The Economics of Sustainable Aquifer Ecosystem Services: A Guideline for the Comprehensive Valuation of Aquifers and Groundwater

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

As groundwater gains increasing recognition in South Africa, so the efforts have been bolstered to detail the extent to which the unseen resource is utilized and consumed. As the emphasis for water resource development shifts away from surface water resources towards alternative supplies, there is an increasing need to understand the economic incentives/arguments for groundwater use.

In order to understand these incentives/arguments, it is necessary to consider groundwater resources and aquifer systems holistically, looking at their role in the fresh water supply value chain, and within the larger economic framework. Herein lays the challenge, and the objective of this study, which is to begin to construct a comprehensive and integrated framework for the economic assessment of groundwater resources and aquifer systems.

However, in order to understand the economic contribution of a given groundwater resource to the water supply system, and to the economy as a whole, it is first necessary to identify and isolate the particular sources of value attributable to groundwater resources, after which consideration needs to be given to their quantification.

Surface water and groundwater resources each make up distinct components of the hydrological cycle, with unique water inflow, retention and outflow profiles. In particular, the unique characteristics of the groundwater hydrologic profile (recharge, retention, discharge) attribute groundwater resources and their associated aquifer systems with a set of ecosystem services that possess certain advantageous benefits relative to surface water resources.

The field of research regarding groundwater ecosystems services is in its early phases of development. Ironically, it is not due to lack of data or real world experience that groundwater ecosystems are not thoroughly understood. Rather, it was for lack of a suitable framework for the economic assessment and accounting of ecosystem services. This knowledge gap has been filled by the Millennium Ecosystem Assessment Framework (MEAF) which provides a comprehensive, evidence based point of departure for the categorization of ecosystem services.

Using this framework, in combination with a work-shopping method known as a Comparative Risk Assessment (CRA), this study investigated the ecosystem services of groundwater resource through the expert analysis of 3 case studies, specifically the fractured rock aquifer systems being utilized in the Hermanus area, the dolomitic aquifer systems in the Krugersdorp area and the primary aquifer in the Sandveld region. The exercise identified the following priority ecosystem services, including:

Provisioning Services: Provisioning of Fresh Water, Provisioning of Biodiversity and Genetic Resources;

Regulating Services: Water Regulation, Storage and Retention, Water Purification and Waste Treatment;

Cultural Services: Recreation and Tourism.

Although the field of understanding regarding groundwater ecosystems services is in the relatively early phases of research, there are several groundwater ecosystems services that

are of particular interest, specifically water regulation, storage and retention. The reason for these ecosystem services to be of particular interest is they are uniquely responsible for the mechanisms that mute the fluctuations in the availability of water within an aquifer from the fluctuation of external inputs, i.e. rainfall.

The availability of water within an aquifer, and the rate at which that water is recharged, is dependent on several prior recharge/rainfall events, as opposed to a surface water resource (i.e. dam) where the content of the resource is a function of only the previous recharge/rainfall event. Ground retards the flow of water, retains it and slows its transit. This brings a particular benefit to a water supply system whereby groundwater resources shield the availability of the supply of water from the volatility (frequency and intensity) of recharge/rainfall events, thereby increasing the efficiency of the system, all other things being equal.

However, in order to provide evidence for the efficiency gains attributable to groundwater resources, it is necessary to consider the water supply and demand network as a whole. Fluctuations in demand for water need to be modelled against the ability of a water supply system to meet that demand, whilst retaining consideration for the fluctuations in the frequency and intensity of recharge/rainfall events.

In order to achieve this aim, a stochastic model was compiled, incorporating the key stock and flow elements of a conjunctive use water supply system. The model was compiled according to a framework for analysis set forth by Quereshi et al. (2012) and was based upon the parameters of one of the case study areas investigated in this study, specifically the Hermanus case study area. This case study was deemed the most useful for the exercise as it was both a readily isolated conjunctive use system (its parameters could be well defined without having too much concern around interaction with adjacent systems) and it possessed a balanced user profile, having a good balance between domestic, agricultural and commercial/industrial usage.

The model was compiled in spreadsheet format, incorporating stochastic elements to model the random fluctuations of specific components of the system, including, but not limited to, rainfall patterns and water demand patterns. The relationships between rainfall, recharge and run-off were also incorporated stochastically. The key components of the system, where possible, were modelled based on real world historical data. Components, for which historical data did not exist, were modelled to express a functional interpretation of the specific components.

The model takes the form of a Monte Carlo Simulation, whereby successive randomly generated trials are generated by the model, with the multiple trials being collectively assessed to determine the performance of the overall system. By generating and analyzing a sufficiently large sample of trails it is possible to deduce the mean values and variances for certain indicators within the system, allowing one to quantitatively assess the risk profile of the system. By varying the various components of the model, it is possible to alter the risk profile of the system. Thus two different systems configurations may be contrasted with one another, on order to ascertain which configuration may be more efficient.

Another aspect of the modeling that needs to be detailed is the logic-based system controls that govern the overall functioning of the water supply system. These system controls are intended to simulate the governing institutional framework that manages the water supply system. The systems controls determine the allocations and restrictions of water usage within the system based on the relative availability of water supplies. They also control the relative contributions of surface water and groundwater towards meeting the demand simulated by the system.

Once the stochastic model had been compiled and scaled to approximate the Hermanus conjunctive use water supply system, it was subjected to scenario analysis. Three basic scenarios were compiled, based around 2 set of criteria, specifically “Control” and “Supply” as noted in the figure below.

		Control	
		SW	SW + GW
Supply	SW + GW	**A**	**B**
	SW	**C**	

Control: Control refers to the relationship between water allocations/restrictions within a system and the availability of water supplies within the storage component of the system. Scenario A is attributed with a control regime that only considers the status/availability of surface water resources when allocating/restricting water consumption. Scenario B considers the status of both surface and groundwater resources when allocating/restricting water consumption.

Supply: Supply considered the availability of both surface water and groundwater resources to supply the system with water. In scenario A systems storage is evenly split between groundwater and surface water resources. In scenario C, systems storage is 100% attributed to surface water resources, i.e. Scenario C assumes the absence of groundwater resources in the system. However, the total availability of water within each of the scenarios is equivalent to each other.

All other systems parameters were kept constant, so that these criteria, “Supply” and “Control” could be isolated and assessed in terms of their overall impact on the efficiency of the system simulated in the model.

Assessment of each of the scenarios yielded the following results:

1. *Scenario A vs Scenario B*: Scenario A, which had a control regime based around the status of only surface water resources, generated an inferior efficiency profile relative the scenario B which considered the status of both surface water and groundwater resources. The greater efficiency profile generated in scenario B is attributable to greater availability of information for decision making. Controlling water allocations and restrictions can yield better results if the control mechanisms consider both sources of water supply, surface water and groundwater.

2. Scenario A vs Scenario C: Scenario A, which had a total available water supply split between surface water and groundwater resources, displayed a greater efficiency profile relative to scenario C which had its total available water supply attributable to surface water. The proportional allocation of water between scenarios A and C was equivalent to each other, implying that the difference in systems efficiency/performance between the two scenarios was attributable purely to the hydrological dynamics of surface water systems relative to groundwater systems.

These findings have two implications for this study:

Firstly, the findings support the notion that the regulation, storage and retention ecosystem services provided by groundwater resources improve the efficiency profile of a water supply system.

Secondly, water allocation and restriction controls that are compiled in relation to the status of both groundwater and surface water resources, as opposed to just surface water resource are a more efficient means of systems control, benefiting from consideration for a wider pool of information.

The controls that guide/manage the allocation of water resources within a given entity (i.e. community, municipality, etc.) are designed based on the constraints of surface water resources, and do not, as yet, factor in the constraints associated with groundwater resources and aquifer assets. Allocation/restriction control within a conjunctive use water supply system should be designed around the availability of both surface water and groundwater resources.

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AGRP	Average Groundwater Resource Potential
AMD	Acid Mine Drainage
BWM	Beaufort West Municipality
COH WHS	Cradle of Humankind World Heritage Site
CRA	Comparative Risk Assessment
DLM	Delmas Local Municipality
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EEA	Environmental Economic Accounting
GC	Gateway Compartment
GDE	Groundwater Dependent Ecosystem
GDP	Gross Domestic Product
GRA	Groundwater Resource Assessment
GMA	Groundwater Management Area
GMU	Groundwater Management Unit
IAV	Invasive Alien Species
IGRAC	International Groundwater Resources Assessment Centre
IPPC	International Plant Protection Convention
KNR	Krugersdorp Nature Reserve
MCLM	Mogale City Local Municipality
MEA	Millennium Ecosystem Assessment
MEAF	Millennium Ecosystem Assessment Framework
MPT	Modern Portfolio Theory
MRA	Mine Residue Areas
NPV	Net Present Value
NWA	National Water Act
NWRS	National Water Resource Strategy
SAB	Stampriet Artesian Basin
SADC	Southern African Development Community
SEEA	System of Environmental Economic Accounting
SEEAW	System of Environmental Economic Accounting for Water
SKKAB	Stampriet Kalahari Karoo Artesian Basin
StatsSA	Statistics South Africa
TMG	Table Mountain Group
TSF	Tailings Storage Facility
UGEP	Utilizable Groundwater Extraction Potential
WC/WDM	Water Consumption and Water Development Management
WMA	Water Management Area
WRC	Water Research Commission
WTW	Water Treatment Works
WWTW	Waste Water Treatment Works

1 INTRODUCTION

1.1 BACKGROUND TO THE PROJECT

As groundwater gains increasing recognition in South Africa so the efforts have been bolstered to detail the extent to which the unseen resource is utilized and consumed.

The WR2005 water resources assessment project initiated by the Department of Water Affairs (DWA) was groundbreaking in its inclusion of groundwater, providing the first real insight into the extent that groundwater is utilized in South Africa. This work is set to continue in the WR 2012 initiative.

As the emphasis for water resource development shifts away from surface water resources towards alternative supplies there is an increasing need to understand the economic context of groundwater use.

Groundwater resources have the potential to significantly augment South Africa's water supplies with an estimated untapped potential of 6-8 billion m^3 per annum available to harvest. Of particular interest is the scale of groundwater abstraction projects as government looks to serve smaller scale communities where the large surface water schemes are prohibitively expensive.

However groundwater resources have additional benefits relative to surface water resources which include a higher assurance of supply and the potential for aquifers to be used as natural water banks for excess runoff during the wet season. Groundwater resources have qualities that could well serve to reduce South Africa's water supply risks and the added security provides an additional economic value.

Of course, in order to guide the avenues of water resource investment it is important to understand the potential economic impact that groundwater could contribute. Significant exploration costs are incurred in the process of mapping and quantifying groundwater resources, and if these efforts are to proceed at the desired rate it will first be necessary to potential return that may result from such investments.

This project aims to quantify the economic value of groundwater resources on a national scale by estimating their potential contribution to GDP and Green GDP. In addition, this project also aims to produce a practical set of guidelines for the valuation of aquifer systems which will serve to guide groundwater investment and management on the local scale.

Water resources are complex to evaluate economically because of all the intricate system dynamics on both the demand side (uses and value chains) as well as on the supply side (water cycle, aquifer properties and all of associated water dependent ecosystems) of the equation.

Groundwater resources add an additional layer of complexity to all of these considerations. The assessment of sub surface water resources is far more complex, due to the hidden nature of the resources. In addition, groundwater resources are intimately connected to surface water resources, both in terms of recharge and in terms of the hydraulic interact between groundwater and surface water bodies.

This project addresses many of these considerations by bringing together a wide range of material to begin to construct a more comprehensive picture of groundwater economics. This includes:

(a) The size and importance of the groundwater economy remains severely underestimated;

(b) Individual aquifers are not managed as valuable ecosystem assets (akin to mineral reserves);

(c) Wholly inadequate management instruments exist for optimal (sustainable) management of individual aquifers.

The purpose of the work proposed here is to address the key fundamental aspects of these problems. The strategic importance of aquifers in the water economy of South Africa will not be recognized until these problems have been addressed.

In 2008, Statistics South Africa (StatsSA) published a draft Water Resource Account for South Africa which estimated the size of the groundwater economy in South Africa at approximately R620 million per year (expressed in terms of contribution to Gross Domestic Product (GDP)). The StatsSA data was based on groundwater harvesting data obtained from the National Water Resources Strategy (1,088 million m3/a), from which GDP can be inferred using Water Sector GDP data collected annually by StatsSA.

This is however a gross under-estimation of the value of groundwater, for a number of reasons. First, it is possible that the NWRS harvesting data is outdated. Second, average GDP component of the water sector does not apply (accurately) to groundwater supply. Thirdly, the groundwater from secondary and dolomitic aquifers is, in many urban and rural local economies in South Africa, the only source of their sustainable water supply, and is therefore not substitutable. Finally, national GDP type data do not have the ability to adequately capture the asset value of aquifers. For any case to be made for the importance of aquifers in the economy, this underestimation must thus first be corrected.

Closely related to the above is the treatment of aquifers, at a management level, as ecosystem assets. A common failure in many groundwater management approaches is to view an aquifer merely as a source of groundwater, in other words the provision of water is regarded as the sole benefit derived from the aquifer. This is however not true, as aquifers play important supporting and regulating roles in supplying a range of ecosystem services to the economy of South Africa.

Sustainable management of aquifers require managers, investors and the wider public to appreciate the extent and importance of individual aquifers as assets which have to be managed sustainably. Valuation of groundwater resources also provides an important input to the Water Resource Classification System and hence integrated management of all water resources, if the interaction between groundwater, surface water and ecosystems are recognised and included in the socio-economic consideration.

The report begins by dissecting the factors that influence the economic value of aquifers, discussing both the supply and demand side considerations. Chapter 3 looks at the contributions of water and groundwater to the South Africa economy, and is able to contribute a reasonable amount of understanding in terms of the contributions of water use to GDP, and constructs a simple estimate for the asset value of surface and groundwater resources. This chapter relates only to the value of water and groundwater with respect to freshwater provisioning.

Chapter 4 zooms in on the key issue of the marginal cost of supply for water resources. This draws on recently provided evidence put forth by the DWA (2010), which looks at the future marginal cost of supply for water in South Africa. The case of the Western Cape is focused on.

All other ecosystem services are discussed at length in chapters 5 and 6. The former elaborates upon the necessary considerations for the valuation of ecosystem services and for their inclusion into a more comprehensive measure of economic contribution, namely “Green GDP”. Chapter 6 details the various ecosystems services attributable to groundwater resources and aquifers.

Chapter 7 outlines some of the key consideration and definitions relating to groundwater and aquifer systems. A brief overview is given of the various simple forms of aquifer systems that are found and outlines the key aspects make each type of formation unique. The chapter also outlines a host of groundwater dependent surface water bodies and the manner in which they depend on or interact with subterranean water resources.

It is in chapter eight that the shift is made toward a practical description of groundwater ecosystem services and the manner in which they interact or respond to exogenous risks. Three study areas are with a correspondingly wide range of groundwater/aquifer settings are detailed and the ecosystem services relating to each of these study sites is expounded through the application of a comparative risk assessment (CRA). The rationale and methodological description of the CRA is provided in the chapter.

The various chapters develop their arguments somewhat separately, and although they do begin to join the dots between the considerations for the economic valuation of groundwater resources, there is still much that needs to be done in terms of the practical aspects. Theory, in such cases, is insufficient, and as the project progresses into the field work phases, the practical considerations will be laid out. Chapter 9 details, rather briefly, the intended way forward for the proceeding phases of the project.

2 Design and Methods

We propose to address these problems through building on the outputs of the WRC Groundwater Management Framework (Riemann et al., 2011), and developing a Guideline for the Valuation of Aquifers and Groundwater.

There are several recent initiatives and research projects that proposed a methodology for groundwater valuation:

1. Groundwater Management Framework (Riemann et al., 2011)
2. Groundwater Valuation (Pearce et al., 2011) and,
3. SADC Groundwater Valuation Methodology

These will be assessed and the approaches incorporated in the proposed Guideline for the Valuation of Aquifers and Groundwater. This proposal will investigate the key aspects of groundwater economics with the purpose of establishing a sound resource economic based point of departure for groundwater planning.

The project will proceed through four distinct phases through which each of the Aims are to be achieved. The four phases are also logically connected and will be completed in series:

2.1 Research Approach

2.1.1 Phase 1: Identification of Potential Study Sites

Phase 1 identified a range study sites, for the purpose of demonstrating a range of hydrogeological and economic settings. The selected sites served as the foundation from which latter project phases would select the appropriate study sites.

2.1.2 Overview of Groundwater Economy

Phase 2 developed an updated estimate of the size of the groundwater economy in South Africa for the selected areas. The key methodology used here was based on the methods described in the System of Environmental-Economic Accounting for Water (SEEAW) of the United Nations.

The methods described in the SEEAW provide guidelines for the correct, accurate and standardized quantification of water resources. Where the groundwater method prescribed by SEEAW is inadequate (as it sometimes is), we will adapt mineral resources accounts valuation methods (also prescribed by the UNs System of Environmental-Economic Accounting (SEEA), and for which a precedent exists in Statistics SA (following the work of J. Blignaut).

A number of key aspects required consideration. First, groundwater harvesting data was be updated. This was achieved through collaboration with the Department of Water Affairs (who recently released a new groundwater resource database); relevant WRC research providers; and selected expert interviews.

Second, additional indicators of welfare (in addition to GDP) were explored. A variety of options exist with which the strategic importance of aquifers could be demonstrated. Thirdly, once indicators had been selected, the most appropriate economic valuation techniques were applied. This phase focused on the traditional role of aquifers as a source of fresh water, and did not include other ecosystem services delivered.

Statistics South Africa published an environmental economic accounts, the “National Accounts: Water Accounts for South Africa 2000” (StatsSA, 2009) which details, in the form of social accounting matrices the economic contribution of water resources to various sectors of the economy. Groundwater is included in this document but only to a limited extent. The project will seek to update these water accounts, to delineate the sectoral contribution of groundwater resources. This phase will focus on the traditional role of aquifers for the provisioning of fresh water, and will not include other ecosystem services delivered.

2.1.3 PHASE 3: APPLICATION OF THE MILLENNIUM ECOSYSTEM ASSESSMENT FRAMEWORK

Phase 3 applies the Millennium Ecosystem Assessment (MEA) framework of ecosystem services to 3 of the aquifers systems identified in phase 1 of the project. The criteria for selecting the appropriate cases were dependent on two factors:

1. Firstly, the availability of data to facilitate the application of the MEA framework and;
2. Secondly, the diversity of aquifer settings and economic context for each of the cases, so that a range of ecosystem services could demonstrated.

The MEA defines four sets of ecosystem services delivered by ecosystem assets. An aquifer is an example of such an asset. These four sets of ecosystem services are the supporting, regulating, provisioning and cultural services.

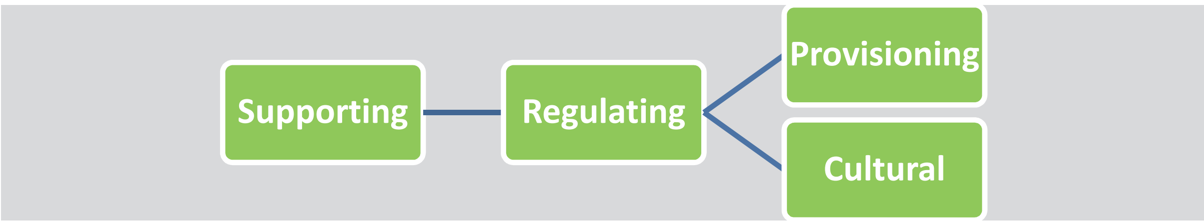


FIGURE 2-1: ECOSYSTEM SERVICE CATEGORIES AS IDENTIFIED BY THE MILLENNIUM ECOSYSTEM ASSESSMENT FRAMEWORK

Each of the four categories, according to Ginsburg et al. (2010) may be defined as follows:

Supporting Services: This refers to the fundamental/foundational functions of a given ecosystem from which all other functions/services are birthed.

Regulating Services: Regulating services are the direct effect of the supporting services provided by an ecosystem. These include, water regulation, erosion regulation, water purification and waste treatment, etc.

Provisioning Services: These are the ecosystem products that are, for the most part, directly consumed by society. This includes food, raw materials, naturally occurring compounds, etc.

Cultural Services: These are the passively enjoyed less definable cultural, religious and aesthetic benefits that ecosystems afford us.

The framework emphasizes the "connected" nature of the four value categories with "supporting" and "regulating" being termed intermediary services whilst "cultural" and "provisioning" are termed final services (Ginsburg et al., 2010).

In virtually all groundwater literature, only one of the services defined with these four sets of services are acknowledged namely, fresh water provisioning. Thus other valuable ecosystem services delivered by aquifers, such as supporting and regulatory services, soil water provision, and possibly some cultural services, are currently external to the water economy. This has to be rectified.

Appendix E lists a range of possible goods and services that may be derived from aquifers, however these are not organised according the MEA framework.

In this phase three representative cases of aquifer assets, with a correspondingly broad range of demonstrable ecosystem services, were selected for further investigation. The MEA framework of ecosystems services was applied to each of the cases in a workshop setting with the assistance of key groundwater experts with localised knowledge for each of the cases.

The Comparative Risk Assessment (CRA) methodology was selected for the workshop and was systematically applied to identify and prioritise key groundwater ecosystem services in each of the cases. Of particular interest was the identification of ecosystem cause and effect relationships.

The outputs of this workshop have been compiled and presented in this report, which has been integrated into deliverables 1 and 2 as per the process for a rolling draft report.

Comparative Risk Assessment will be used as a workshop methodology to identify and prioritise key ecosystem services, and develop aquifer ecosystem cause and effect relationships. On completion of the workshop Deliverable 2 will be updated to define a more inclusive definition of the value of the groundwater economy, with an emphasis on the asset nature of aquifers. The output of this phase will be Deliverables 3 and 4.

2.1.4 PHASE 4: QUANTITATIVE OPTIMISATION OF AQUIFER MANAGEMENT

Phase 4 will build on Deliverable 3 and propose a micro-economic approach to managing aquifers, based on best practice resource economic techniques. Deliverable 4 will comprehensively define all the benefits obtained from aquifers and which thus have to be managed at some steady-state level.

In addition, the sustainable flow of these benefits depends on the dynamic use levels of aquifer ecosystem services, recharge and negative effects of ground water pollution.

Thus the aquifer optimization problem requires an optimization approach as defined by Lagrangian optimization methodology. Similar methodology is applied in the analysis of mining optimization problems. This method has been applied in various ways and demonstrated in the literature (Provencher, 1993; Zachariah et al., 1999).

In theory the optimisation of aquifer management would focus upon the maximisation of the economic benefits generated by the ecosystems services of an aquifer system. Constraints factored into the objective function would include at least (but not limited to) three sets of parameters which include:

Utilizable Groundwater Exploitation Potential: This is a function of aquifer recharge, storage, etc.

Resource Impacts of Economic Activity: This is defined by a set of parameters to guide management of the aquifer to prevent resource degradation.

Economic Outputs of Groundwater Usage: The economic value of a water/groundwater resources is partially determined by the type of production for which it is utilized (*Domestic, Industrial, Agricultural, etc.*)

In this phase we will select one case study out of the pilot areas and specify the aquifer optimization problem for the full set of ecosystem services, subject to the relevant constraints, within a dynamic setting.

The analysis will be used to demonstrate the practical use of the methodology in a South African setting, to specify data future requirements and to feed into groundwater management guideline studies (of the WRC and DWA).

Once a functional optimisation model has been compiled, the model will be subjected to quantitative risk analysis to demonstrate the “water security” benefits of groundwater resources. Criteria will be developed for water resources risk management. That is, the model will be subjected to the identification, assessment and prioritization of risks.

This form of risk analysis may be best described by modern portfolio theory (MPT) which is a theory of finance which attempts to maximise the expected return/benefits for a given amount of risk within a portfolio (Correia et al., 2000).

To illustrate, MPT is a mathematical formulation of the concept of diversifying your investments (Not putting all your eggs in one basket, i.e. having access to more than one supply of water for a given economic zone.) The theory rests upon the notion the given collection of investment assets has a collectively lower risk than any individual asset. Intuitively this makes sense, as having multiple resources to supply water would reduce the risk to the town of losing one of the sources. The risk reduction is increased if the assets in the portfolio are fundamentally different in nature, such as surface water and groundwater. The differences in their nature of make them resistant to a differing set of environmental impacts, thus reducing the overall risk to water supplies.

Mathematically this models the return of an asset as a normally distributed function with the standard deviation (and in turn the variance) of the function being equivalent to the risk on the asset (Keller and Warrack, 2000). The may be compared to the assurance of supply for a given water resource, as the supply functionally varies according to a set of exogenous factor such as rainfall and run-off. Reduction in the standard deviation of the return on the asset is equated with reduced risk on the asset.

2.2 STOCHASTIC MODELING

2.2.1 OVERVIEW

Stochastic modeling concerns the use of probability to model real-world situations in which uncertainty is present. Since uncertainty is pervasive there are a wide range of possible applications for which stochastic modeling could potentially prove useful.

Some examples of areas in which stochastic modeling would prove particularly valuable may include:

- Epidemiology
- Meteorology and Weather Patterns
- Economic Forecasting
- Product/Service Demand Forecasting
- Product Reliability and Warranty Analysis

Basic Steps of Stochastic Modeling

i. Identifying the sample space
ii. Assigning probabilities to the elements of the sample space
iii. Identifying the events of interest
iv. Computing the desired probabilities of the events in question

2.2.2 KEY CONCEPTS AND DEFINITIONS

Presented here are a number of key concepts and definitions related to the stochastic elements of the study:

Causality: Causality, also known as causation, may defined as the relationship between two events, event A (the cause), and event B (the effect), where the outcome of event B is understood to result as a consequence of event A.

Sample Space: The sample space of a random experiment may be defined as the set of all possible outcomes or results of the experiment.

Random Variables: A random variable or stochastic variable is a variable whose value is subject to variation due to chance. The possible values of a random variable might represent the outcomes of a yet-to-be performed experiment

Stochastic System/Process: Is a process/system which has a random probability distribution or pattern that may be analyzed and defined statistically but which may not be predicted precisely.

