DEVELOPMENT OF A GROUNDWATER MANAGEMENT PLAN AND APPLICABILITY ON DIFFERENT AQUIFER TYPES

Stefanus Andreas Fourie

Submitted in fulfilment of the requirements for the degree

Magister Scientiae in Geohydrology

in the

Faculty of Natural and Agricultural Sciences

(Institute for Groundwater Studies)

at the

University of the Free State

Supervisor: Prof. Danie Vermeulen

January 2020

DECLARATION

I, Stefanus Andreas Fourie, hereby declare that the dissertation hereby submitted by me to the Institute for Groundwater Studies in the Faculty of Natural and Agricultural Sciences at the University of the Free State, in fulfilment of the degree of Magister Scientiae, is my own independent work. It has not previously been submitted by me to any other institution of higher education. In addition, I declare that all sources cited have been acknowledged by means of a list of references.

I furthermore cede copyright of the dissertation and its contents in favour of the University of the Free State.

In addition, the following two papers have been:

- **presented at the 46th IAH Congress Malaga, Spain 2019,**
- **presented at the 16th Groundwater Division Biannual Conference, Port Elizabeth, 2019**
- **submitted and are under review at the corresponding journal:**

PAPER submitted for publication:

1. Fourie, S.A., Vermaak, N. & Vermeulen, D., 2020. The relationship between Groundwater Governance and Management at Local Municipal Level. *Journal of African Earth Sciences*.

2. Fourie, S.A., Vermaak, N., Vermeulen, D. & Lourens, P., 2020. A practical guide to conserving groundwater underground. *Journal of African Earth Sciences.*

SA Fourie

15 January 2020

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to all who have motivated and helped me in the completion of this dissertation:

- Firstly I would like to prise to my Lord and Saviour who blessed me, gave me the knowledge and strength to writeup this dissertation.
- My colleagues in Integrated Hydrological Planning for their support and encouragement. However, special thanks to Awodwa and Thandilizwe shared late nights and early morning together the last three years, finishing our M.Sc.'s.
- To the Institute of Groundwater Studies especially Eelco, Anneke and Paul, for the positive encouragement, financial support and sponsorship to IAH congress in Spain.
- To Danie Vermeulen for his support, encouragement, guidance to push for excellence and his belief in me.
- To Nicolette Vermaak that got me started with my studies, motivated, guided, and that was always there for a quick word of support and encouragement.
- And lastly but not least, my family. My wife, Carina, who is my biggest support, whom I owe a lot of sleep and date nights. Furthermore, my children, Fanie and Estmari who were always there with a cup of coffee.

ABSTRACT

The sustainability of groundwater as a domestic source of water is sometimes questioned because of the regular failure of water supply from groundwater to communities. The sustainability of the supply from groundwater sources cannot be only linked to the amount of groundwater that is abstracted from the aquifer but is directly linked to the management of the external environment around the aquifer or wellfield. The basic understanding and the complexity of groundwater management, the various aspects of groundwater management that can be identified and addressed in a management plan, and that can be implemented in a specific time frame, is the aim of this study. The concept of 'management' and a 'plan', including the difference between management and governance and how the difference is managed at a local scale provide a clear understanding for which groundwater management actions the Local Authority responsible for. The concept of groundwater management is divided into twelve principles and described in detail to explain the notion of each principle for when the management objectives are developed during the plan. The external drivers and legal framework setting that influences groundwater management are also explored. The characteristics of Groundwater Management Plans (GwMPs) were analysed from 32 GwMPs of world organisations, international (outside RSA) which included transboundary aquifers and authorities within South Africa. The five world organisations GwMPs were explicitly analysed for the development approach: preparation, development and implementation phases. The twenty international and sewen local GwMPs provide the opportunity to assess the legal/regulatory background, the purpose, the validation period, the elements, structure and format of each GwMP. The management objectives of all the GwMPs were tabled and classified according to the twelve groundwater principles. The result of the detailed assessment was a generic three-phase approach to prepare, develop and implement a GwMP. A Table of Content with element or chapters that can be used with the develop the GwMP to ensure all aspects are addressed and implementation is feasible. A final list of 150+ management objectives is addressing the most possible actions to manage the groundwater at a local authority. The challenges of implementing a GwMP can mostly be addressed by leadership and institutional arrangements. A summary template was developed to extract the operational information from the GwMP for daily use. Ultimately, this study concluded with the applicability of the summary template at three different aquifer types.

Keywords: groundwater management plans, governance, principles

TABLE OF CONTENTS

CHAPTER 1 : INTRODUCTION 11

1.1 BACKGROUND 11

1.2 PROBLEM STATEMENT AND RATIONALE 11

1.3 AIMS AND OBJECTIVES 13

1.4 SCOPE OF THE STUDY AND OUTLINE 13

CHAPTER 2 : GROUNDWATER MANAGEMENT 14

2.1 INTRODUCTION 14

2.2 GOVERNANCE VS MANAGEMENT 14

2.2.1 Water Governance and Management 15

2.2.2 Groundwater Governance 16

2.2.3 Groundwater Management 19

2.2.4 Functional Levels 20

Institutional relations 21

2.2.5 Governance and Management Relationship 22

Government Levels 22

Governance and Management Functions Relationship 24

Functions 26

Scenarios 29

2.2.6 Summary 33

2.3 WHAT IS A "PLAN"? 34

Management plan 35

2.4 PRINCIPLES 35

2.4.1 Protection 38

Protection Zones 38

Borehole protection 40

2.4.2 Regulation 41

Authorisation 41

Measures 42

2.4.3 Use 43

2.4.4 Planning 44

Resource Investigational Planning phase 45

Planning Cycle 46

Resource Development and Operational Planning phases 47

2.4.5 Monitoring 49

Collection 49

Capturing & reporting 51

2.4.6 Conservation 51

Recharge enhancement 53

2.4.7 Operation 54

Operating rules 54

Borehole rules *54*

Wellfield rules *55*

Aquifer rules *56*

2.4.8 Infrastructure 58

Maintenance 58

2.4.9 Assessment 59

2.4.10 Institutional Arrangements 61
2.4.11 Capacity and Skills 63
2.4.12 Awareness, Information, Communication and Stakeholder participation 64
2.4.13 Summary 66
2.5 'EXTERNAL DRIVERS' 68
2.6 LEGISLATION AND REGULATORY FRAMEWORK 69
2.6.1 Legislation 69
2.6.2 Framework and tools 71
National Water Resource Strategy 71
National Groundwater Strategy 72
Other regulatory tools 73
2.6.3 Enforcement 73
CHAPTER 3 : GROUNDWATER MANAGEMENT PLAN 74
3.1 INTRODUCTION 74
3.1.1 Characteristics 74
Planning horizon 76
3.2 EXAMPLES OF EXISTING GROUNDWATER MANAGEMENT PLANS 76
3.2.1 World Organisations 77
Development Approaches 77
Goals/Objectives 78
3.2.2 International 81
Purpose and Validity Period 82
Elements, Structure and Format 84
Author and Implementation Champion 87
Preparatory phase information 88
Goals or Objectives 89
3.2.3 Local 90
Development Approaches 92
Elements, Structure and Validity Period 94
Management Objectives 95
3.2.4 Summary 96
3.3 DEVELOPMENT OF AN GWMP FRAMEWORK 97
3.3.1 Development Approach 98
3.3.2 Table of Content 100
Elements or Chapters 100
Management Objectives 101
3.3.3 Implementation Approach 106
Operations and maintenance plan 109
3.3.4 Summary Template 109
Generic GwMP Summary Template 109
3.4 IMPLEMENTATION CHALLENGES 112
3.4.1 Leadership, institutional or organisational arrangements 112
CHAPTER 4 : APPLICABILITY OF GROUNDWATER MANAGEMENT PLANS AT DIFFERENT AQUIFER TYPES 113
4.1 INTRODUCTION 113
4.2 APPLY GWMP FRAMEWORK AT AN ALLUVIAL AQUIFER: GROOTWATER AQUIFER 114

4.3 APPLY GWMP FRAMEWORK AT AN ALLUVIAL AQUIFER SYSTEM: WEST COAST AQUIFER SYSTEM 115
4.4 APPLY ON FRACTURE ROCK AQUIFER: BEAUFORT WEST LM 116
4.5 DISCUSSION 117

CHAPTER 5 : CONCLUSIONS 119

REFERENCES 121

OPSOMMING

APPENDIX A: TABLES OF CHAPTER 3

Table 3.10: List of Management Objectives from twenty international GwMPs
Table 3.14 List of Management Objectives from seven South African GwMPs that appear ONLY in the South African GwMPs
Table 3.15: List of ALL the Management Objectives from South African GwMPs that appear ONLY in the South African GwMPs AND that appear BOTH in the international and South African GwMPs

APPENDIX B: GENERIC FORMAT OF A GWMP SUMMARY (A3 SIZE)

LIST OF FIGURES

Figure 2.1: Governance and management functions across government levels; (Riemann et al., 2016:32) 23

Figure 2.2: Comparison between Governance and Management functions at different government levels 23

Figure 2.3: Straight line relationship between Governance and Management 24

Figure 1.1: Flexible line relationship between Governance and Management with two examples (line C and D) 24

Figure 2.5: The relationship between Governance, Implementation Governance and Management at different government levels..... 28

Figure 2.6: The Local Governance focus area in relationship with Governance, Implementation Governance, and Management 29

Figure 2.7: The relationship between Governance and Management in Blouberg Local Municipality..... 30

Figure 2.8: The relationship between Governance and Management in Beaufort West 31

Figure 2.9: The relationship between Governance and Management in Calvinia..... 31

Figure 2.10: The relationship between Governance and Management in the City of Cape Town 32

Figure 2.11: The relationship between Governance and Management in Rural Village 33

Figure 2.12: The Principal groundwater management tasks (adapted from DWAF, 2004 and Riemann et al., 2010) 37

Figure 2.13: Idealized scheme of groundwater capture areas and transit-time perimeters around boreholes: a) unconfined aquifer and b) locally confined aquifer (Foster et al., 2002) 40

Figure 2.14: Groundwater availability versus water use change over time with timeous planning and development groundwater resources (adapted from Robins et al., 1997)..... 44

Figure 2.15: Water resource planning phases to develop a groundwater resource (DWS, 2017). 47

Figure 2.16: Groundwater resource planning phases to develop a groundwater resource (DWS, 2017 and Fourie, 2017)..... 48

Figure 2.17: Example of the pumped volume received at the reservoir per hour according to the wellfield operating rule 56

Figure 2.18: Contrasting response and recovery functions of groundwater and surface water to drought (Robins et al. 1997) 57

Figure 2.19: Institutional levels of government with horizontal management linkages within the groundwater sphere (FAO, 2016a) 63

Figure 2.20: NGS Groundwater Governance Framework (NGS, 2017) 72

Figure 3.1: Examples of tasks, timelines and actions 108

Figure 3.2: Example of an Implementation Schedule 108

Figure 3.3: Generic format of a GwMP Summary 111

LIST OF TABLES

Table 2.4: Tasks of an operator of a borehole (adopted from DWA; 2009, Riemann et al., 2010; Cobbing et al. 2014 and CDM, 2013) 59

Table 2.5: Some groundwater management Strategic Actions from the NGS 73

Table 3.1: Groundwater management interlinking factors 75

Table 3.2: Aligning GwMP pragmatic frameworks or planning approaches of three Organisations 78

Table 3.3: List of Management Objectives from GwMPs of five world organisations 79

Table 3.5: Purpose and Validity Period of the various Groundwater Management Plans 82

Table 3.7: The Format of 6 Groundwater Management Plans 86

Table 3.8: Water Resources information 88

Table 3.9: Other additional data/information 88

Table 3.10: List of Management Objectives from twenty international GwMPs 89

Table 3.11: List of seven South African GwMPs with Status and Purpose 91

Table 3.12: The development approaches from four Local GwMPs 93

Table 3.13: Elements of the Structure from 6 Groundwater Management Plans from South Africa 94

Table 3.14: List of Management Objectives from seven South African GwMPs that appear ONLY in the South African GwMPs..... 95

Table 3.15: List of ALL the Management Objectives from South African GwMPs that appear ONLY in the South African GwMPs AND that appear BOTH in the international and South African GwMPs 96

Table 3.16: The three-phase approach to prepare, develop and implement a GwMP (adapted from FAO, 2016a)..... 98

Table 3.17: Element of a generic GwMP Table of Content 100

Table 3.18: Management Objectives of GwMPs. 101

Table 3.19: Posible Short term implementation actions 106

CHAPTER 1 :

INTRODUCTION

1.1 BACKGROUND

More than sixty present of South Africa's population is making use of groundwater as a source of water for their livelihood. The management of a water resource that you cannot see makes it even more challenging to manage. In most cases, the responsibility of managing the groundwater resource is the responsibility of the users themselves or the local municipality and not government like in the case of most surface water (dams and run-of-river schemes).

The sustainability of the supply from groundwater sources cannot be only linked to the amount of groundwater that is abstracted from the aquifer but is directly linked to the management of the external environment around the aquifer or wellfield.

The management of these groundwater resources depends on different factors that need to be in place to ensure the supply of sustainable water. Any surface activity may have an impact on the groundwater underneath the activity or a few kilometres away.

1.2 PROBLEM STATEMENT AND RATIONALE

The sustainability of groundwater as a domestic source of water is sometimes questioned because of the regular failure of water supply from groundwater to communities. Over the past years, some research has been done on possible reasons and solutions to the problem. The recommendation focuses mainly on one thing, and that is the management of the groundwater scheme/wellfield or borehole. The management of a groundwater does not include only the pump operation rules but much more. A recent study indicated that only 13% and 29% of towns that use groundwater in the Northern Cape and Free State respectively have some kind of a plan to manage groundwater (Kotzé et al. 2019).

The FAO (2016a) Groundwater Governance project provided guidance on ways to address groundwater governance and improve groundwater management. The National Groundwater Strategy incorporates the Groundwater Governance project framework (NGS, 2016). Transforming

the governance framework into action in pursuit of policy goals for groundwater systems, various planning processes are required that will result in a structured programme of action for priority aquifer systems.

The planning process is evidence-based, transparent and contestable — and the resulting plans create a framework of accountability.

