite the perceived benefits.

CHAPTER 5: COST-BENEFIT ANALYSES

When drafting the guidelines for conducting a Cost-Benefit Analyses for Conjunctive Use, the authors of this guide relied substantially on the third edition of "A Cost-Benefit Analyses Manual for Water Resource Development" by Mullin *et al*. (2014), first released under the Water Research Commission in 2006, the New South Wales Government (2017) Guide to Cost-Benefit analysis and Elgar (2021). These sources should be consulted for an in-depth description of the CBA and factors to consider during an analysis.

5.1 WHAT IS A CBA?

A cost-benefit analysis (CBA), sometimes referred to as benefit-cost analysis, is a project evaluation method used to assist decision-making regarding the value provided to society by a project. It provides a logical framework within which the net social benefits of a project to society can be assessed when selecting projects to invest in. Determining the net social benefits to society is a key characteristic of a CBA. The identified cost and benefits are presented in monetary terms to reflect the impacts on individuals or groups that benefit directly and./or indirectly. The analysis does not assume that direct beneficiaries adequately measure society's social benefits and actual costs. As a result, when conducting a CBA, a wider scope of cost and benefits must be considered other than profit determination.

5.2 WHY SHOULD A CBA BE CONDUCTED?

Access to water of suitable quality is entrenched in South Africa's constitution, and therefore, a CBA regarding water should be concerned about the well-being of individuals and not necessarily the number of users and rates of consumption. The value gained from the implementation of conjunctive use should be quantifiable. Although sufficient literature points to the benefits of conjunctive water use, a CBA is a valuable tool where a proposed project's significant benefits and costs can be quantified. Therefore, a CBA completed in support of implementing conjunctive water use must first identify quantifiable social value gained from the project outcomes or outputs compared to the current conditions (base case). If the major benefits or costs cannot be quantified, then a CBA might not be the appropriate tool for the analysis. Options such as a Cost Effective Analysis may be more appropriate for the project appraisal, where major benefits can only be identified and quantified physically and not be valued in monetary terms. Throughout the appraisal process, the need to maintain the well-being of the individual need to be balanced with the need to protect the ecological reserve and increasing demand from different sectors such as agriculture and industry.

5.3 CBA STEPS

The steps below are presented as a guide regarding the aspects that must be considered when conducting a CBA, and the order should not be seen as fixed when completing an analysis.

The application of a CBA requires a multidisciplinary team with technical skills, broad knowledge and profound insight with regard to the problem that is being solved. During the process, care should not mix critical aspects important to deciding with secondary information that may need to be noted. Expert knowledge and insight will likely be needed to apply the CBA successfully.

Additionally, the source of funds for the project should be consulted early in the CBA process to confirm alignment in scope and valuation of costs and benefits.

5.3.1 Defining the Objectives and Scope

The project boundaries and scope within which the analysis is conducted must be stated as a first step. This ensures an understanding of the context within which the project is to be analysed and the factors that must be considered when solutions and recommendations are being made. Stating that the scope is to implement conjunctive water use within the municipality is not enough. The scope should specify the type of conjunctive use that the municipality would like to implement, that is, the use of surface and groundwater abstraction or the use of surface water, groundwater abstraction and MAR. It should be indicated whether this supply will be within the whole municipality or only specified locations where conjunctive use will be implemented.

Since the CBA is being used to assess the outcomes if a project is implemented compared to if it is not, the envisioned outcomes should be stated in the form of project objectives. This step aims to document the motivation for implementing conjunctive use; therefore, the completion of a process should not be an objective of the project within the CBA context. Ideally, this step should be preceded by an options analysis and need analysis.

Needs analysis and Options Analysis are required minimum information if capital funding is to be sourced through Treasury. The needs analysis should articulate why the conjunctive water use project is in the public interest, identify the infrastructure needs and expected outputs, and outline the current and anticipated water demand for the areas to be serviced. The Options Analysis should have indicated all the feasible options to achieve the intended objectives.