Stochastic Model: A stochastic model is a simulation in which certain variables are defined as a range of possible values represented in the form of a probability distribution. Models may be wholly stochastic or contain certain stochastic elements, which are incorporated into the model in the form a random variable, whose probability distribution reflects that of the stochastic element in question.

Deterministic Model: A deterministic model has no stochastic elements, and where the relationship between the inputs and outputs is wholly and conclusively determined.

Monte Carlo Method: in the case of simulation of a stochastic model, it is usual that a random number be generated by some or the other method to execute a trial of the model. Multiple trials are utilized to determine the probability distribution (sample space) of the possible outcome of the model. This particular method is known as the Monte Carlo method, or Monte Carlo Simulation.

2.2.3 APPLICATIONS

Here, an example is given of the application of stochastic modeling. The example of “rainfall” is used.

Rainfall

Stochastic models for generating or imitating rainfall and precipitation are frequently used in hydrogeological, ecological and water resource studies. These models rely on certain assumptions about the probability distributions of rainfall for a particular landscape (Duan et al., 1995).

Stochastic models of rainfall may be used to:

- Imitate the system in question
- Extending hydrologic records beyond the scope of the available empirically measured rainfall records
- Fill in missing data points in long term measurement records

The outputs from a stochastic precipitation/rainfall model can be used as inputs into hydrologic and ecologic model components that predict:

- Run-off
- Soil moisture
- Groundwater recharge
- Etc.

In this report we detailed a simple stochastic approach to simulating the rainfall for a given case study area. The assessment of the model if based on historical data for the region and is used to approximate the historical performance of the system, as well as to forecast rainfall probabilities into the future.

Development of the rainfall model reflects the conception of natural phenomena whereby nature’s behaviour is wholly deterministic and randomness emerges simply due to a lack of understanding with regards to the underlying mechanisms at play (Camerer and Loewenstein, 2002).

Thus variation within the system that can be identified and quantified is measured and accounted for through the inclusion of deterministic elements. Elements of variation that cannot be accounted for are stochastically quantified, incorporated into the model through inclusion of a random variable, whose probability distribution is approximated according to the distribution of the error, as identified through the analysis of the historical data. In essence:

1. Historical records are regressed against a set of deterministic variables to determine their significance.

2. Significant deterministic variables are subsequently assessed relative to the historical data to isolate the unaccounted for variation.
3. The variation within the system that is not accounted for by the significant deterministic variables is then incorporated into the model in the form of a random variable/s that approximates that probability distribution of the error.

The construction of a conjunctive use water supply model required the incorporation of sets of deterministic and stochastic elements into the various components of the model.

Example:

Monthly Rainfall = F[Seasonal variation; Extra-seasonal variation; Error]

Where the components of the model are defined as:

Seasonal Variation: Variation in monthly rainfall pattern that occurs as a result of changes in seasons. [Deterministic – based on seasonal index] (Pearce et al., 2012)

Extra-seasonal Variation: Variation in monthly rainfall that occurs as a result of the long term wet/dry cycle. [Deterministic]

Error: The variation in monthly rainfall that cannot be accounted for through either seasonal or extra-seasonal variation. [Stochastic]

Thus the rainfall component of the model consists of two deterministic elements, identified through the analysis of historical rainfall records, and a single stochastic element, which has been isolated through the analysis of the unaccounted variation in the system.

2.3 COMPARATIVE RISK ASSESSMENT METHODOLOGY

Comparative risk assessment (CRA) provides a structured way for experts to describe how a change might impact on an ecosystem service in question. It is explicit about assumptions and certainty, can quantify, and help focus other extraction of evidence.

The CRA method is both an analytical process and a methodology for prioritizing complex problems. A recent authoritative publication on this concept is titled Comparative Risk Assessment: Concepts, Problems and Applications (Schütz et al., 2006). The discussion below was adapted from this publication.

Comparative risk assessment is a multi-attribute evaluation procedure which allows for a theoretically sound and structured progression by way of manageable individual steps. For each step (such as structuring the problem, structuring and weighting the attributes, sensitivity analysis) a range of practically tested techniques exist. The strength of the CRA is that it facilitates an explicit examination of assumptions and values and thus aids in a transparent comparative risk evaluation.

This approach is therefore suitable for those comparative risk assessment processes in which a variety of evaluators, both experts and other stakeholders take part.

Risk assessment begins with the identification of hazards. Three problem areas are of significance here. Firstly, the degree of evidence required to substantiate a causal link between the causes and effects in question, secondly, the classification of an effect as adverse or undesirable, and thirdly, possible exposure effects. The evaluation of evidence is a substantial problem. Dose-response type assessments are generally applied. In the light of the importance of hazards, exposure assessments are also of considerable significance. Thus the risk characterization brings together the results of the identification of hazards, dose-response assessments, and exposure assessments.

This examination of the data is also a factual prerequisite for comparative analyses. Risk evaluation constitutes the link between the predominantly scientific / technical risk assessment and a socio-politically oriented valuation of risks. A consensus on what are tolerable risks, reached through societal debate, can be the basis for an evaluation of quantifiable risks. Many risks may be unquantifiable, and thus criteria for differentiating (on the basis of scientific expertise) between averting a substantiated danger and precautionary measures often need to be developed.

However, standards of quality for the scientific understanding of risk have yet to be developed.

A benefit of a CRA lies in the comparison of a new development fields (and by inference also complex systems), in the comparison of public risk perceptions for different cases, and in the comparison of cost and benefit effects. Risk assessment is focused on the evaluation of evidence. “This is however where scientific controversy is often found and a comparison of different evidence evaluations, for instance with the use of tried and tested guidelines and categories of evidence, could contribute considerably to the solution of the problem” (Robu, 2007). Risk evaluation is generally characterized by four components: (a) the evaluation of intensity, (b) the evaluation of exposure, (c) the evaluation of the vulnerability of beneficiary populations, and (d) the comparative evaluation of the various risks.

Comparative risk assessment, as a combination of scientifically based risk assessments and value judgments, requires the cooperation of experts and societal stakeholders. A challenge to a successful CRA is that experts and general public (civil society) frequently have very different understanding and interpretation of risk. A substantial problem, from the point of view of experts is that the final results of analyses are separated from their principal constraints, methodological uncertainties, and scope, of which the public remains unaware.

Generally, the technical conception of experts is from the public’s point of view, extremely narrow and encompasses only a fraction of the aspects and values that the general public – broadly represented by societal stakeholders – consider important to an appraisal of risk. Even the consideration of frequency and loss equivalent, which is derived from the insurance industry, is disputed. Both factors are related by lay people (i.e. those who are not risk experts) individually; in particular, the upper limit of potential damages is seen as an independent issue and is increasingly demanded. In addition, the concept of risk underlying risk assessments usually encompasses only a few of the dimensions of loss, often only loss of life and harm of health, and, in rare cases, loss of prosperity.

CRA thus provides an objective process for prioritizing risks, and therefore the nature and extent of ecosystem effects resulting from development, captured in a risk description for each asset.

2.4 Risk of Each Scenario-asset-service Interaction

With the assets and scenarios spatially and temporally bound, the effect of the scenario on each asset in terms of ecosystem service delivery is assessed.

For each scenario-asset combination, the ecosystem services are assessed.

For each scenario-asset-service combination, the question asked is ‘What is the likelihood that this ecosystem service in this significant water resource will be affected under this scenario? What would be the consequences of this scenario in this significant water resource to the delivery of this ecosystem service?’

The likelihood is the probability of the scenario having an effect on the asset. Likelihood takes into account an element of uncertainty, in that the likelihood that an ecosystem service will be affected under the scenario in question over a specified time frame is rated. Uncertainty with regards to the knowledge upon which the statements or connections between scenario-asset-service linkages are made, is also stated explicitly for each CRA. This level of certainty (e.g. high, medium or low) is a statement based on the expert's judgment of the certainty of and confidence in the risk assessment. For example, a low level of certainty indicates that evidence to bear out the assessment is weak or lacking.

TABLE 2-1. QUALITATIVE AND QUANTITATIVE CLASSES OF LIKELIHOOD OF A SCENARIO (ENVIRONMENTAL EFFECT, OR RESULTANT CHANGE IN THE FLOW OF AN ECOSYSTEM SERVICE) EVENTUATING FROM A MANAGEMENT DECISION AND OF HAVING AN ENVIRONMENTAL CONSEQUENCE TO A SERVICE FROM AN ENVIRONMENTAL ASSET IN THE ECOSYSTEM ADAPTED FROM THE CLASSIFICATION ADOPTED BY THE IPCC (2007).

Likelihood rating	Assessed probability of occurrence	Description
Almost certain	> 90%	Extremely or very likely, or virtually certain. Is expected to occur.
Likely	> 66%	Will probably occur
Possible	> 50%	Might occur; more likely than not
Unlikely	< 50%	May occur
Very unlikely	< 10%	Could occur
Extremely unlikely	< 5%	May occur only in exceptional circumstances

The consequence is the change in the service from the environmental effect of the management scenario on the exposed asset. The assessment of consequences can follow, or adapt in an appropriate manner, the severity ratings in King et al. (2003) (Table 10).

TABLE 2-2. QUALITATIVE MEASURES OF CONSEQUENCE TO ENVIRONMENTAL SERVICES IN AN ECOSYSTEM ARISING FROM THE HAZARDS LINKED TO A MANAGEMENT DECISION.

Level of consequence		**Environmental effect**
1	Severe	Substantial permanent loss of environmental service, requiring mitigation or offset.
2	Major	Major effect on the on the asset or service, that will require several years to recover, and substantial mitigation.
3	Moderate	Serious effect on the on the asset or service, that will take a few years to recover, but with no or little mitigation.
4	Minor	Discernible effect on the asset or service, but with rapid recovery, not requiring mitigation.
5	Insignificant	A negligible effect on the asset or service.

During the CRA it is useful to identify all appropriate compensation measures (mitigation and offsets).

The level of risk is the product of likelihood and consequence in the event of an environmental effect on an asset. Figure 2-2combines the likelihood and consequence rating to determine risk as:

- Low (L) requiring no to little response;
- Medium (M) requiring local level response;
- High (H) requiring regional level response; or
- Very High (VH) requiring national level response.

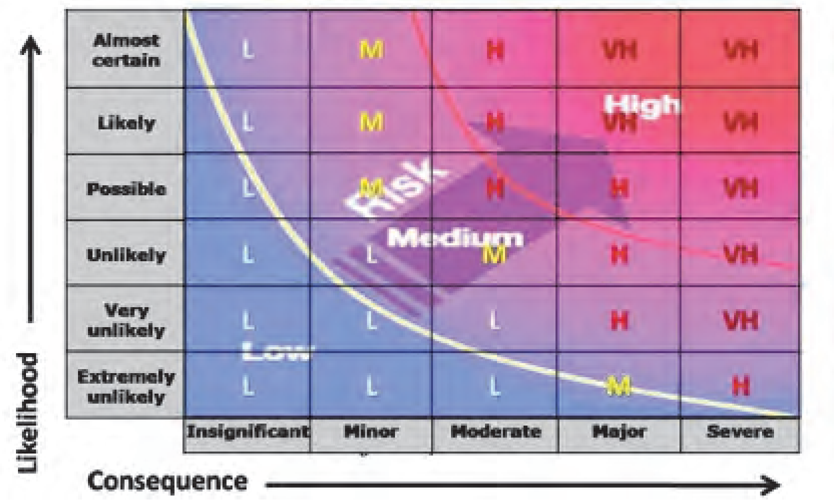


FIGURE 2-2. LEVELS OF RISK, ASSESSED AS THE PRODUCT OF LIKELIHOOD AND CONSEQUENCE IN THE EVENT OF AN ENVIRONMENTAL EFFECT ON AN ECOSYSTEM ASSET (ADAPTED FROM AUSTRALIAN/NEW ZEALAND STANDARD ON RISK MANAGEMENT (2004)).

The outcome of the CRA should include:

- Description of the environmental effect statement, including hazard and effect statement, scope of consequence, outcome statement and likelihood of outcome.
- Table of ecosystem services with the likelihood and consequence of environmental effect, and the level of risk.
- Statement of the level of certainty associated to the above risk assessment, based on the availability of existing evidence and certainty of expert knowledge.

3 GROUNDWATER UTILIZATION

Groundwater has historically been given limited attention, and has not been perceived as an important water resource, in South Africa. This is reflected in general statistics showing that only 13% of the nation's total water supply originates from groundwater. The Groundwater Resource Assessment Project, Phase II (GRA II; DWAF, 2006) provided an estimate of the total groundwater use by 2004 of 1.77 billion m3/a (see Table 1 and Figure 7). The main water sectors are:

- Urban and rural domestic supply
- Agricultural use for irrigation and stock watering
- Mining
- Industrial use

TABLE 3-1: UTILIZABLE GROUNDWATER EXPLOITATION POTENTIAL (UGEP) PER WMA (WR2005)

Water Management Area	UGEP (million m^3/a)
Limpopo	644.3
Luvuvhu/Letaba	308.9
Crocodile West and Marico	447.8
Olifants	619.2
Inkomati	667.8
Usutu to Mhlathuze	862.0
Thukela	512.6
Upper Vaal	564.0
Middle Vaal	398.1
Lower Vaal	645.1
Mvoti to Umzimkulu	704.9
Mzimvubu to Keiskamma	1,385.9
Upper Orange	673.0
Lower Orange	318.0
Fish to Tsitsikamma	542.4
Gouritz	279.9
Olifants/Doring	175.5
Breede	362.9
Berg	249.0
Total	**10,361.3**

Table 4-1 above illustrates that utilizable groundwater exploitation potential (UGEP) for each of the 19 WMAs. Total UGEP for South Africa is estimated at 10,361 million m^3/a

Over 426 towns, and a far higher number of villages and rural settlements, depend solely on groundwater, but there is very little monitoring and management to ensure that abstraction does not exceed recharge rates, with the result that many boreholes, and in extreme cases, aquifers, are being over-pumped. (DWAF, 2008)

However, a growing number of municipalities utilize groundwater on a regular basis and groundwater supply has been identified as one of the main next possible interventions to augment the water supply to many towns and metropolitans (DWA, 2011).

About 80% of the groundwater use is for irrigation and livestock in the agricultural sector, especially in the arid and semi-arid regions of the country.

Groundwater also plays a significant role in providing water for food processing (e.g. beer breweries, water bottling plants) and other industrial processes.

Both open pit and underground mines have to abstract groundwater for keeping their mining areas dry during operation. In some instances this water is utilized by other water sectors (e.g. domestic or agricultural supply).

Table 3-3 illustrates estimated amount of groundwater being used for each for the economic sectors within each of the WMAs (DWAF, 2006)

On the whole agriculture is by far the most significant user of the resource utilizing some 1,144 million m3, which accounts for approximately 65% of all groundwater being utilized in South Africa.

The three WMAs which utilize the largest amount of groundwater are Fish to Tsitsikamma, Limpopo and Crocodile West and Marico which utilize 383 million m^3, 198 million m^3 and 166 million m^3 of groundwater respectively.

TABLE 3-2: PERCENTAGE OF WATER SUPPLY OBTAINED FROM GROUNDWATER.

Water Management Area	Domestic/Commercial/Industrial	Agricultural
Limpopo	48.39	61.85
Luvuvhu/Letaba	47.43	0.40
Crocodile West and Marico	6.93	19.68
Olifants	12.56	14.93
Inkomati	9.56	0.29
Usutu to Mhlathuze	6.48	3.59
Thukela	3.98	1.03
Upper Vaal	5.66	14.28
Middle Vaal	7.82	19.51
Lower Vaal	43.84	7.96
Mvoti to Umzimkulu	2.47	0.21
Mzimvubu to Keiskamma	15.94	11.53
Upper Orange	4.74	15.48
Lower Orange	95.89	1.52
Fish to Tsitsikamma	6.55	46.10
Gouritz	18.70	22.98
Olifants/Doring	21.98	23.53
Breede	18.66	11.03
Berg	7.25	8.46

TABLE 3-3: SECTORAL GROUNDWATER USE ACCORDING TO WMA (GRA II, DWAF, 2006)

(million m3 /a)

Water Management Area	Rural	Municipal	AgIrrig	AgLive	Mining	Industry	Aquaculture	Total
Limpopo	13.50	15.85	152.72	3.27	5.56	7.65	0.03	198.58
Luvuvhu/Letaba	10.92	9.11	0.88	0.14	0.05	0.29	0.00	21.40
Crocodile West and Marico	18.64	29.09	97.03	7.74	11.48	2.06	0.18	166.21
Olifants	17.40	2.64	87.41	1.66	30.87	3.82	0.04	143.85
Inkomati	9.02	0.28	1.60	0.17	1.59	0.47	0.14	13.27
Usutu to Mhlathuze	11.38	0.48	14.69	1.35	0.00	0.28	0.00	28.18
Thukela	5.41	0.10	0.89	1.37	0.00	0.02	0.00	7.79
Upper Vaal	4.61	2.69	3.69	16.03	39.99	16.57	0.33	83.92
Middle Vaal	0.40	6.74	18.28	13.92	7.38	2.53	0.00	49.26
Lower Vaal	13.86	25.56	23.21	19.51	11.50	1.94	0.01	95.59
Mvoti to Umzimkulu	13.35	1.46	0.06	0.49	0.05	1.50	3.50	20.41
Mzimvubu to Keiskamma	23.04	0.56	22.13	1.37	0.00	0.01	0.00	47.11
Upper Orange	0.96	4.72	109.96	18.30	2.18	1.60	0.00	137.72
Lower Orange	0.01	8.07	5.12	10.21	41.79	0.46	0.04	65.71
Fish to Tsitsikamma	0.28	8.33	366.65	8.23	0.32	0.01	0.00	383.82
Gouritz	0.16	10.41	62.14	1.44	0.02	3.47	0.01	77.65
Olifants/Doring	0.15	2.04	82.93	1.24	1.04	0.31	0.00	87.70
Breede	0.30	7.21	64.96	0.46	0.02	2.07	0.12	75.14
Berg	0.19	16.29	29.79	2.00	0.02	19.99	0.56	68.84
Total	143.57	151.64	1144.14	108.91	153.85	65.05	4.97	1772.13

3.1 WHAT DETERMINES THE ECONOMIC VALUE OF AQUIFERS?

Aquifers are important contributors to South Africa's economy. It contributes to the economy through producing fresh water for use in various forms of production and consumption, and through supporting a range of ecosystem functions, which in turn deliver valuable ecosystem services into the economy.

Several factors affect the economic value of aquifers. Before we discuss these factors, it is important to distinguish between the concepts of natural asset value and ecosystem service value. Ecosystem services are the benefits that humans receive from ecosystems, and are officially defined by the Millennium Ecosystems Assessment. Ecosystems produce these ecosystem services on an annual basis, and the value of these services accrue on a country's national income statement, and should ideally be measured through indicators that relate to Gross Domestic Product (GDP). Thus the total value of aquifer ecosystem services can be thought of to contribute to green GDP.

Aquifer themselves are natural assets. They form part of the ecological infrastructure of a country. And the values of these assets theoretically appear on a country's natural resources balance sheet. The asset value can be determined by calculating the Net Present Value (NPV) of the perpetual stream of aquifer ecosystem services delivered.

Natural assets of this kind are characterized by complex inter-temporal and inter-ecosystem service characteristics. For instance, although overharvesting an aquifer may yield short term benefits (on the income statement), it will reduce the asset value of the aquifer if it reduces the future water yield of the aquifer and/or if it reduces the delivery of ecosystem services supported by the aquifer.

Thus it is important to understand the links between the hydrogeology of aquifers systems and the groundwater dependent ecosystems that are linked thereto. Only by incorporating this wide range of factors will be possible to comprehend the significance of the extractive and non-extractive uses of groundwater. Qureshi et al. (2012) present a diagram to elaborate groundwater resource linkages/interactions:

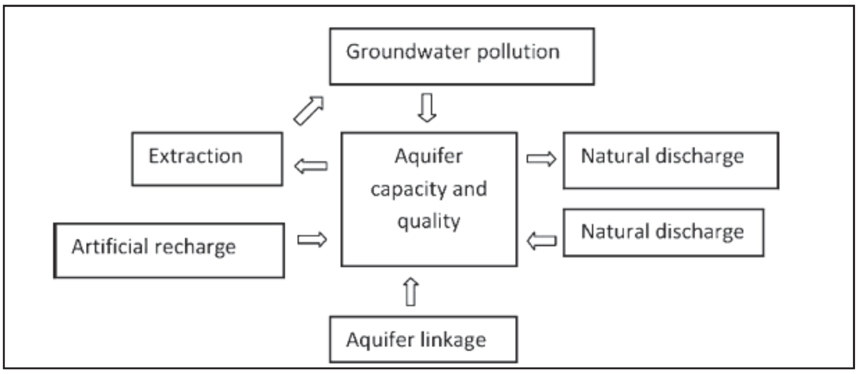


FIGURE 3-1: HYDROGEOLOGICAL CONSIDERATIONS RELEVEANT TO THE ECONOMIC ASSESSMENT OF GROUNDWATER RESOURCES (QURESHI ET AL. 2012)

These in essence represent the supply side considerations relating to the assessment of groundwater resources. Simply put, they determine the cost of extraction, the amount of water available to be extracted, the quality of the water available and the linkages of groundwater to other ecosystems that be of value, and that may be affected by abstraction. These include surface water impacts of groundwater abstraction (Qureshi et al., 2012; Katic and Grafton, 2012).

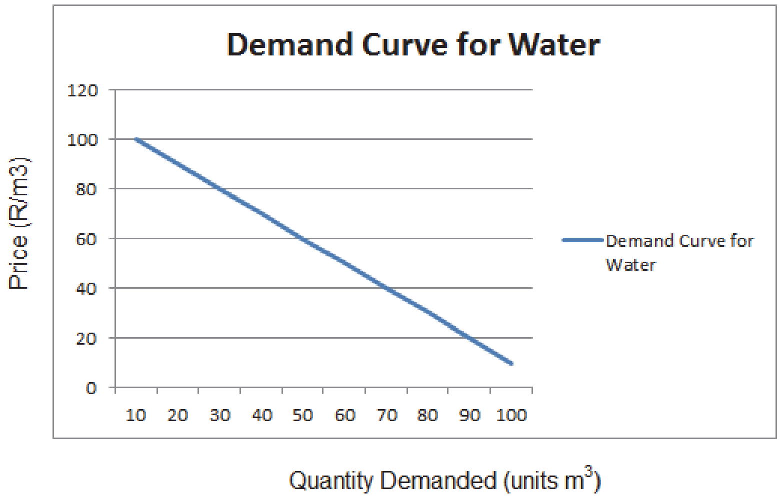
Thus, in order to understand the value of aquifers, we need to understand the full range of ecosystem services which it supports (including ground water provisioning).

Another consideration in the value of groundwater is the relative scarcity of water. Where surface water resources are abundant, sufficient and inexpensive compared to groundwater, it is likely that aquifers play a relatively small role in the economy, and thus the value of the aquifer will be low. This situation may vary geographically, and may also change over time as water demand increases.

The long residence time of groundwater in and of itself provides a particular kind of economic value. It gives groundwater a greater stability, as the hydrologic fluctuations within the aquifer are muted from fluctuations in climatic conditions (Colvin, 2009). The quantity of water captured by a surface water storage scheme such as a dam is the function of two or three (possible) seasons of rainfall and runoff. The amount of water contained within an aquifer is the function of a much longer set of consecutive seasons of rainfall, runoff and infiltration, thus the water content of an aquifer is muted from the fluctuation of the climatic cycles, a property which makes groundwater resources particularly resilient to climatic shifts and periods of drought. This characteristic of aquifers serves to increase the marginal value of water.

This adds a strong inter-temporal consideration to the abstraction and use of groundwater resources. Qureshi et al. (2012) states that "*from an economic perspective optimal (aquifer) management is defined by the rate of extraction over time and space that maximizes the net present value of benefits minus costs, subject to the physical hydrology of the aquifer and the related water sources.*".

The marginal value of water can be represented with a downward sloping demand curve, which illustrates that inverse relationship between price and quantity demanded.



An important consideration derived from the simple curve is that users allocate water to the highest value uses first and subsequently to lower value uses (Qureshi et al.,2012; Hansen, 2012). This has very powerful implications for scenarios where is water resources are becoming particularly scarce. This also implies that the marginal value decreases as more value is used.

Under such circumstance the market forces will begin to reallocate water to users with a relatively higher marginal use values.

The assessment of the available supply of groundwater is an important step towards sustainable groundwater use. Of course this needs to be placed into the context of groundwater demand, and the uses that are driving that demand. Reinelt et al. (2012) state that as the era involving the enhancement of water supply passes, more emphasis is being placed on the efficiency of water supply systems, which requires an integrated consideration of demand-side and supply-side factors.

In the sections that follow we contextualize the value of aquifers through:

- Investigate the current demand for groundwater by analyzing available use volumes
- Explore the concept of the marginal value of groundwater, and present evidence showing the increasing value of aquifers; and
- Provide a preliminary discussion of ecosystem services.

3.2 Marginal Cost of Water Supply

3.2.1 Definition of marginal cost

Marginal cost is defined as the addition to total cost from producing one extra unit of output (Griffiths and Wall, 2000). In the context of the water market a unit of output is defined as a m^3 of potable water. Fundamentally related to the concept of marginal costs is the concept of marginal returns. The two concepts are inversely related, in that in increasing marginal cost of production/supply will correspond to decreasing marginal returns to production.

We explain these concepts by illustrating the law of diminishing marginal returns here:

The law of diminishing marginal returns is a law of economics that states that usually in the short run the marginal output for a given factor of production, whilst all other factors of production are being held constant, will eventually begin to decrease as a the quantity of that factor employed is increased passed a certain point (Nicholson, 2005).

To illustrate this we take the example of a firm employing laborers to produce its product.