The planning process and the resulting programmes of action bring several advantages. They create a transparent, evidence-based process that involves stakeholders and is open to contest. Plans are prepared as a cooperative effort between national ministries, local agencies and relevant stakeholders, which leads to co-ownership. The process produces a formal document that can be validated, with time-bound actions and indicators that can be monitored, and outputs and outcomes that can be evaluated. It includes a budget linked to outputs and is subject to review as performance is tracked and conditions change. Planning thus forms the bridge between governance provisions and practical management.

Various “groundwater management plans” were developed around the world, but the format varies tremendously. In South Africa, very few attempts were made to provide a plan. Hermanus and Botleng (Delmas) serve as an example of a framework, but no specific standard format was provided (Riemann et al. 2010) or it has not been implemented yet (Pietersen et al. 2011).

The groundwater strategy developed in 2002 (with the DANCED project) for South Africa already identified the gaps in “management plans” for a borehole or wellfield to manage the risk of over-use (DANCED, 2004) and focus specificly on the operations. In 2016 the this view was elivated in the National Groundwater Strategy with the referral to the implementation and development of aquifer management plans (more than seven times in the strategy) (NGS, 2016) which includes activities outside that impacts the wellfield.

What information must be in a detailed groundwater management plan? How would a groundwater management plan be developed for different types of aquifers like coastal and Karoo rock aquifer?

1.3 AIMS AND OBJECTIVES

The main aim of the study is to investigate whether existing groundwater management plan methodologies can be standardised and applied on different types of aquifers for South African conditions.

The objectives of the study are to evaluate the principles of how groundwater is managed at the local municipality level, as well as the methodologies of various internationally and locally groundwater management plans. By evaluating various existing plans, a generic groundwater management plan framework can be developed. This generic groundwater management plan framework can be applied on different levels, scale and aquifer types in South Africa.

1.4 SCOPE OF THE STUDY AND OUTLINE

The basic understanding and the complexity of groundwater management, the various aspects of groundwater management that can be identified and addressed in a management plan, and that can be implemented in a specific time frame, is the aim of this study. In order to achieve a practical and implementable groundwater management plan (GwMP), the following methodology followed with this dissertation:

- The difference in understanding of groundwater governance and groundwater management with the relationship defined at various municipal scenarios.
- Review the current groundwater management principles to understand the complexity and the components involved with the regulatory framework groundwater operates;
- Review current GwMPs that is available from world organisations, internationally and locally.
- Develop a generic GwMP framework for different levels (catchment, local, aquifer) with a approach, Table of Content and Implementation challenges;
- Test the applicability of current available information in a primary aquifer, an aquifer system and an Karoo fractured aquifer.

CHAPTER 2:

GROUNDWATER MANAGEMENT

2.1 INTRODUCTION

Groundwater has distinctive characteristics that make it difficult for efficient and effective management. The invisible-slow-distributed (ISD) signature of groundwater presents the opportunity to be negatively exploited and polluted under a reactive management setup, rather than a pro-active structure of governance and planning (Villholth and Conti, 2018). The character of groundwater involves the governance of the environment as well as other land and water resources. The civil society pressure for improved environmental quality and climate change adaptation is mounting, which in return can have a positive influence on the efforts for enhanced groundwater resource governance (Foster et al., 2010).

This chapter starts by exploring the concept of 'management' and a 'plan', including the difference between management and governance and how the difference is managed at a local scale, the various principles under the concept of groundwater management, and external drivers that influence groundwater management. However, groundwater management can only work within a set legal framework.

2.2 GOVERNANCE VS MANAGEMENT

The terms 'Management' and 'Governance' are used interchangeably when referring to groundwater policy, protection, operations, financial systems, infrastructure, etc. to name a few. The difference between the broad terms 'governance' and 'management' needs to be defined in order to understand what the meaning of groundwater management is and what it entails.

Various definitions are used to describe governance, but 'Governance' in a broad sense involves the institutions, processes and mechanisms where the country's people can raise their concerns or interests; reconcile their differences; and fulfil their legal rights and responsibility (UNDP, 2001 cited in Rodgers and Hall, 2003; Foster et al., 2010). Villholth and Conti (2018) summarise governance in four concepts, namely: a process, a relationship, an interaction and a framework. In the FAO/GEF project "Groundwater Governance: A Global Framework for Country Action" Wijnen

et al. (2016) define governance in a more simplified way as “the operation of rules, instruments and organisations that can align stakeholder behaviour and actual outcomes with policy objectives”. It relates to the “power, relationships and accountability: who has influence, who decides, and how decision-makers are held accountable” (Graham et al., 2003; Riemann et al., 2016). The fundamental principle of good governance includes responsiveness, transparency, accountability, equity, participation, direction, effectiveness and efficiency (Graham et al., 2003).

The FAO/GEF project “Groundwater Governance: A Global Framework for Country Action” (FAO, 2016b) also define management as follow:

> *“Management: The term ‘management’ is perhaps easier to grasp intuitively than it’s more layered and ambitious cousin ‘governance.’ We tend to think of management as the “nitty-gritty of day-to-day operations” that emphasise the results of decisions (Linton and Brooks, 2011). Other similar notions are: “approaches, models, principles, and information used to make decisions” (Bakker, 2007, cited in Nowlan and Bakker, 2010); “regimes based on institutions, laws, cultural factors, knowledge, and practices” (Solanes and Jouravlev, 2006); or purposeful activities that enable the accomplishment of goals and objectives (de Loe and Kreutzwiser, 2005; Pahl-Wostl, 2007), with a common caveat, “by definition, based on conflicting interests” (Wolf, 2007). All these definitions share a concern for routine, practical, and effective ways to achieve predetermined objectives.”*

The difference in the two definitions can be summarised as the process vs the practical ways to achieve the objectives.

2.2.1 Water Governance and Management

To bring ‘governance’ into the water spectrum, “water governance” can be defined as the corresponding framework for effective water resource management that will include the delivery of all water services in an environmentally-sustainable, economically-efficient and socially-responsible manner (Foster et al., 2010). In simple terms, it is ”the set of systems that control decision-making with regards to water resource development and management” (Batchelor, 2007).

Water governance comprises the **processes** (Foster et al., 2010):

- of defining policy options;
- of translating them into goals;
- of providing institutions, procedures, means, monitoring and accounting;
- of enabling stakeholder participation; and
- of taking responsibility for outcomes.

The relationship between water governance and water management can also be seen in a layered approached (like an egg) with the institutional arrangement as the middle layer (Riemann et al., 2016). The outside protective layer (the "shell") represents governance where the policies and the crosscutting implementation is taking place at different sectors and different scales. The middle layer (the "egg white") represents the institutional setup that is needed to make sure the policies are implemented and form the link between the local water user and the highest level of government. These institutions will include the Department of Water & Sanitation National and Regional offices, Catchment Management Agencies, and Water Users Associations. Management is the central layer (the "egg yolk") of this relationship with the main aspects being the Operation & Maintenance and monitoring.

2.2.2 Groundwater Governance

The concept or term of groundwater governance is relatively new and only surfaced in the late 2000s. Before this time, integrated water resource management (IWRM) and sustainable water management (SWM) approaches were used to describe the way we manage our groundwater resources. Both IWRM and SWM approaches have been challenging to implement (Biswas and Tortajada, 2011 cited by Villholth and Conti, 2018) and a new way was needed to address all the aspects that may be affecting the way groundwater is being impacted, used, protected and managed.

Foster (2010) define groundwater governance as:

> *"the exercise of appropriate authority and promotion of responsible collective action to ensure sustainable and efficient utilisation of groundwater resources for the benefit of humankind and dependent ecosystems".*

Varady (2016) adapted the Saunier and Meganck definition of governance in the *Dictionary and Introduction to Global Environmental Governance* (2007) to define Groundwater governance as:

> *"The process by which groundwater is managed through the application of responsibility, participation, information availability, transparency, custom, and [the] rule of law. It is the art of coordinating administrative actions and decision making between and among different jurisdictional levels-–one of which may be global*."

Foster and Garduño (2013) later changed his definition to be more in line with Saunier and Meganck (2007) and later Varady (2016), and defined groundwater governance as follows:

> *"the enabling framework and guiding principles for responsible collective action to ensure control, protection and socially - sustainable utilisation of groundwater resources for the benefit of humankind and dependent ecosystems."*

Effective water governance is needed:

- to alleviate the pressure of the increasing demand
- the access to clean water because unpolluted water is becoming scarce
- to be more accountable and transparent due to corruption
- to decentralise the management of the water sector and thus to reform the sector to have decision making at lower levels
- to minimise the insecurity of water rights and the unequal distribution of water rights and
- to achieve gender equality (Batchelor, 2007).

The outcome of the FAO/GEF project "Groundwater Governance" (FAO, 2016a; 2016b, 2016c) indicated that groundwater governance involves, 'an enabling framework and guiding principles' and the 'promotion of responsible collective action' or in simple terms a process to ensure an outcome. This is based on four components, namely: legal and institutional frameworks; actors; policies and plans; and information, knowledge and science.

> *"Groundwater governance comprises the enabling framework that establishes **who** formulates policies and strategies and is responsible for their execution (**the actors**) and **how** different stakeholders interact (**the legal and institutional framework**). Decisions made by the actors regarding what to do in pursuit of societal goals are driven by **information, knowledge and science**, and result in*

> ***policies and plans*** *which define* ***why*** *activities are needed and* ***when*** *they should be undertaken or completed."* (FAO, 2016c)

Villholth and Conti (2018) developed the definition further and offered a definition that highlighted the 'who', 'what', 'where', and 'how' of groundwater governance. The split between management and governance can also be noted:

> *"Groundwater governance is a framework encompassing the processes, interactions, and institutions, in which actors (i.e. government, private sector, civil society, academia, etc.) participate and decide on management of groundwater within and across multi-geographic (i.e. sub-national, national, transboundary, and global) and institutional/sectoral levels, as applicable."* (Villholth and Conti, 2018)

Seward (2015) puts it in a simple definition as groundwater governance is the process of making, implementing and enforcing the rules that relate to groundwater.

Sometimes there is also confusion between groundwater governance and the approaches of integrated water management (IWM), integrated water resource management (IWRM) and sustainable water management (SWM).

Bosman (2007) refers to the 2003 World Water Forum that defines the objectives of IWM as *"a Strategic means of balancing water use and protection across entire catchments/ river basins in order to achieve economic, social and environmental goals …. through institutions at the catchment level … and also includes assessment and monitoring to obtain reliable management information about consequences, risks and liabilities".*

Burke (2007) defines IWRM as "*an approach that seeks to reach an appropriate balance between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other*". The Global Water Partnership has a more 'integrating' definition: "*IWRM is a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems"* (GWP, 2000).

SWM comprises of the following elements: meeting protection of the components in the sustainability triple bottom line: economy, environment, and society; should contribute to the objectives of society and maintain hydrologic integrity, environmental, and ecological; and current water demand for all water users without impairing future supply (Russo et al., 2014).

2.2.3 Groundwater Management

The word “Management” is described as “the **control** and **organisation** of something” according to the Cambridge Dictionary (2018) with the emphasis on a practical ‘action’ that needed to be executed.

The Synthesis Report of the FAO/GEF project “Groundwater Governance: A Global Framework for Country Action” (FAO, 2016b) defines groundwater management as follow:

> *“the set actions to implement decisions that derive from the process of governance”.*

And groundwater resources management (FAO, 2016b) defined as follow:

> *“a planned and on-going activity to optimise the exploitation and use of local, regional or national groundwater resources, taking into account the sustainability of the groundwater resources and the groundwater-related environment and ecosystems”.*

It is action-orientated and uses regulatory and legal instruments, technical instruments, and incentives or disincentives to achieve its goals (FAO, 2016c). It can only be reached through the involvement of scientist that determine the rules about groundwater availability and water managers implementing those rules (Mukherji and Shah, 2005 cited by Seward et al., 2015). Foster (2010) takes the stand that the focus must be on influencing the behaviour of the individual groundwater user and the potential polluters rather than the top-down allocation of a clearly defined natural resource. Seward (2015) simplified groundwater management as “*implementing those decisions*” made by the groundwater governance process.

The definition evolved and in the last document published by the project ‘Groundwater Governance: A Global Framework for Action’ (2011-2016) the “Global Framework for Action to achieve the Vision on Groundwater Governance” (FAO, 2016a) groundwater management was defined as follows:

> *“Groundwater management comprises the activities undertaken by mandated actors to sustainably develop, use and protect groundwater resources.”*

It further built upon by adding “control” the groundwater resources to the definition (FAO, 2016c).

Stakeholder participation is also needed but needs to be facilitated by the local organisation (Garduño, G. and Foster, S. 2010) like a municipality or water board that takes the responsibility

and sustainably manage groundwater. By ensuring groundwater management, stakeholder participation can occur at different levels, and it also contributes to groundwater protection and conservation.

Seward (2015) summarises the difference between groundwater governance and groundwater management as "groundwater governance involves a lot more than groundwater management". In other words, groundwater governance is the process of making decisions (the 'who', 'how', 'why' and 'when' to do) and groundwater management is about implementing those decisions (the 'what' and the 'where' to do). Alternatively, in the words of the FAO project (FAO, 2016c):

> *"Groundwater management is **what** the actors do within the governance framework; activities related to the development and protection of groundwater to implement the policies and plans which have been established. The hydrogeological conditions and distribution of human activities will determine **where** these management activities are required."*

2.2.4 Functional Levels

Governance and management are not separate scales of action, but different processes. Both processes can take place together at local, regional, national or global scales (Seward, 2015). Groundwater management at local level are challenging to pull to scale because of the different elements of the aquifer settings (Moench et al., 2016). There are several frameworks used to assess/analyse groundwater governance levels. The analytic framework (Wijnen et al., 2016) distinguishes three levels of the groundwater governance system, namely: policy level, strategic level and the local government level:

- *Policy level*: the nation sets its objectives for groundwater
- *Strategic level governance* functions: setting up the institutions and instruments to align stakeholder behaviour and actual outcomes with policy objectives, and
- *Local-level governance*: organisations and institutions that control the actual outcomes on the ground and which respond in varying degrees to rules and incentives from a strategic governance level.