5.3.2 Defining The Counterfactual and Alternate Options

The base case or counterfactual scenarios must be defined. The base case or counterfactual refers to the state of water supply without implementing conjunctive water uses. It involves projecting the future costs and benefits should conjunctive use of water not be implemented. This should reflect the “Business as Usual” activities that would have taken place whether or not the conjunctive uses were implemented. Essentially, the CBA needs to illustrate the social benefit gained through conjunctive water use compared to a scenario where things remain as planned. It includes the minimum interventions or improvements that would naturally occur, such as maintenance, planned replacement of infrastructure or maintaining the quality and quantity of water supply. The base case should note this factor if demand management was a planned strategy to manage the anticipated supply deficit. It is important not to compare the proposed conjunctive use with an unrelated base case or activities that are not feasible or would not have otherwise been implemented. The documented base case indicates costs and benefits given the minimum expected investment and efforts to meet the objectives.

The option analyses, at this stage, would have identified feasible alternative options to the base case, which should be considered for assessment and motivation provided for the exclusion of certain options. Each catchment or municipality is most likely to have different conjunctive use options dictated by factors such as aquifer type, characteristics, socio-ecological impacts or even availability of technology or feasibility of public-private partnership opportunities. If the alternate projects are feasible, meet the outlined objectives, and meet the minimum requirements to conduct a CBA, they should go through the analysis process.

Additionally, consideration must be made regarding the interactions between mutually inclusive projects and interrelated projects, as this can influence the assessment of costs and benefits. Consider whether the proposed conjunctive water use projects need to be implemented independently from existing infrastructure or whether the existing water infrastructure and systems can be leveraged.

5.3.3 Identifying Costs and Benefits

Cost and benefit are often challenging to measure and can be difficult to identify since they are often “hidden”. Similar challenges can be experienced when a choice has to be made between projects that are intended to achieve the same goal through various routes but are mutually exclusive.

When identifying the costs and benefits, it must be remembered that it is not enough that a project has social benefits. The CBA must illustrate that the benefits of the alternative option exceed the base case.

These benefits can be directly experienced by the primary recipients of the service or indirect benefits experienced by third parties for that water market. Both direct and indirect costs and benefits should be identified and included when conducting forecasts where applicable. Direct costs and benefits are likely to be experienced by the direct recipients of water services in the community, including private groundwater abstraction users and water service providers. The gains and losses experienced in sectors or regions linked to the implementation of conjunctive water use should be noted and included in the CBA.

Indirect benefits should not be confused with secondary benefits. Secondary benefits due to the implementation of conjunctive use should be excluded as a general rule of conducting a CBA. This approach is based on the understanding that the experienced costs could have been spent on a different project which may have also generated identical outcomes. Therefore, it is thought to be incorrect to consider one project's secondary effects while excluding those of an alternate project.

A number of costs and benefits could be experienced across multiple catchments and provincial and international boundaries. These impacts should be included and presented separately. It should be noted that the source of funding could influence the spatial boundaries (regions vs local vs national) within a CBA contextualised.

The identified benefits or costs associated with economic gain compared to financial gain should be differentiated and accounted for separately. The New South Wales (2017) guide to cost-benefit analyses highlights common types of benefits and costs:

- Savings or avoided costs – defined as expenditures that did not occur or reduced costs due to the implementation of a project. The reason for the saving should be documented for cases where a post-project implementation review will be conducted. Such a saving could be reduced on water use tariffs due to less reliance on inter-catchment water transfers.
- Government revenues – defined as gradual gains in revenue due to the project. Revenues that would have been gained regardless of the conjunctive use implementation should be excluded. Additionally, revenues from expenditures by one department or division within the institution should also be excluded as they are neither a benefit nor a cost.
- Consumer surplus – is characterised by the undercharging of a service or good provided compared to the costs users are willing to pay due to the nature of the service or as a result of equity factors that the pricing policy must take into account.
- Producer surplus is the difference between the producer's price and production costs.
- Labour surplus – refers to the difference between actual wages and what the worker is willing to accept. An increase in employment is only considered a benefit if the individuals would have otherwise been unemployed without the project.
- Benefit to the broader community – characterised by gains that flow to the whole society and businesses. These benefits may not always be reflected in the prices charged, such as time saved or reduced medical expenditures.
- Capital costs are incurred from buying a new asset, replacing it, or major maintenance or refurbishment.
- Recurrent costs – ongoing costs to maintain the service such as salaries and wages as well as operation and maintenance costs.