If all other factors of production remain constant, and as the firm increases the number of laborers, at some point each additional laborer will provide less output than the previous laborer. At this point, each additional employee provides less and less return. This is illustrated in Figure 3-2 below.

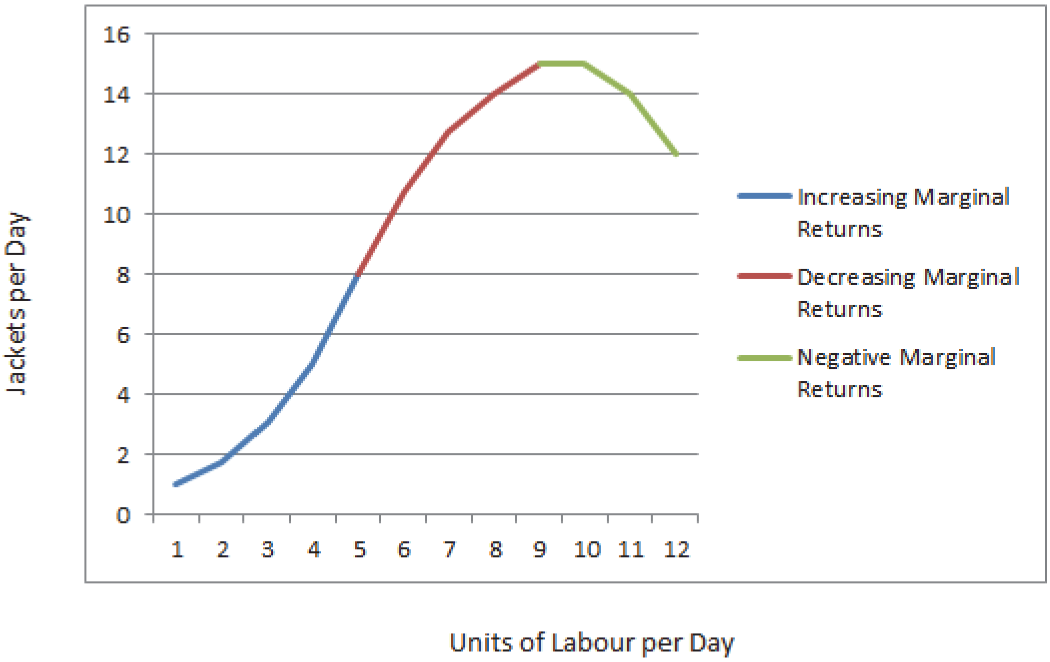


FIGURE 3-2: ILLUSTRATTION OF THE DECREASING MARGINAL RETURNS FOR LABOR IN THE PRODUCTION OF JACKETS.

The example of why this would be so is that if new employees are constantly added, the plant will eventually become so crowded that additional workers actually decrease the efficiency of the other workers, decreasing the production of the factory.

Only by increasing the other factors of production relative to labor, such as increasing the size of the plant relative to the number of laborers, will the firm postpone the point at which diminishing marginal returns take effect.

The relationship between marginal costs and marginal returns is inverse as demonstrated by Figure 3-3: Comparison of marginal costs and marginal Return/product graphs is shown below. Decreasing marginal returns are directly associated with increasing marginal costs, which implies that as the marginal decreases on the development of a given water resource increases, so the marginal costs for the development of that resource.

The argument is that the increasing marginal cost of water supplies is driving the development of groundwater resources; this is explored further in the proceeding chapter.

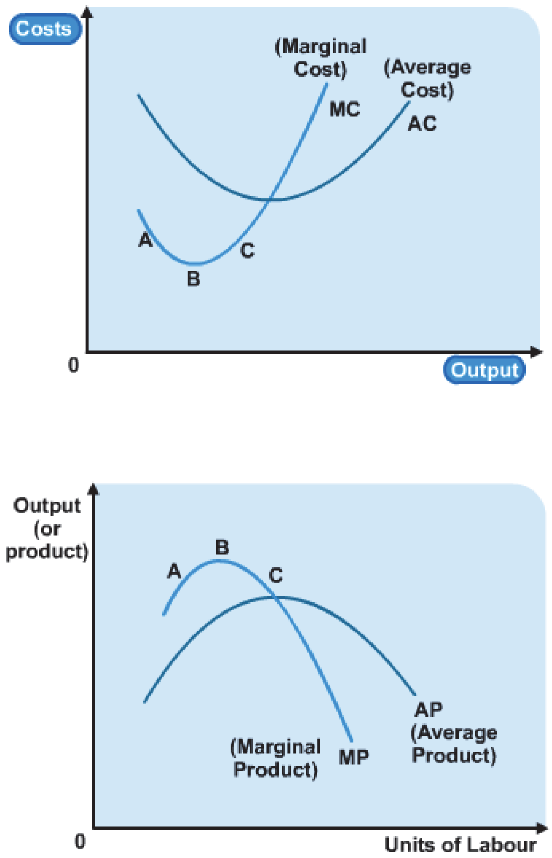


FIGURE 3-3: COMPARISON OF MARGINAL COSTS AND MARGINAL RETURN/PRODUCT GRAPHS

3.2.2 Marginal Cost of Supply in the Water Economy

There is strong evidence to support the notion that the marginal cost of supply in South Africa has reached a point of being less favorable towards the development of large scale surface water storage schemes, or dams, and is shifting in favor of alternative sources of augmenting supply or towards increasing the efficiency of the current supply systems.

The range of activities aimed at increasing the efficiency of the existing supply systems are collectively known as water consumption and water demand management (WC/WDM) interventions. These interventions focus primarily on reducing the quantity of unaccounted for water lost through the reticulation systems.

Alternative methods of augmenting the supply of fresh water, in the context of this document refer to those methods which do not include the damming of rivers. These include:

- Removal of invasive alien species (IAVs):
- Development of groundwater supplies
- Treatment and reuse of effluent
- Augmentation of existing dams
- Desalination of seawater or brackish water

Costing information from the Olifants Water Reconciliation Strategy (DWA, 2011) provides some insight into the relative costs of each of these alternatives (including building dams).

TABLE 3-4. MARGINAL COST OF WATER RESOURCES DEVELOPMENT IN THE WESTERN CAPE (DWA, 2012)

Marginal Cost of Water Supply for the Western Cape			
	URV (R/m3)	Vol (million m3)	Cost (R' Million) Cumulative
Voelvlei Augmentation	1.30	35	45.5
TMG Groundwater	1.60	70	112
Molenaars Diversion	1.80	30	54
Michelle's Pass Diversion	3.40	55	187
Voelvlei Augmentation Phase 2&3	3.70	110	407
Reuse of Water	7.50	85	637.5
Desalination of Seawater	12.00	200	2400

Table 5-6 illustrates the marginal costs for the development of water resource in the Western Cape; costs are shown in a cumulative form. The position of groundwater in the order of development demonstrates that the increasing marginal costs of water resource development are making groundwater a much more attractive option.

The marginal cost of abstracting water from a resource increases over time. If the natural landscape and the climatic consideration such as the hydrological cycle are viewed as the inputs into a production process then it also may be inferred that those inputs cannot be significantly altered (with the exception of climate change) by man over time.

This implies that the marginal cost of supply curve for water may be compared with the theoretical short run marginal cost of supply curve for a firm. In such, certain input into production are fixed, which in this case would be the environmental system which provision freshwater supplies.

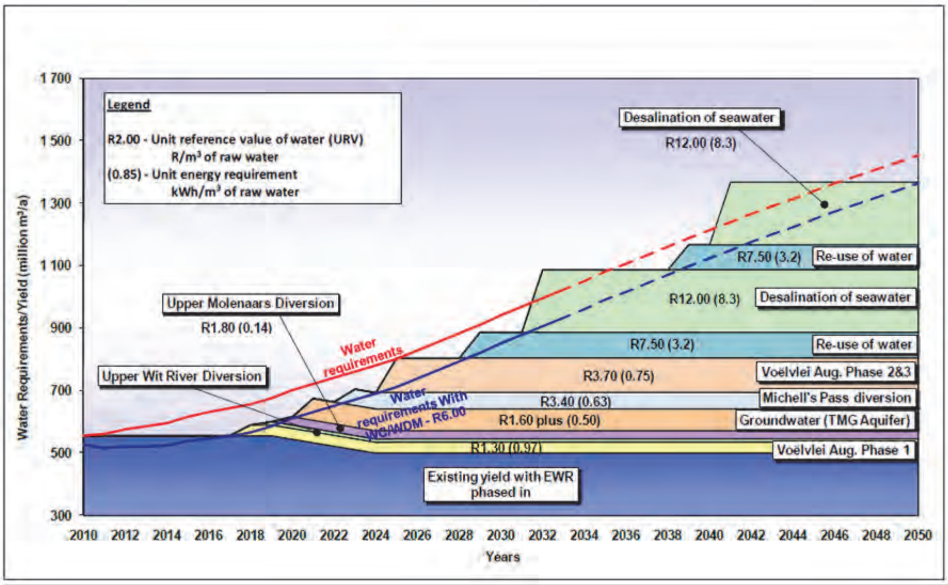


FIGURE 3-4: INCREMENTAL PRIORITISED COMPARISON OF THE WESTERN CAPE'S OPTIONS FOR THE AUGMENTATION OF THE WATER SUPPLY (DWA, 2010)

Building on the arguments for marginal cost and marginal benefit given earlier, it may be directly inferred that that the marginal cost of obtaining water will decrease at first as the economies of scale take effect, yet past a certain point of production, as the resource becomes increasingly scarce the marginal cost of supply will begin to increase.

The building of large scale surface water storage schemes (dams), which assisted in the expansion of the vast urban zones known as cities, corresponds with the decreasing slope of the marginal cost curve. The scale of dam construction allows for economies of scale and correspondingly low unit reference value for the water supplies obtained therefrom.

As a particular type of water resource is developed, and as it reaches a certain point of scarcity the marginal costs of developing that supply source will increase, not only through the direct costs (dam building, pumping, etc.), but also through the environmental impact that result from these efforts.

As in the case of the reconciliation strategy for the Olifant's catchment (DWA, 2011) several dams are proposed to augment the exiting water supplies, each with a lower URV than several other options (which include groundwater, treatment and reuse of effluent, etc.). Yet none of these options are recommended for the augmentation of the water supply. The reasoning for this is given by the following excerpt from the strategy:

Environmental screening was focused on the possible schemes considered in the strategy and aims to:

- summarize any key environmental or social issues that should be taken into account when considering and comparing options;
- identify any environmental or social "fatal flaws" or "red flags" associated with any of the projects; and
- identify environmental authorizations that will be required for any of the projects.

Point two of this excerpt relates to why large scale surface water schemes are not falling out of favor. These types of projects often have a very large environmental footprint in areas of high biodiversity value (common in high rainfall areas). Also there are social impacts for such projects. These amount to negative externalities that diminish the marginal returns to society.

The marginal cost of supply curve shown for the Western Cape illustrates a case where the marginal cost of supply has begun to increase and thus we are seeing an increased emphasis on the importance of groundwater development, both for increasing system yield and for diversification of supply source.

This situation may be extrapolated to the various other water stressed catchments of South Africa, and will ultimate drive the development of alternative water supplies, of which groundwater will be an integral component.

3.3 BACKGROUND TO THE EVALUATION OF GROUNDWATER ECOSYSTEM SERVICES

Changes to the state water resources that may result from over-abstraction, water pollution or changes to biophysical components of aquatic ecosystems result in economic costs. Some of these costs borne by borne downstream users, through additional costs incurred, and are termed economic externalities of ecological damage. The rest of these costs are borne by society, through damage suffered, and are termed environmental externalities. It is very difficult to quantify these ecological damage externality costs at a national scale; however, this section of the report demonstrates these costs at the hand of a few examples.

Gross domestic product (GDP) is a useful economic indicator because it represents an important bottom line: how much the market economy produces, and what it is worth (Boyd, 2006). However, conventional measures of GDP do not internalize the four types of benefits provided by water resources.

A Green GDP, defined here as the conventional GDP adjusted for environmental externalities, would be required to internalize at least two of these benefits.

The four types of ecosystem service benefits, as defined by the Millennium Ecosystem Assessment Framework, are the units that should be counted to determine the beneficial products of nature. Economic principles are used to define these services (Boyd, 2006).

In the MEA system, water resources comprise aggregate assets that yield a flow of aquatic ecosystem services, all of which benefit households and firms. These include four types of services:

1. provisioning services (including the production of fresh water, foods, fuels, fibres and biochemical and pharmaceutical products);
2. cultural services (including non-consumptive uses of the ecosystem for recreation, amenity, spiritual renewal, aesthetic value and education);
3. regulating services (including the absorption of pollutants, storm buffering, erosion control and the like); and
4. supporting services (a fourth category of ecosystem services which includes services such as photosynthesis).

The social opportunity cost of developments that change water resources accordingly includes the value of the resulting change in ecosystem services. This makes it possible to evaluate ecological externalities alongside the other costs and benefits of the development options, and so estimate the social value of distinct development options *inclusive of ecological effects*.

It is important to recognize that the utilitarian values (the benefits consumed, used or enjoyed) of these services are not additive. Regulating services and supporting services (a fourth category of ecosystem services which includes services such as photosynthesis) can be considered to be similar to intermediate consumption in the economic sense. Provisioning and cultural services are those that enter final consumption, thus, in order to avoid double accounting, only the final consumption services should be valued in a Green GDP. The supporting and regulating services in the MEA system comprise the ecosystem functions and processes upon which the provisioning and cultural services depend. They are therefore embedded in those services, and are not evaluated separately, but through production functions. The value of these services is akin to an insurance value, as it regulates and insures the production of final consumption services (Perrings, 2006).

The valuation of ecosystem services is complex, mostly because these services are often not traded in markets, and thus very little economic information is available. Thus, in the absence of good data on ecosystem service value, the estimation of Green GDP is also difficult.

Statistics SA has done much work on developing Environmental Economic Accounts (EEA), for natural resource asset classes such as minerals, fisheries and water. The University of Pretoria has developed forest and water EEAs for South Africa. Although these EEAs are precursors to estimating Green GDP, the available data is still insufficient for estimating a Green GDP for South Africa.

The estimation of a Green GDP should proceed through 4 steps:

1. Identification of all the ecological asset classes that comprise water resources;
2. Conducting an ecosystem service valuation for each of these asset classes;
3. Identifying which of these ecosystem services are ecological externalities (ecological infrastructure is an important production factor into eco-tourism, an economic activity that is already part of the conventional GDP estimate); and
4. Adjusting GDP for those ecosystem services that are externalities.

The above analysis would also enable the valuation of the underlying ecological infrastructure assets, through discounting of future flows of ecosystem services (As illustrated in chapter 4.2).

The resultant Green GDP would, however, still be an insufficient indicator through which to estimate the insurance value provided by the supporting and regulating services. The regulating services are particularly important wherever there is a distribution of outcomes, and wherever decision-makers care about the properties of that distribution. Both variance and kurtosis matter to risk-averse decision-makers. The regulating services of ecological infrastructure affect the distribution of outcomes through both the capacity to respond to perturbations and the severity of those perturbations (Perrings, 2006). Regulating services are thus to be valued through the same method of risk valuation as used in financial portfolio theory, i.e. the standard deviation of the return on ecological infrastructure, i.e. the standard deviation of Green GDP based on changes in ecological infrastructure (Perrings, 2012, personal communication).

4 GROUNDWATER ECOSYSTEM SERVICES

4.1 MILLENNIUM ECOSYSTEM ASSESSMENT

The Millennium Ecosystem Assessment (MEA) framework, released in 2005, is a synthesized framework for the assessment of ecosystems and the good and services that they generate. The MEA framework assesses the relationship between ecosystem functionality and human benefits.

The MEA defines ecosystems services as the benefits humans derive from ecosystems. The MA provides a sound and well established framework for the assessment of ecosystem services and the benefits to human well-being.

According to the MEA ecosystem services may fall into one of four categories which include supporting services, regulating services, provisioning services and cultural services. These are defines as follows:

- **Provisioning services** are the most familiar category of benefit, often referred to as ecosystem 'goods', such as foods, fuels, fibers, biochemicals, medicine, and genetic material, that are in many cases: *directly* consumed; subject to reasonably *well-defined property rights* (even in the case of genetic or biochemical material where patent rights protect novel products drawn from ecosystems); and are *priced in the market*.
- **Cultural services** are the less familiar services such as religious, spiritual, inspirational and aesthetic well-being derived from ecosystems, recreation, and traditional and scientific knowledge that are: mainly passive or non-use values of ecological resources (*non-consumptive uses*); that have *poorly-developed markets* (with the exception of ecotourism); and *poorly-defined property rights* (most cultural services are regulated by traditional customs, rights and obligations); but are still *used directly* by people and are therefore open to valuation.
- **Regulating services** are services, such as water purification, air quality regulation, climate regulation, disease regulation, or natural hazard regulation, that affect the impact of shocks and stresses to socio-ecological systems and are: public goods (globally in the case of disease or climate regulation) meaning that they "offer non-exclusive and non-rival benefits to particular communities"; and are thus frequently undervalued in economic markets; many of these are *indirectly used* being intermediate in the provision of cultural or provisioning services.
- **Supporting services** are an additional set of ecosystem services referred to in the MA, such as nutrient and water cycling, soil formation and primary production, that capture the basic ecosystem functions and processes that underpin all other services and thus: are embedded in those other services (*indirectly used*); and are not evaluated separately.

4.2 GROUNDWATER IN THE CONTEXT OF THE MEA FRAMEWORK

Thus far there has been limited research that analyses the ecosystem services of groundwater through the MEA framework. Bergkamp and Cross (2006) approach the prospect of assessing groundwater ecosystem services using the MEA framework. They go as far as to describe/define some of the key forward and backward linkages in groundwater ecosystems and they round up the fundamental list of groundwater ecosystem services.

The key ecosystem service produced by groundwater resources is fresh water. Fresh water is both a basic human need, and a limiting input into economic production.

All South Africans depend upon water in four ways:

- fresh water for everyday use for drinking, cooking, washing and sanitation;
- fresh water for everyday use for domestic purposes;
- water for use in economic production such as agriculture, mining, power generation, and numerous other economic production activities; and
- livelihood benefits from healthy aquatic systems such as, livestock watering in rural areas, fishing, collection of medicinal herbs, spiritual uses, recreation, the tourism sector, human health and others.

In addition to fresh water, groundwater ecosystems produce other ecosystem services which also yield socio-economic benefits. These ecosystem services are defined as per the MEA framework of ecosystem services. These ecosystem services include other provisioning services (such as collection of animal, woody and plant material), cultural services and regulating and supporting services. Among the regulating services, the role of water resources in water purification and waste absorption – thus the water quality aspect – is of specific importance.

A delineation of various categories of ecosystem services attributable to groundwater is provided in the proceeding chapters.

4.3 GROUNDWATER PROVISIONING SERVICES

The MEA (2005) defines provisioning services as the “products we obtained from ecosystems”.

4.3.1 FRESHWATER PROVISIONING

Most of the world’s unfrozen freshwater is in fact groundwater. Groundwater accounts for 94% of all unfrozen freshwater (Ward and Robinson, 1990)

In 2005 it was estimated that South Africa was utilizing around 1.77 Mm^3/a, though expert opinions suggests that this amount could be 2 to 3 times greater than that.

Over 426 towns, and a far higher number of villages and rural settlements, depend solely on these stores of groundwater (DWAF, 2009).

Although there are estimates for the total amount of groundwater stored in South African aquifers, the Average Groundwater Resources Potential (AGRP) is estimated at 49,25 Mm^3/a (GRAII, DWAF, 2006) under normal rainfall conditions and only if an adequate and even distribution of production boreholes could be developed over the entire South African aquifer system.

However, the utilizable amount of groundwater that that could practically be provisioned is far less than this at 10,350 Mm^3/a. (DWAF, 2005). This estimate accounts for a range of factors including and adequate and even distribution of boreholes in accessible parts of the catchments and on management restrictions on the volumes of water that may be abstracted.

4.3.2 Provision of Biodiversity and Genetic Resources

The definition of groundwater-dependent ecosystems and species according to Murray et al. (2006) is that “the ecological structure and function of these ecosystems depends on access to groundwater”. Although the definition refers directly to groundwater dependent ecosystems, this is inclusive of communities and species.

Groundwater plays host to a wide range of biodiversity. Groundwater contains essential nutrients that help to support a range of invertebrate life (Bergkamp and Cross, 2006). However the links between biodiversity, ecosystem function and ecosystem services for groundwater is still very little understood.

4.3.3 Provision of Minerals and Nutrients

The relatively slow passage of groundwater through the rocks and sediments of the earth’s crust influence its chemical character. Groundwater tends to increase in mineral content as it moves along through the pores and fracture opening in rocks (NRC, 1997).

Mineral that may get dissolved into groundwater may include Manganese, Calcium, magnesium, sodium, potassium, carbonate, bicarbonate and others. There Are approximately 20 different nutrients essential for life that cycle through ecosystems and are found in varied concentration in the different stages of that cycle (MEA, 2005).

Some of these nutrients are especially important for different microorganisms when biodegrading organic compounds, such as the case of sulphate reducing bacteria which require sulphate to break down carbon based compounds.

4.4 Groundwater Regulating Services

Regulating services may be defined as the benefits obtained from the regulation of ecosystem processes (MEA, 2005). The regulating services for groundwater include water regulation, water purification and waste treatment, erosion regulation and flood control as well as climate regulation.

4.4.1 Water Regulation

Groundwater plays a very important role in the regulation of the hydrological cycle. The nature of its roles centers on the storing and subsequent release of water which goes on to sustain river flows, wetlands and springs (Morris et al., 2003).

Groundwater resources are fundamentally connected to surface water resources and it is the long residence time of groundwater that allows it to sustain stream flow during dry periods. Shifts in the surface water hydrology will impact on groundwater supplies. Over abstraction can result in groundwater depletion which can disrupt groundwater dependent ecosystem such as wetlands and springs and result in environmental degradation.

4.4.2 STORAGE AND RETENTION

Aquifers perform the important ecosystem service of retaining and storing water underground. These storage spaces serve as natural subsurface dams, and if they are suitable can provide a readily accessible store of water. South Africa has about 235,000 Mm^3 of groundwater stored in aquifers (DWAF, 2005).

This is one the most important ecosystem services provided by groundwater as it provides a ready store of freshwater for domestic, industrial and agricultural uses (Bergkamp and Cross, 2006)

Another important consideration for this groundwater ecosystem service, is that groundwater has a much higher assurance of supply due to the fact that a far larger amount of groundwater is stored in aquifers compared to dams (Colvin, 2009). This allows it to act as a buffer during periods of drought, and reduces risk associated with the assurance of water supplies.

4.4.3 WATER PURIFICATION AND WASTE TREATMENT

Groundwater provides biodiversity and genetic resources, (Boulton et al., 2008) most notably in the form of organisms that are able to breakdown contaminants. These organisms provide the essential ecosystem service of water purification and waste treatment through the microbial degradation of organic compounds and potential human pathogens (Bergkamp and Cross, 2006).

An example of such ecosystem services is described here by Boulton et al. (2008):

" In some aquifers, feeding, movement and excretion by diverse assemblages of stygofauna potentially enhance groundwater ecosystem services such as water purification, bioremediation and water infiltration."

4.4.4 EROSION REGULATION AND FLOOD CONTROL

The main mechanism by which groundwater regulates erosion and controls flooding is through the absorption of surface water runoff (NRC, 1997).

4.4.5 CLIMATE REGULATION

Groundwater regulates climate through the regulation of the hydrological cycle (discussed above) (NRC, 1997). By sustaining surface water system such as wetlands, rivers and lakes, groundwater is able to partially mitigate the effects of long dry periods.

4.5 GROUNDWATER SUPPORTING SERVICES

Supporting Services Definition: "Services which are necessary for the production of all other ecosystem services." They differ from provisioning, regulating and cultural services in that their impacts on people are indirect or occur over a very long time, whereas changes in other categories have relatively direct and short term impacts on people (MEA, 2005).

4.5.1 SUPPORT OF LIFE

Freshwater provides a key supporting service through its support of the different forms of life that require it to exist. Groundwater, being a source of freshwater is thus a source of the ecosystem service (Bergkamp and Cross, 2006).

4.5.2 SUPPORT OF WATER CYCLING

The stages of the hydrological cycle are all interdependent and dependent on the continuous movement of water, in its varied forms, through the different phases of this cycle. Groundwater with its properties of recharge, retention and discharge is an essential component to the water/hydrological cycle (Ward and Robinson, 1990).

Changes to the condition of a groundwater resource, such as depletion of water levels or degradation of the quality of the resource can have knock-on repercussions for the interlinked components of the hydrological cycle.

4.5.3 SUPPORT OF NUTRIENT CYCLING

Nutrient cycling is an important ecosystem service provided by groundwater and aquifers. There are approximately 20 different nutrient essential to life that are pass through the ecosystems and the role that groundwater plays is one of storage, recycling, processing and acquisition of nutrients (MEA, 2005).

4.6 GROUNDWATER CULTURAL SERVICES

Cultural services definition, “the nonmaterial benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences” (MEA, 2005)

Groundwater is part of everyday life for many communities and its existence is integrated into the lives of the individuals that comprise those communities. It is an important component of many different cultural ecosystem services including social relations, spiritual and religious value, as a component of knowledge systems and in providing educational value.

4.6.1 SOCIAL RELATIONS

Ecosystems have an influence on the different forms of social relations that are interwoven into societies and cultures (MEA, 2005).

An excellent example of this is the matter of income inequality. With groundwater, as with other natural resources, matters of access to the resource can affect income levels and levels of wealth inequality within a given society. Those who can afford to access the resource, through drilling or otherwise, will benefit from the access to the resource.

4.6.2 RELIGIOUS AND SPIRITUAL VALUE

There is often a spiritual or religious value associated with ecosystems in a society (MEA, 2005).

Groenfeldt (2005) gives the example of the Hopi and Navajo Tribes in the State of Arizona in the USA. The tribes use their local groundwater for traditional religious ceremonies. However the groundwater in the region has been over abstracted by a local coal mine which has a contract with the tribes which allows them to pump water.