The Groundwater Governance: A Global Framework for Action project (FAO, 2016a) also distinguishes between different levels of groundwater management, namely National, Provincial/Basin and Local (District/catchment) levels.

- *National level management*: resource status reporting, financing measures, legal provision, policy integration or harmonisation.
- *Provincial / Basin level management*: resource allocation, detailed planning, monitoring strategy or data management.
- *Local level management* (District / catchment): resource administration / regulations, demand/supply-side measures, use/resource monitoring, plan elaboration/ implementation, resource / source protection.

The concept of Local Groundwater Governance and Local Groundwater Management is sometimes mixed up by different authors in the literature because it so closely linked and the concept of governance at the local scale is relatively new (late 2000's) in the groundwater sector. The term for governance was in the past linked to what the government is doing at a national and provincial level and the concept of management to the municipal or local level. However, this has changed with the concept of local groundwater governance. The management of an aquifer is within the framework of groundwater governance.

The 'effective governance' of groundwater resources can only take place at the aquifer level (Foster, 2010). This concept was taken further by Wijnen et al. (2016) with the term 'local governance' to describe the local implementation of the rules and incentives from higher governance levels.

Institutional relations

There is an organisational arrangement in the water sector from a state level to a local level with different departments, agencies and local authorities involved. The same processes occur on political, social and ecological environments – 'parallel-track approach' (Foster, 2010). This approach is being supported by the Groundwater Governance project (FAO, 2016a) with 'horizontal policy integration' at each level with other organisations and sectors impacting on groundwater to provide for inter-sectoral and inter-agency coordination, joint planning, etc.

Groundwater always has a governance and management component. The influences from the different levels of government are also linked. National-level policies and initiatives will influence

the local level and vice versa. Although governance is seen as a more national government function, some governance function can only be facilitated at a micro (local) level and not at the macro (national) level. This concept gave rise to the approach of national thinking but local implementation.

On strategic planning (macro or national) level the national water use and land use properties; food and energy policies; river basin context; legal framework; and institutional provisions can be governed. On the local (or aquifer) level groundwater use rights and protection policies; the role of local government; and stakeholder awareness and participation need to be governed. The strategic planning level and the local aquifer level are linked, by demand and supply interventions. The economic instruments are determining the effectiveness of the facilitation at local level management of groundwater. These four elements are all linked, and now the groundwater resource governance and practical management can result in a 'top-down' and 'bottom-up' approach. Thus Foster coined the phrase "top-down facilitation of local action" (Foster, 2006 cited by Braune et al., 2008 and NGS, 2017).

2.2.5 Governance and Management Relationship

Governance and management can, in most cases, not be split into two blocks and handled separately. To have a sustainable groundwater resource supply to a community both groundwater governance and groundwater management need to be in place. At all governance's levels, both governance and management tasks are performed.

Government Levels

Riemann et al. (2016) provide a figure (Figure 2.1) to indicate the various institutions responsible for water resource management working at different levels of government. At the national government level, the responsibility to govern is more significant than to manage with a responsibility like policies, authorisations and legislation. The opposite is then also true that at the local municipal level, more management is taken place than governance with responsibilities like operations, monitoring and compliance.

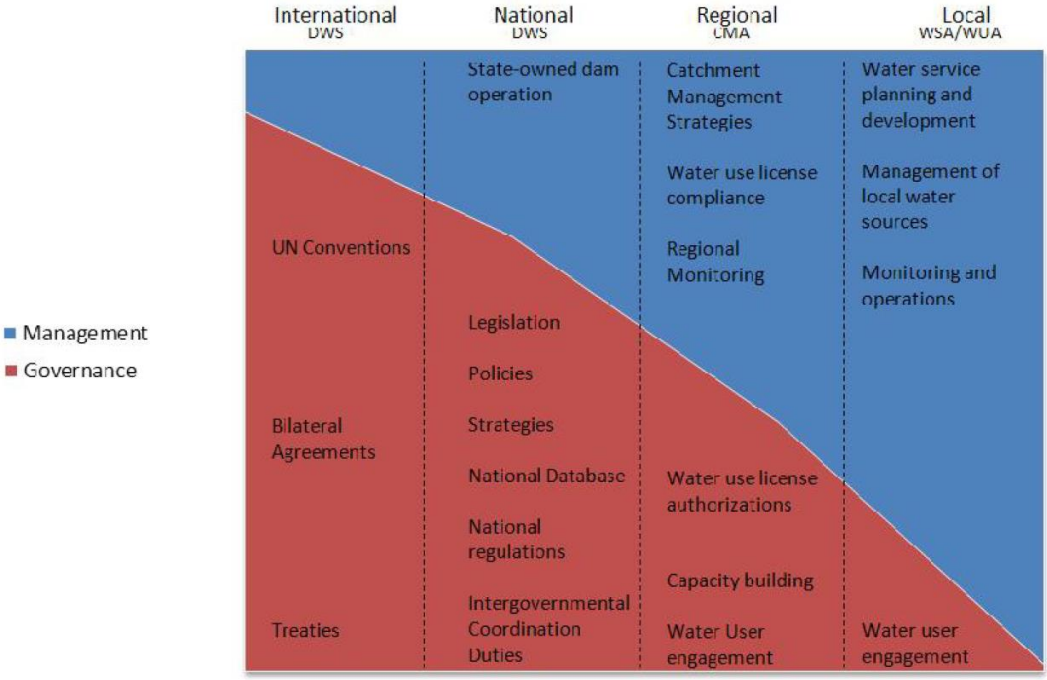


Figure 2.1: Governance and management functions across government levels; (Riemann et al., 2016:32)

The description above indicates that all the different levels of government have governance and management functions, responsibilities and roles. The number of functions, responsibilities and roles at the different levels of government will differ. Figure 2.2 compares the various government levels to each other in respect to the amount of governance and management functions, responsibilities and roles they perform.

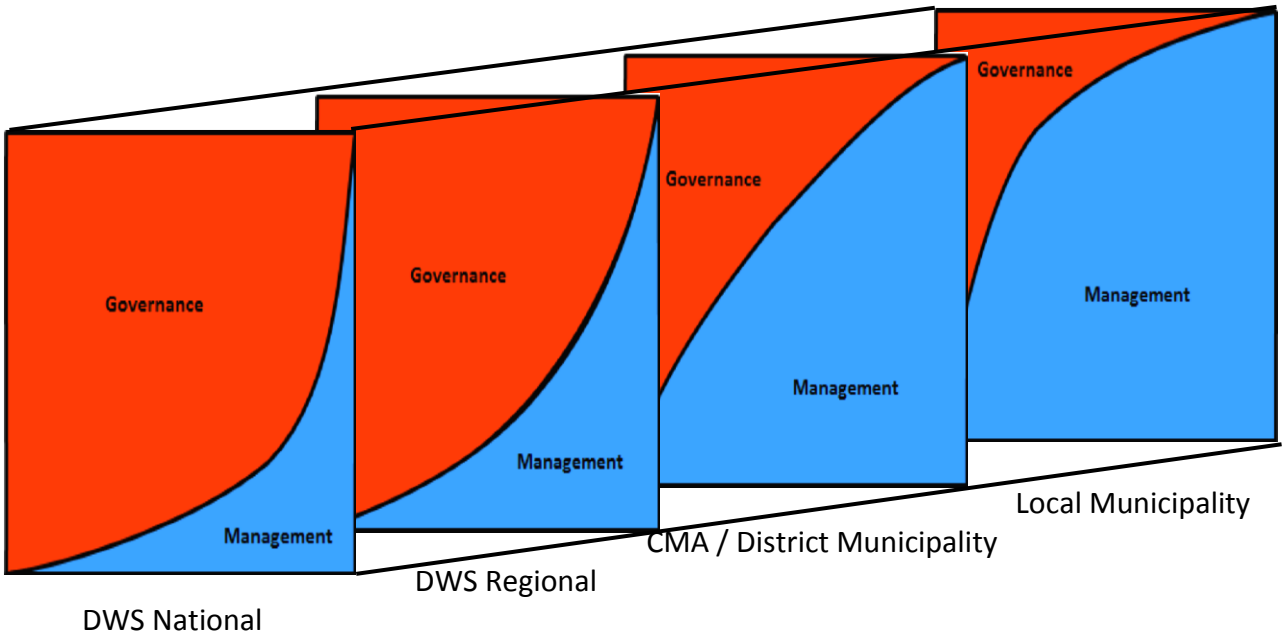


Figure 2.2: Comparison between Governance and Management functions at different government levels

Figure 2.1 of Riemann (2016) is viewed as a 2D version of governance and management functions across the government levels, and by adding the "parallel-track approach" of Foster (2010), Figure 2.2 can be seen as a 3D representation of the different levels.

Governance and Management Functions Relationship

In most cases, we think the line between governance and management is a straight line with a direct relation (Figure 2.3). The more governance occurs, the less management occurs with a fixed proportional relation between the different government levels with regards to government and management functions.

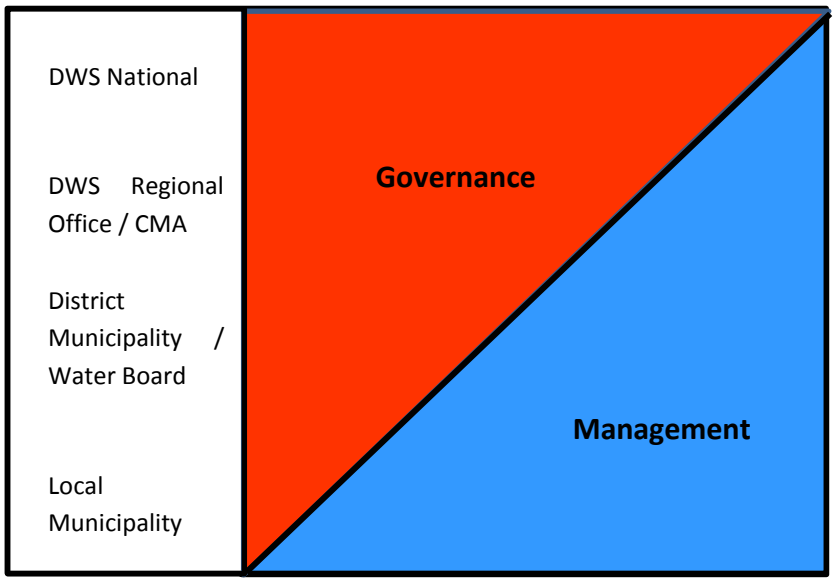


Figure 2.3: Straight line relationship between Governance and Management

In practice, this is rarely possible with governance or management functions always done at a fixed relationship at the different government levels. At the various government levels, some will perform more governance then management functions, and in other situations, the functions swing more towards the management functions. This relationship creates a more curved relation between governance and management functions.

Local municipalities may only perform management functions, and some or not any governance functions. On the other side, the national government may only function on a governance level and not any or limited management functions. At some government levels, it is not always

possible to find both governance and management functions performed; it may be only one of the two – governance or management functions.

The degree of governance vs management differs per level of government from institution to institution. The line between governance and management is thus very flexible between the different areas/location or aquifers, where groundwater is being used and protected. The line can in one case be leaning more towards governance if more management functions are preformed and vice versa. Figure 2.4 provides a wide range of possible options. It is thus creating three areas:

a) a fixed area that represents roles, functions and responsibilities that will only be done through governance at a particular governance level (red area – left of fixed-line A)

b) a fixed area that represents roles, functions and responsibilities that will only be done through management at a particular governance level (light blue area – right of fixed-line B), and

c) an area in the middle (the grey-green area – between line A and B) where the roles, functions and responsibilities of governance and management are flexible and can be performed at any governance level.

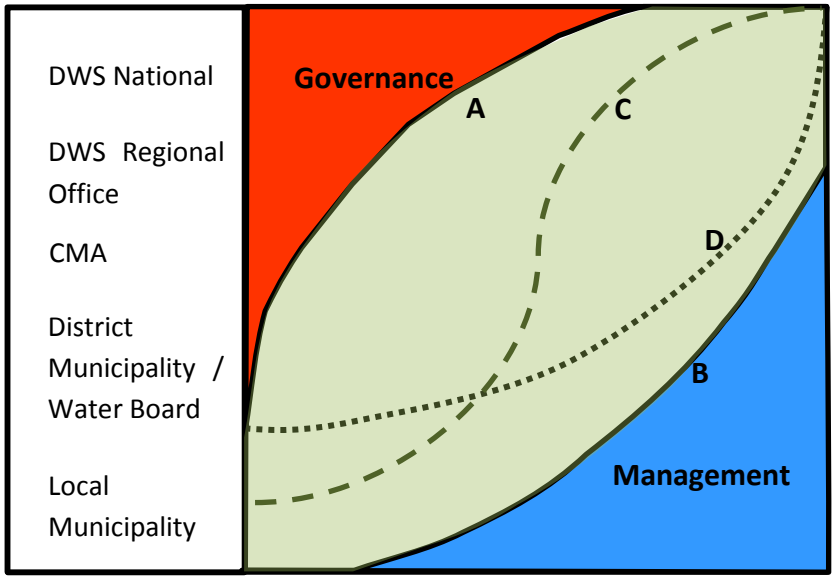


Figure 2.4: Flexible line relationship between Governance and Management with two examples (line C and D)

Line C (dashed line in Figure 2.4) represents the scenario at a groundwater use institution where the local municipality mostly operates only on a management function and only a bit of governance. The district municipality and the DWS regional office or Catchment Management Agency (CMA) are involved in the local management and governance of the groundwater resource. The national DWS office is also involved in the management but focuses more on

governance. Line D (dotted line) represents a non-active national DWS office with regards to management and only concentrate on governance. The district municipality is much more involved in the management of the aquifer than the CMA/DWS regional office. The local municipal are only focused on management and are not involved in any governance.

Functions

The line between governance and management is not thin but rather a thick grey band. Seward (2015) argued that governance and management are not separate scales of action, but different processes. Both processes can take place together at local, regional, national or global scales. However, on the other hand, some functions, roles and responsibilities can be done as management or as governance process. Below is a table listing some functions, roles and responsibilities related to groundwater that split into purely governance, a mix of governance processes and management activities; and purely management activities (Table 2.1).