- Negative externalities – costs experienced by third parties like the reduced availability of a resource due to a project or introducing new risk. Negative externalities can often point to the overconsumption of a resource compared to what is economically efficient.
- Ancillary costs – indirectly incurred costs needed before the project can commence, such as environmental impact studies.

Increasing costs and effects on cross-boundary relations need to be considered. The base case and alternatives should show relevant costs, the benchmarks that are used should be validated with data, and assumptions and forecasts that are used should be documented

5.3.4 Quantifying Impacts

All costs and benefits should be presented in monetary value at the end of the CBA. That is, the impacts from the project should be presented in their rand value without factoring in inflation and future price escalations where possible. The final amount should indicate the present value, future costs, and discounted benefits. The valuation used can follow one of two approaches. The opportunity cost principle considers the value of the resource or service in its most appealing alternative use or willingness to pay, which refers to the maximum price a stakeholder is willing to pay. The opportunity cost principle assumes that benefits can be estimated based on costs avoided by not engaging in a related or alternate activity. When applying the principle, resources committed to the project must be excluded from other projects. It must be noted that the opportunity cost of a resource or service remains generally fixed regardless of the ease with which it can be accessed. For example, should a wellfield be installed or MAR implemented on land that a service provider owns, the value of the land in an opportunity cost assessment should be maintained at the maximum value under its land zoning at the time of the CBA. Labour inputs should be indicative of the value of a worker's forfeited output as a result of being part of the project, although the real cost can be the minimum amount that will draw work towards a specified job.

On the other hand, the individual willingness to pay principle assumes that individuals' and businesses' preferences are key indicators of value. The maximum value that a stakeholder is willing to pay is adopted as an indication of value. The value can be determined through different types of surveys and observations of stakeholder behaviours. The challenge with this assumption, especially for water services, is that the market-related rates are likely not to provide an accurate indicator of the value of some services or resources.

The scarcity of water In South Africa illustrates that there are opportunity costs (economic costs) associated with water since several catchments have additional demands that exceed availability. This is a consequence of additional demand taking away from current or future water users of water. The 2021 National State of Water Report showed that in 2019, South Africa had a deficit of 96 Mm^3 and demand for water is projected to continue to exceed supply. Theoretically, the opportunity cost of water is linked to the highest economic use of water which will differ from catchment to catchment. Using the available data in South Africa to calculate the economic value of water or water provision service might not be a true reflection of the value of the resource. However, the available market-like transaction data and information can be used as an indicator of the willingness of users to pay a specific price. This price can be used to serve a lower limit of the value that is being approximated.

It should be anticipated that different sector will have different economic values of water. That is, the economic value in the agricultural sector compared to the industrial sector and forestry will differ. Consequently, the economic value of water in sectors with higher value should reflect the economic cost to the country for those sectors with a lower value. Ideally, data and information should be collected to produce a demand curve. For the sectors that have enough data on the amount of water used and tariffs, a consumer demand curve should be plotted from which the estimate of the marginal values/benefits of water at different demand levels can be made. If a demand relationship cannot be determined, an alternate cost concept can be used to determine the economic value of water. The alternate cost concept determines a proxy value using the least expensive alternative to estimate the maximum a user could be willing to pay for the water. It must be noted that the opportunity cost becomes zero for areas with abundant water. The abundance of water does not refer to wet season high flows or water levels only but volumes that can meet demand throughout the year.