The naturally occurring groundwater fed streams have begun to dry up as a result of the over abstraction which has compromised the ability of the tribes to perform their religious ceremonies.

4.6.3 KNOWLEDGE SYSTEMS AND EDUCATIONAL VALUE

Ecosystems can have an influence on the traditional as well as the formal knowledge systems that operate within a society (MEA, 2005).

Certain traditional societies have passed on their knowledge of water and groundwater sources from generation to generation, a practice which is particularly common to ancient agrarian societies.

In the modern setting, successful location and abstraction of groundwater resources is enabled through a group of expertise ranging from hydrogeology through to engineering, in addition to others. This knowledge is transferred and developed through the formal knowledge systems within a society (Bergkamp and Cross, 2005).

5 HYDROGEOLOGICAL SETTINGS

The valuation of the range of ecosystem services of an aquifer requires an understanding of geology, geohydrology and ecology of a certain groundwater resource. Hydrological and geohydrological information includes numerous factors such as rainfall, runoff, depth to groundwater, whether the aquifer is confined or unconfined, the groundwater flow rates and direction, type of vadose and water bearing zone materials and water quality associated with different strata.

5.1 AQUIFER TYPES

Scientific definitions of groundwater generally indicate all water in the saturated zone (e.g. DWAF on-line Groundwater Dictionary). Geologic formations that contain groundwater in sufficient quantities to be used for domestic, agricultural, commercial, industrial or mining purposes are referred to as aquifers. Subsurface water in the saturated zone includes water stored in aquitards, perched water tables and temporarily saturated deep soil horizons. Groundwater, however, does not include subsurface water in the zone of aeration immediately above the water table, which can range from a few meters to tens of meters.

Aquifers have different types of permeability, which develop as a result of the physical and chemical composition of the rock type and its geological and hydrological history. Permeability is termed primary if it is formed as the rock is formed (intergranular) and secondary if it forms after the rock (fissures and caverns, fractures, joints and faults). Figure 1 below illustrates the main types of permeability found in different rock types.

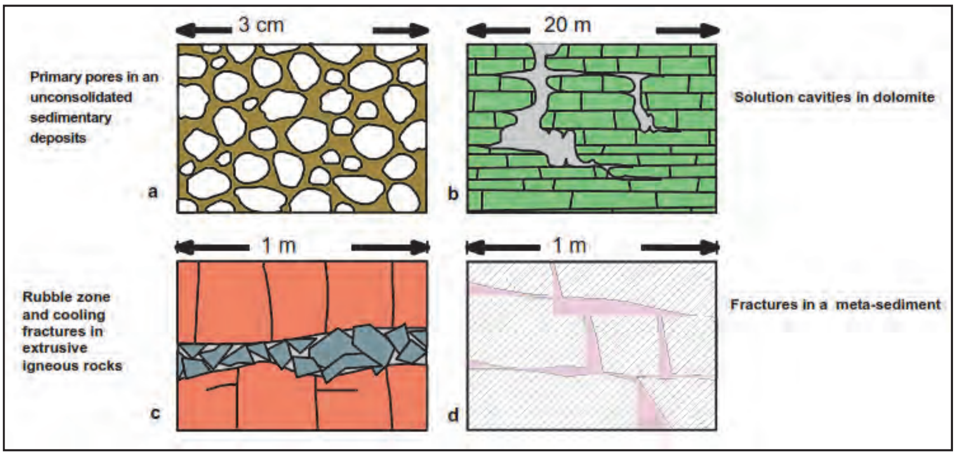


FIGURE 5-1 DIFFERENT AQUIFER PERMEABILITY TYPES AND SCALES: INTERGRANULAR PERMEABILITY IN UNCONSOLIDATED (PRIMARY) SEDIMENTS; FISSURES IN A CARBONATE DOLOMITE; A COOLING ZONE IN AN EXTRUSIVE LAVA; FRACTURES IN A META-SEDIMENT (FROM COLVIN ET AL., 2007).

In order to better understand the hydrostratigraphy adopted for this study, clear definitions of different aquifer types are useful, as in the existing 1: 500 000 hydrogeological mapping of South Africa (DWAF, 2000). These maps present spatial distribution of aquifer types based on surface outcrop of lithology and further subdivided based on borehole yield.

The following four types of aquifer are distinguished:

- type a – intergranular (“primary” or porous sandy aquifers),
- type b – fractured (“secondary” aquifers where groundwater flow occurs predominantly along fractures),
- type c – karstic (also termed “dolomitic” aquifers), and
- type d – intergranular-and-fractured (also termed “regolith” aquifers, in which porosity and permeability is related to a combination of near-surface fracturing and chemical weathering).

Colvin et al. (2007) used slightly different type settings, distinguishing the fractured aquifers between sedimentary, intrusive (granites and dykes) and extrusive rocks (see Figure 2).

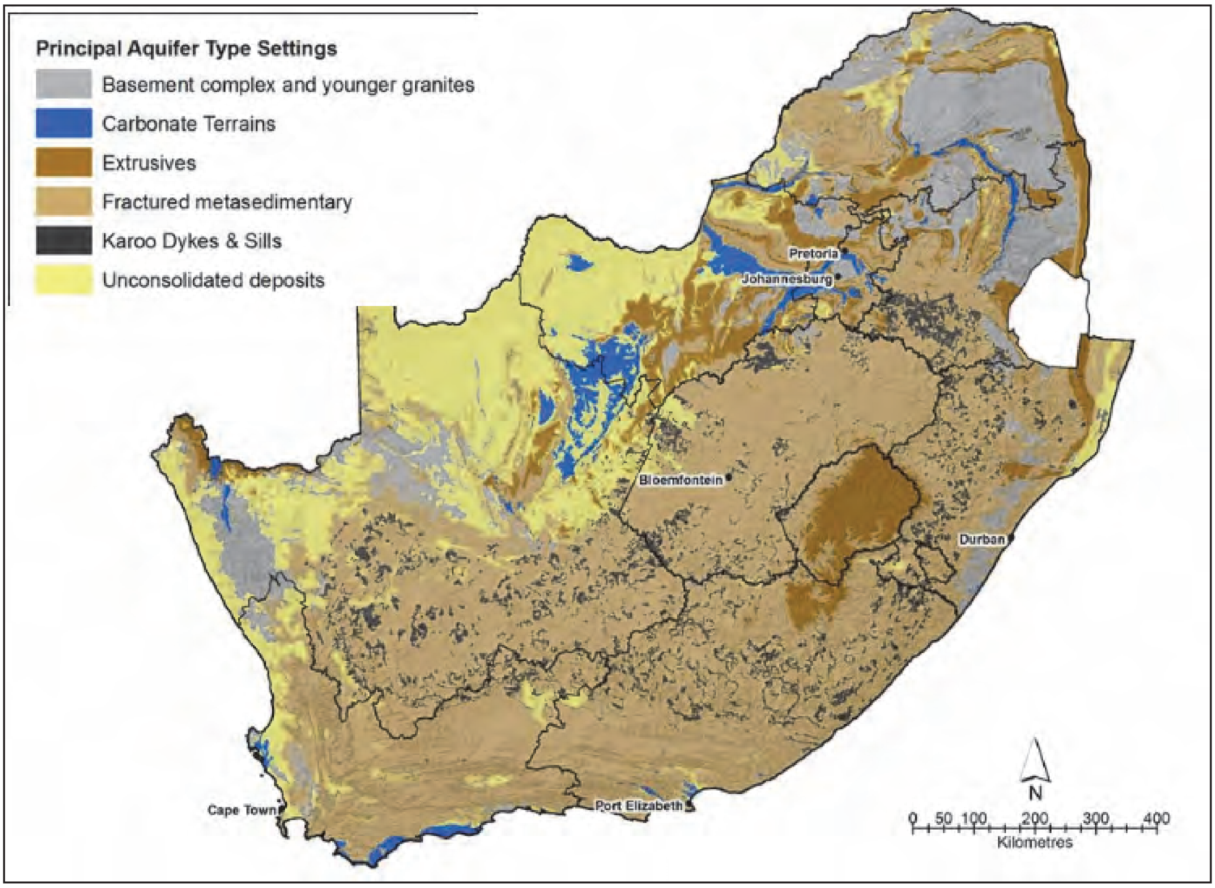


FIGURE 5-2 MAP OF MAIN AQUIFER TYPES BASED ON PRIMARY LITHOLOGY. (FROM COLVIN ET AL., 2007; SOURCE DATA – COUNCIL FOR GEOSCIENCE 1: 1000 000 LITHOLOGY)

5.1.1 PRIMARY AQUIFER

Primary aquifers consist of unconsolidated materials, where the water flows through the pores between the grains (i.e. primary porosity). Depending upon the grain size and compaction, the permeability of these aquifers can vary widely. High yielding aquifers are found in fluvial gravel and sand deposits as well as marine deposits.

Primary (sandy) aquifers generally are restricted to the coast, alluvial and aeolian valley deposits (e.g. the Karoo or along main river banks) and the Kalahari. Examples of significant primary aquifers are found at Atlantis and on the Cape Flats of Cape Town, along the

Zululand coast north of Durban and in major river channels such as the Breede River in the Western Cape, and the Mokolo and Crocodile Rivers in the Northern Province.

5.1.2 FRACTURED AQUIFER

The fractured mode of groundwater occurrence describes aquifers associated with fractures, fissures and joints that are developed as secondary porosity. Often the primary porosity of the aquifers is infinitesimal. The difference between fractured aquifers and regolith aquifers is determined by the origin of the fractures and joints, and their extent throughout the aquifer thickness.

The true fractured-rock systems comprise a thick quartzite succession of high compressive and tensile strength, and are capable of supporting open, permeable fractures to depths of several kilometers. These sandstones and quartzites are stratabound aquifers (i.e. having significant fracture porosity), and therefore constitute "coincident" hydrostratigraphic units, as defined by Al-Aswad and Al-Bassam (1997), in that the hydrostratigraphic boundaries generally coincide with those of the lithostratigraphic units.

Structural complications such as faulting may, however, introduce some ambiguities in the hydrostratigraphical classification. For example, where a highly fractured and thus sufficiently permeable fault zone has a sufficiently large stratigraphic throw, it may juxtapose and thus create a leakage junction between two otherwise separate aquifers.

The rocks of the Witwatersrand Supergroup, the Kameeldoorns and Bothaville Formations of the Ventersdorp Supergroup, the sandstone and quartzite of the Wilge River Formation (Waterberg Group), and the quartzite and sandstone of the Table Mountain Group and Natal Group all display the characteristics of the fractured regime.

The yield of these aquifers varies widely, mainly depending upon the characteristics of the fracture network. Groundwater types vary between magnesium-carbonate for the Witwatersrand Supergroup aquifers, sodium-chloride for the TMG and Natal Group and calcium-magnesium-bicarbonate for most of the other aquifers of this regime. The groundwater quality for the aquifers of the fractured regime is generally good as EC values of between 26 and 100 mS/m indicate.

5.1.3 DOLOMITIC AQUIFER

Karst is a special type of landscape that is formed by the dissolution of soluble rocks, including limestone and dolomite. Karst regions contain aquifers that are capable of providing large supplies of water – more than 25% of the world's population either lives on or obtains its water from karst aquifers. Common geological characteristics of karst regions that influence human use of its land and water resources include ground subsidence, sinkhole collapse, groundwater contamination, and unpredictable water supply. Gauteng province is almost 70% overlayed with karst, and South Africa holds 12% of the world's karst system, making the largest single repository for karst in the world today.

The karstic aquifer, denoting cavities associated with fracturing and jointing, is represented by the carbonate rocks of the Chuniespoort Group. These sediments alternate between the chert-rich dolomite of the Monte Christo and Eccles Formations, and the chert-poor dolomite of the Oaktree, Lyttleton and Frisco Formations. A few dolomite "outliers" represent remnants of the Transvaal Supergroup enclosed by the younger Bushveld Complex. The dolomites of the Chuniespoort Group arguably constitute one of the most important aquifer in South Africa. Recharge values of between 9 and 13.9% of mean annual precipitation have been calculated for various portions of the aquifer. Groundwater yield is excellent and 50% of boreholes yield more than 5 l/s.

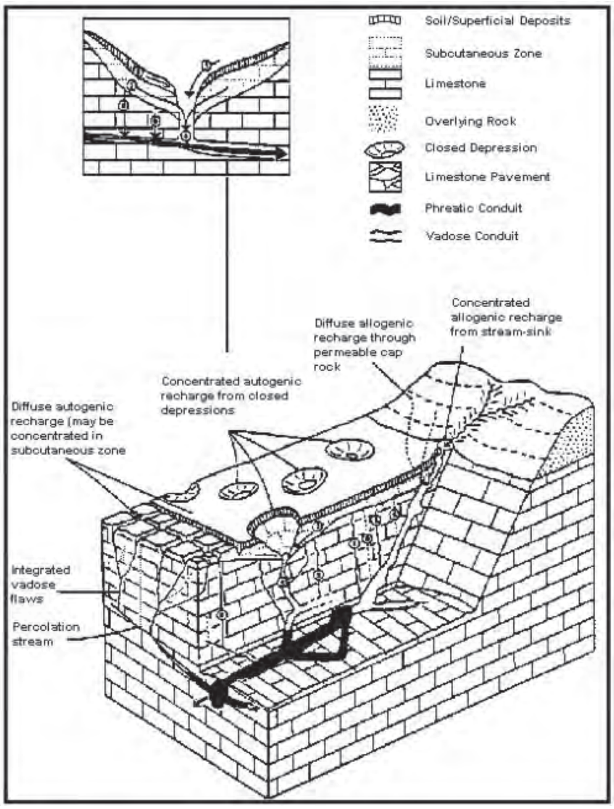


FIGURE 5-3 TYPICAL FEATURES OF A DOLOMITIC AQUIFER (FROM XXX)

5.1.4 REGOLITH AQUIFER

The intergranular and fractured mode of groundwater occurrence depicts groundwater contained in intergranular interstices and in fractures, notably in crystalline rocks, but also in a number of sedimentary rock groups. These are also secondary porosity aquifers, but the aquifer thickness is restricted to the weathered zone, while the bedrock part of the formations is usually considered an aquiclude.

The following rock units display characteristics of the intergranular and fractured regime: the granite and gneiss of the Basement Complex, andesite of the Klipriviersberg Group and the Rietgat and Allanridge Formations of the Ventersdorp Supergroup, andesite, rhyolite and shale of the Pretoria and Rooiberg Groups (Transvaal Supergroup), granodiorite, gabbro, norite and granite of the Bushveld Complex, syenite, foyaite and carbonatite of the Alkaline Complexes, and mudstone, shale and sandstone of formations of the Karoo Supergroup.

5.2 GROUNDWATER DISCHARGE – GDES

Aquifer discharge is controlled by climate and the rock type of the aquifer. The typical habitats associated with aquifer discharge are terrestrial aquifers, wetlands, seeps, springs, in-aquifer ecosystems, riverine aquatic ecosystems, riparian zones, estuaries and the coastal zone. Only springs and in-aquifer ecosystems are exclusively aquifer dependent. All the other habitats may rely on surface water, soil moisture or direct rainfall, and often distinguishing those which are aquifer dependent is not easy.

Colvin et al. (2007) distinguish between groundwater dependent ecosystems (GDEs) and aquifer dependent ecosystems (ADEs). The term groundwater dependent ecosystem (GDE) is difficult to define and means different things in different countries. A broad definition is given by Murray (2006)

> *"Groundwater-dependent ecosystems (GDEs) are ecosystems that must have access to groundwater to maintain their ecological structure and function".*

Aquifer Dependent Ecosystems (ADEs) occur throughout the South African landscape in areas where aquifer flows and discharge influence ecological patterns and processes. They are ecosystems which require groundwater from aquifers for all or part of their life-cycle, to maintain a habitat with a water budget, or water quality that contrasts with the surrounding ecosystems.

Different permeabilities result in different aquifer discharge patterns which supply groundwater to the surface environment. Fractured meta-sediment aquifers may discharge via discrete fractures or fault zones resulting in linear seeps or wetlands and discrete zones of discharge to rivers. An unconsolidated, primary sandy aquifer may have an extensive shallow water table supporting terrestrial vegetation or forming broad wetland areas.

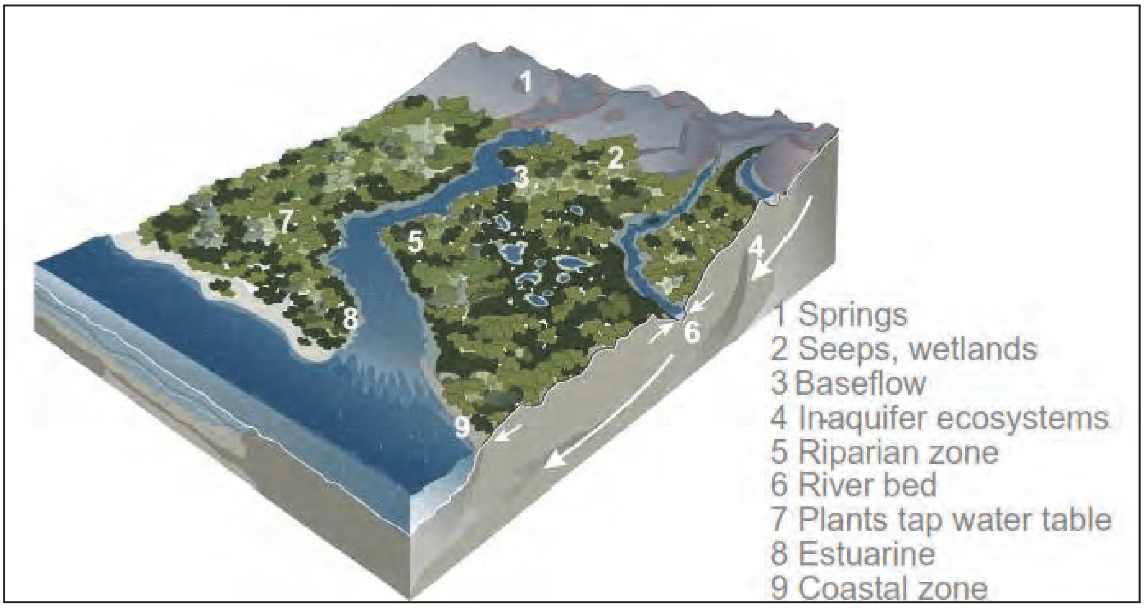


FIGURE 5-4 ADES IN THE LANDSCAPE (FROM COLVIN ET AL., 2007; SOURCE: WINTER ET AL., 1999)

5.2.1 SPRINGS

Spring and seep are often closely linked to other habitat types such as riparian and wetland ecosystems. They occur in most aquifer types of South Africa, excluding the unconsolidated Kalahari sands because the water table in this extensive primary aquifer is generally too deep for direct discharge as liquid groundwater. Where alluvial aquifers occur on impermeable bedrock they may support springs and seeps in this region.

Springs and seeps generally support relatively lush vegetation and in many areas are associated with biodiversity hotspots for plants, amphibians, birds and insects.

Dolomitic eyes commonly support ecological communities which have evolved independently of one another, driven by particular local factors (e.g. temperature, flow, etc.). For example, the algal and diatom community in the Molopo Eye is different to that at the Malmanies Eye, indicating that each eye could be a unique ecosystem (Nel et al., 1995).

Spring Classification

Type 1 – shallow seasonal springs and seeps emanating from perched water tables; represents localised discharge of interflow, not connected to the groundwater flow system and will not be impacted by groundwater abstraction.

Type 2 – lithologically controlled springs, often discharges at lithological contacts; flow is more permanent and plays an important role in sustaining baseflows; susceptible to the impacts of localised groundwater abstraction.

Type 3 – fault controlled springs that are permanent in character; may discharge either hot or cold water; only potentially impacted by large scale regional abstraction.

(Kotze, 2001)

FIGURE 5-5 SPRING CLASSIFICATION (FROM PARSONS, 2003)

5.2.2 SEEPS AND WETLANDS

Groundwater-fed wetlands, like springs, are known to occur on all the main aquifer type settings in South Africa, excluding the Kalahari sands. Wetlands and springs are often grouped together because there often isn't a clear distinction between them. This is particularly true in secondary aquifers such as those associated with dykes and sills, fractured rocks and the basement. A spring typically has a distinct discharge point whereas wetlands tend to have a more diffuse area of discharge. Wetlands fed by alluvial aquifers are often closely linked to the riparian zone and those on the coastal sands to estuarine and coastal brackish habitats.

Under the South African National Water Act (1998) a wetland is defined as:

> *"land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil."*

This definition links wetlands to groundwater and unconfined (phreatic) aquifers through the use of 'water-table' as one of the possible defining features. However, many wetlands occur as a result of surface rather than sub-surface drainage and ponding on low permeability soils. It is important to understand whether wetlands are linked to aquifer discharge areas before classifying them as groundwater (or aquifer) dependent.

Wetlands associated with both sinkholes (points of recharge) and springs (points of groundwater discharge) are very important aquatic features in the dolomitic karstic area of South Africa, which is dominated by the dolomite aquifer. Due to the relative geographical isolation of these habitats, many of the springs and wetlands sustain rare or endemic flora and fauna (Stephens et al., 2002). The flow regime of the South African dolomites, and therefore the occurrence of wetlands, is largely controlled by low-permeability contact (e.g. dykes) which compartmentalise the carbonates.

5.2.3 RIVER REACHES

South African rivers have been classified in terms of their geomorphology, ecology, climate and geology (e.g. ecoregions – Kleynhans, 1999), but they have not yet been comprehensively assessed in terms of their relation to aquifers.

In most natural river flow systems, the low flow or baseflow is partly maintained by groundwater discharge from aquifers. Although groundwater contribution to base flow is generally regarded as the most critical role of aquifers in surface water systems, groundwater also contributes to peak flows.

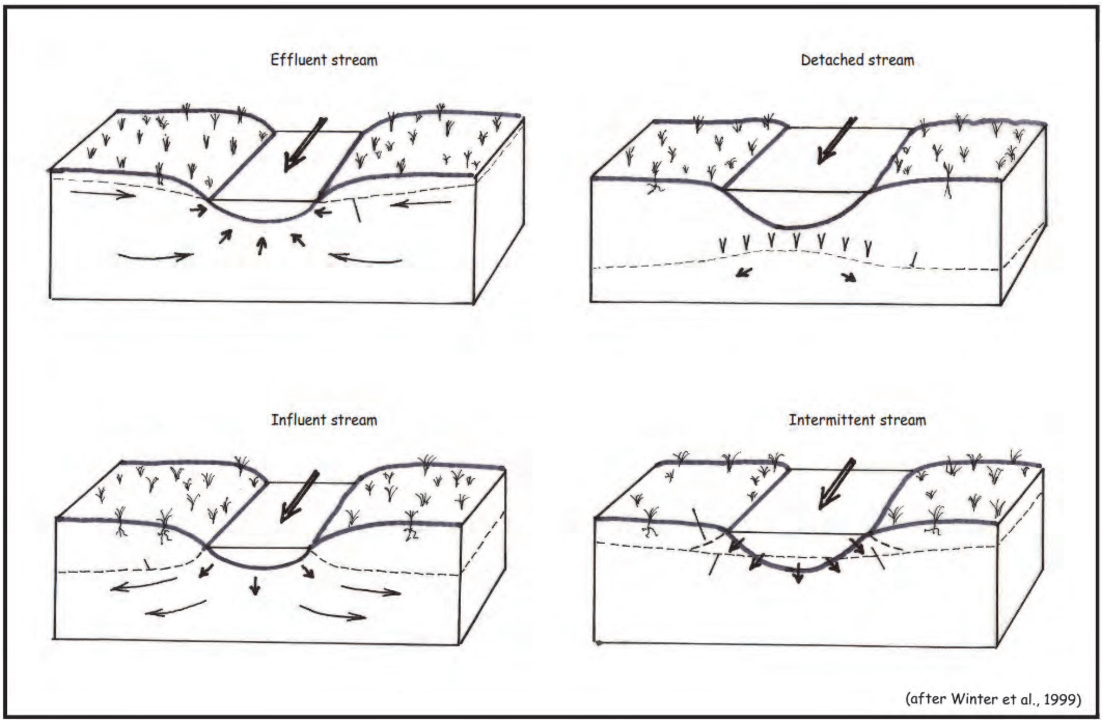


FIGURE 5-6 TYPE OF SURFACE WATER-GROUNDWATER INTERACTION WITH RESPECT TO RIVER REACHES (FROM PARSONS, 2003)

Interactions between groundwater and surface water are typically dynamic depending on the hydraulic and topographic gradients (Woessner, 2000). Thus a river may be losing water to the aquifer at high flows and gaining water at low flows and the situation may vary along the length of a river. For example, the Orange River is a gaining river for the upper half of the catchment but is a losing river for the rest, as are many of the other rivers which rise in the montane regions (e.g. along the escarpment) and flow through more arid regions.

In some river systems with alluvial beds there are permanent pools which are maintained by groundwater discharge from the surrounding aquifer. These pools often occur where there is a rock sill formed by a dyke or by vertical displacement along a fault line.

Riparian ecosystems are associated with groundwater dependency in a range of aquifer types, but most importantly with unconsolidated alluvial aquifers. These form important keystone ecosystems in the semi-arid and arid areas of the country, particularly where surface flows are seasonal and ephemeral.

5.2.4 ESTUARIES

Estuarine ecosystems are known to be important in the unconsolidated coastal sand aquifers of South Africa, but are also linked to other aquifer types where they discharge at the coast. For instance the alluvial aquifers of the North West coast feed brackish wetlands in arid areas with ephemeral surface water flow, e.g. the Buffels River close to the Namibian border and the desolate skeleton coast.

On the humid east coast, groundwater in the extensive coastal sands feeds lakes and wetlands in northern KwaZulu-Natal. Lake Sibiya, Lake Mzingazi and the St Lucia wetlands are examples where detailed monitoring of relative groundwater heads and lake levels and the hydrochemistry have indicated the importance of groundwater inflows (Kelbe et al., 2001). Relatively fresh groundwater discharge to these systems often maintains brackish refugia habitats during high salinity periods.