Table 2.1: Examples of functions, roles and responsibilities that relate to Governance and Management of groundwater

Purely Governance processes	A **mix** between Governance and Management	**Purely** Management
Policies[2,9] Acts Regulation[2] Setting Standards Departmental interaction Funding Strategies[2,9] IWRM Approaches Environmental taxes[4] Transboundary aquifer management agreements[2,5,9]	By-laws Stakeholder engagements[2,7] and participation[8] Awareness Developing guidelines[9] Water use licence authorization[2] Water use licence compliance Resource planning[9] Conservation Institutional Arrangements Infrastructure development Tariffs/pricing Audits & auditing compliance Management plans Databases	Monitoring: pump rate (abstraction), levels (4 types[7]), electricity use, water demand, quality, maintenance, contamination sources, operations[2,5,6,7] Maintenance Operations[2,7] Skills training (in-house[8] + external) Capacity building[8] Data capturing Reporting Resource assessment Resource protection[2,5] and zoning[5] Implementing groundwater laws[1] Building models[1] Surveying[4]

	Water use restrictions IWRM – plans[4] Aquifer management plan[5]	Modeling[4] Sustainable aquifer yield estimates[4] Land use and spatial planning[4] Environmental impact assessments[4] Operating rules Borehole registration[4] / inventory[5] Drilling restrictions/bans (no-go areas) Integrated water model (crop-soil-aquifer)[5]

References notes in Table 2.1: 1) Villholth and Conti, 2018; 2) Riemann et al., 2016:32; 3) Foster et al., 2010; 4) Varady et al., 2016; 5) Garduño and Foster, 2010; 6) DWA, 2009; 7) DWAF, 2004; 8) FAO, 2016a; 9) Pietersen et al., 2011

Table 2.1 present the several functions, responsibilities and roles that can be divided under certain governance levels. For example, the legislative duty to development of an act will lay with the national government, but with the development of by-laws, the responsibility will reside with the local municipality. Although both these processes fall under governance, it will be done at different government levels. The same will be true for management.

Some of the functions, responsibilities and roles are very difficult to place under governance or management alone and can fall under both. The function involves both governance and management roles and responsibilities. The same function can be seen by one organisation as a governance function because they see the function as a process, and the other organisation see the function as a management function because it involves the implementation. For example, with Groundwater Resource Planning the planning involves engagement with various stakeholders or the practical developing of a plan with resource assessments, funding and development. Thus the function involves a process and practical implementation of the function. This overlap or mix of governance and management functions, responsibilities and roles can be viewed from a management or governance point of view. From a governance point of view, it can be called various names like 'Practical Governance', 'Implementation Governance' or 'Effective Groundwater Governance'. From a management point, it can be called 'Process Management', 'System Management' or 'Framework Management'. From the whole discussion above on Groundwater Functions and Relationships, the focus has been moved from management to governance over the last decade, with a more democratic approach than an autocratic approach.

For this reason, the term 'Implementation Governance' is selected. 'Implementation Governance' also links closely to the term 'Local Level Governance' that focuses on governance at the local municipal level. Figure 2.5 illustrates the relationship between Governance, Implementation Governance and Management at the different levels of government.

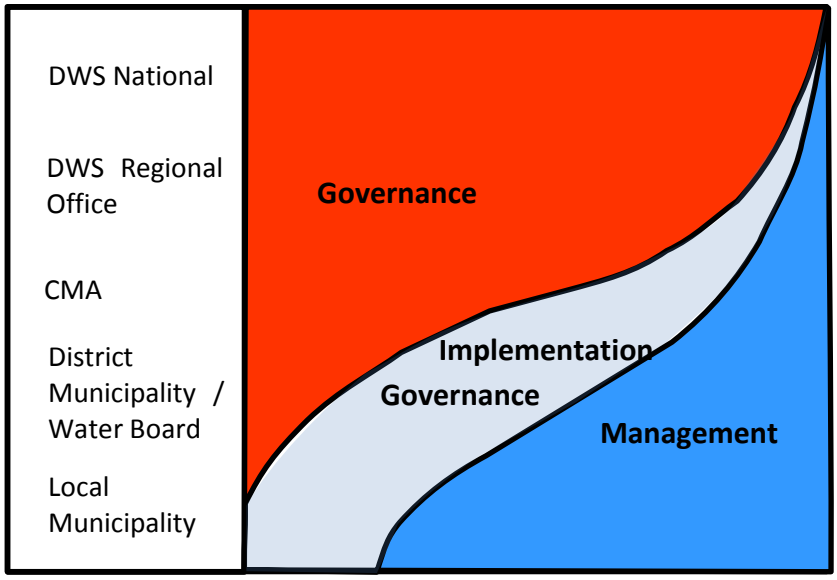


Figure 2.5: The relationship between Governance, Implementation Governance and Management at different government levels

Local Governance by definition is organisations and institutions that control the actual outcomes on the ground and which respond in varying degrees to rules and incentives from a strategic governance level (Wijnen et al., 2016). A management groundwater resource at a local level requires a cross-sector and cross-level cooperative governance approached (Riemann et al., 2016; Seward et al., 2015 and Foster et al., 2010) (see Figure 2.6). There are various challenges which are being affected by the polluters and local users which require special attention as an example.

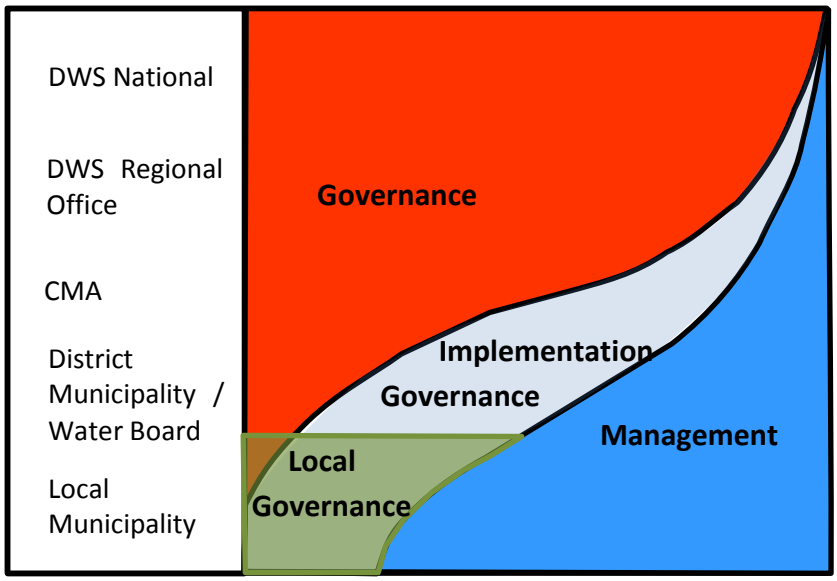


Figure 2.6: The Local Governance focus area in relationship with Governance, Implementation Governance, and Management

Scenarios

Table 2.1 indicates that various functions, responsibilities and roles that lean more towards some government organisation. At a national level, more governance level functions, responsibilities and roles will take place than management and vice versa at the local municipality level. At a local level, it will lean more to management then governance. However, this also differs from municipality to municipality. Below are five scenarios or examples of the different governance and management functions, responsibilities and roles of the different government organisations at the municipal level, namely:

A) Local Municipality: Water Service Authority but not a Water Service Provider (District Municipality)

B) Local Municipality: Water Service Authority and Water Service Provider with CMA involvement;

C) Local Municipality: Water Service Authority and Water Service Provider with Regional Office involvement;

D) Metro Municipality and

E) Rural Village.

A) The Capricorn District Municipality (CDM) is the Water Services Authority (WSA) for all the Local Municipalities (LM's) in the CDM area like Blouberg Local Municipality (BLM). Neither DWS National and Regional nor the CMA plays a significant role in management in the BLM. The reason for the low level of involvement from the BLM side is the institutional role of the CDM as the Water Service Provider (WSP). The management functions of the groundwater preside with the Water Service Provider (CDM) and not with the Water Services Authority (BLM) (Figure 2.77). The BLM only manage the distribution of the water and are also responsible for the reticulation infrastructure.

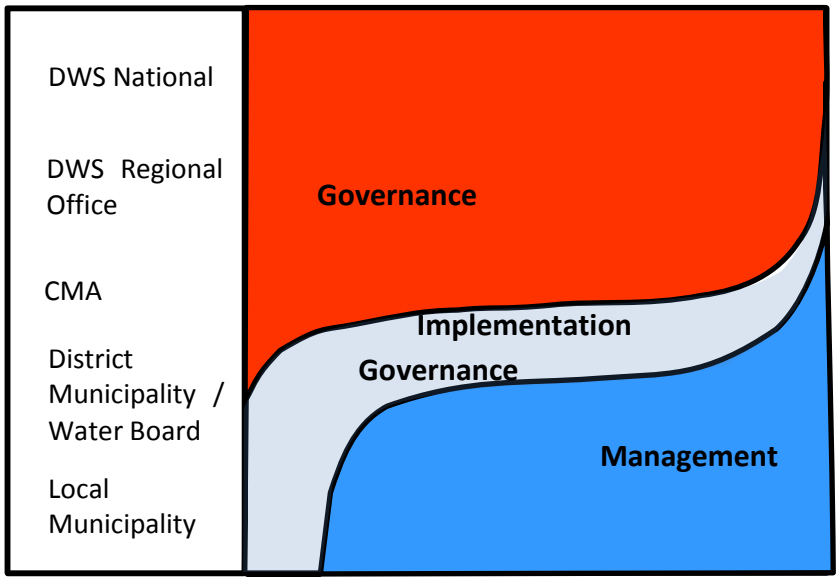


Figure 2.7: The relationship between Governance and Management in Blouberg Local Municipality

B) The Beaufort West LM (BWLM) is the WSA and WSP. The DWS National and Regional offices are involved in some management functions, but the Breede – Gouritz Catchment Management Agency (BGCMA) is much more closely involved (Figure 2.8). Regular interaction between the BWLM and BGCMA resulted in open communication on regulatory compliance drought management and resource development. The role of WSA and WSP also involves a bigger function of implementation governance.

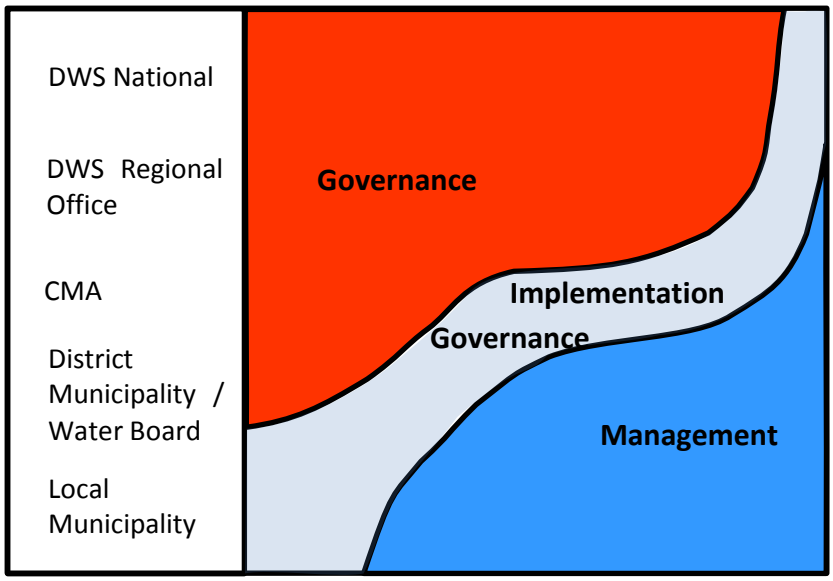


Figure 2.8: The relationship between Governance and Management in Beaufort West

C) The Calvinia LM has almost the same governance and management relationship as Beaufort West but with the difference that the DWS Regional office is the government organisation that is involved (Figure 2.9). The DWS Regional office is involved in the monitoring, drought management and resource development functions at the LM. The CMA functions are currently still the responsibility of by the DWS Regional office. The role of WSA and WSP also involves a bigger function of implementation governance.

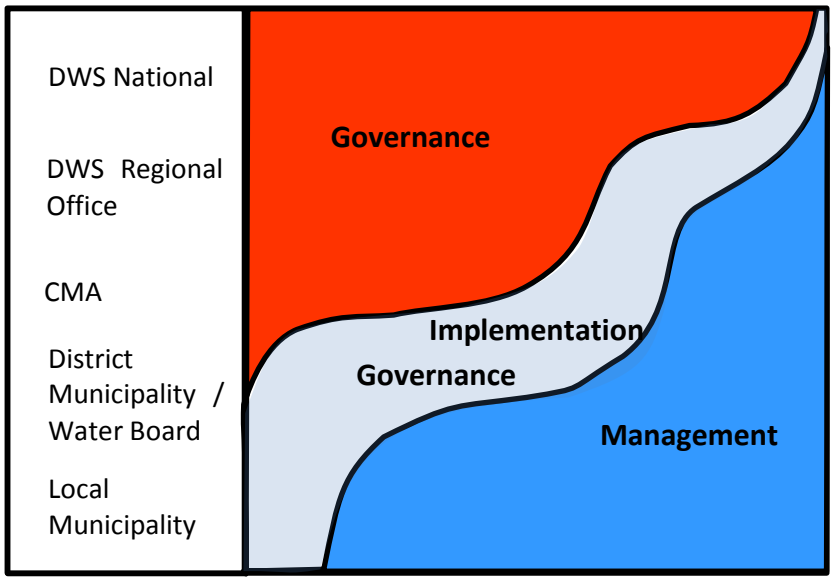


Figure 2.9: The relationship between Governance and Management in Calvinia

D) The City of Cape Town (CoCT) (or a Metro) is managed as a separate entity when it comes to government organisations (see Figure 2.10). The Metros need to manage and govern their water resources (this includes groundwater e.g. Atlantis and Silwerstroom wellfields, and small metro owned dams) with very little involvement and support from DWS National, Regional or CMA. From the surface water (bulk water) side the DWS National and Regional offices provide support through operational infrastructure and management as a bulk water supplier. DWS owns and operates the dam infrastructure from where CoCT bulk water is coming.