5.3.4.1 Valuation Principles

When conducting a CBA, the costs and benefits values should be determined based on market prices or reasonable substitute values. A general valuation principle that should be remembered is that direct and indirect impacts should be valued relative to the base case, and multiplier effects should be excluded.

In competitive markets, the price is generally considered to reflect the going rate of a service or resource. This might not be true for all aspects that need to be considered for the conjunctive water used project assessment. However, aspects such as the replacement of equipment or damage mitigation costs can be indicative of market prices. Water provision services in South Africa tend not to be competitive because the price paid does not always reflect the service's value. Especially for municipalities that are subsidised, the customer charges will not reflect the value of the benefits received. In case studies where this is particularly relevant, the market price should be adjusted to reflect distortions hidden by subsidies, externalities and legal or institutional processes.

The value placed on the service or resource can be presented in different ways that, include:

- Private use value – defined by the costs users are willing to pay for a service or good
- Non-use value is defined by the perceived value placed on a service or good such as biodiversity, that exists separately from any use value.
- Option value – defined by the value placed on a service or good resulting from future anticipated use by the consumer, like a school.
- Altruistic value – defined by the willingness of one user to pay for another's use of a service or good including future generations.

According to Donnerfled *et al*. (2018), the results of apartheid, which include an extreme level of structural inequality, need a sensitive and nuanced approach to water pricing. Nonetheless, South Africa has a raw water pricing strategy based on the principle that revenue from certain catchments should pay for the cost of delivery of the relevant water into that catchment. This is aligned with the basic principles of costing. The strategy is set up so that the unique needs of the country where social equity, ecological sustainability and financial sustainability are considered. The raw water pricing strategy must be consulted during the analysis. The proposed pricing or revenue-generating strategy needs to address operation and maintenance issues and be mindful of the raw water strategy. There are different costs allocated to different users and sectors. These need to be taken into consideration:

- Allocate the cost to manage water to a sector according to the proportion of the volumetric average annual sectoral use.
- Ensure that no dam safety control costs or "Working for Water" programme are assigned to the forestry sector
- Incorporate unit cost per sector for the Water Management Area
- Incorporate subsidies that have been granted concerning the pricing strategy
- Incorporate under-recovery of revenue that the government subsidises

The water sector does not have a well-established approach to measuring willingness to pay for services provided. Surveys undertaken can be used to approximate the environmental impacts. Environmental impacts and travelling time saved are examples of costs or benefits that need non-market valuation since they tend to have non-traded outputs. Non-market valuation methods that are established and can be referred to for valuation include:

- Contingent valuation method – consumers' willingness to pay or willingness to accept compensation is determined by assessing actual customer behaviour
- Stated preference methods – consumers are asked directly about their willingness to pay either through a contingent valuation survey or through choice (predetermined options) modelling surveys
- Hedonic pricing method – considers that the value of a good or service can be influenced by characteristics of the good or service and the characteristics of external factors such as the associated environmental services such as air quality.
- Well-being valuation methods – have similar characteristics as social impact assessment. The first step of the analysis is to assess the overall life satisfaction of the sample group, and econometric methods are then used to estimate the life satisfaction received from a non-market good or service to convert these into monetary value.
- Benefit transfers – involves reviewing the available studies that measure specific benefits of previous studies, which can then be used as a proxy for values of benefits for the proposal. Consumption behaviour in related markets is used to approximate the value of non-market environmental goods.
- Production function approaches – the valuation method connects environmental quality changes to stakeholders' responses. Decreasing

environmental quality can be tracked through the costs of mitigation and protection measures taken by stakeholders.

As already stated, not all impacts can be presented in monetary value. These impacts can be included qualitatively to inform decision-making; ideally, subjective weighting systems should be avoided. The benefits gained could be reflected in the effects of reduced water restrictions during drought conditions.