6 AQUIFERS AND ECOSYSTEM SERVICES: CASE STUDIES

In this chapter we present the outputs of a Comparative Risk Assessment undertaken to demonstrate the systemic connections between aquifers and ecosystem services, for three case study sites.

6.1 RESULTS OF THE GROUNDWATER CRA

The purpose of the comparative risk assessment is to assess the primary risks to groundwater aquifers and the subsequent impact on the delivery of groundwater based ecosystem services. The primary risks to groundwater aquifers can be divided into two general categories: over-abstraction by a wide variety of economic sectors and contamination of the aquifer through various activities.

The selection of the three case studies is an attempt to understand the impact of these risks over a wide variety of aquifer types under the diverse economic, social and environmental conditions in which they exist in South Africa. Taking these factors into consideration the following three case studies were selected:

1. The fractured aquifers in the Hermanus area, primarily utilized for municipal and agriculture purposes;
2. The dolomitic aquifers of the Krugersdorp area, which is utilized by a variety of users; and
3. The primary aquifer of the Sandveld region, which is utilized predominately by agriculture.

6.1.1 ECOSYSTEM SERVICES AT RISK

Specific groundwater resources within each of the study areas were identified for assessment; these are termed the “ecosystem assets”. Each of the ecosystem assets was subsequently analyzed under varying groundwater utilization scenarios termed “scenarios/hazards”.

The full range of assets and scenarios/hazards is listed here:

1. **Fractured Aquifers in the Hermanus Area:**
    a. **Ecological Asset**: Gateway Compartment. **Scenario**: Status Quo, Groundwater abstraction of license volume, i.e. 1,6 million m^3/year.
    b. **Ecological Asset**: Hemel en Aarde Compartment. **Scenario:** Municipal groundwater abstraction of license volume (1,6 million m^3/year)
2. **Dolomitic Aquifers of the Krugersdorp Area:**
    a. **Ecological Asset:** Dolomitic Aquifer below Krugersdorp Nature Reserve up until Cradle of Humankind World Heritage Site (COHWHS). **Scenario:** Status Quo, i.e. no remediation of the acid mine drainage (AMD).
    b. **Ecological Asset:** Dolomitic Aquifer below Krugersdorp Nature Reserve (KNR) up until COHWHS. **Scenario:** Treatment of AMD and remediation of old mines to prevent current and further decant.

c. **Ecological Asset:** Dolomitic Aquifer below KNR up until COHWHS. **Scenario:** Scenario 2 + removal of Tailings Storage Facility (TSF) component of the mine residue areas (MRA).

3. **The Primary Aquifer of the Sandveld Region:**
   a. **Ecological Asset:** Aquifer in Quaternary G30C, G30D, G30E, G30F and G30G. **Scenario**: Status Quo, i.e. continued abstraction.
   b. **Ecological Asset:** Aquifer in Quaternary G30C, G30D, G30E, G30F and G30G. Scenario: Implementation of Management Class III Recommended Category C.

6.2 Case Study 1: Fractured Aquifers in the Hermanus Area

6.2.1 Economic and Hydrogeological Overview

Hermanus is approximately 115 km east of Cape Town along the shores of Walker Bay. The town of Hermanus is situated on a coastal plain at the south- western foot of the Kleinrivier Mountains and the Onrus Mountains, which expose units of the Table Mountain Group. The total population in the area is about 60 000 people.

Hermanus has established itself as the cultural and business hub of the Overstrand area over the last decade. Though the town has transformed its image from a sleepy holiday town to a sophisticated tourist and commercial hub it has managed to maintain much of its essence, as its fishing village heritage is still apparent. The town now boasts modern infrastructure, sophisticated retail facilities and some of the best restaurants in South Africa, all of which has helped to cement its identity as one of the premier tourist destinations in South Africa. The increasing popularity of the regions is evident in the massive increases in the number of residential projects that have been or are planned to be built (Bbrokers, 2011).

There has been a tremendous influx of individuals seeking employment as may be noted by the rapid growth in the nearby township of Zwelihle. The primary draw cards are jobs in the hospitality industry and construction. Employment is available in the local agricultural sectors but growth here is limited.

Overstrand is the 2nd largest municipality in the Overberg and if population growth continues as expected it will soon be the most populous municipality as well. The Overstrand contributes 34,4% (R1,22 billion in 2006) to the Overberg regional GDPR and is the second largest contributor (Bbokers, 2011).

Hermanus is a leader in the commercial farming of Abalone and the aquaculture sector is expected to expand substantially. On the whole the region has shown strong economic and has a well-diversified economy.

The topography of the area is characterised by a relatively narrow coastal cliff plain with an average elevation of about 20 m, along which the major towns of the Greater Hermanus Area are situated. The coastal cliff plain forms the base of a steep embankment (elevations ranging from approximately 400 m to 900 m), which extends northwards forming the Onrusberge, Babilonstoringberge and Kleinrivierberge.

The centre of the area is the Hemel en Aarde Valley, which is bounded in the north by the Babilonstoringberge, in the southwest by the Onrusberge, and in the east by the Fernkloof Mountains. The Onrus River flows through the valley between the Onrusberge and Fernkloof Mountains, and enters the ocean at Onrusriviermond.

The wider area is bounded in the west by the Bot River and Bot River Lagoon, which separates the Palmietberge from the Onrusberge and Babilonstoringberge. The extended coastal plain to the south of the Klein River Lagoon and west of Stanford forms the eastern boundary of the supply area.

The Greater Hermanus Area currently obtains its bulk water supply from the De Bos Dam on the Onrus River and the Gateway Wellfield in Hermanus. The dam alone cannot support the current growth demands and projected future demands. The water allocation from the De Bos Dam to the municipality for domestic use is 2.8 million m^3 per annum which in not enough to supply the municipality, as the water demand for the area was about 4.6 million m^3 in 2010, and is expected to increase to over 5 million m^3 per annum in 2015.

Overstrand Municipality has implemented water demand management strategies to reduce the rising supply/demand deficit. Demand management alone, however, will not provide a long-term solution. The Municipality therefore initiated a programme to evaluate the feasibility and viability of using groundwater to augment the area's water supply, and to manage the groundwater resource in conjunction with surface water.

The municipality is currently in the process of developing and establishing two additional wellfields in close proximity to Hermanus to augment the water supply (see Figure 7 2):

- The existing Gateway Wellfield consists of four production boreholes, connected via a booster pump station and pipeline to the existing raw water treatment works. The wellfield was recently upgraded and delivers up to 1.6 million m^3/a. The Overstrand Municipality was awarded a license from the DWA to abstract groundwater from the Gateway Wellfield in 2011.
- The Camphill and Volmoed wellfields in the Hemel en Aarde Valley are currently developed and connected to the Preekstoel treatment works. It is expected that they deliver up to 0.8 million m^3/a of water for augmentation of the water supply by the end of 2013.

The TMG in the greater Hermanus area is subdivided into hydraulically bounded fault units. The Gateway wellfield targets 'Structural Sub-Area 1' which receives recharge from 'Structural Sub-Area 3', and these are disconnected from 'Structural Sub-Area 2', which the Camphill Wellfield and two boreholes of the Volmoed Wellfield penetrate. The total groundwater stored in the Peninsula within these Sub-Areas is 2 876 million m^3 and 1 882 million m^3 respectively, based on an assumed porosity of 5%, a conservative estimate.

Desalination of seawater is seen as a potential future supply source for Hermanus. A feasibility study was undertaken and the design for a pilot plant is available for implementation, if required. The following interventions are recommended for implementation (DWA, 2010):

- Full implementation of the Water Conservation / Water Demand Management Strategy.
- Full implementation of the Gateway wellfield.
- Implementation of the Camphill and Volmoed wellfields.
- Desalination.
- Non-potable and indirect water re-use.

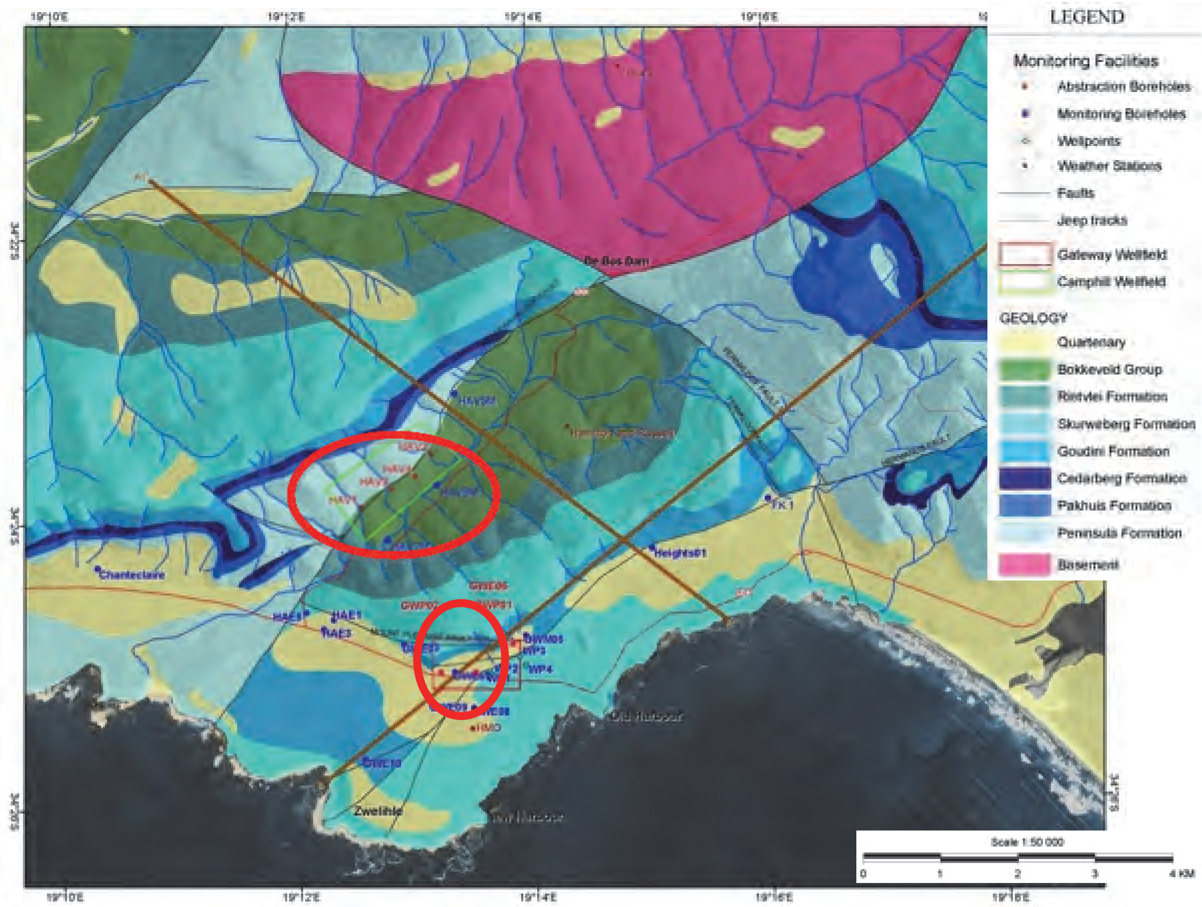


FIGURE 6-1. GEOLOGICAL MAP AND LOCATION OF WELLFIELDS AROUND HERMANUS. THE GATEWAY (INCORPORATING THE GATEWAY COMPARTMENT) AND CAMPHILL (INCORPORTING THE HEMEL EN AARDE COMPARTMENT) WELLFIELDS ARE HIGHLIGHTED

6.3 SCENARIO 1: CONTINUED ABSTRACTION FROM THE GATEWAY COMPARTMENT

The continued abstraction of the licensed volume of 1,6 million m^3/year of groundwater from the Gateway Wellfield could have an impact on the Gateway Compartment and the subsequent delivery of ecosystem services.

6.3.1 ENVIRONMENTAL EFFECT STATEMENT

- Assets within the Gateway Compartment:
  - Onrus River;
  - Onrus Lagoon;
  - Fernkloof Nature Reserve.

- Impact:
    - The potential sources of contamination are saline intrusion into the Peninsula Aquifer, the Hermanus Waste Water Treatments Works (WWTW) and the Hermanus Cemetery. The shallow aquifer, which is less than 10 m.b.g.l, is particularly vulnerable to the landfill and sewage site.
    - Over abstraction (possibly due to a miscalculation of the 1.6 million m^3/a allocated in the area, or due to mismanagement of the wellfield) can lead to saline intrusion. Saline intrusion would have detrimental, long-term effects to the water quality of the aquifer system. Despite the existence of geological structures that will stop upconing for the most part, parts of the aquifer system could be susceptible.
    - The residential users that have shallow well points 5-6 m deep in a superficial aquifer (runoff from the escarpment) can be affected. If over abstraction from the deeper aquifer (recharged in the Fernkloof Nature Reserve) occurs, it may draw down the superficial aquifer and potentially dry the boreholes of these residential users.
    - Over abstraction can have an impact on the ecologically sensitive recharge zone located in the Fernkloof Nature Reserve as well as affect the groundwater dependent ecosystems in the area.
    - Decrease in fresh water supply due to overabstraction, saline intrusion or contamination would lead to increase competition between water users (municipality and agriculture).
    - Over abstraction and contamination would lead to long term (5-10yrs) management challenges.
    - Decrease in aquifer yield or contamination of groundwater would undermine or cease the current optimisation process between surface and groundwater usage for the De Bos Dam.
    - Decrease of freshwater discharge into the ocean with possible impact on biodiversity, i.e. fish and abalone.

- **Scope of consequence:** The environmental effect of the hazard on the asset would have consequences on the following ecosystem services: fresh water provisioning, fresh water quality, genetic resources, and recreation and ecotourism.

- **Certainty of outcome:** Possible to Likely

Risk description:

Continued abstraction of 1.6 million m^3/a could primarily affect fresh water quality.

This is mainly because over abstraction in the Gateway Compartment can lead to possible saline intrusion into the aquifer system. Other potential contamination sources for the shallow aquifer are the Hermanus Waste Water Treatment Works (WWTW) and Hermanus Cemetery.

Fresh water provisioning can be impacted as over abstraction can lead to a lower yield and as the groundwater is used to augment the dam supply, especially in the summer months, the decrease in yield will have an impact on water provisioning to the municipality.

The decrease of fresh water into the ocean can have a likely impact on genetic resources, in particular an impact on the biodiversity of fish and abalone as a result of the dependency of marine life on fresh water estuaries.

Risk assessment:

TABLE 6-1. ECOSYSTEM SERVICES DELIVERED BY THE "GATEWAY COMPARTMENT" AQUIFER ASSETT IN HERMANUS

Ecosystem services benefit	Impacted	Assets exposed	Likelihood of effect	Consequence	Notes	Level of Risk
Fresh water provisioning	Y		Unlikely	Moderate	Over-abstraction leads to a decrease in yield	Medium
Fresh water quality	Y		Unlikely	Major	Possible contamination sources: WWTW, landfill site and further up towards Fernkloof; Hermanus Cemetery.	High
Genetic resources	Y		Likely	Minor	Recharge/discharge (2 mcm-1,6 mcm) Decrease of freshwater discharge into the ocean with possible impact on biodiversity: fish abalone	Medium
Recreation and ecotourism	Y		Very Unlikely	Minor	Groundwater dependent ecosystems in the Fernkloof NR.	Low

Mitigation and Offsets:

- Maintain current monitoring protocol in the Gateway Compartment.
    - Well fields in the GC have a water level alarm system that monitors water quantity to ensure that the minimum acceptable water level is maintained during the abstraction process.
- Development of a numerical model of the aquifer system.
    - The understanding of the groundwater system is imperative.

6.4 SCENARIO 2: CONTINUED ABSTRACTION FROM THE HEMEL EN AARDE COMPARTMENT

The continued abstraction of the licensed volume of 1,6 million m^3/year of groundwater from the Camphill Wellfield will have an impact on the Hemel en Aarde Compartment and the subsequent delivery of ecosystem services.

Environmental effect statement

- Assets within the Hemel en Aarde Compartment:
  - Onrus River
  - Onrus Lagoon
- Impact:
  - Over abstraction leads to a decrease in yield that has an effect on the fresh water provisioning. An overestimation of the potential abstraction amount of 1.6 million m^3/a is possible. The agricultural usage of groundwater may be underestimated due to possible unaccounted well fields.
  - Diffuse source pollution from agricultural return flow will impact the fresh water quality in the area.
  - The water quality of the Bokkeveld aquifer is poorer than that of the Peninsula aquifer system. Possibility of leakage from the Bokkeveld aquifer to the Peninsula aquifer if there are incorrectly constructed boreholes in the area.
  - A potential decrease in fresh water supply will lead to increase competition between water users (municipality and agriculture).
  - Onrus Lagoon dependent on releases from De Bos Dam, however the freshwater flow can be decreased or unavailable due to over abstraction from the upper areas.

- **Scope of consequence:** The environmental effect of the hazard on the asset would have consequences on the following ecosystem services: fresh water provisioning, fresh water quality, genetic resources, recreation and ecotourism.

- **Certainty of outcome:** Possible to Likely

Risk description:

The fresh water provisioning to the surrounding agricultural areas and other water users would be primarily impacted. This is mainly due to the possible overestimation of the allowed 1.6 million m^3/a and the probable unlawful or unregistered abstraction of groundwater that has yet to be evaluated.

The decrease of fresh water discharge into the ocean can have possible impacts on marine biodiversity.

Diffusion of agricultural return flow and leakage from the poorer water quality of the Bokkeveld aquifer to the Peninsula aquifer system is also is a concern.

Risk assessment:

TABLE 6-2. ECOSYSTEM SERVICES DELIVERED BY THE "HEMEL EN AARDE" AQUIFER COMPARTMENT IN HERMANUS

Ecosystem services benefit	Impacted	Assets exposed	Likelihood of effect	Consequence	Notes	Level of Risk
Fresh water provisioning	Y		Possible	Moderate	Over abstraction leads to a decrease in yield. Overestimate of 1,6 farmer's use unaccounted	High
Fresh water quality	Y		Unlikely	Minor	Diffuse from agricultural return flow. If borehole construction is faulty. Leakage from Bokkeveld to Peninsula	Low
Genetic resources	Y		Likely	Minor	Recharge/discharge Decrease of freshwater discharge into the ocean with possible impact on biodiversity: fish abalone	Medium
Recreation and ecotourism	Y		Very Unlikely	Minor	Onrus lagoon dependent on releases from De Bos Dam. Mitigate through environmental release from De Bos and loss to AIS. Dependent on optimization of surface water and ground water resources.	Low

Mitigation and Offsets:

- The Onrus Lagoon is dependent on releases from the De Bos Dam, however mitigation can take place through the optimization of the conjunctive use system.
- Hydrocensus in the Hemel en Aarde Compartment
  - An evaluation of active boreholes and approximate monthly abstraction amounts to gain better insight of demand of groundwater particularly for the agricultural sector.
- Cooperative governance from water users in the upper area is essential.

6.5 CASE STUDY 2: DOLOMITIC AQUIFERS OF THE KRUGERSDORP AREA

6.5.1 ECONOMIC AND HYDROGEOLOGICAL OVERVIEW

Krugersdorp is largely a mining community with a population of just over 400,000 people. The town was founded in 1887 and was named after Paul Kruger. The town was originally intended to service the needs of the local mines after gold was discovered in the Witwatersrand. Minerals mined in the area include gold, manganese, iron, asbestos and lime (MCLM, 2011).

Krugersdorp no longer has a separate municipal government as it has instead been incorporated in the greater Mogale City Municipality along with several surrounding towns.

Economic growth in the area dropped from a steady 5% down to -3% in 2008/2009, but has since increase to approximately 2.5% and is expected to stabilize at 3.5% by 2014 (MCLM, 2010).

The area has districts with significant agricultural potential. Due to the strategic location of the area in relation to the Gauteng Province, the agriculture sector has huge potential to grow and stimulate economic development.

However mining is the most important economic sector and will continue to be for the foreseeable future. The perspective of local city planner is still to maintain the mining sector as the catalyst to stimulate local economic activities.

The Gauteng dolomites are among the most productive aquifers in South Africa and are pivotal in meeting the increasing demand of the urban areas. Groundwater from the Steenkoppies and Bapsfontein dolomite compartments in the western and eastern parts of the Province is extensively used for irrigation and also contributes to public water supply (e.g. Johannesburg and Tshwane municipalities). They are important for thousands of small-scale groundwater users and also for sustaining ecosystems. Ongoing over-exploitation of the resource has resulted in declining water levels, diminishing spring flows and sinkhole formation, thereby calling for appropriate management of the resource to secure future water supplies.

Groundwater from the Steenkoppies dolomite compartment near Tarlton supports a specialised agricultural industry worth hundreds of millions of Rands, which employs thousands of people, while the Zwartkrans compartment to the East houses the World Heritage Site of the Cradle of Humankind. Krugersdorp is located within the Zwartkrans compartment and the decanting of AMD contaminated groundwater from the gold mines around Krugersdorp effects negatively the groundwater and streams in that compartment. Groundwater in the Zwartkrans compartment drains north-east to the Zwartkrans, Danielsrust and Kromdraai Eyes.

The Steenkoppies dolomite compartment falls within the larger 312 km^2 Steenkoppies groundwater management area (GMA) and was recently subdivided into three groundwater management units (GMUs). The GMUs are based on surface water drainage and hydrogeological considerations that require consistent management actions to maintain the desired level of use or protection of the resource.

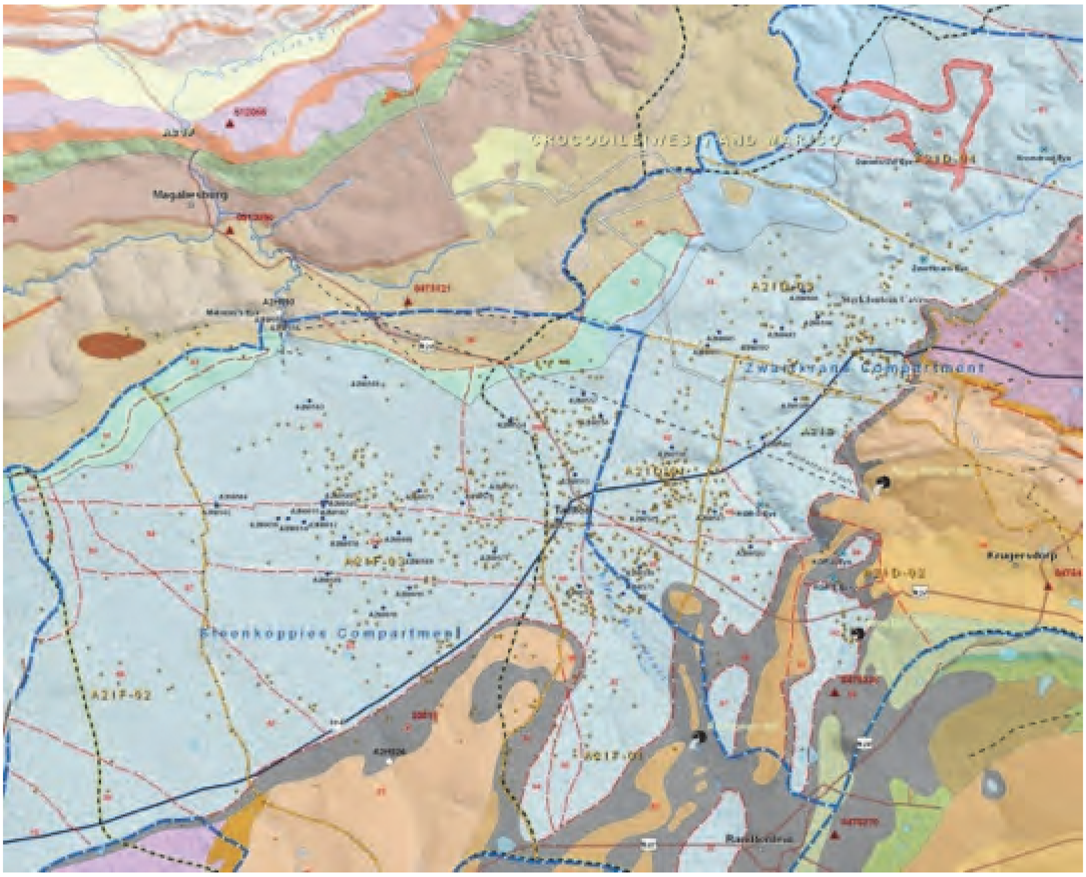


FIGURE 6-2: GEOLOGICAL MAP OF THE STEENKOPPIES AND ZWARTKRANS COMPARTMENTS

Water levels in the Steenkoppies compartment vary between 50 and 60 m.b.g.l. (metres below ground level) and aquifer conditions are unconfined to (semi-)confined (the latter due to weathered overlying material). Groundwater drainage in the Steenkoppies compartment is to the north towards Maloney's Eye and the flat groundwater gradient suggests highly transmissive or conductive conditions.

The water level of the main drainage area of the Eye represents the discharge elevation of the spring. The flow at Maloney's Eye correlates very well with rainfall over most of the 100 year records. In the past fifteen years, the spring flow has declined more than rainfall records would suggest. In addition, groundwater level data from boreholes in the area under irrigation show a clear correlation between water levels in the compartment, and flows at the Eye. Therefore, declines observed in spring discharge and in groundwater levels can be attributed mainly to over-exploitation.

Krugersdorp is located within the Zwartkrans compartment and the decanting of AMD contaminated groundwater from the gold mines around Krugersdorp negatively affects the groundwater and streams in that compartment. Groundwater in the Zwartkrans compartment drains north-east to the Zwartkrans, Danielsrust and Kromdraai Eyes. The overflow or decant AMD within the Western Basin of the Witwatersrand goldfields occurs from the Black Reef Incline and No 18 Winze in the headwaters of the Tweelopiespruit. Currently discharging at an annualised average rate of 30 million litres per day, the flow of AMD has already caused severe environmental damage within the nearby Krugersdorp Nature Reserve (KNR) and poses a severe threat to one of the world's most historically important and environmentally sensitive sites, the Sterkfontein caves within the Cradle of Humankind World Heritage Site (COH WHS).