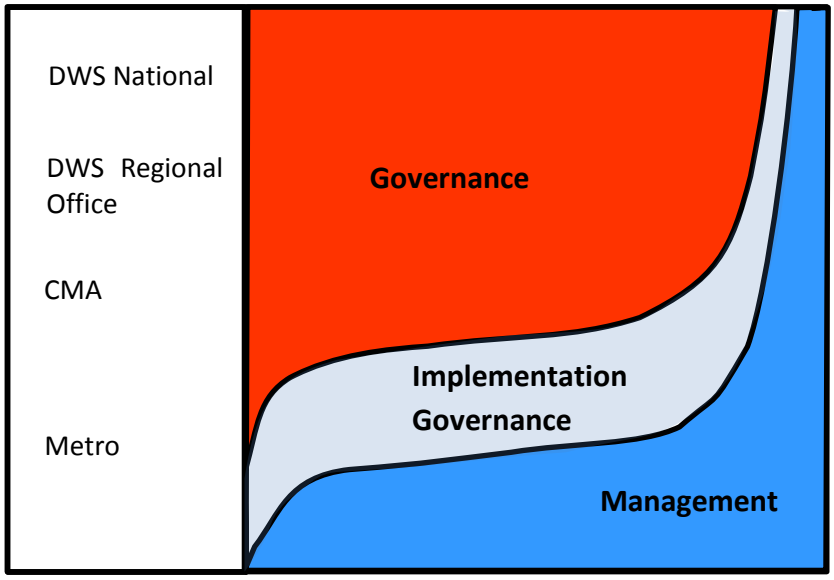


Figure 2.10: The relationship between Governance and Management in the City of Cape Town

E) In rural communities, the responsibility to supply and the protection of water resides with the users or communities themselves (Figure 2.5). The local municipality provides very little support to the community, and some communities do not want the local municipality to be involved, as in the case of Wolkberg community (P. Hobbs, 2014 pers. comm.). Although these communities do not have groundwater models, access to groundwater data or implement groundwater by-laws, the day-to-day management of their groundwater resources still takes place. The management happens through the broader planning concerns of the community, informal rules of conduct or procedures and the historical knowledge of trends in groundwater levels (Villholth and Conti, 2018).

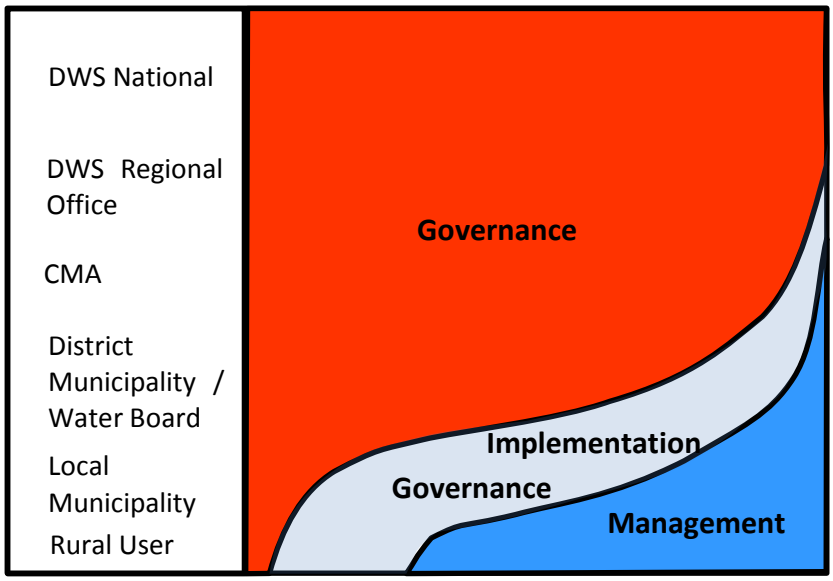


Figure 2.5: The relationship between Governance and Management in Rural Village

2.2.6 Summary

The following points can be seen as a summary:

- Groundwater Governance is the process of developing, implementing and enforcing the rules that relate to groundwater.
- Groundwater Management is the activities undertaken by mandated actors to develop, use and protect groundwater resources.
- Governance and management are not separate scales of action, but different processes. Both processes can take place together at local, regional, national or global scales.
- There is an organisational arrangement in the water sector from a state level to a local level with different departments, agencies and local authorities involved.
- At all governance's levels, both governance and management tasks are performed.
- The roles, functions and responsibilities of governance and management are flexible and can be performed at any governance level.
- The same function can be seen by one organisation as a governance function and by others as a management function. One organisation can see the function as a process, and the other organisation see the same function as a management function because it involves the implementation.

- The governance and management functions, responsibilities and roles of the different government organisations will differ at a municipal level.

2.3 WHAT IS A "PLAN"?

As is the misunderstanding between governance and management, a bigger confusion exists with the term "plan". There are various documents and formats available for different ways and means to express actions or methods to follow to get to a specific goal. By comparing different terminologies, confusion can be cleared on the question of "What is a Plan?" For constancy the definition of all the terms that were sourced from the same dictionaries – the Cambridge Dictionary (2018) and Oxford Dictionary (2018) respectively (Table 2.2).

Table 2.2: Description of various "plan" terms in the Cambridge and Oxford Dictionaries

Term	Cambridge Dictionary	Oxford Dictionary
Framework	*"A system of rules, ideas, or beliefs that are used to plan or decide something."*	*"A basic structure underlying a system, concept, or text."*
Strategy	*"A detailed plan for achieving success in situations such as war, politics, business, industry, or sport, or the skill of planning for such situations."*	*"A plan of action designed to achieve a long-term or overall aim."*
Guideline	*"Information intended to advise people on how something should be done or what something should be."*	*"A general rule, principle, or piece of advice."*
Manual	*"A book that gives you practical instructions on how to do something or how to use something."*	*"A book giving instructions or information."*
Master plan	*"An organised set of decisions made by one person or a team of people about how to do something in the future."*	*"A comprehensive plan of action."*
Action plan	*"A detailed set of instructions to follow in order to solve a problem or achieve something"*	*"A proposed strategy or course of action."*
Plan	***"A set of decisions about how to do something in the future" and "to think about and decide what you are going to do or how you are going to do something."***	***"A detailed proposal for doing or achieving something".***

Management plan

In the medical profession, a management plan is defined as a suggestion of immediate and long-term treatment characteristics linking the patient's examination and diagnosis to a resolution of the patient's current condition (Free Dictionary, 2018). Foster et al. (2015) link onto the medical approach by defines it as an effective way to capture the basic understanding, sustainable management measures and a focused action plan in a single document. A management plan can be summarised as capturing the link between the basic understanding of the resource and sustainable management measures into a detailed set of instructions/actions into a single document to achieve something. Fallding (2000) indicates that a management plan is an agreement on 'purpose, values, objectives and implementation processes'.

Groundwater can never be governed or managed as a separate entity or on its own. It is always part of the bigger and integrated system.

Integrated Water Resource Management Plan (IWRMP) is, by definition, a plan aimed at dealing with the socio-economic, technical, financial, institutional and environmental issues as they pertain to management of the water resource (Burke, 2007).

Thus an **Integrated Groundwater Management Plan (IGwMP)** is, by definition, a plan aimed at dealing with the socio-economic, technical, financial, institutional and environmental issues as they pertain to management of groundwater.

A Groundwater Management Plan needs to be developed through governance processes but implemented through management activities (see chapter 3 for more detail).

2.4 PRINCIPLES

Groundwater management can only be achieved if there is an adequate understanding of the groundwater system and hydrogeological data are regularly collected to prevent possible over abstraction or pollution of the aquifer systems (Davies et al., 2013). To manage groundwater at the local level depends on the aquifer's (specific location) technical, institution and economic conditions (Moench et al., 2016). The Groundwater Management Framework (Riemann et al., 2010) divide groundwater management into two main groups namely aquifer protection and aquifer utilisation with the regulatory tools in between and in a monitoring and evaluation environment linked to the valuation of the groundwater resource. The groundwater management

tools that are mostly used in the United States includes monitoring; permits; planning; and protected areas (Gerlak et al., 2013). Key issues that need to be understood with regards to groundwater management are (Garduño and Foster, 2010):

- Groundwater supply & demand management: aquifer systems (*assessments*); the vulnerability to be impacted by abstraction (*use*); as well as surface-groundwater interaction that include baseflow or recharge reduction effects (*protection*) (Tuinhof et al., 2002).
- Groundwater regulation management: effective and implementable regulatory interventions (*regulations*), government (include all levels of government) capacity to enforce and user capacity to compliance (*capacity*) (Tuinhof et al., 2002). Legal provisions (*regulations*) should be formulated and promulgated, specifically to the peculiarities of groundwater management (Braune, 2000).
- Groundwater socio-economic management: economic tools with a high level of user participation (*stakeholders*) (Tuinhof et al., 2002). The foundation for social agreements and a vital tool for conflict resolution (*communication*) are the data to understand and quantify the aquifer systems (FAO, 2003).
- Groundwater technical management: all critical activities to a groundwater scheme need to be monitored to promote a sustainable scheme (*monitoring*) (DWAF, 2004). To meet the demand but also to avoid over-exploration and to resolve the situations of water scarcity or shortage in individual sectors in the medium and long term range, a plan needs to be developed (*planning*) (Margane, 2003). Small things like ensuring that pumps are set at the appropriate discharge rates for a borehole will optimise the operation of the wellfield or scheme (*operation*) (DWAF, 2004). Ensuring regular maintenance on such equipment as pumps, pipelines and reservoir (*infrastructure*) will minimise water loses (*conservation*) and prolong the life span of the infrastructure.
- Groundwater organisation & communication management: social development goals and cross-sector coordination need to be effective (*institutional arrangements*) (Tuinhof et al., 2002); to integrate all aspects of groundwater management water authorities should have the competence (*skill*) (ECE, 1989).

Multi-pronged mechanisms (*plan*) will be required for practical approaches to groundwater management with a balance between government, community and individual roles and

regulatory, economic, educational and legal mechanisms (Burke and Moench, 2000 cited by Braune et al., 2008).

In 2004 the Department of Water Affairs and Forestry (DWAF, 2004) (now the Department of Water and Sanitation) developed the feedback cycle for the main tasks of groundwater management (see Figure 2.6), and it was amended by Riemann (2010) to include the perspective of the institutional arrangement. Groundwater management comprises of different tasks, but the tasks cannot be seen as standalone and need to part of a process. The feedback cycle is a good example thereof and follows the change approach. To know you need to monitor to obtain data; data need to be transformed into information through capturing the data; the information needs to be changed into knowledge through analysing the information; the knowledge will turn into wisdom if a change in operations happens and possible amendment to monitoring (E Bertram, 2009, pers. comm.). This change approach provides a clear link to the definition of the word "management" above as a process that needs to be followed.

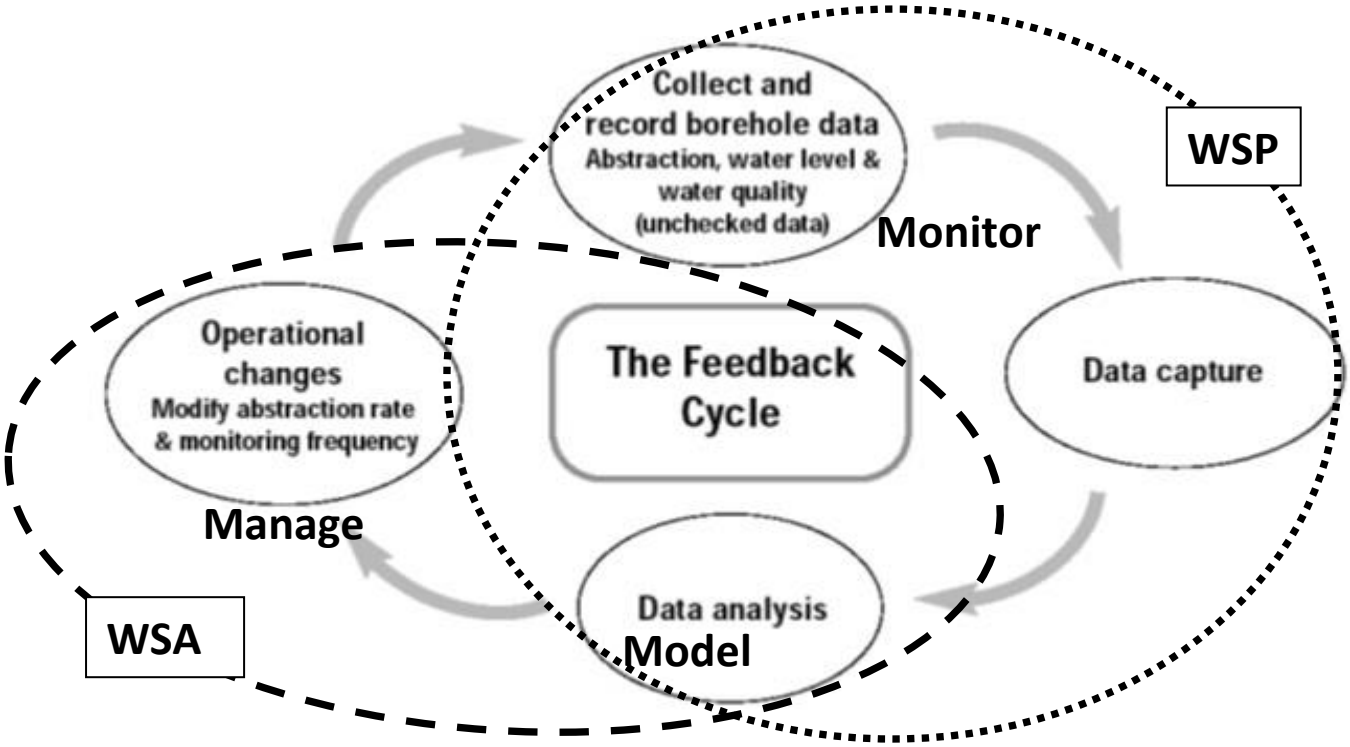


Figure 2.6: The Principal groundwater management tasks (adapted from DWAF, 2004 and Riemann et al., 2010)

2.4.1 Protection

The National Water Act (NWA, 1998) stipulates that 'the protection of water resources is fundamentally related to their use, development, conservation, management and control'. The present use of the groundwater resources should be managed in a way that does not undermine the life-support system, thereby compromising use by future generations of the same source (GWP, 2000). Protection of an aquifer can be divided into two actions namely the prevention and the remediation of the pollution (Riemann et al., 2010). The function of protection is more related to the municipal level (resource level), but certain functions or roles can also be performed at national or district/CMA level like guidelines and standards (See Table 2.1).