5.3.4.2 Analysis Period

Before forecasting can be conducted, the period of analysis should be selected. The selected duration should be long enough to capture the base case's major costs and alternatives' benefits. The anticipated economic life of the project should be equal to the project life. If multiple alternatives are being assessed, the period may vary from one project to another. In this regard, the factors that influence the selected economic life should be noted as they significantly impact the outcome of the CBA. The expected growth rate of the benefit stream over the selected project life is also expected to have a notable impact on the economic life and outcome of the CBA. For example, demand for water processes in the industry could increase due to favourable market conditions for new producers.

Some assets may remain at the end of project life. These assets can either positively or negatively impact the cost stream. Items that are likely to have a positive impact are those that can be sold. Items that need to be destroyed or some forms of rehabilitation are likely to have a negative impact. These residual items must be accounted. Some assets may have an economic life shorter than the project life and are simply accounted for through capital expenditure for their replacement, if applicable.

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5.3.4.3 Forecasting

Since the CBA assessment is completed for a period that can be years in the future, forecasting will need to be done. This is also one of the key features of any CBA. There should be a clear differentiation between forecasting of volume and monetary forecasting per unit volume over the lifecycle of a project. Forecasting will be needed for the volume of water that can be abstracted or recharged and other resources such as labour, capital, costs of maintenance and operations, as well as revenue generated. If production costs and benefits include taxes and subsidies, these can influence the application of production factors and therefore need to be considered when forecasting the combination of inputs when the project is implemented.

The project design and technology used could be sensitive concerning time and therefore influence the capital and operational costs. The assumptions regarding these changes in the project design should be highlighted and supported with evidence.

Forecasting can be challenging when causes and effects experienced by the primary users need to be identified and understood to what extent the project outcomes will influence the stakeholders' behaviour change. It has been shown that consumers tend to use more water when it is readily available than when it is not. The potential changes in the behaviour of stakeholders over time as a result of the implementation of the projects, such as consumption rates, should be noted. Therefore, extrapolation informed by past patterns can be misleading if not validated. Any data used to project future demand should be used with more caution if demographic characteristics influence the data. Improving water security and access to water can unintentionally impact increasing future demand.

Additionally, risk and uncertainty in predicting outcomes can be mitigated by using the probability of higher or lower forecast outcomes. Challenges that may arise when forecasting for conjunctive use include (but are not limited to):

- Insufficient data on groundwater availability
- Lack of data regarding the interaction between surface water and aquifers
- Accounting for climate change impacts
- Little to no data on the long-term impacts of MAR on ecosystems in South Africa

Different approaches can be used to forecast. Here, two approaches are highlighted, which include using natural data and experimental data. Parameters that can rely on natural data should be identified. Changes in demographic and water resource trends rely on natural data for forecasting. Using natural data can assist with estimating the effects of unplanned scenarios on the behaviour of stakeholders and the service or resource. Suitably qualified specialists should be engaged to assist with data collection and interpretation of, for example, hydrometeorological and hydrogeological data to forecast changes in resource availability and impacts on receptors/stakeholders due to the implementation of conjunctive water use options. Additionally, an economist will provide relevant knowledge of the water sector since the analysis may need economic understanding and reasoning.

The second approach involves undertaking experimental studies. The studies can be (non)random design investigations with(out) baseline data or before and after investigations. An example of such an investigation is the use of pilot studies to predict the system's response to, for example, wellfield development with MAR compared to wellfield without MAR. A mix of techniques for the specific topic that needs forecasting should be considered, including predictive modelling and meta-analysis (use of multiple studies to conclude). Note that not all impacts can be identified and projected with high confidence. Therefore, the available information or available data should be leveraged, and the unqualified impacts should be documented and discussed.

Experimental approaches, surveys and natural data can be used when forecasting. Forecasting may be required with regard to:

- The size of the population that needs to be serviced
- Long-term availability of water resources
- Pricing strategies and funding

5.3.4.4 Socio-Economic Implications

The South African government has taken on water legislation that promotes equity, sustainability, efficiency, water use licensing, and the development of water rights markets to address rural poverty and inequalities inherited from the apartheid regime (Perret, 2002). A CBA process is designed to improve the allocation of limited resources. However, this can be challenging since the project can affect people (beneficiaries and losers) belonging to a range of income groups, different educational backgrounds, health statuses, etc. at different times throughout the project.