A large part of the COH WHS is underlain by the Malmani Dolomite of the Chuniespoort Group. The Malmani Dolomite is the most common karstified rock in South Africa and is demonstrated in the over 200 caves found in the COH WHS.

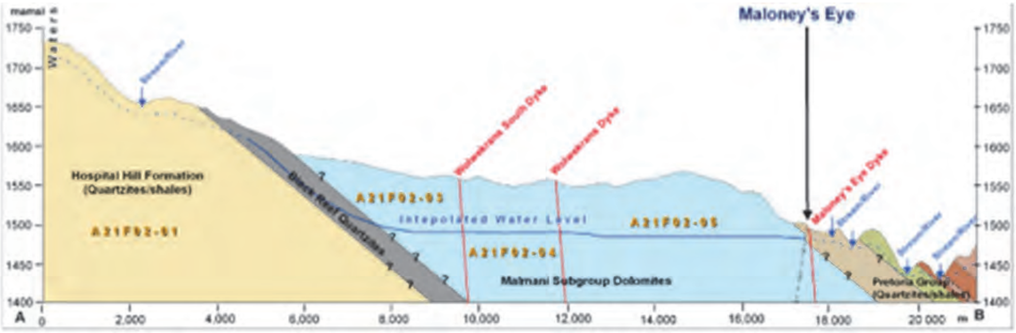


FIGURE 6-3: GEOLOGICAL SECTION OF THE STEENKOPPIES COMPARTMENT

6.5.2 Scenario 1: Status Quo

The continued and unmitigated decant of acid mine drainage from abandoned mining activities into the Steenkoppies Compartment will have an impact on the delivery groundwater based ecosystem services.

Environmental effect statement

- **Assets within the Krugersdorp Dolomitic Aquifer**
  - Cradle of Humankind World Heritage Site (COH WHS)
  - Krugersdorp Nature Reserve
  - Tweelopies River

- **Impact**
  - Sources of contamination:
    - Existing mine dump, decant and the waste water treatment works
  - Issue of surface groundwater interactions and seepage from tailings stands to groundwater.
    - Water table is in the tailing stand and seeps into the shallow groundwater and to surface water. Further acidity occurs when there is a flow from groundwater to the shallow water due to chemical changes.
    - Mine residues in particular tailings are seen as areas of enhanced seepage due to the volume of water entering the mine void which is relatively high.

- Source of decant water is at the black reef (mainly) and the water is discharged from Magali gold and treated water from Gold One at the black reef incline which then flow towards Tweelopiespruit. This has occurred reportedly since 2002.
- The current waste disposal from the Percy Stewart Waste Water Treatment Works (WWTW) is nearly at 200% capacity. There is therefore approximately 100% of untreated effluent discharged from this facility. The current persistence of poor bacteriological quality as reflected in *E. coli* values associated with surface water in the Bloubank Spruit is a direct result of the conditions at Percy Stewart WWTW.
- Areas with a high mine residue areas hazard ranking is mainly in the Western Basin: Krugersdorp, between JNB and Soweto, Boksburg and Nigel. The most hazardous sites are Koek and Millsite Tailings Storage Facility (TSF).
- The contaminated groundwater can propagate along trenches, which create connections between aquifers and/or compartments. This is due to their sandy bedding cradle that lines the pipe that acts as a preferential pathway for groundwater.
- The continued contamination of the Krugersdorp Dolomitic Aquifer will negatively affect the COHWHS (e.g. loss of the Sterkfontein Caves fossil site) as well as to the Krugersdorp Nature Reserve.
- The genetic resources may be affected as natural bacteria may be exterminated or mutated due to the presence of contamination in the ground water.

- **Scope of consequence:** The environmental effect of the hazard on the asset would have consequences on the following ecosystem services: fresh water quality, genetic resources and recreation and ecotourism.
- **Certainty of outcome:** Possible to Likely

Risk description:

The continuous decanting process has serious ecosystem service ramifications. The freshwater quality will be primarily affected due to the fact that there is currently a decrease in water quality in the area.

Sources of contamination are not only from the current decanting, but also the existing mine dump**s** and the overstressed Percy Stewart WWTW.

Recreation and ecotourism will also suffer as the COH WHS will lose its appeal as well as its features, e.g. Sterkfontein Caves Fossil Site.

The genetic resources in the form of bacteria within the system can undergo alteration or mutation due to the continued decanting and contamination processes.

The propagation of contaminated groundwater can take place due to the existence of trenches.

The dolomitic aquifer is compartmentalized due to the geological structures (dykes), however trenches create connections between compartments. In addition, springs are formed at locations that are linked to the geological structure and can spill over into other compartments.

Risk assessment:

TABLE 6-3. SCENARIO 1: STATUS QUO. RISK ASSESSMENT OF ECOSYSTEM SERVICES DELIVERED BY THE GROUNDWATER RESOURCES AREA INCLUDING COHWHS, KRUGERSDORP NR, TWEELOPIES RIVER

Ecosystem services benefit	Assets exposed	Likelihood of effect	Consequence	Notes	Level of Risk
Fresh water quality		Almost certain	Severe		Very high
Genetic resources		Possible	Moderate	Bacteria ‘exteremophiles’ Halicephalobus mephisto Nematode spp.	High
Recreation and ecotourism		Almost Certain	Severe	COH WHS loss of Sterkfontein Caves, etc.	Very High

Mitigation and Offsets:

- Implementation of a monitoring network in surface streams can be established in most of the surface streams draining the Witwatersrand. This is in order to quantify the amount of AMD coming from the mine dumps and decanting areas.
- Removal and treatment of decanted effluent.
- Removal of most AMD Sources.
- Increased infrastructure and management of the Percy Water WWTW.

6.5.3 Scenario 2: Treatment of AMD and Remediation of Old Mines

The treatment of AMD and remediation of old mines to prevent current and further decant into the Steenkoppies Compartment will reduce the impact on the delivery of ecosystem services. However the continued AMD impacts from the Tailings Storage Facility (TSF) remain and continue to impact on the delivery of groundwater based ecosystem services.

Environmental effect statement

- Assets within the Krugersdorp Dolomitic Aquifer:
    - Cradle of Humankind World Heritage Site
    - Krugersdorp Nature Reserve
    - Tweelopies River
- Impact:
    - The current waste disposal from the Percy Stewart Waste Water Treatment Works is nearly at 200% of their capacity. There is therefore approximately 100% untreated effluent discharged from this facility. Persistence of poor bacteriological quality as reflected in *E. coli* values associated with surface water in the Bloubank Spruit
    - The contaminated groundwater can propagate along trenches, which create connections between aquifers and/or compartments. This is due to their sandy bedding cradle that lines the pipe that acts as a preferential pathway for groundwater.
    - The continued contamination of the Krugersdorp Dolomitic Aquifer will negatively affect the COHWHS (e.g. loss of the Sterkfontein Caves fossil site) as well as to the Krugersdorp Nature Reserve.
    - The genetic resources may be affected as natural bacteria may be exterminated or mutated due to the presence of contamination in the ground water.

- **Scope of consequence:** The environmental effect of the hazard on the asset would have consequences on the following ecosystem services: fresh water quality, genetic resources and recreation and ecotourism.

- **Certainty of outcome:** Possible to Likely

Risk description:

The treatment of AMD and remediation of old mines to prevent current and further decant into the Steenkoppies Compartment will reduce the impact on the delivery of ecosystem services. However the continued AMD impacts from the Tailings Storage Facility (TSF) remain and continue to impact on the delivery of groundwater based ecosystem services. The continued decrease in water quality (although decreased) will have an effect on the recreation and ecotourism/cultural heritage values as the COHWHS will be negatively affected. The genetic resources within the natural system (i.e. bacteria) may be affected to some extent.

Risk assessment:

TABLE 6-4. SCENARIO 2: THE REMOVAL OF MAJOR SOURCES OF AMD. RISK ASSESSMENT OF ECOSYSTEM SERVICES DELIVERED BY THE GROUNDWATER RESOURCES AREA INCLUDING COHWHS, KRUGERSDORP NR, TWEELOPIES RIVER

Ecosystem services benefit	Assets exposed	Likelihood of effect	Consequence	Notes	Level of Risk
Fresh water quality		Almost certain	Moderate		High
Genetic resources		Possible	Minor	Bacteria 'exteremophiles' Halicephalobus mephisto Nematode spp.	Medium
Recreation and ecotourism		Possible	Moderate	COHWHS loss of Sterkfontein Caves, etc.	High

Mitigation and Offsets:

- Removal of most AMD sources including the Tailings Storage Facility (TSF).
- Increased infrastructure and management of the Percy Water WWTW.

6.5.4 Scenario 3: Scenario 2 + Remediation of the Tailings Storage Facility

The treatment of AMD and remediation of old mines to prevent current and further decant into the Steenkoppies Compartment will reduce the impact on the delivery of ecosystem services. The added remediation of the Tailings Storage Facility (TSF) will further lead a further reduction in the loss of groundwater based ecosystem services.

Environmental effect statement

- **Assets within the Krugersdorp Dolomitic Aquifer**
  - COHWHS
  - Krugersdorp Nature Reserve
  - Tweelopies River
- **Impact:**
  - The current waste disposal from the Percy Stewart Waste Water Treatment Works is nearly at 200% of their capacity. There is therefore approximately 100% untreated 'effluent' discharged from this facility. Persistence of poor bacteriological quality as reflected in *E. coli* values associated with surface water in the Bloubank Spruit

- **Scope of consequence:** The environmental effect of the hazard on the asset would have consequences on the following ecosystem services: fresh water quality, genetic resources and recreation and tourism.
- **Certainty of outcome:** Possible to Likely

Risk description:

The combination of stopping the decant of contaminated water, treatment of the water and removal of the TSFs ensure that fresh water quality would be impacted to a lesser degree than previous scenarios. The effect on genetic resources and recreation and ecotourism would be minimal.

Risk assessment:

TABLE 6-5. SCENARIO 3: REMOVAL OF ALL MAJOR AMD SOURCES. RISK ASSESSMENT OF ECOSYSTEM SERVICES DELIVERED BY THE GROUNDWATER RESOURCES AREA INCLUDING COHWHS, KRUGERSDORP NR, TWEELOPIES

Ecosystem services benefit	Assets exposed	Likelihood of effect	Consequence	Notes	Level of Risk
Fresh water quality		Unlikely	Moderate		Medium
Genetic resources		Unlikely	Minor	Risks to bacterial diversity Bacteria 'exteremophiles' Halicephalobus mephisto Nematode spp.	Low
Recreation and ecotourism		Very unlikely	Moderate	COHWHS loss of Sterkfontein Caves, etc.	Low

Mitigation and Offsets:

- Increased infrastructure and management of the Percy Water WWTW.
- Establish a groundwater-monitoring network in the Krugersdorp Dolomitic Aquifer system to identify possible contamination areas.

6.6 Case Study 3: The Primary Aquifer of the Sandveld Region

6.6.1 Economic and Hydrogeological Overview

The Sandveld region is one of the primary potato growing regions in South Africa producing some 220,000 tons of potatoes each year.

The Sandveld is also recognized as the second most highly threatened ecosystem in South Africa and the primary potato production areas overlaps with the greater Cederberg Biodiversity Corridor, a significant ecological corridor in Cape Floristic Region (Baadjies, 2007).

It is home to some 58 rare and threatened plant species, 30 of which are endemic. Potato farming uses approximately 6500 ha of the physical land area and puts pressure on the local ecology through the clearing of natural vegetation and through the intensive use of local water sources for irrigation (Baadjies, 2007).

The Sandveld area consists of 8 quaternary catchments (G30A-H) within the coastal strip to the south of the Olifants River mouth. The area is primarily an irrigation farming area where the main water resource is groundwater.

The groundwater in the Sandveld is from both the shallow primary aquifer and from the deeper TMG Aquifer. There is anecdotal evidence to suggest that water flow in the TMG in the Upper Olifants sub-area is linked to that in the Sandveld. Recharge occurs from local rainfall as well as these postulated linkages with the fractured-rock aquifers to the east. The aquifer plays a significant role in supporting the aquatic ecosystems, but this is under threat from water abstraction for agriculture.

The groundwater in the area is heavily used, mainly for agricultural purposes, resulting in some catchments being highly stressed. The aquifer is poorly managed, with little or no coordinated well-field management. It is likely that problems related to contamination of groundwater by seawater could be attributed to this rather than to a paucity of available groundwater.

The Sandveld to the west of the Olifants-Doring Basin is dominated by three parallel systems that drain westwards to the Atlantic Ocean. These are (from north to south) the (now) seasonal Langvlei, Jakkals and Verlorenvlei rivers and their associated wetlands, pans and vleis. Of these, the RAMSAR-designated Verlorenvlei is perhaps the best known. Rainfall in the region grades from a winter rainfall into a desert climate, with coastal fogs and low, unreliable rainfall of <250 mm per annum, and all the systems are subject to considerable pressure from abstraction of both surface and groundwater. Numerous sumps have been dug into streambeds for the purposes of crop irrigation, and many wetlands have dried out or shrunk as a consequence of abstraction. The remaining portions of these wetlands are sustained through isolated springs and eyes, which are also targeted for water supply.

The mainstem of the Langvlei River exists as a series of saline pools. Exceptions to this are pools fed by fresh to slightly saline groundwater. While historical records extending back to the 1700s indicate that the river dried up during the summer, abstraction appears to have exacerbated this condition such that surface flows virtually no longer occur. When it flows, the river feeds the Wadrif wetland, a small palustrine environment situated at the foot of the step in the Langvlei river plateau. Historically, sources of water to the wetland would have comprised those from the Langvlei River, the Wadrif eye, as well as other seeps and springs located in and adjacent to the wetland. The Wadrif wetland is considerable degraded and is the site of a large well-field used for water supply to Lamberts Bay, as well as for local irrigation.

The Jakkals River flows from the farm Jakkalsvlei in the south-east, north-west and westwards to Lamberts Bay where it terminates in the Jakkalsvlei. The river has a single tributary, the Peddies, which joins the Jakkals River just downstream of Graafwater. The Jakkalsvlei formerly had an intermittent connection to the sea, but this was virtually cut off following the construction of the harbour breakwater, the consequent widening of the beach and the construction of a berm across the outlet.

The Verlorenvlei system comprises several rivers and three quaternary catchments draining some 2000 km^2 of low relief, sandy coastal plain, with most of the water originating in the western edges of the Cape Folded Belt in the upper reaches of the river. The system originates as a multitude of streams draining the eastern and northern Piketberg, which collectively form the Kruis River. Other tributaries comprise the Bergvallei, Krom Antonies, Hol and Wittevallei rivers. Flow in the Verlorenvlei River is seasonally variable. A large wetland system begins upstream of Redelinghuys, and extends downstream into the extensive reed-beds that continue for much of the length of the large coastal lake, Verlorenvlei. Verlorenvlei has a short estuarine connection of some 2.5 km, and which opens annually. At the time of its promulgation (1986) as a RAMSAR site Verlorenvlei was described as a ‘fresh oligotrophic lake’ with areas of marsh and reed-swamp covering a total area of 1 500 ha. Anthropogenic impact in the Verlorenvlei catchment is mainly confined to the upper reaches of the Kruis River and its three large tributaries.

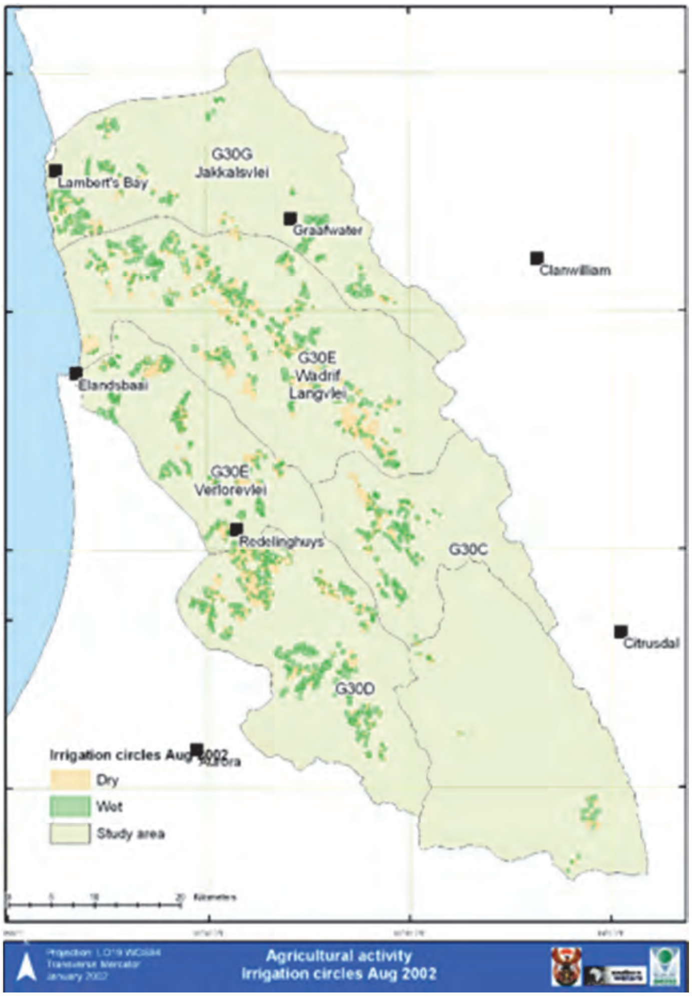


FIGURE 6-4: AGRICULTURAL ACTIVITY IN SANDVELD AREA WITH IRRIGATION FROM GROUNDWATER (FROM DWAF, 2003)

6.6.2 SCENARIO 1: STATUS QUO

The continued unsustainable rate of abstraction from the primary aquifer will result in a loss of the delivery in groundwater based ecosystem services.

Environmental effect statement

- **Assets within the Sandveld Aquifer:**
  - Verlorenvlei (estuary and wetlands) RAMSAR Site
  - Langvlei River
  - Jakkals River

Additional Assets:

- Wadrif Wetland
- Wadrif Pan
- Jakkalsvlei Pan
- Verlorenvlei Lake

- **Impact:**
    - Verlorenvlei's estuary and wetlands experiences a decrease in the volume of water. This is the primary issue and has an effect on the current water quality issues.
    - Water quality trends: some negative due to possible sources:
        - Saline intrusion
        - Irrigation return flows
        - Poor water quality in other areas
    - Elandsbay at the Verlorenvlei: Serious water quality issues were established as boreholes were decommissioned due to poor water quality and new well fields were constructed.
    - The current utilisation of the groundwater resource will decrease the amount of fresh water for the Verlorenvlei RAMSAR site and therefore the ecotourism and recreation will be negatively affected.
    - The current agriculture and demand for this resource currently outweighs supply and therefore not only causes competition between users, but due to the large agricultural sector, it also experiences a large amount of irrigation return flow.

- **Scope of consequence:** The environmental effect of the hazard on the asset would have consequences on the following ecosystem services: fresh water provisioning, fresh water quality and recreation and ecotourism.

- **Certainty of outcome:** Possible to Likely

Risk description:

The continued amount of abstraction and usage of the groundwater in the Sandveld aquifer will and has affected the recreation and ecotourism and fresh water quality, respectively. The ongoing agricultural demand will also have an effect on the fresh water provisioning for the study area.

Risk assessment:

TABLE 6-6. ECOSYSTEM SERVICES DELIVERED BY THE SANDVELD AQUIFER AT RISK FROM

Ecosystem services benefit	Assets exposed	Likelihood of effect	Consequence	Notes	Level of Risk
Fresh water provisioning		Almost certain	Moderate		High
Fresh water quality		Likely	Major	Elands Bay had to move well fields	Very high
Recreation and ecotourism		Almost certain	Major	Verlorenvlei Ramsar site	Very high

Mitigation and Offsets:

- A decrease in agriculture within the area can be used to decrease the water demand and potential irrigation return flow.

6.6.3 SCENARIO 2: IMPLEMENTATION OF MANAGEMENT CLASS III RECOMMENDED CATEGORY C

The implementation of a Management Class III configuration as well as Recommended Category C as recommended by DWA, will provide the groundwater resources of the Sandveld region with a greater level of protection and should ensure the sustainable use of the resource.

Environmental effect statement

- **Assets within the Sandveld Aquifer:**
  - Verlorenvlei (estuary and wetlands) RAMSAR Site
  - Langvlei River
  - Jakkals River

Additional Assets:

  - Wadrif Wetland
  - Wadrif Pan
  - Jakkalsvlei Pan
  - Verlorenvlei Lake
- **Impacts**
  - The current agriculture and demand for this resource currently outweighs supply and therefore not only causes competition between users, but also large amounts of irrigation return flow.

- **Scope of consequence:** The environmental effect of the hazard on the asset would have consequences on the following ecosystem services: fresh water provisioning, fresh water quality and recreation and ecotourism.

- **Certainty of outcome:** Possible to Likely

Risk description:

Fresh water quality would be primarily affected as the irrigation return flow in the area would still be a contributing factor to the water quality of both' surface water and ground water'.

Risk assessment:

TABLE 6-7. ECOSYSTEM SERVICES DELIVERED BY THE SANDVELD AQUIFER AT RISK FROM

Ecosystem services benefit	Assets exposed	Likelihood of effect	Consequence	Notes	Level of Risk
Fresh water provisioning		Unlikely	Minor		Low
Fresh water quality		unlikely	Moderate	Irrigation return flow....	Medium
Recreation and ecotourism		Unlikely	Minor	Verlorenvlei Ramsar site	Low

Mitigation and Offsets:

- Recommend a Category D for groundwater (65%) to ensure a Category C overall rating.
- Possible catchment transfer from the Olifants Valley close to the catchment boundary.
- Curtailment is needed on water allocation to the area including the large agricultural industry. However, the curtailment of allocation (possibly 66%) will have socio-economic effects (e.g. job loss).
- Desalination plants may be possible to curtail municipal use of the water resource at Lamberts Bay.

6.7 COMBINED ASSESSMENT OF RISKS

Taking the outputs of the CRA into account, the combined assessment of risks is given in the Table below.

TABLE 6-8. COMBINED ASSESSMENT OF RISKS

	Ecological Asset	Fractured Aquifers in the Hermanus Area		Dolomitic Aquifers of the Krugersdorp Area			Primary Aquifer of the Sandveld Region	
Ecosystem Services	Scenario	Scenario a	Scenario b	Scenario a	Scenario b	Scenario c	Scenario a	Scenario b
	Fresh Water Provisioning	Medium	High	NA	NA	NA	High	Low
	Fresh Water Quality	High	Low	Very High	High	Medium	Very High	Medium
	Genetic resources	Medium	Medium	High	Medium	Low	NA	NA
	Recreation & Tourism	Low	Low	Very High	High	Low	Very High	Low

7 HERMANUS CASE: UNPACKING THE SYSTEM COMPONENTS

7.1 INTRODUCTION

Prior to groundwater exploration, the Greater Hermanus area was solely dependent on the De Bos Dam for the supply of fresh water. The need for additional potable water arose due to a decrease in winter rainfall and the increase in water demand in the years leading up to 2001. Water restrictions were enforced in April 2001; however despite the restrictions the De Bos Dam was reported to be at a record low four months later. Groundwater usage was subsequently proposed to combat the critical water supply situation in Hermanus.

Groundwater exploration has led to the establishment of the Gateway and Hemel en Aarde Valley Wellfields. There are currently four operational boreholes at the Gateway Wellfield. These boreholes are drilled into the Peninsula aquifer and were drilled at various depths between 60 to 200 m.b.g.l.

The Hemel en Aarde Valley has seven boreholes that are equipped, but are in various stages of the testing phase (e.g. Camphill and Voelmoed boreholes). The Hemel en Aarde boreholes are partly drilled into the unconfined aquifer and partly in to the confined aquifer through a fault to reach the Peninsula aquifer.

The Greater Hermanus water supply system consists of both surface and groundwater. The De Bos Dam is the primary supplier of fresh water for the study area. The overflows and predetermined outflow from the dam is released into the Onrus River that flows to the Onrus Lagoon. Due to the widespread agricultural land usage of the area, water from the river is also used for irrigation. The De Bos Dam distributes fresh water to the Preekstoel Water Treatment Works (WTW) through a main gravity pipeline. The surface water and groundwater undergoes various treatment processes at the newly upgraded Preekstoel WTW to ensure good quality water to the consumer. The water is then distributed to various reservoirs and to the consumers. The system also supplies treated effluent from the Hermanus Waste Water Treatment Works (WWTW) to seven consumers in the study area. The following is an overview of the water supply components in the Greater Hermanus water supply system.

7.2 CATCHMENT

7.2.1 LOCATION

The Overstrand municipality has a land area of approximately 2 125 km^2, with a population density of 27 people per square kilometre. The Greater Hermanus Area forms part of the Overstrand Municipality in the Western Cape Province. It consists of the towns Hermanus, Voëlklip, Onrus River, Sandbaai, Vermont, Hawston and Fisherhaven which lie along the coast of the Indian Ocean. Hermanus is built along the shores of Walker Bay, near the southernmost tip of Africa, about 100 km east of Cape Town.