Protection of groundwater resources involves various aspects to achieve, which includes aquifer resource planning, use allocations and licensing, ecological zone, land use planning and waste management, to name a few. Although each of these aspects is standalone management functions, the institutional setup needs to ensure joint management (FAO, 2016a).

Prevention involves the potential impact of activities on the groundwater quality and quantity (land use planning) and the direct measures to ensure that the potential impact is reduced further and mitigated against (pollution control) (Riemann et al., 2010; Foster et al., 2010). Sililo et al. (2001) list twenty possible pollution sources and divide the sources that can contaminate groundwater into six categories: municipal, agriculture, industrial, atmospheric deposition, mining and groundwater development. Wetlands as an ecological infrastructure play an essential role in preventing polluted water infiltrating to the aquifer (Rebelo and Morris, 2019)

Land-use planning can be for zoning of land for specific activities or prevent specific activities happening in certain areas of land (protection zoning) (NGS, 2017). The zoning can be implemented through the spatial development framework (SDF) or with by-laws. Industrial zones and waste disposal sites will be placed in areas (zones) where no aquifer exists, or the aquifer is the least vulnerable.

Protection Zones

Human activities that occur on the land surface or subsurface have the potential to contaminate or impact the quality and/or the recharge of the groundwater below (quantity). The pathways to the groundwater can be indirect pathways (soil) and direct pathways through human-made structures which intersect the aquifer like boreholes, trenches and quarries. The delineation of

protection zones for aquifers needs to be based on the understanding flow path in the aquifer (DWAF, 2008a).

Different protection levels can be determined from the potential impact on the aquifer that is directly related to the distance from the aquifer or wellfield or borehole. Source protection zones can be divided into most case five zones namely (DWAF, 2008a and 1995; EA, 2012; Nielsen, 2017; Miljøstyrelsen, 2000; Foster et al., 2002; Chave et al., 2006):

- *Wellhead Operational Zone (WOZ*: immediately adjacent to the borehole or wellfield to prevent rapid ingress of pollutants or damage to the borehole – 10m to 20m around borehole (often referred to as the 'Accident Prevention Zone').
- *Inner Protection Zone (IPZ)*: based on the time expected to be needed for a reduction in pathogen presence to an acceptable level. The zone can be divided into more subdivisions to allow gradational land use control base on time-of-travel or distance-from-abstraction. The IPZ often referred to as the 'Microbial Prevention Area' – fifty days and/or 'Sanitation Inspection Zone' – 200m)
- *Outer Protection Zone (OPZ)*: the zone base on time required for effective attenuation and dilution of slowly degrading elements to an acceptable level. Alternatively, defined by 400-day travel time from a point below the water table.
- *Source Catchment Protection zone (SCPZ)*: sometimes covers the total catchment area of a specific abstraction where all water (surface and groundwater) will eventually reach the abstraction point (often referred to as the 'Total Source Capture Area'). Alternatively, it can be defined for a single source of which it is receiving its recharge from (Recharge Zone). In areas where the aquifer is confined beneath impermeable strata, the recharge zone (capture area) will be located a distance from the actual wellfield (site of groundwater abstraction) (See Figure 2.7).
- *Zones of Special Interest (ZSI)*: usually represents a surface water catchment which drains into the aquifer feeding the groundwater supply (such as karstic groundwater flow and recharge or a catchment draining to a disappearing stream).

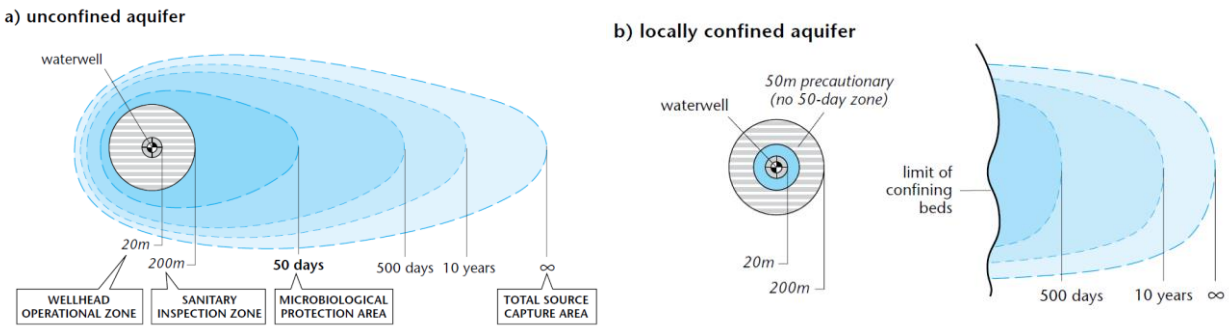


Figure 2.7: Idealized scheme of groundwater capture areas and transit-time perimeters around boreholes: a) unconfined aquifer and b) locally confined aquifer (Foster et al., 2002)

Borehole protection

Borehole protection does not just relate to the WOZ (groundwater resource quality) as described above but also to the security and infrastructure that includes the fencing, enclosure, sanitation seal and the activities allowed near the borehole.

De Lange (1999) develops 'Wellhead Protection Zones' or 'BPZONE' to proactively protect the groundwater polluters, and land uses. Three protection zones were recommended for the protection of the wellhead, namely I) Fencing; II) Microbial and Nitrate pollution, and III) Hazardous elements. The three zones needed to be determined through a wellhead protection plan. A 'BPZone' tool was developed to assist with the determination of the plan.

The access to the borehole needs to be regulated, and only an authorised person needs to have access to the borehole enclosure area and borehole infrastructure. Vandalism and theft are in some areas a considerable challenge and water security and service delivery are hampered by infrastructure that has been damaged and cannot supply water. The sanitation seal needs to be installed properly to prevent any contaminants from entering the groundwater along the borehole casing. Special care needs to be taken when fuel engines are used as a power source; additional flooring in the enclosure or around borehole needs to be in place. An area of 10m radius around the borehole needs to be regulated/secured as a 'protection belt' / 'physical security zone' / 'fencing' (Miljøstyrelsen, 2000 and De Lange, 1999). The area must free of fertiliser, poisons or pesticides or any other substances that can pollute the borehole or aquifer.

2.4.2 Regulation

The management of groundwater resources is greatly supported by the regulatory framework. The National Water Act of 1998 (NWA, 1998) divided the regulations into the authorisation of the use and the protection of groundwater.

Authorisation

The National Water Act (1998) makes provision for the regulation of groundwater use through the registration of water use, and different types of authorisations. Different types of water use authorisations include (NWA, 1998; DWA, 2010a; NGS, 2017):

- *Schedule 1 Water Use* – permissible, small quantities of water use with minimal or no risk of impacts that do not require registration or a licence. Schedule 1 water use applies to all aquifers throughout the country – widespread use.
- *General Authorisations (GA)* - General permission for slightly larger water uses from less-stressed sources allowing a user to use water without a licence provided that the water use – low-risk impacts - is within set limits and conditions to protect the water resource. A general authorisation is only applicable to specific catchments or aquifer systems and is not generally applicable throughout the country, but registration is required. The strength of GA's is thus that it can be applied to specific areas and with specific conditions attached. The GA's accept the 50% ceiling value of the 'Groundwater Harvest Potential' for the different regions as the basis for the different zones.
- *Water Use Licences* – A user must apply for a licence for any new water use that exceeds the limits outlined in Schedule 1 and allowed for under general authorisations. There would be a likely impact with the water use, and each licence will have specific conditions attached. It will include monitoring and reporting.
- *Existing Lawful Use* – Any lawful water use before 1998.

The cumulative effect of Schedule 1 use in close procsimity of eachother may have negative impact on an aquifer and can lead to over abstraction of the aquifer. Legislation like bylaws may need to be implemented to limit the impact especially it the municipal groundwater supply is tapping into the same aquifer.

Measures

The NWA (1998) further allows for the different measures to support efficient, sustainable groundwater resource management and ensure the comprehensive protection of all resources, i.e.:

- The *Water Resource Class* and *Resource Quality Objective* of the groundwater resource determined through the Water Resource Classification System. The purpose of the resource quality objectives is to "establish clear goals relating to the quality of the relevant water resources". In determining resource quality objectives, a balance must be found between the sustainable water resources and need to protect side, and the need to use and develop side.
- The *Reserve* is determined as part of the resource quality objectives and includes the ecological reserve and the basic human needs (BHN) reserve. The ecological reserve relates to the "water required to protect the aquatic ecosystems of the water resource". The BHN Reserve provides for the "essential needs of individuals served by the water resource in question and includes water for drinking, food preparation and personal hygiene". The Reserve refers to both the quantity and quality of the water in the resource and will vary depending on the class of the resource.

The regulation does not just include the groundwater use authorisation and resource protection but a lot more. Below is a list of some elements that are also involved and influence regulation (Lazerus, 1997; NGS, 2017):

- Municipalities are required to provide a regulatory oversight role on the sustainable groundwater use in the form of monitoring of performance, setting of prices, standard-setting, etc. of the groundwater component of the infrastructure.
- Land use management and activities which impact the groundwater resources.
- Some parts of the groundwater industry lacks professionalism, specifically in the registration of boreholes.
- The development of norms and standards will guide regional and local groundwater management practices, which can include utilisation, conservation resource characterisation, etc.
- The uploading of groundwater use monitoring information as required regarding the licences on the relevant database.

- Subterranean government water control areas.

2.4.3 Use

Groundwater is very vulnerable to the “tragedy of the commons” (Foster and Garduño, 2013) where everybody can tap into groundwater without taking consideration of the other users using the same groundwater resource (aquifer). Municipalities cannot just consider their own abstraction when managing their groundwater but need also be aware of other users in the same aquifer (FAO, 2003) as:

- Irrigation abstraction from farmers
- Industrial use
- Mining use and dewatering and
- Communal abstraction from a small holdings area “plotte” and residence in town areas (built-up area).

Each user has a different patent of use, abstract at different periods and time of the year, month and day. For example, the irrigators will abstract water during the growing period of their crop (November till March), while the industries will be abstracting water throughout the year.

With all users wanting to take their share of the groundwater resource, the knowledge of the aquifer’s characteristic, storage, recharge mechanism, the abstraction of users and threats to the aquifer are crucial (see section 2.4.9 Assessment for a further discussion). The knowledge will also help to protect (section 2.4.1 Protection) and develop (section 2.4.4 Planning) the groundwater resources for the future.

Groundwater use is likely to increase near the latter part of a dry period when the other sources of water disappear. The yields will decrease steeply in the dry season and steadily decrease from year on year (see Figure 2.14). The increased water use will intersect the groundwater availability after several dry seasons of low rainfall (Robins et al., 1997).

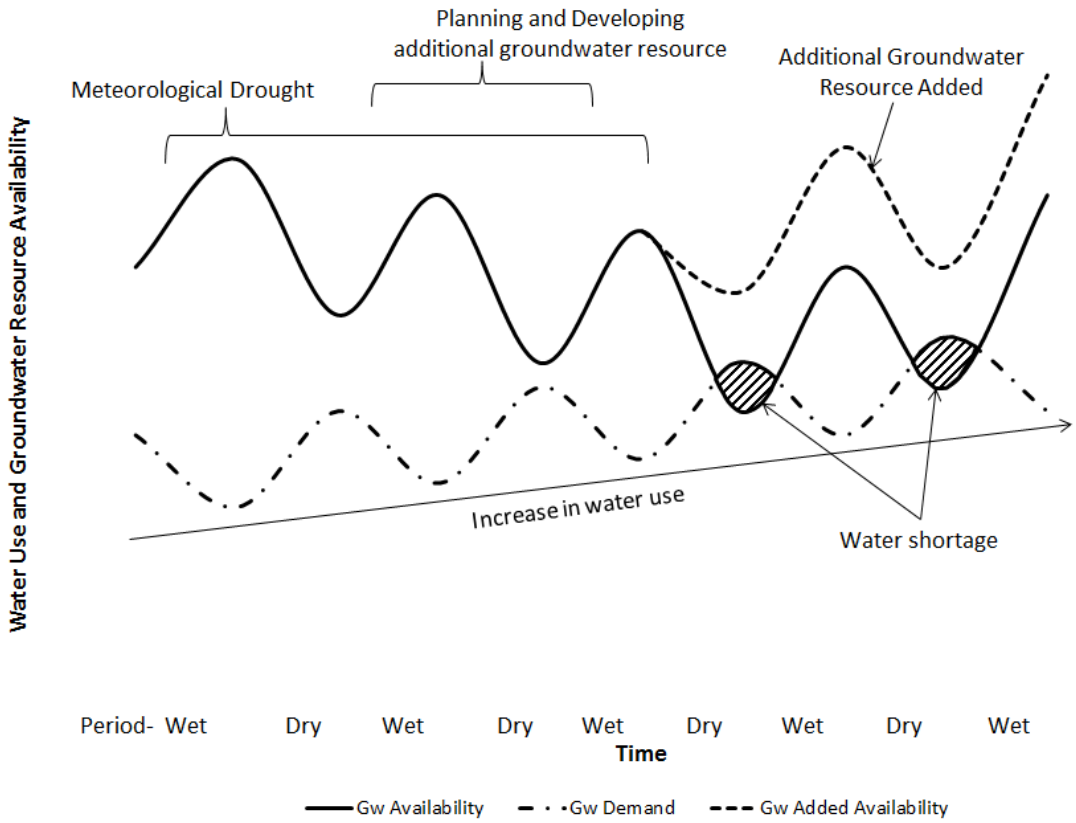


Figure 2.8: Groundwater availability versus water use change over time with timeous planning and development groundwater resources (adapted from Robins et al., 1997)

2.4.4 Planning

The future development of a groundwater resource requires detailed planning and insight into the water requirements of the users. By ensuring sustainable groundwater abstraction, adequate infrastructure and finances, detail planning need to be in place. At the municipal level, the Water Service Authority (WSA) need to develop a Water Services Development Plan (WSDP) that focus on the increasing access to water services that includes the water supply sustainability (WSAct, 1997 and NGS, 2017)

Planning within IWRM framework involves a process of matching water availability with water requirements of all users, which include the environment. Planning typically involves the investigation of development options to balance the water requirements. The planning happens through a predetermined sequence of increasingly detailed phases by scale and level of detail and by increasing the confidence in the yield estimations. Planning generally follows an assessment during which the various water development options (including groundwater options) are

identified. Planning ensures that the information is made clear to the decision-maker (DWAF, 2008b and Riemann et al., 2010).