Understanding the distributional impacts and strategies to manage distributions of gains and losses is important. The distributional impact between beneficiaries should inform the decision regarding who should pay for the project's costs. Where there are lower income groups that are impacted by the project, this needs to be highlighted to put measures in place to manage the distribution of gains and losses equitably. The equitable distribution of consumption between communities and individuals must be factored into the CBA. This can be achieved by allocating weights to specific groups. In this regard, the winners and losers in the project should be determined, and the following effect should be noted:

- Stakeholders will pay more, and those will pay less due to implementing the project.
- Stakeholders will receive more, and those that will receive less due to the project.
- The different ways that different stakeholders can benefit and lose as a result of the project.

5.3.4.5 Environmental Impacts

The impacts of water resource development on the environment can mainly be classified as non-market effects, meaning there is no readily available monetary value. Environmental aspects that are related to water development such as water supply regulation, food production, scenery, etc. Environmental goods and services can be accounted for through willingness to pay and willingness to accept compensation.

5.3.5 Discounting of Project Cost and Benefits

A homogenous process needs to be used when combining the costs and benefits. Costs and benefits are likely realised over different periods; hence a discounting is conducted. The process of discounting is used to determine the value of forecasted benefits and costs in their present value. Present value is the worth of the service or resource according to prices at the time of the analysis. Discounting allows decision-makers to compare projects with benefits and costs that can only be gained in the future. Furthermore, it can be used to allow a comparison of projects with different analysis periods. A discount rate greater than zero is used, which suggests that the value of benefits and costs declines with time. This approach is founded on the idea that individuals tend to value current consumption more than future consumption or the understanding that for consumers, money received today is worth more than money received in the future. This is referred to as time preference. There is also the opportunity cost of capital which acknowledges that public investment into one project could mean forgoing an alternate public or private investment since capital is limited. It should be noted that regardless of the source of the funds used in the project, an opportunity cost of the investment remains.

A social discount rate is used in a CBA to calculate the value that a given group attaches to the present consumption compared to future consumption. Therefore, by discounting anticipated impacts, their present value can be determined. In addition, social discounts are used to indicate that assigning a resource or service to one project means forfeiting other potential uses in another project. That is, it can be used to show the opportunity costs of a service or resource in the long term for the collective community.

The selected social discount should reflect the unavoidable market risks that affect the project and should not be reduced by diversifying the project. Changes in the discount rate should not be made for the analysis period as the assumption of change implies that the opportunity cost of the resource is lower on all future dates. This applies to projects with decades' economic life cycle (i.e. intragenerational). The sensitivity analysis should be used to test the applied social discount rate.

There is a wide range of social discount rates that vary between developing and developed countries. Selecting the appropriate social discount rate is critical for a CBA and significant for allocating resources. In South Africa, a discount rate of 8 percent considering international benchmarks and the marginal return on capital, is generally used.

Discounting can either be intragenerational, meaning the impacts on future generations are not considered as the time frames are short (decades), or Intergenerational, which applies discounts over extremely long-term periods for impacts that can occur within multiple generations. Intergenerational discounting is best suited where climate change effects need to be considered. The consequence of using the intergenerational discount rate is that hyperbolic discounting (discount rate does not remain constant over time) may need to be applied.

5.3.5.1 Intrageneration Discount

The proposed social discount rate for South Africa is based on the principle of the social rate of time preference (SRTP) method. “The SRTP is the rate at which households are willing to trade a unit of current consumption in exchange for more future consumption”. The SRTP is estimated by 1) calculating the after-tax rate return of low-risk marketable securities or government bonds or 2) using the Ramsey formula which is derived from economic growth models. Although considered the best option for intergenerational projects, SRTP does not factor in the social opportunity costs of public investments

Other methods that can be applied for calculating the discount rate for intragenerational projects include:

- Social opportunity cost – the discount rate is based on the rate of return of the next best alternative use of funds. It does not consider the impacts on consumption spending due to public investment
- Weighted average approach – weighted average of SRTP and social opportunity cost
- The shadow price of capital – an approach used to reconcile the SRTP approach and SOC while addressing the shortcomings of the weighted average approach.