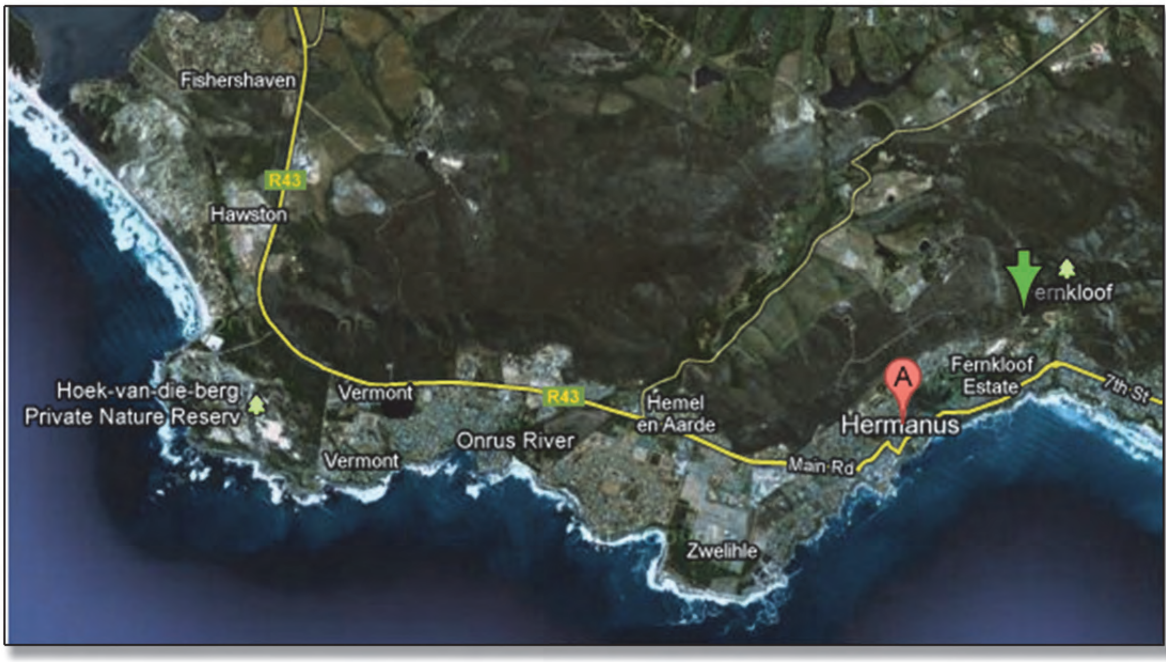


FIGURE 7-1: GREATER OVERSTRAND MUNICIPAL AREA (GOOGLE MAPS)

7.2.2 Geology and Hydrology

The main stratigraphic units represented in the study area belong to the Malmesbury Group, Cape Granite Suite, Table Mountain Group (TMG), Bokkeveld Group and Bredasdorp Group. The deposits of the Malmesbury Group and the intrusions of the Cape Granite Suite are the oldest formations in this context and form the basement on which the thick layers of the TMG and the Bokkeveld Group were deposited. The Overstrand stratigraphy is seen below.

TABLE 7-1: LITHOLOGIES OF THE OVERSTRAND STUDY AREA

Lithologies of the Overstrand Study Area

Group		Subgroup	Formation		Aquifer Properties	Max Thickness (m)
	Bredasdorp			Qg	Primary Aquifer	50
Cape Super Group	Bokkeveld	Ceres Subgroup	Gamka	Dgs	Aquifer	70
			Gydo	Dg	Aquitard	150
	Table Mountain Group (TMG)	Nardouw Subgroup	Rietvlei	Dr	Aquitard	200
			Skurweberg	Ss	Aquifer	300
			Goudini	Sg	Aquitard	200
			Cedarberg	OSc	Aquitard	120
			Pakhuis	Opa	Aquitard	80
			Peninsula	Ope	Aquifer	2000
	Cape Granite Suite		Hermanus Pluton	N-hp	Aquiclude	

Exploration drilling, testing and hydrocensus operations by Umvoto Africa in the recent years have led to new surface and subsurface geological information. The subsequent results have led to a revision of certain aspects of the published geological map (1:250 000 scale) of the Hermanus area. The main focus of attention has been on the revision of the pattern of faulting with regards to the Hermanus Fault, Fernkloof Fault and Attakwaskloof Fault.

The main hydrological features are the Onrus River and Onrus Lagoon. These surface water bodies are dependent on releases from the De Bos Dam.

7.2.3 LAND USE

There are varied land uses in the study area. The areas surrounding the Gateway Wellfield mainly consist of commercial and residential land use. Whilst the Hemel en Aarde Valley land use is mainly agricultural.

7.2.4 DESCRIPTION OF WATER BODIES

The De Bos Dam Scheme was implemented in 1976 and is currently the main fresh water contributor for the study area. The De Bos Dam has a capacity of 6000 mega litres (Ml) or 6 million m^3. The allocation of water from the dam for municipal is 2.8 million m^3/a. This is due to the fact that the total capacity of the dam has to be distributed to different users as well as the ecological Reserve. The De Bos Dam has a sustainable yield of approximately 3300 Ml/a. The Mosselrivier Dam has an allocation of 230 Ml/a; and the Fisherhaven Dam has an allocation of 240 Ml/a to the Overstrand area.

7.2.5 FLOW AND RELIABILITY OF SOURCE WATER

The De Bos Dam is the primary source of fresh water and is affected by seasonal variation of rainfall. The dam level has decreased to less than twenty percent in recent years. Furthermore, the study area is a tourism destination which ensures that there is a seasonal variation in demand of water. The larger Overstrand area is reported to quadruple the population during the high tourism season.

7.2.6 GROUNDWATER

The decrease in winter rainfall and increase in water demand in Hermanus led to a critical water supply shortage in the area. Additional water supplies were required and groundwater exploration became a priority in the year 2001. Exploration projects primarily targeted the strongly fractured zones in quartzites and sandstones of the TMG and led to the identification of three wellfield sites in the Peninsula Aquifer. The recharge area of the Peninsula Aquifer is located in the Fernkloof Nature Reserve.

The Gateway Wellfield is situated within the town of Hermanus and consists of four boreholes that are targeting the confined Peninsula aquifer. Though the groundwater abstracted from the Gateway wellfield is potable, pre-treatment and blending is necessary to remove the excess amounts of manganese and iron content. The facilities at the Preekstoel Water Treatment Works (WTW) have been upgraded to include the pretreatment of the groundwater before blending and distribution to water users.

The Camphill Wellfield and Volmoed Wellfield both target the unconfined and confined parts of the Peninsula aquifer. The wellfields consist of 7 boreholes currently in the testing phase and are situated in the Hemel en Aarde Valley. The boreholes are located in a hydraulically separate unit to the Gateway Wellfield. Cumulatively, the three wellfields can provide approximately an additional 2.6-3 million m^3/a.

7.3 TREATMENT SYSTEMS

7.3.1 PREEKSTOEL WTW

The main functional tasks of the Preekstoel WTW are chemical dosing with alum, poly-electrolyte and lime, flocculation, sedimentation, filtration using rapid gravity sand filters, stabilization (lime) and disinfection utilizing chlorine gas. The Preekstoel WTW has been upgraded from 24 Ml/d to 28 Ml/d through a recent refurbishment by the Municipality. The groundwater in Hermanus undergoes the following treatment: pre-oxidation, chemical dosing with caustic soda and potassium permanganate and disinfection using chlorine gas. A biofiltration facility has been included into the plant as part of the upgrade.

7.3.2 THE HERMANUS WWTW

Hermanus is serviced by the Hermanus WWTW and the Hawston WWTW. The sanitation system in the Greater Hermanus Area is a conventional water-borne sewage system with the exception of Vermont, Onrus and Voëlklip, which have small-bore systems.

The Hermanus and Hawston WWTW have a design capacity (hydraulic load) of 7 300 and 1 000 kl/d respectively. During 2007 120 523 and 1 926 864 kl of sewerage were treated at the Hawston and Hermanus works respectively.

Both the treatment works at Hermanus and Hawston operate using an activated sludge system. The Hawston works is in good physical condition, while the Hermanus works is only in average physical condition.

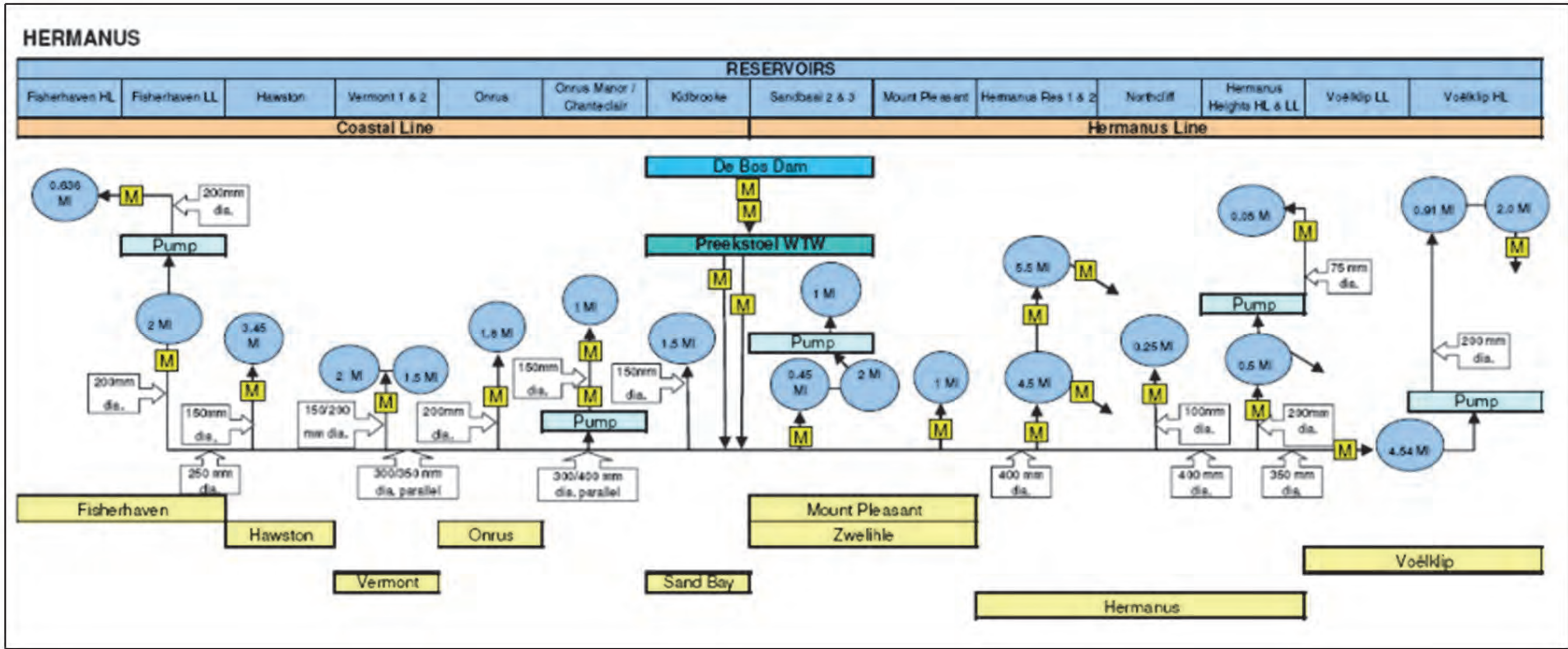


FIGURE 7-2: DETAILED DIAGRAM OF THE OVERSTRAND MUNICIPALITY WATER SUPPLY AND DISTRIBUTION SYSTEM

7.3.3 DISTRIBUTION SYSTEMS

The distribution system of the bulk surface water supply is primarily derived from the De Bos Dam. This water is transported through a gravity pipeline from the dam to the Preekstoel WTW. Groundwater from the Gateway wellfield is pumped directly from the boreholes into the WTW. Following the treatment process, water is then gravity fed to the various reservoirs and to the subsequent users.

Treated water (grey water) is used for irrigation purposes for seven consumers (e.g. golf courses and sports fields).

The main users of water in Hermanus are:

- Domestic,
- The Local Authority,
- Industry and Agriculture
- Institutional organizations such as sports clubs and schools.

Competition between water users such as the agricultural sector and the local authority can occur if the usage of both groundwater and surface water not are managed in the study area.

7.4 OVERSTRAND MUNICIPALITY: HERMANUS

The Overberg District Municipality (DM) Summary report gives an overview of the Overberg DM area in general and a summary of the main features of each Local Municipality (LM). This chapter summarise the water situation in the Overberg DM and highlights the recommendations and regional actions to ensure sufficient and sustainable water supply to all towns within the Municipal Area.

7.4.1 LOCALITY

The Overberg DM is situated east of Cape Town and covers the area between the Riversonderend Mountains and the ocean. The coastal area stretches from the Kogelberg Biosphere Reserve in the east to the De Hoop Nature Reserve and Breede River Mouth in the west.

The Overberg DM comprises four local municipalities, each with an administrative urban centre:

- Cape Agulhas – Bredasdorp
- Overstrand LM – Hermanus
- Swellendam LM – Swellendam
- Theewaterskloof LM – Caledon

7.4.2 DEMOGRAPHICS

According to the Overberg DM Integrated Development Plan (IDP) 2010/2011, the population of the Overberg DM is quite young, with 32% of the population age 17 years or below.

In terms of social grants child support is received by 35% of the population, and 28% receive old age pensions. There are low enrolment rates for primary education and the illiteracy rate (people over 14 years of age with less than a grade 7 level of education) is at 27%.

The Overstrand LM consists of 24 communities (DWA data) consisting of 24 083 households (DWA Water Services Community Database-April 2008). Its population is 74 547 (Community Survey-2007) with an annual population growth rate of 8%.

7.4.3 Socio-economic profile

According to Census 2011 data, 28% of households had an income of R800 or less per month, 42% earning between R800 and R3200. The Overberg DM contributed 2.4% to the provincial GDP in 2007 and grew at an annual rate of just over 5% in 2006/2007.

Between 1996 and 2007, the Overberg economy grew at a slower pace than the Western Cape overall and displayed a high degree of instability compared to the Western Cape. However, there is a positive and increasing economic output over time in between 1996 and 2004.

7.4.4 Existing Infrastructure

There are a number of dams within the district municipal area, most of which are used for agriculture. The largest dam in the area is the Theewaterskloof Dam on the Riversonderend River, which is shared between domestic supply to the City of Cape Town and the Overberg Water Board, and agricultural users downstream of the dam and in the Berg River catchment.

Major dams in the Overberg DM include the De Bos dam located in Hermanus which has capacity of 6.3 million m^3.

7.4.5 Institutional Capacity

The local municipalities act as Water Services Authorities, and it appear that they perform at an acceptable to good level. Despite the fact that these municipalities are small and have only a small staff component, they manage their water supply systems with sufficient skills, as illustrated by their Blue Drop and Green Drop performances.

7.4.6 Water Resources and Existing Infrastructure

The larger towns in the Overstrand LM have surface water schemes for their water supply, often augmented with groundwater sources. The smaller towns and settlements are mostly supplied by groundwater schemes, either from natural springs or boreholes.

The Overstrand LM achieved an average Blue Drop score of 71.6% during the 2010 assessment, which was significantly improved to an average score of 90.56% in the 2011 assessment. Three out of eight water supply systems were awarded with the Blue Drop Award for excellence in their drinking water quality management.

The effluent water quality management is of similar high quality, with an average Green Drop of 88.8% in the 2011 assessment and the Green Drop Award for the Hermanus Waste Water Treatment Works (WWTW).

7.5 Hermanus Water Supply System: Key Risks

Water supply systems are usually designed, constructed, operated, and managed in an open environment, thus they are inevitably exposed to varied uncertain threats and conditions. In order to evaluate the reliability of water supply systems under threatened conditions, risk assessment has been recognized as a useful tool to identify threats, analyze vulnerabilities and risks, and select proper mitigation measures.

The proceeding sub-chapters details the key risks as identified in the Hermanus case outline. These serve to inform the structure and relationships in modeling exercise undertaken in the later chapters.

7.5.1 General:

Overall mismanagement of the water resource due to limited catchment information, a low skill set of the workforce, the institutional setting and the policies that govern water management is a major risk factor to the water supply system.

7.5.2 Geology and Hydrogeology:

The main stratigraphic units represented in the study area belong to the Malmesbury Group, Cape Granite Suite, Table Mountain Group (TMG), Bokkeveld Group and Bredasdorp Group. The main hydrological features are the Onrus River and Onrus Lagoon.

The areas surrounding the Gateway Wellfield mainly consist of commercial and residential land use. Whilst the Hemel en Aarde Valley land use is mainly agricultural.

7.5.3 Surface Water:

The De Bos Dam has a capacity of 6000 mega litres (Ml) or 6 million m^3. The allowed maximum usage of water for domestic use from the dam is 2.8 million m^3/a. The De Bos Dam is the primary source of fresh water and is affected by seasonal variation of rainfall.

7.5.4 Groundwater:

Exploration projects primarily targeted the strongly fractured zones in quartzites and sandstones of the TMG and led to the identification of three wellfield sites in the Peninsula Aquifer. The recharge area of the Peninsula Aquifer is located in the Fernkloof Nature Reserve.

The Camphill Wellfield and Volmoed Wellfield both target the unconfined and confined parts of the Peninsula aquifer. The wellfields consist of 7 boreholes currently in the testing phase and are situated in the Hemel en Aarde Valley.

7.5.5 Treatment Systems:

The Preekstoel WTW has been upgraded from 24 Ml/d to 28 Ml/d through a recent refurbishment by the Municipality. Hermanus is serviced by the Hermanus WWTW and the Hawston WWTW. During 2007, 120 523 and 1 926 864 kl of sewerage were treated at the Hawston and Hermanus works respectively.

7.5.6 Distribution Systems

Groundwater form the wellfields is pumped to the Preekstoel WTW. Water from the De Bos Dam is transported through a gravity pipeline from the dam to the Preekstoel WTW.

7.5.7 DEMAND / USERS

- Domestic Use Risk Factors
  - Growth Rate: Dependent on a) the different types of usage rates and number of households and b) the seasonal fluctuations attributed to the environmental/weather conditions as well as tourism.
  - Water quality: Issues may arise due to lack of sufficient infrastructure in certain areas.
- Industrial Use Risk Factor
  - Contamination: Dependent on the type of industry, the potential contamination from industries can affect the water supply and water quality, e.g. Petrochemical stations.
- Agricultural Use Risk Factor
  - Growth Factor: Dependent on the irrigation schedule VS crop type and amount which can lead to 'over-abstraction'.
  - Potential contamination from agricultural runoff to surface water bodies (e.g. Onrus River) can become a concern.
- Commercial Use Risk Factor
  - Growth Rate: Increased growth in this sector will increase demand.
- Environment (Reserve) Risk Factor:
  - Fluctuation of water supply due to a change in climate, rainfall distribution, and/or drought will affect supply and water quality.
  - Change in environment distribution and composition.

8 MAPPING SUPPLY AND DEMAND IN A GENERIC SYSTEM

Drawing upon the components of this study, a water supply systems model was developed to assess the performance of water supply systems against a set of random conditions. These random conditions pertain specifically to:

- Variations in rainfall patters
- Variations in consumption demand

At the component level, components of a water supply system are viewed as different and functional objects. Associated with each object, there are states transition diagrams that explicitly describe the risk relationships between hazards/threats, possible failure states, and negative consequences. At the system level, the water supply system is viewed as a network composed of interconnected objects. This is recognized as an object oriented approach to systems modeling.

Assessments are conducted to evaluate the risks of components and the water supply system. This is a natural and straightforward mechanism for organizing information of real world systems, to represent the water supply system at both component and system levels.

PLEASE SEE ACCOMPANYING XLS DOC – GW_Data Model.xls

This model presented in the accompanying spreadsheet maps out the individual components of a conjunctive use water supply system, as well as the relationships between these components.

PLEASE SEE DOCUMENT TABS; AS FOLLOWS:

- *Rainfall*
- *SW (Surface Water)*
- *GW (Groundwater)*
- *Treatment*
- *Reticulation*
- *System Controls*
- *Demand*

The proceeding sub-chapters outline the components of this model detailing the nature of each of the components and it relationships/inter-linkages with the overall system.

The nature of each sub-component is listed as either deterministic, or stochastic.

8.1 RAINFALL SUB-COMPONENTS:

Rainfall Baseline: The rainfall baseline is representative of the average monthly rainfall for the region profile for the region in question. [Deterministic]

Random Rainfall Pattern Fluctuations: The model generates random rainfall fluctuations whilst maintaining a constant overall pattern for the regions in question. [Stochastic]

Rainfall Simulated: The randomly generated, rainfall profile that mimics the regional rainfall profile whilst accounting for monthly and seasonal fluctuations. [Stochastic]

8.2 Surface Water Sub-Components:

The surface water tab is divided into the following components:

Dam Capacity Percentage and Current Storage: The amount of water supply that is currently available in the main surface water body storage scheme. [Deterministic]

Inflow: The inflow is determined by the amount of rainfall the catchment area and is expressed as a percentage of rainfall. [Stochastic]

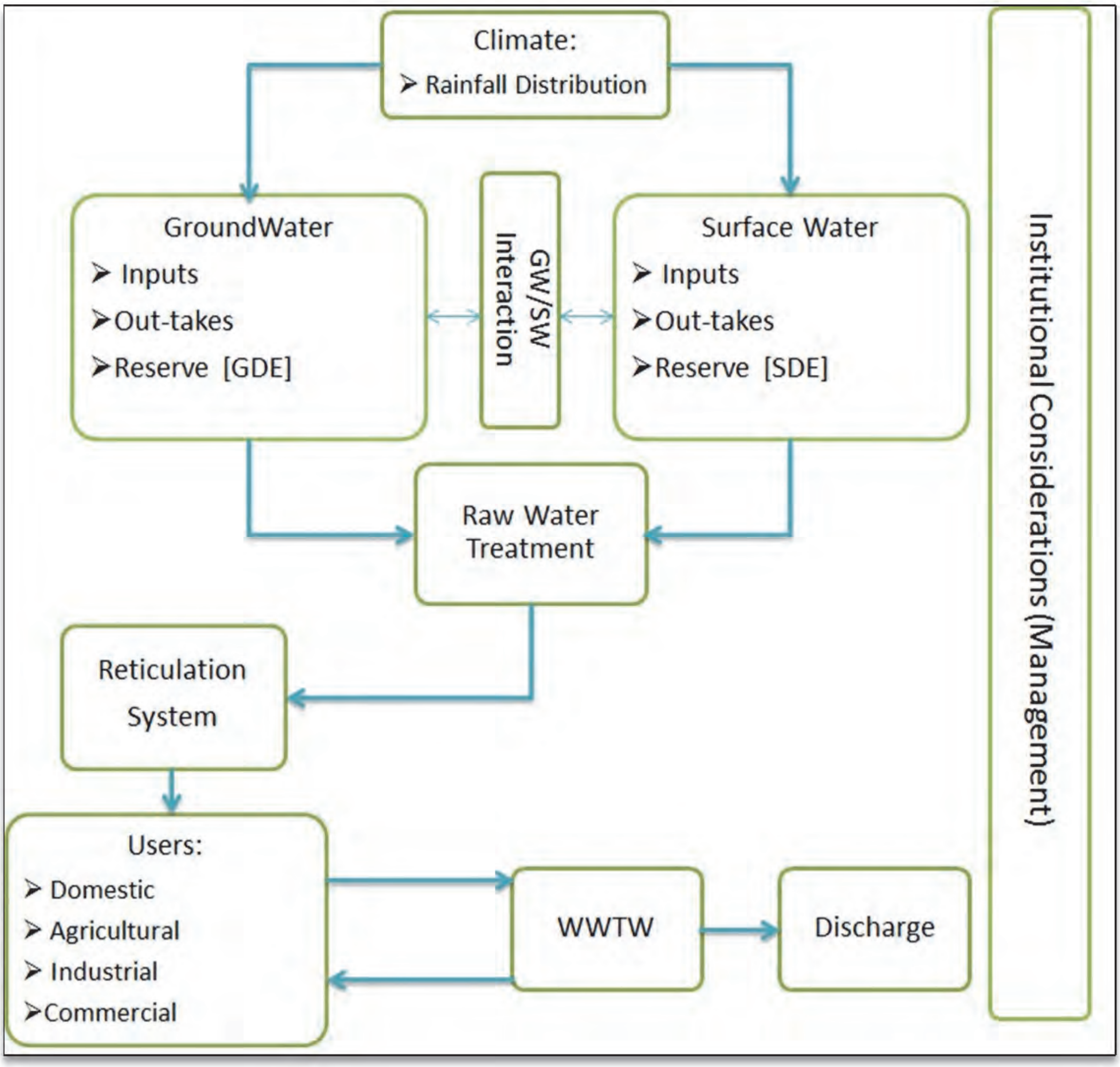


FIGURE 8-1: CONJUNCTIVE USE WATER SYSTEMS DIAGRAM

Environmental Releases: Includes all water released from the surface water storage to support the downstream environment. [Deterministic]

Agricultural Releases: The release of water for the purpose of providing the allocated water supply for the irrigation of crops. [Deterministic]

Evaporation: The evaporation that takes place over the surface of the surface water storage schemes is taken into account and assigned an evaporation rate. [Stochastic]

Outflow: The outflow of surface water represents the available water supply that can be utilized (before treatment) for the various users in the Hermanus area. [Deterministic]

Spillage: Potential losses will be represented in this sub-component. [Deterministic]

8.3 GROUNDWATER SUB-COMPONENTS:

Aquifer Storage Volume/Yield: The aquifer capacity in m^3 is estimated and provides the basis for the current groundwater supply available for abstraction. [Deterministic]

Abstraction: The cumulative abstraction from all well points in the aquifer system. [Deterministic]

Recharge: The recharge is calculated as a percentage of the rainfall in the area. [Stochastic]

8.4 TREATMENT SUB-COMPONENTS:

Water Treatment is represented in the model as follows:

Inflow: This is the cumulative amount of water from both the groundwater and surface water sources. [Deterministic]

Treatment Losses: This is a representation of the losses of water supply that can occur due to backwashing. [Stochastic]

Outflow: The resultant treated water (Inflow-treatment loss) is then labeled as outflow and will be sent to users via the reticulation network. [Deterministic]

8.5 RETICULATION SUB-COMPONENTS:

Supply: The supply is calculated as the outflow from the water treatment works to the users. [Deterministic]

Losses: Estimated operational losses due to inferior infrastructure or operational problems of the gravity-fed reticulation system are calculated as a percentage of the water supply. [Stochastic]

Supply-Actual: The actual water supply is the final amount of water that will be issued to the users in the area. [Deterministic]

8.6 DEMAND SUB-COMPONENTS:

Usage: The current usage in m^3 is calculated for all users. [Stochastic]

Cost: The economic value is assigned for the water usage. [Deterministic]

Waste Discharge: The waste discharge is calculated as a percentage of the current usage of water. [Deterministic]

Number of households: The number of households undergoes a seasonal fluctuation due to development and increase in population growth. The annual seasonal fluctuation due to tourism is also taken into account. [Stochastic]

8.7 WASTE WATER TREATMENT WORKS SUB-COMPONENTS:

Waste Water Treatment is taken into account and the sub-components are relatively simple.