Long term increases in water requirement can harm the source during meteorological droughts (Robins et al., 1997). The timeous planning and development of additional groundwater resources can prevent water shortages (Figure 2.15). Planning for drought will prevent a reactive response to drought. An effective proactive response will involve determining the status of the water supply; mapping the areas that are vulnerable to drought; groundwater monitoring and develop an early warning system. The early warning system needs to include monitoring data (meteorological, hydrological and geohydrological data), user indicators and triggers, and responses (Calow et al., 1996 and Robins et al., 1997).

Resource Investigational Planning phase

Planning is undertaken at a reconnaissance level of detail at the national level where various options are weighed for a further detailed study. The level of detail and accuracy improves during a pre-feasibility study at the catchment level, where specific options are assessed as identified through the reconnaissance phase. A full feasibility study and optimisation of designs are undertaken at the site-specific level (DWAF, 2008b).

At the municipal level, the same planning process needs to be followed to ensure that groundwater resources are protected, timeously developed, and that infrastructure is in place to supply the water.

Various planning procedures exist, but all have the same primary process. The most frequently used procedures and also recommended by the Department of Water and Sanitation are the:

- Conceptualisation
- Reconciliation
- Prefeasibility study
- Feasibility study
- Option Analysis

This process will provide the municipality with the best feasible new water supply options by social considerations, potential environmental impact, economic and financial viability, technical feasibility, long-term land use, and regulatory considerations (Riemann et al., 2010). One of these

options can be a scheme to enhance the recharge which include artificial recharge and pasive recharge systems (see section 2.6.4). The investigational phase allows the municipality to identify some future resources to develop when the need arises without investigating the resources again. Some updating of information may need to be required, for example, the costing and the latest technology changes.

At different stages of a study, different stakeholders are involved. Communication with different stakeholders can be done on different platforms such as forums, workshops, meeting, newsletters and one-on-one sessions. (Jensen, 2018).

Planning Cycle

Traditionally the planning is divided into the resources investigation, development and the operational phases. The three phases are linked, but in most cases, each phase is implemented separately and treated as separate phases where the three phases form a loop that repeat itself. Resource planning always starts with the investigation phase; one of the options identified during the feasibility and options analysis component will be implemented during the resource development phase. After the development (including the borehole equipping and distribution infrastructure) the scheme/wellfield will be operated, maintained and evaluated. From the evaluation, a recommendation may be that the current water requirement is almost the same as the scheme's sustainable yield (in balance). Thus an additional resource needs to be developed. The planning cycle needs to start again with the investigational phase except if another option from the feasibility and options analysis component is chosen to be taken to the development phase (see Figure 2.15) (Fourie, 2017; DWS, 2017 and Riemann et al., 2010).

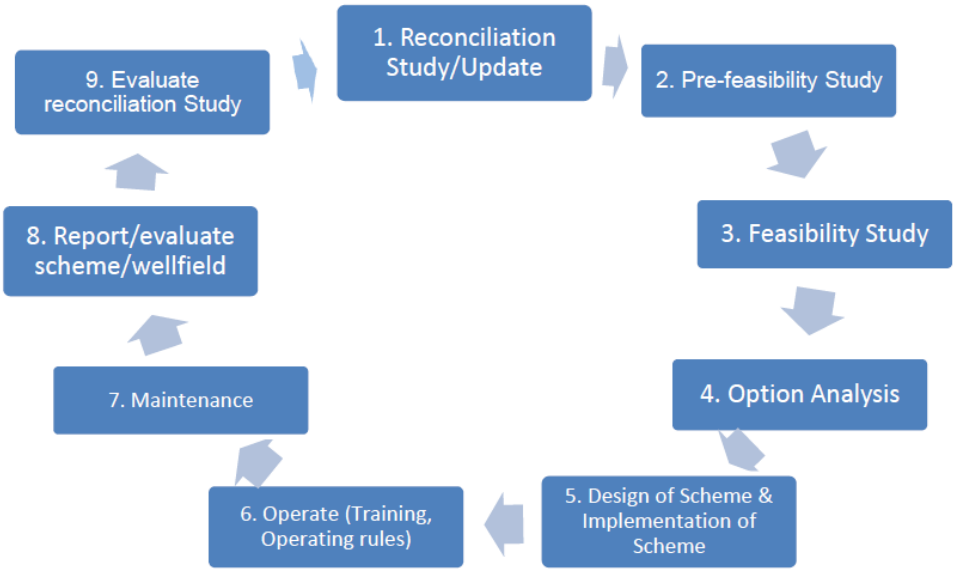


Figure 2.9: Water resource planning phases to develop a groundwater resource (DWS, 2017)

Various management options need to be considered for the operational phase when the scheme or wellfield is designed and during the construction of a project (Riemann, 2010).

Resource Development and Operational Planning phases

The planning of where, when and how to develop a resource is, in a sense easy to do, but it still does not provide any water in a tap – only paper water. The implementation of the outcome of the feasibility study, options analysis and then the operation of the scheme is also a necessary process. The implementation or development needs to be followed by the operation, training, maintenance, evaluation and monitoring.

The implementation or development of a new scheme or wellfield needs to be developed in a structured manner to ensure the operation, maintenance and monitoring and can be done in a cost-effectively and efficiently way during the operational phase (see Figure 2.10) (DWS, 2017 and Fourie, 2017). Sami et al. (2002) provides a guideline on the methodologies to be used in the investigation and the exploration of groundwater which includes hydrocensus; geological review; tectonics and geodynamics; structural mapping through strain analysis in the field; remote sensing; potential target features; constraints; and ground-based geophysics. The funding of the new scheme or wellfield, as well as the cost to operate and maintain it, needs to be known before the new scheme or wellfield is developed.

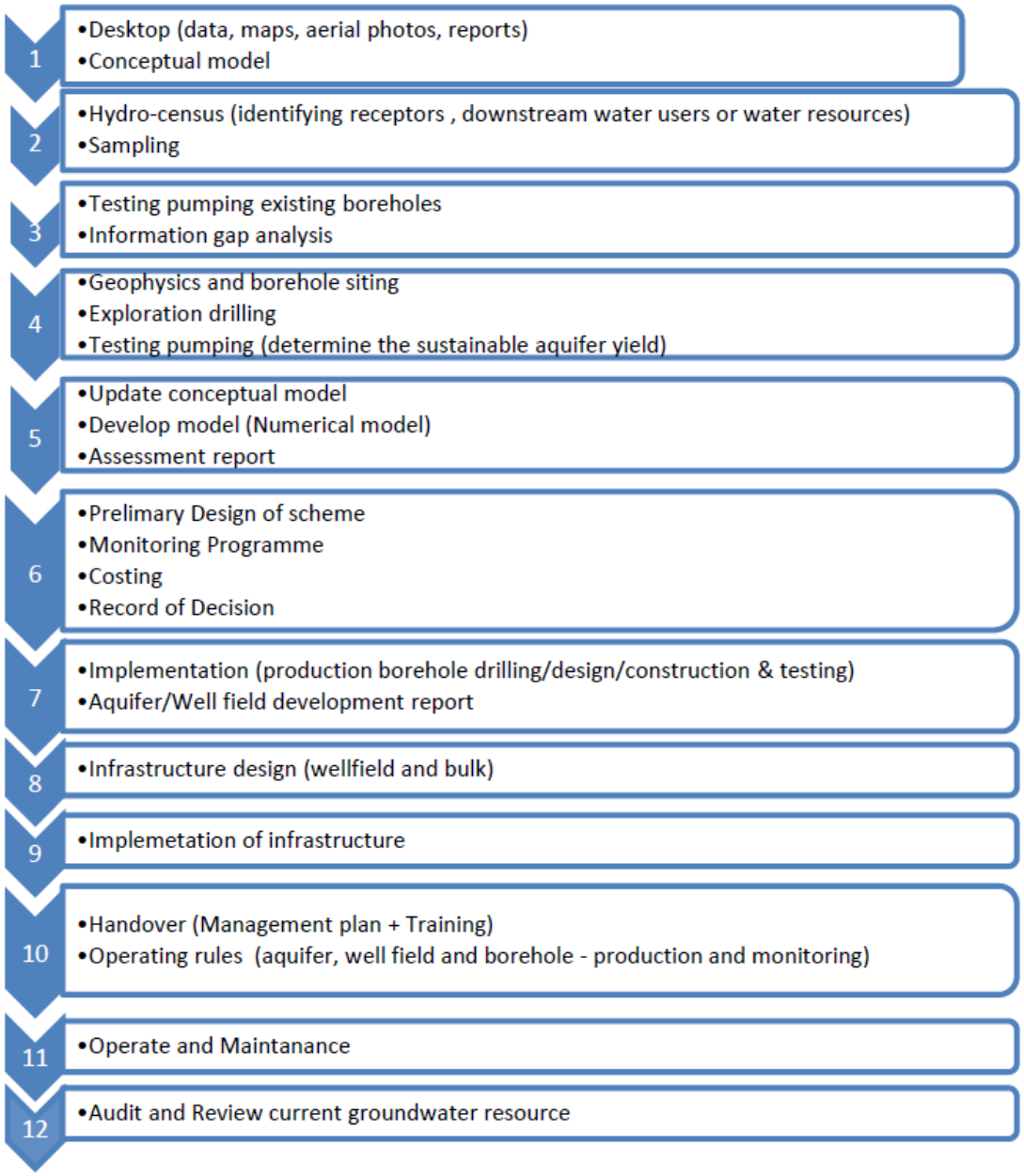


Figure 2.10: Groundwater resource planning phases to develop a groundwater resource (DWS, 2017 and Fourie, 2017)

During the operational phase, personnel need to be trained to operate the infrastructure but also to understand the aquifer response. The training will generally happen during the handover period by the engineering/construction companies for the infrastructure and the hydrogeological company with operation rules. A wellfield needs to be monitored, this includes infrastructure, such as the boreholes, pipelines and housing, who needs to be maintained and evaluated (DWS, 2017 and Fourie, 2017). The assessment or evaluation needs to implemented through amendments to the operational rules and procedures (Riemann, 2010).

It can be explained with the following acronym:

TMOMEC = **T**raining – **M**onitor – **O**perate – **M**aintain – **E**valuate – **C**hange/adjust

2.4.5 Monitoring

Groundwater is classified as a 'common-pool-resource' (Foster, 2013) that means that everybody can tap into groundwater from where they locate, but this makes groundwater inherently vulnerable to the pollution and over-abstraction if all the groundwater users do not protect and abstract the groundwater in a sustainable manner.

Monitoring is seen as one of the main building blocks in managing the water resources of South Africa. The National Water Act (NWA, 1998) spend a whole chapter on monitoring, assessment and evaluation – Chapter 14. Effective monitoring also provides the stakeholders with trust in the aquifer managing organisations (village committees, the municipality or water board) through the sharing of the data and the effectiveness of the monitoring (Ostrom principle cited by Foster et al., 2010).

The management of the groundwater can only be achieved through the gathering of information (data) that influence and impact the groundwater status and may include physical, environmental, users, financial, social, legislative, and economic factors. All the factors need to be monitored to manage the groundwater resources effectively, but for this dissertation, the physical factors of groundwater will be the focus.

Collection

The monitoring cannot start before the purpose of the data collection, and the level monitoring is defined in Monitoring protocol (Riemann et al., 2010) or monitoring framework (DWAF, 2004; Murray, 2007. Some of the issues to consider with the development of the monitoring protocol are (Riemann et al., 2010):

- parameters to be observed; equipment requirements
- methods for the analysis of the data collected
- methods of data collection
- timing and scheduling of data collection
- personnel requirements (regarding trained personnel)
- the frequency of measurements

- data access
- locations to be monitored
- data dissemination and
- revision policy.

The design and setup of a monitoring network need to consider the purpose of the monitoring and aquifer characteristics. The objective of the monitoring can include establishing the natural conditions or background situation (reference monitoring); compliance to authorisation (regulatory monitoring); information for emergency response (early warning and surveillance monitoring) and to meet specific objectives like research data gaps (specific purpose monitoring) (DWAF, 2004; Calow et al.,1996).

The main physical elements of monitoring related to the hydrological cycle include groundwater levels, groundwater quality, surface water levels, surface flow, surface water quality, rainfall volume and intensity, and abstraction rate or volume (outflow from the system) (see Table 2.3) (Meyer, 2002). It can further be divided into the quantity and quality components and the influences upon these components as well as the ecosystem factor. A monitoring protocol and network design (Riemann et al., 2010) will determine the different stages of the monitoring; level and purpose of data collection and also the different locations of the monitoring activities. Some elements and parameters that are usually collected are listed in Table 2.3.

Table 2.3: List of elements and parameters collected to manage groundwater

Elements	Parameters	Description
Groundwater	Water levels	Static and pumped levels
	Volumes abstraction:	Individual boreholes and wellfield
	Water quality	A sampling plan needs to be setup. The 'where?' (location), 'when?' (how often), 'how' (sampling and analysis method) and 'what?' (determinants and substances that will be tested) (DWAF, 2004).
Consumption	Volume use from reticulation	Reservoir and district flow meters vs water sales
Rainfall		At wellfield and recharge area
Equipment /	Groundwater resource	Leakages, breakages, cleaning, spillage (oil,

infrastructure	infrastructure: maintenance	fuel), maintenance or servicing schedule. Monitoring the infrastructure, together with the pump rates and electricity usage can indicate efficiency (DWAF, 2004).
	Pump schedule	
Environment	Vegetation	Groundwater dependent ecosystems

Capturing & reporting

All monitored or collected data need to be captured, stored and processed in the database system of some sort so that the data can easily be extracted, analysed and reported on. The data and information need to be assessed and reported to the public, stakeholders and decision-makers (Jorgensen, 2008; Meyer, 2002; DWAF, 2004 and NGS, 2017). Some of the data in the database need to be uploaded to the regulatory databases like the National Groundwater Archive (NGA), Water Services or CMA (Burke, 2007 and NGS, 2017)

All data need to be available to the public, but not all monitored data need to be reported to all stakeholders and decision-makers (e.g. council or CMA), the only information that is relative to the specific groups. No need to flood the stakeholders and decision-makers with all the detail monitoring data. Usually, a summary of the data or the interpretation of the data can be supplied. The data need to be always available to ensure transparency. The CMA needs to know the behaviour of the wellfield and aquifer and for this only a few boreholes that represent the wellfield can be reported to the CMA (as determined by the license conditions) (Riemann et al., 2010) or summarised in a graph related to the long term averages (Meyer, 2002)

The captured data on the database need to be analysis (low level of assessment- biannually) to optimise the operations that will result in an efficient data collection process (see Figure 2.13) (DWAF, 2004; Riemann et al., 2010; Meyer, 2002 and Murray, 2007).