5.3.5.2 Intergeneration Discount

Two methods for calculating intergeneration discounting are highlighted:

- Social welfare planner approach – based on optimal growth analyses where the social rate of discount is equivalent to the sum of two factors; 1) discount rate for pure time preference and 2) adjustment that reflects the fact that satisfaction gained from consuming a product will decrease with time as consumption per capita increases.
- Individual’s preference with regards to time and consumption – it relies on the current individual’s preference to approximate the discount rate. This approach completely excludes the need to balance the needs/interests of the population today versus the future.

5.3.5.3 Environmental Discount Rate

It should be noted that although the need to apply a discount for environmental impacts is recognised, there is still much debate about social discounting for environmental purposes. This remains a challenge that needs to be addressed since environmental impacts tend to continue in the long term, and the conventional discount rate method does not accommodate this. While developing countries use low discount rates of 2 to 3 percent, Multilateral Development

Banks, which represent predominantly developing countries, promote the use of higher discount rates. Before applying the lower discount rates that are preferred by developed countries, consider the point that these countries mostly have relatively lower interest rates too.

The proposed discount rate for projects with an environmental component is the 8 percent commonly used for South Africa. However, the hyperbolic discounting factor and not the conventional exponential discount rate should be used. The identified environmental issues should be discounted over a relatively longer period to internalise their impacts correctly.

5.3.6 Sensitivity Analyses

It is expected that the decision maker on a project understands that the predicted outcomes of a project cannot be interpreted in absolutes; however, they should still be provided with an estimation of the extent of uncertainty the project might be subjected to. Determining the sensitivity of project outcomes to key assumptions, key risks, and inputs is one of the crucial steps of a CBA. It is an opportunity to present the CBA under different conditions in line with the expected average costs and benefits. For example, the economic appraisal could be sensitive to the social discount rate. In this case, providing the break-even rate and the sensitivity analysis results would be informative. During the analysis, the robustness of the proposed changes in variables that determine the project viability, such as population growth or scarcity of resources, can be tested.

5.3.6.1 Selective sensitivity analysis

A limited number of key variables subject to a range of variability and can have a significant effect on the outcome of the CBA should be selected and tested on the CBA. The worst-case scenario and best-case scenario are tested on the CBA, from which the potential results for each project can be presented. The disadvantage of using this method of analysis is that only a limited number of variables can be tested at a time, and presenting the results in a scientific manner can be a problem. Furthermore, the approach excludes a substantial amount of information important to decision-makers.

5.3.6.2 General Sensitivity analysis

Unlike Selective Sensitivity Analysis, General Sensitivity Analysis can handle more variables to be tested. General Sensitivity is grounded on the deriving probability distribution of possible outcomes. It involves:

- Using all possible combinations of the input variable to calculate the results
- The probability of occurrence of each combination
- Cumulative probability distribution function construction

5.3.7 Determining Acceptability of Risk

Ecosystem and socio-economic situations are, by nature, complex systems, and when predictions of the future situation are made, a level of uncertainty is added to the results. Modelling such systems often means that there is no unique solution for the forecasted issue, and uncertainty is an inherent feature of the results. Therefore, it must be expected that the calculation in a CBA is subject to a level of risk and uncertainty. The extent of the risks and uncertainty involved should be characterised and discussed to be used in the decision-making processes.

A risk assessment can be used, especially for projects with different rates of return for different risks and trade-offs between higher net benefits and higher net risk. The assessed base case and alternative risk rating should be captured for the quantified benefits and costs and tested through a sensitivity analysis. This can allow decision-makers to make an informed selection of how much risk is acceptable.