Inflow: The inflow is derived for the waste water of the users. [Deterministic]

Treatment Losses: The treatment of the waste water undergoes operational losses that are represented as a percentage of the inflow amount. [Deterministic]

Grey Water: The treated effluent is redistributed at a cost to suitable users for re-use. [Deterministic]

Outflow: The remaining treated effluent is calculated and discharged from the water supply system. [Deterministic]

8.8 INSTITUTIONAL CONSIDERATIONS: SYSTEM CONTROLS

The institutional considerations relate to the decision making frameworks that inform and guide the development and management of water supply networks.

Systems Stress Response: The components that comprise the water supply system possess a range of operating conditions depending on the level of stress that the system experiences. The conditions relate specifically to the manner in which water resources and water supply systems are managed under those conditions.

Component Stress Response: The parameters that define specific components of the systems assessment model can alter under certain conditions of stress. For example, the storage capacity of an aquifer system might be reduced if the system is subjected to abstraction rates that reduce water levels beyond a certain point.

Systems controls are comprised of the sets of regulation and management mechanisms that are either explicitly or implicitly at play with the water supply management system.

Explicitly defined mechanisms would include:

Dam Operating Rules: The rules which determine the amount of water that may be released from a dam for consumptive and non-consumptive purposes; usually defined in relation to the water levels within the dam.

8.9 MODEL OUTPUTS: ASSESSING SYSTEM PERFORMANCE

Assessments the systems overall performance under a given set of conditions can help decision makers to prioritize their maintenance and management strategies in water supply systems.

In order to quantitatively evaluate the framework of aggregative risk, the model measures the occurrence of certain stress indicators for a given systems design, and a certain set of random rainfall and demand conditions.

Results of this analysis are likelihood of the occurrence for a specific event and importance measures of the possible contributing events. These results can help risk analysts to plan their mitigation measures to effectively control risks in the water supply system.

The outputs of the model include, but are not limited to:

- Mean Rainfall for the System
- Variance in Rainfall
- Probability of a "Moderate Stress Event" - As defined in the context of the model.

- Probability of a "Severe Street Event" - As defined in the context of the model

By altering the parameters of the system, and by running multiple simulations of the performance of the system under random conditions, it becomes possible to compare various system configurations relative to each other.

8.10 MODEL OUTPUTS: ECONOMIC INTERPRETATION

The socio-economic approach followed in this study is based on the concept of ecosystem services as defined by Millennium Ecosystems Assessment (MEA) and TEEB. Ecosystem services are defined as the set of benefits provided by ecosystems, which contributes to human welfare. The primary ecosystem services considered in the model is fresh water provisioning and groundwater storage and retention. The system accounts, to a limited extent, for several other ecosystem services.

As its point of departure, the MEA states that the major reason for degradation of ecosystems is the exclusion of the value of ecosystems' assets and the services they provide to humans from development policies/projects. Through the inclusion of the "storage and retention" services of aquifer systems, significant inroads are made into quantifying the "hidden" value of groundwater resources.

This exclusion is attributed to a propensity by mainstream development economists to judge ecosystems as luxury goods which would improve as wealth improves; and to the low visibility of continuous ecosystem degradation. This neglect directly contributes to overexploitation and degradation of ecosystems, especially in developing countries. The analytical challenge is thus to attempt to internalize ecosystems' assets into development economics, through estimating and integrating shadow prices of ecosystem services and the trade-offs involved between elements in bundles of services in development decisions.

The challenge in this study is to estimate the contribution of the bundle of aquatic ecosystem services, attributable to groundwater resources. A particular challenge here is in valuation, as the local economy is range of economic activities through the domestic, agricultural and commercial sectors of the economy. A production function approach is therefore appropriate. This will enable the establishment of linkages between the water resource ecosystem services to be econometrically specified.

9 CONCLUSION AND RECOMMENDATIONS

9.1 GROUNDWATER MANAGEMENT VS AQUIFER MANAGEMENT

There are usually multiple sets of users accessing aquifers systems and abstracting groundwater. However, it is prevalent that only a portion of these users are monitored / controlled.

Management of groundwater abstraction is usually only monitored from the perspective of a single user, i.e. the municipality. To a limited extent the access of relatively large scale users is also monitored. The management framework does not account for multiple competing users all accessing the same aquifer system.

As is often the case in the agricultural community, groundwater serves as a fall back resource during times of inadequate surface water supply. The same is also true for many municipalities.

The complication arises where municipalities attempt to curtail agricultural usage of water resources. However, in conjunctive use systems, municipalities are often not equipped to control access to groundwater resources, leading to cases of over abstraction where both the municipality and the agricultural sector are depending on groundwater resources for supply.

The paradigm needs to shift towards one of holistic “Aquifer Management” as opposed to just management of abstraction from a single user’s perspective; the access of all relatively large scale users’ needs to be accounted for in order to achieve affective control of groundwater/aquifer systems.

9.2 WATER SUPPLY SYSTEM CONTROLS

The controls that guide/manage the allocation of water resources within a given entity (i.e. community, municipality, etc.) are designed based on the constraints of surface water resources, and do not, as yet, factor in the constraints associated with groundwater resources and aquifer assets.

Surface water resources (i.e. dam water levels) are the primary consideration when determining water allocations/restrictions in the coming period (usual one year, for larger water management institutions). This is due in part to limited understanding of groundwater resources in term of availability, and in terms of groundwater interaction with surface water resources.

This limitation in the design of allocation/restriction control introduces inefficiencies into the utilization of water resources, particularly during periods of constrained supply.

Allocation/restriction control within a conjunctive use water supply system should be designed around the availability of both surface water and groundwater resources.

9.3 FACTORS THAT INFLUENCE THE ECONOMIC VALUE OF GROUNDWATER/AQUIFERS

The value of a resource within a given economy is directly influenced by its relative availability/scarcity. Groundwater expertise is relatively scarce within the South African context, making them relatively costly to retain.

The principles of supply and demand state that the value of a resource is inversely correlated to the availability/scarcity of that resource within a given economic system.

Relative to surface water supply schemes, groundwater supply schemes require relatively greater levels experienced input to ensure their adequate on-going maintenance and operation. This factor, in combination with the relative scarcity of groundwater/hydrogeologic expertise in South Africa, is a significantly influencing factor in the motivation to develop groundwater resources.

Continued development of human resources within the groundwater sector needs to be ensured.

9.4 GROUNDWATER ECOSYSTEM SERVICES

Aquifers are viewed primarily as a source of groundwater, with the provision of water being regarded as the sole benefit derived from aquifers.

The prevailing approach to groundwater management in South Africa is almost entirely centered on the abstraction of water resources for economic consumption, and does not account for the broader range of ecosystem services provided by aquifer systems.

Methods for analyzing the, assessing and categorizing the ecosystem services derived from natural resources do exist, and have shown success in application in the case of groundwater resources. Project K5-2165 demonstrated the application of the Comparative Risk Assessment Methodology, in terms of identifying groundwater ecosystem services and assessing the impact of groundwater utilization regimes on the ecosystem services.

There exists, within South Africa, a pool of hydrogeologic expertise that have qualified insights into the functioning of the broader range of groundwater ecosystem services. Efforts should be made further investigate the ecosystem services provided by groundwater resources, and this pool of expertise should be utilized to inform and guide this process.

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Appendixes

Appendix A: New CMA Boundaries

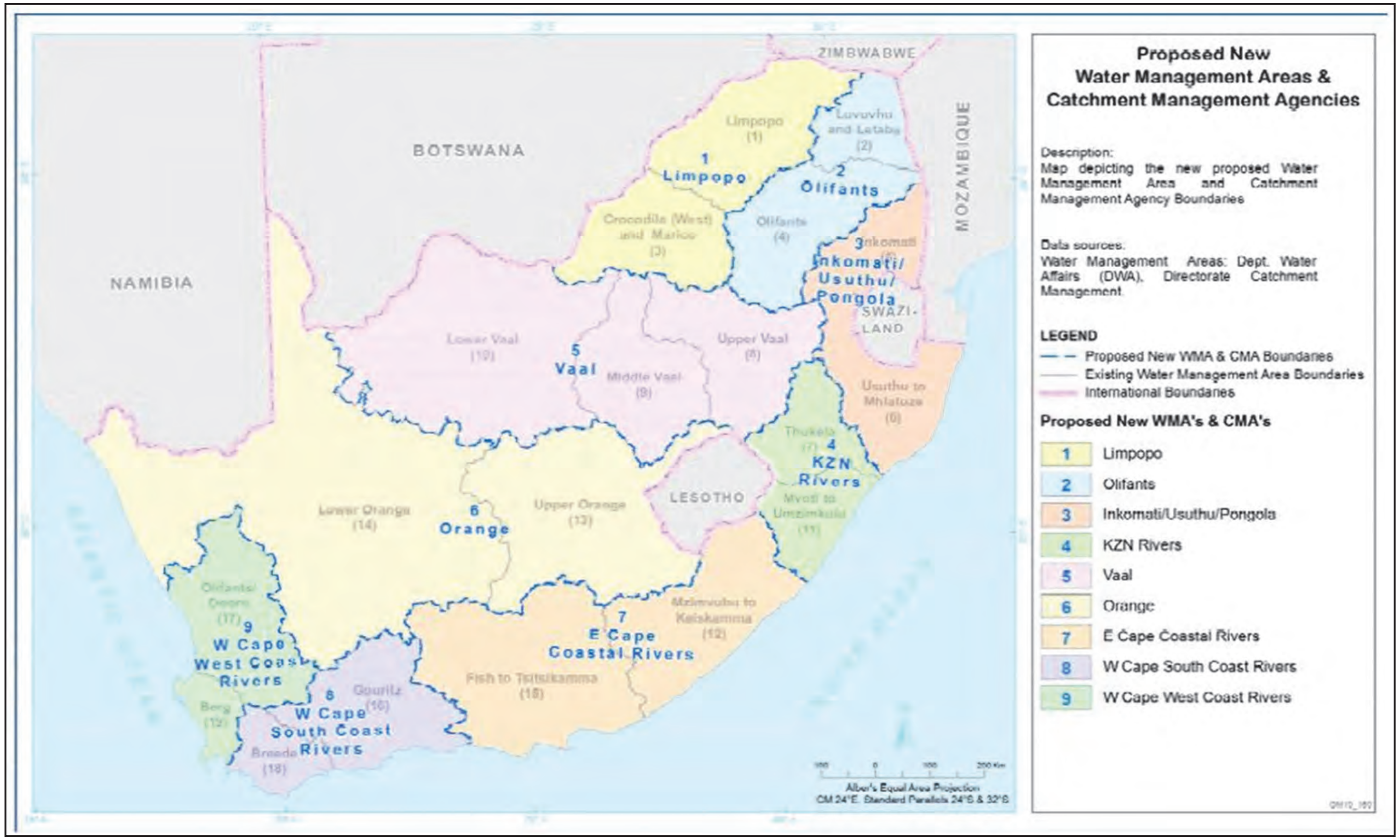

FIGURE A-1: MAP DEPICTING THE NEW WATER MANAGEMENT AREAS

APPENDIX B: SECTORAL WATER USE PER WMA

TABLE A-1: SECTORAL WATER USE PER WATER MANAGEMENT AREA

Water Management Area	**UGEP (million m^3/a)**	D&I	Irrigation	*Urban*	*Rural*	*Mining*	*Power*	Aff	Total
Limpopo	644.3	88.0	252.2	*36.0*	*29.7*	*14.8*	*7.4*	1.1	341.2
Luvuvhu/Letaba	308.9	43.0	253.7	*10.2*	*31.7*	*1.0*	*0.0*	44.0	340.7
Crocodile West and Marico	447.8	884.3	532.5	*654.5*	*44.3*	*152.0*	*33.5*	0.0	1 416.7
Olifants	619.2	435.8	596.4	*94.2*	*47.1*	*100.7*	*193.8*	3.2	1 035.5
Inkomati	667.8	118.8	623.6	*66.3*	*27.3*	*25.2*	*0.0*	145.1	887.6
Usutu to Mhlathuze	862.0	187.4	447.2	*51.8*	*41.4*	*94.2*	*0.0*	107.7	742.3
Thukela	512.6	139.2	218.5	*55.7*	*33.2*	*49.3*	*1.1*	0.0	357.7
Upper Vaal	564.0	1 127.6	138.1	*769.1*	*52.1*	*209.5*	*96.9*	0.0	1 265.7
Middle Vaal	398.1	218.0	165.1	*96.5*	*33.2*	*88.2*	*0.0*	0.0	383.1
Lower Vaal	645.1	120.6	536.5	*69.5*	*45.0*	*6.1*	*0.0*	0.0	657.0
Mvoti to Umzimkulu	704.9	661.3	260.3	*513.0*	*55.3*	*93.0*	*0.0*	81.7	1 003.3
Mzimvubu to Keiskamma	1 385.9	148.1	203.9	*106.2*	*41.9*	*0.0*	*0.0*	49.4	401.4
Upper Orange	673.0	199.6	828.3	*133.8*	*63.7*	*2.1*	*0.0*	0.0	1 027.9
Lower Orange	318.0	52.5	1 005.6	*25.7*	*17.5*	*9.3*	*0.0*	0.0	1 058.1
Fish to Tsitsikamma	542.4	136.4	813.2	*119.4*	*17.1*	*0.0*	*0.0*	7.5	957.1
Gouritz	279.9	75.2	276.7	*56.7*	*12.0*	*6.5*	*0.0*	15.3	367.2
Olifants/Doring	175.5	16.1	357.6	*7.0*	*6.0*	*3.0*	*0.0*	1.0	374.7
Breede	362.9	51.4	593.3	*40.1*	*11.3*	*0.0*	*0.0*	6.2	650.9
Berg	249.0	503.0	375.7	*485.5*	*17.5*	*0.0*	*0.0*	0.0	878.7
Total	**10 361.3**	**5 206.3**	**8 478.4**					**462.0**	**14 146.8**

APPENDIX C: SECTORAL WATER USE PER WMA

TABLE A-2: SECTORAL WATER USE PER WATER MANAGEMENT AREA (NEW WMA CONFIGURATION)

Water Management Area	**UGEP (million m^3/a)**	D&I	Irrigation	*Urban*	*Rural*	*Mining*	*Power*	Aff	Total
Limpopo	1 092.1	972.2	784.7	690.6	73.9	166.8	40.9	1.1	1 758.0
Olifants	928.1	478.8	850.1	104.5	78.8	101.7	193.8	47.2	1 376.1
Inkomati / Usuthu / Pongola	1 529.8	306.2	1 070.8	118.0	68.8	119.4	0.0	252.8	1 629.8
KZN Rivers	1 217.5	800.6	478.7	568.7	88.5	142.3	1.1	81.7	1 361.0
Vaal	1 607.2	1 466.2	839.6	935.1	130.3	303.9	96.9	0.0	2 305.8
Orange	991.0	252.1	1 833.9	159.5	81.2	11.4	0.0	0.0	2 086.0
E Cape Coastal Rivers	1 928.3	284.5	1 017.1	225.6	58.9	0.0	0.0	56.8	1 358.4
W Cape West Coast Rivers	424.5	519.1	733.3	492.6	23.5	3.0	0.0	1.0	1 253.4
W Cape South Coast River	642.8	126.6	870.1	96.8	23.3	6.5	0.0	21.4	1 018.1
	10 361.3		**8 478.4**					**462.0**	

APPENDIX D: PROS AND CONS OF VARIOUS WATER SOURCES

TABLE A-3: PROS AND CONS OF VARIOUS WATER SOURCES (DWAF. 2004)

	WC/WDM (Water Recycling)	**Surface Water**	**Groundwater**	**Desalination of Seawater**
Economic	Maximises use of available resources	Associated uses for dams, (recreational, fishing, etc.) flood control	Often most inexpensive option, with higher assurance of supply	Small scale possible for coastal communities
	Cost of treatment is high for some uses	generally expensive infrastructure costs increasingloy higher as easy sites disspear	Resource assessment costs high	High Operational and capital costs
Social	Educates communities on the value of water	Is often the prefered source and dams create recreational environment	Local control/management is possible	Relatively Secure
	Cultural aversion to the use of recycled water	Population displacement in relation to larger dams	Hand or wind pump delivered perceived as second rate	Alienating technology
Availability	Education is most important. Technology for retro fitting is available	Allow storage and planning	Distributed widely, seasonally reliable	Seawater quantity not a limiting factor
	Re-use of wastewater requiremsn advanced treament	Limited distribution, evaopration losses, Seasonally variable	difficult to understand for the layperson	Restricted to coastal areas
Environment	Redeuces resource impacts	Increased aqautic habitat with dam construction	Generally limited impact on ecosystems	Limited impact on water resource
	Treatment may be energy intensive	Potentially large environmental impact when dam building	May impact on groundwater dependent ecosystems	Waste byproduct and significant energy impact

APPENDIX E: GROUNDWATER GOOD AND SERVICES

Potential Services Flows and Effects of Those Services for Groundwater stored in an Aquifer:

- Potable water for residential use
- Landscape and turf irrigation
- Agricultural crop irrigation
- Livestock watering
- Food product processing
- Other manufacturing processes
- Heated water for geothermal power
- Cooling water for power plants
- Prevention of land subsidence
- Erosion and flood control through absorption of surface runoff
- Medium for wastes and other byproducts of human economic activity
- Improved water quality through support of living organisms
- Nonuse services (existence/bequest values)

Modified from NRC (1997, as quoted by Boyle and Bergstrom, 1994)

Potential Service Flows and Effects of Those Services for Surface Water and Wetland Surfaces Attributable to Ground Water Reserves:

- Surface water supplies for drinking water
- Surface water supplies for landscape and turf irrigation
- Surface water supplies for agricultural crop irrigation
- Surface water supplies for watering livestock
- Surface water supplies of food product processing
- Surface water supplies for manufacturing processes
- Surface water supplies for power plants
- Erosion, flood and storm protection
- Transport and treatment of waste and other byproducts of human economic activity through surface water supplies
- Recreational swimming, boating, fishing, hunting, trapping and plants gathering.
- Commercial fishing, hunting, trapping, and plants gathering supported by groundwater discharges

- On-site observation or study of fish, wildlife, and plants purposes supported by groundwater discharges for leisure, educational or scientific purposes.
- Indirect, off-site fish, wildlife, and plant uses (e.g. Viewing wildlife photos)
- Improved water quality resulting from organisms related to groundwater discharges
- Regulation of climate through support of plants
- Provision of nonuse services associated with surface water bodies or wetland environments or ecosystems supported by groundwater discharges.

Modified from NRC (1997, as quoted by Freeman, 1993)

APPENDIX F: DELINEATION OF SURFACE WATER AND GROUNDWATER SUPPLIES, PER CATCHMENT, FOR EACH OF THE ECONOMIC SECTORS FOR 2005

TABLE A-4: GROUNDWATER, SURFACE WATER SHARE OF IRRIGATED AGRICULTURE WATER SUPPLY, 2005 (STATSSA, 2009)

	Irrigation Water Share per WMA (Irrigated agri & Livestock) - million m^3				
Water Management Area	**SW**	**%**	**GW**	**%**	**Total**
Limpopo	96.23	38.15	155.99	61.85	252.22
Luvuvhu to Letaba	252.70	99.60	1.02	0.40	253.71
Crocodile West Marico	427.69	80.32	104.78	19.68	532.47
Olifants	507.37	85.07	89.07	14.93	596.44
Inkomati	621.82	99.71	1.78	0.29	623.60
Usutu to Mhlatuze	431.20	96.41	16.04	3.59	447.24
Thukela	216.24	98.97	2.26	1.03	218.49
Upper Vaal	118.35	85.72	19.72	14.28	138.08
Middle Vaal	132.86	80.49	32.21	19.51	165.07
Lower Vaal	493.75	92.04	42.72	7.96	536.47
Mvoti to Umzimkulu	259.71	99.79	0.54	0.21	260.26
Mzimvubu to Keiskamma	180.40	88.47	23.50	11.53	203.91
Upper Orange	700.04	84.52	128.26	15.48	828.30
Lower Orange	990.28	98.48	15.33	1.52	1,005.61
Fish to Tsitsikamma	438.29	53.90	374.88	46.10	813.17
Gouritz	213.15	77.02	63.58	22.98	276.74
Olifants/Doorn	273.46	76.47	84.16	23.53	357.62
Breede	527.92	88.97	65.42	11.03	593.34
Berg	343.90	91.54	31.79	8.46	375.70
Total	**7,225.38**	**85.22**	**1,253.05**	**14.78**	**8,478.43**

TABLE A-5: GROUNDWATER, SURFACE WATER SHARE OF MINING SECTOR WATER SUPPLY, 2005 (STATSSA, 2009)

	Mining Water Share per WMA, 2005/6 - million m^3				
Water Management Area	**SW**	**%**	**GW**	**%**	**Total**
Limpopo	9.28	62.53	5.56	37.47	14.84
Luvuvhu to Letaba	0.97	94.86	0.05	5.14	1.02
Crocodile West Marico	140.49	92.45	11.48	7.55	151.96
Olifants	69.79	69.33	30.87	30.67	100.66
Inkomati	23.65	93.71	1.59	6.29	25.24
Usutu to Mhlatuze	94.21	100.00	0.00	0.00	94.21
Thukela	49.27	99.99	0.00	0.01	49.27
Upper Vaal	169.54	80.91	39.99	19.09	209.54
Middle Vaal	80.87	91.64	7.38	8.36	88.24
Lower Vaal	-5.37	Error	11.50	Error	6.13
Mvoti to Umzimkulu	92.99	99.95	0.05	0.05	93.04
Mzimvubu to Keiskamma	0.00	0.00	0.00	0.00	0.00
Upper Orange	-0.05	Error	2.18	Error	2.12
Lower Orange	-32.53	Error	41.79	Error	9.26
Fish to Tsitsikamma	-0.32	Error	0.32	Error	0.00
Gouritz	6.52	99.71	0.02	0.29	6.54
Olifants/Doorn	1.98	65.55	1.04	34.45	3.01
Breede	0.98	97.60	0.02	2.40	1.00
Berg	0.98	98.19	0.02	1.81	1.00
Total					

*Error values displayed are due to conflict between the modelled water supply data and the estimated groundwater supply data.

TABLE A-6: GROUNDWATER, SURFACE WATER SHARE OF URBAN DOMESTIC/COMMERCIAL/INDUSTRIAL WATER SUPPLY, 2005 (STATSSA, 2009)

	Urban Domestic/Commercial/Industrial Water Share per WMA, 2005/6 - million m^3				
Water Management Area	**SW**	**%**	**GW**	**%**	**Total**
Limpopo	19.95	45.91	23.50	54.09	43.45
Luvuvhu to Letaba	0.82	8.06	9.41	91.94	10.23
Crocodile West Marico	656.87	95.47	31.15	4.53	688.02
Olifants	281.58	97.75	6.47	2.25	288.05
Inkomati	65.50	98.87	0.75	1.13	66.25
Usutu to Mhlatuze	51.00	98.53	0.76	1.47	51.76
Thukela	56.64	99.78	0.12	0.22	56.77
Upper Vaal	846.75	97.78	19.26	2.22	866.01
Middle Vaal	87.28	90.40	9.27	9.60	96.55
Lower Vaal	41.98	60.42	27.50	39.58	69.49
Mvoti to Umzimkulu	510.01	99.42	2.96	0.58	512.97
Mzimvubu to Keiskamma	105.68	99.47	0.56	0.53	106.25
Upper Orange	127.48	95.28	6.32	4.72	133.80
Lower Orange	17.20	66.82	8.54	33.18	25.73
Fish to Tsitsikamma	111.03	93.01	8.34	6.99	119.37
Gouritz	42.78	75.50	13.88	24.50	56.66
Olifants/Doorn	4.69	66.63	2.35	33.37	7.03
Breede	30.83	76.87	9.28	23.13	40.10
Berg	449.26	92.53	36.28	7.47	485.53
Total	**3,507.32**	**94.18**	**216.69**	**5.82**	**3,724.01**

TABLE A-7: GROUNDWATER, SURFACE WATER SHARE OF RURAL DOMESTIC WATER SUPPLY, 2005 (STATSSA, 2009)

	Rural Water Share per WMA, 2005/6 - million m^3				
Water Management Area	**SW**	**%**	**GW**	**%**	**Total**
Limpopo	16.18	54.51	13.50	45.49	29.67
Luvuvhu to Letaba	20.79	65.57	10.92	34.43	31.71
Crocodile West Marico	25.64	57.91	18.64	42.09	44.27
Olifants	29.71	63.06	17.40	36.94	47.12
Inkomati	18.32	67.01	9.02	32.99	27.34
Usutu to Mhlatuze	30.03	72.53	11.38	27.47	41.41
Thukela	27.79	83.70	5.41	16.30	33.20
Upper Vaal	47.47	91.15	4.61	8.85	52.08
Middle Vaal	32.82	98.79	0.40	1.21	33.22
Lower Vaal	31.10	69.18	13.86	30.82	44.96
Mvoti to Umzimkulu	41.97	75.86	13.35	24.14	55.32
Mzimvubu to Keiskamma	18.82	44.95	23.04	55.05	41.85
Upper Orange	62.75	98.49	0.96	1.51	63.72
Lower Orange	17.49	99.95	0.01	0.05	17.50
Fish to Tsitsikamma	16.77	98.37	0.28	1.63	17.05
Gouritz	11.83	98.67	0.16	1.33	11.98
Olifants/Doorn	5.88	97.53	0.15	2.47	6.03
Breede	11.02	97.38	0.30	2.62	11.31
Berg	17.28	98.91	0.19	1.09	17.47
Total	**483.66**	**77.11**	**143.57**	**22.89**	**627.23**