Attitudes or perceptions of decision-makers and operations towards the type and magnitude of risks inherent in the project should be understood and reflected in the analysis. The institutional environment within which the project will be implemented needs to be contextualised to identify all risks.

A risk assessment can be used to identify and manage risks involved in the project. The nature of implementing a conjunctive water use project may need significant legal, commercial and technical investments to identify and value the associated risks. The type of risk assessment undertaken should reflect the level of the project's complexity. Through the risk assessment:

- The steps involved in project delivery are noted.

- Major risks are identified and rated.
- Risk management techniques and measures are put in place in the design and development of the project.

The risk assessment can also assist with determining the type of sensitivity analysis that should be applied and, in turn, assist with developing risk management strategies.

5.3.8 Reporting

When reporting on the findings from a CBA, it should be remembered that the objective of a CBA is to summarise the net impacts (indirect and direct) to calculate the overall measure of social benefits. The figure that is commonly used to summarise the benefits and costs is Net Present Value (NPV). Deriving the NPV can be challenging due to the abovementioned factors. Some of the impacts might not be easily converted into monetary value, like environmental impacts. This information can be presented in a qualitative format and attached to the NPV that has been calculated. The following should be included when reporting:

- A summary of the base case and the alternatives
- Itemised major costs and benefits, including a description of qualitatively determining costs and benefits
- Key assumptions with their supporting evidence
- Sensitivity analysis results
- Highlight non-use benefits and validation process

At this stage, ensure that the proposed pricing strategy is addressed and there is a commercial strategy to manage assets and facilities. How the assets and facilities will be used efficiently and effectively to meet the project objective should have been demonstrated.

The project's impact across institutions and departments should be highlighted, including the timelines for implementation and capital needed and operational requirements. Budget constraints can influence the decision-making process significantly.

The reported results should have been subjected to a risk analysis to determine the sensitivity of the NPV to changes in key variables.

5.3.8.1 Calculation of NPV

The calculated NPV allows for costs and benefits occurring at different times. The future costs and benefits should reflect the discounted values. It is calculated by subtracting the sum of the costs from the sum of the benefits that have been valued. A negative NPV indicates that the net social benefits do not outweigh the costs. That is, overall social well-being might be reduced as a result of the project.

Budget constraints may make it necessary to complete financial and economic returns analyses even though a CBA is focused on the social profitability of a project. This is because some projects can be socially beneficial with a proportion of costs that need to be covered by revenues. Different pricing strategies, informed by applicable legislation and the country's water pricing strategies, can be used to arrive at different social and financial NPV.

5.4 LIMITATIONS OF CBA

The main challenge of using a CBA comes from the need to quantify value using prices that have been estimated consistently. Using prices simplifies the problem of preference since the arguments for or against a project are supported by numerical criteria. The following are to be kept in mind when conducting a CBA:

- CBA is actually a simplified model of reality within a conceptualised framework that can be dealt with analytically. Therefore, it is not necessarily a complete reflection of society, but it is a tool that policy and decision-makers can use to think through the extent of the repercussions of their expenditure decisions and reduce misunderstandings.
- CBA relies on data projections and assumptions since they are most likely to be conducted regarding future developments. Consequently, there will always be inherent uncertainty associated with the documented outcome.
- A CBA is not suitable for all projects; therefore, clarity should be obtained about the type of expenditure programmes on which the analysis can be performed. If the applicability of a CBA is in question, a cost-effective analysis could be conducted to ensure that the objectives can be achieved with minimal resources.
- The ranking of alternatives will usually need to be supplemented with results from other analyses that are as far as possible quantitatively assessed, in addition to economic and social analyses.

- The manner in which shadow prices and social discount rates are used in CBA remains under expert debate.
- Secondary economic impacts that are outside the immediate sphere of influence of the projects under review are excluded and should be evaluated separately from the CBA if needed as part of the decision-making process.
- There is a risk that a bias towards certain projects or outcomes can lead to over or underestimation of benefits and costs. Therefore, an independent analysis may be needs to counter potential bias.

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