2.4.6 Conservation

The term “Conservation” is most likely linked to the behaviour of the user to use less of the water resource than to use the water resource more efficiently instead. Conservation of groundwater is related to the use of groundwater at the right time and the real purpose of the use.

The right time to use groundwater goes hand in hand with operating the groundwater system or a scheme. Towns like Beaufort West or Calvinia have other water sources available to tap into other than groundwater like surface or reclamation water. The operational rules between these sources can depend on the availability of each source, such as surface water that is mostly available after run-off occurred. The utilisation of the surface water firstly will minimise the evaporation of surface water in the dry climate conditions (Pashkin, 2019). The conjunctive use or rotational operation closely link the in-lieu program – see Section 2.4.7 Operation.

In the Carnarvon case, the town receives water from two aquifers (alluvium riverbed aquifer and a fractured rock aquifer). During and after the rainy season (summer-autumn) the alluvium aquifer is used because the recharge is quick and to minimise evapotranspiration from the alien vegetation which abstract water from the alluvium as well. In the winter and spring months, the fractured rock aquifer is utilised. The six months of no pumping allows the fractured rock aquifer to recharge and recover from the previous dry period (D Rudolph, 2001, pers. comm.).

The purpose of the use is intertwined with the integrated approach with other sources like surface water, reuse, rainwater harvesting, stormwater and desalination. Groundwater can be conserved when other water sources are available, for example, wastewater (WW) from the wastewater treatment works. The WW can be used as replacement water for industrial water where the quality is not of the essence. Flushing toilets where non-potable water can be used will save clean groundwater from being pumped out of the aquifer.

The volumes abstracted from a borehole will influence the equilibrium of the water around the borehole, and a new equilibrium will be created (Seyler et al., 2016). In the case of saline water freshwater lenses (for example the Kalahari) is on top of the saline water or brine. The freshwater is only purged off from the saline water in small volumes, although the borehole yield is mostly higher (Rotz and Milewski, 2019). The same effect is found on island freshwater lenses and boreholes right above the high water level mark next to the sea. In Western Australia and Murray Basin, saline water is targeted explicitly to abstract to create space for infiltration of ‘’fresher” or leaser saline water. The water table is also lowered to prevent land and stream salinisation, and waterlogging that decrease agriculture productivity (Dogramaci, 2014 and Dogramaci et al., 2009).

Banning of specific crop cultivations (like sugar-cane) with high water use and diversification of crops will reduce the groundwater use linked with irrigation water-saving techniques that can support groundwater not been over abstracted and wasted (Garduño and Foster, 2010). Pumping

cost is higher with deeper groundwater levels, and usually, the recharge of the deeper aquifers is much slower than shallow groundwater water levels or aquifers.

The pressure from general society to improve the environmental quality (Foster et al., 2010) is mounting, and groundwater management can play a significant role in linking of the environment, land use and water resources.

The value of water use is proportional to the cost and benefit of supply on the one side, and the volume supplied to a community on the other side. During over abstraction, the net benefit to the community decreases till the benefit diminished and negative environmental impacts occur. The cost of the borehole/wellfield (development and infrastructure), energy and price of water will increase as the cost and benefit of supply, and the volume supplied to a community increased. Pricing of groundwater can be used to constrain consumption to encourage efficient use of the water and so that the utility function of the groundwater user is optimised (Dillon et al., 2016).

The IUCN took the concept of minimising impacts on the environment and society – "do no harm"- further too also contribute to local, national or global targets for environmental and social wellbeing. The measurable targets can be established within the biodiversity, for mitigation of development impacts that would result in net maintenance of biodiversity features thus "no net loss" and a net improvement will be a "net gain" or "net positive impact". Biodiversity Net Gain (BNG) or Net Positive Impact (NPI) is used to describe this approach (IUCN BBP, 2017). In the groundwater context, the NPI can be used to address the impact of over abstraction, pollution, seawater intrusion, etc.

Recharge enhancement

Climate change will impact the frequency and period of the availability of water to recharge or infiltrate. The total volume of rainfall may not change, but the higher intensity rainfall events will generate higher ran-off and less infiltration/recharge. Various technics and methods exist to enhance the recharge through low maintenance infrastructure designs which include contour cultivation and dyking/bunding; infiltration columns with coarse filled material (Fourie et al., 2016); stormwater collection ponds; land use management (grazing, vegetation type, erosion, run-off).

Artificial recharge (or managed aquifer recharge) is an approach to put water back into the aquifer. The purpose can be to store water or storage of water for later use (in the case Windhoek); transfer of water (Williston); purifying the water (Atlantis); groundwater quality

enhancement (Kharkams); enhancing the recharge (Carnarvon); prevention of seawater intrusion (Atlantis); sustain groundwater flow (Elandsfontein, Langebaan); restore aquifer water levels (Prince Albert); and disposing of water (Kolomela, Postmasburg) (Murray and Harris, 2010 and Fourie et al., 2016)

2.4.7 Operation

The sustainability of groundwater are closely linked to the operation of abstraction volumes and activities

Operating rules

Groundwater operating rules can be divided into three groups based on scale, namely borehole, wellfield and aquifer. All three operating rules do not need to be developed if the abstraction impact is small, but the borehole operating rule will always be needed.

Borehole rules

The borehole operating rules are dealing with the borehole operational issues which include pumping period, pump rates, volume, water levels, water sample, monitoring, pump infrastructure, housing, maintenance schedule, access, power source, etc. Most of the borehole operating rules will be determined through the pump test, infrastructure manuals (for the pump, motor, telemetric system) and equipment specifications.

Basic rules may include as an example:

- No drawdown more than 5m in Dolomitic areas
- In areas where iron bacteria or bio-fouling (*Thiobacillus ferrooxidans* and *Leptospirillum ferrooxidans*) (E van Heerden, 2015, pers. comm.) occurs, monitoring equipment needs to be sterilised when using in other boreholes to prevent spreading of the bio-fouling to the other boreholes. Do not allow a drawdown of more than the 5m in the borehole to prevent the deeper part of the borehole column of bio-fouling contamination.
- Maintain groundwater level head above the confined layer to prevent unconfined conditions.

- The electric installation needs to be inspected with each visit for tampering, loose wiring and secure housing or power box.

Wellfield rules

The wellfield operating rules relate to the operation of the wellfield and the borehole communication within the wellfield. How do the boreholes influence each other during pump (cone of depression), recovering time of boreholes, emergencies like drought and breakdowns (Riemann et al., 2013), wellfield infrastructure pipeline constraints, water use peak volumes, etc. will be addressed with the wellfield operating rules. In the case of Beaufort West, the Kleinhansrivier wellfield is located over two aquifers namely the Dorp and Kleinhansrivier aquifers. The water network infrastructure layout in the town determined wellfield and not the aquifer boundaries (see section 4.4). Most of the wellfield operating rules will be determined through the numerical groundwater model (Seyler and Holland, 2016).

An example of a 16-hour pumping and 8-hour recovering schedule of a wellfield operating rule would be:

- Borehole no 1 (yield 2 l/s or 7.2 kL/h): pumping – 01h00 till 17h00; recover – 17h00 till 01h00.
- Borehole no 2 (yield 6 l/s or 21 kL/h): pumping – 05h00 till 21h00; recover – 21h00 till 05h00.
- Borehole no 3 (yield 1 l/s or 3.6 kL/h): pumping – 16h00 till 08h00; recover – 08h00 till 16h00.
- Borehole no 4 (yield 2 l/s or 7.2 kL/h): pumping – 03h00 till 11h00; recover – 11h00 till 15h00; pumping – 15h00 till 23h00; recover – 23h00 till 03h00

Figure 2.17 provides a graphical view of the volume that would be received by the reservoir during the 24 hour day from the wellfield of four boreholes to address the water requirement and accommodate the peak demand periods of the day.

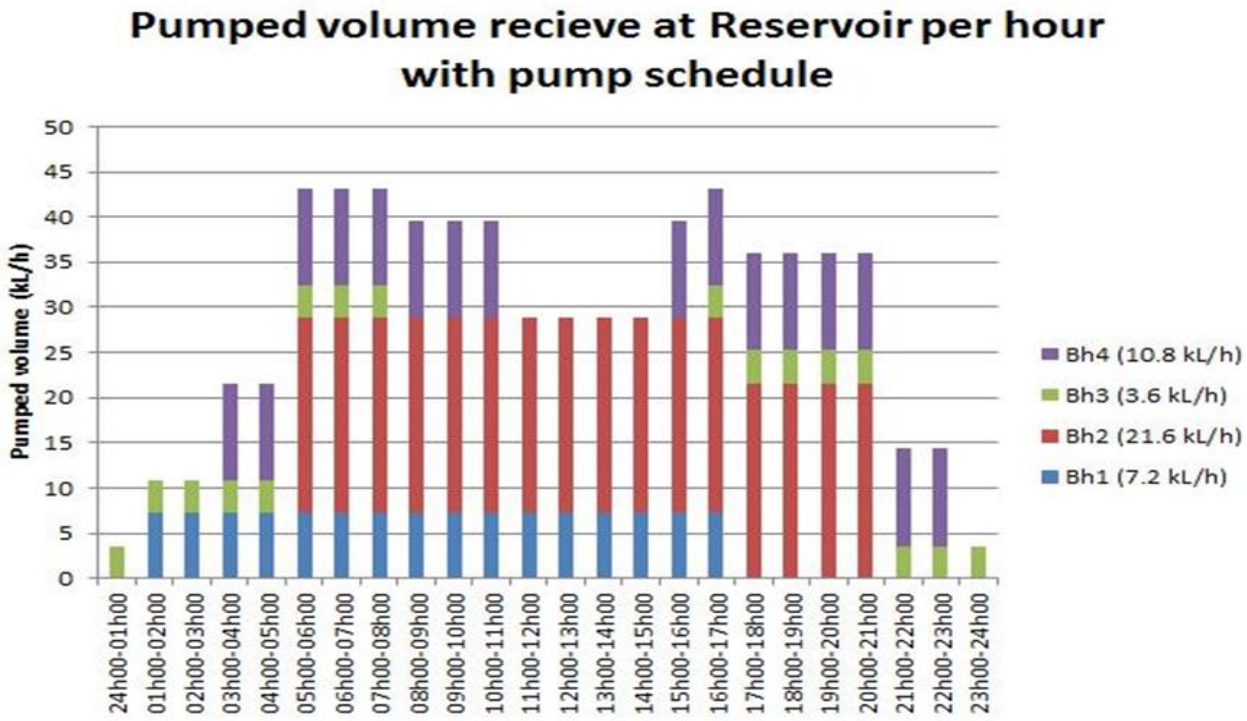


Figure 2.11: Example of the pumped volume received at the reservoir per hour according to the wellfield operating rule

The water requirement from the reservoir is very high in the early morning and late afternoon till the evening with medium to high water requirement during the day. During night time the water requirement is almost zero but the reservoir needed to be filled up for the very high requirement early morning. The pumping schedule in the wellfield operating rule is developed to address the water requirement with the most effective use of the available yield of each borehole and infrastructure constraints.

Aquifer rules

Within an aquifer, more than one wellfield can be developed by a municipality or different municipalities. The influences of the different wellfields (communication) on each other need to be managed.

Bigger municipalities usually have more than one wellfield in usually different aquifers with different hydrogeological characteristics (as mention above, with the example of Carnarvon in section 2.4.6 Conservation). Operations will be rotated or scheduled to fit each aquifer's hydrogeological characteristics. The main benefit or reason for the in-lieu program is to allow recharge to take place. Low rainfall impacts the run-off and the surface dam storage first while groundwater resources have a delay effect to drought. This delay effect acts as a "buffer", but this

also transmits to the delay recovering of water levels or storage after the drought (Figure 2.18) (Robins et al., 1997). Allowing the groundwater resources to recharge an in-lieu program needs a dedicated operational program of 3-5 years. Recharge enhangement scheme can shorten the recovering period of the aquifer (see section 6.4.1).

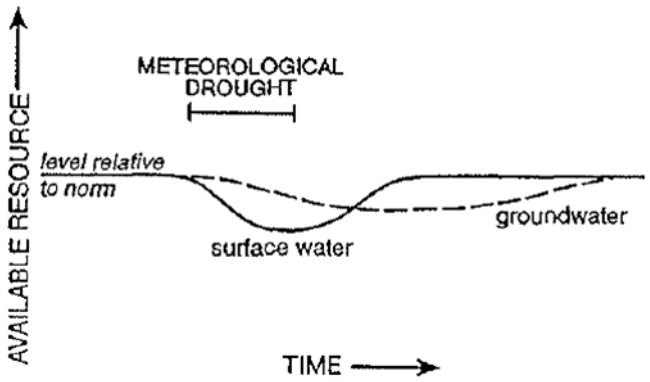


Figure 2.12: Contrasting response and recovery functions of groundwater and surface water to drought (Robins et al. 1997)

Conjunctive use with other water sources like a dam, run-of-river, reclamation, spring, etc. need also be managed because some of these sources are not always available throughout the year (seasonal). A conjunctive water use model can be used to support the decision making process for optimal use of all the water resources (Braune and du Plessis, 2019).

One of the most significant impacts on the aquifer operating rules is the allocation volume according to the water use licences in an aquifer. In South Africa, only surface water use subjected to annual revised water allocations according to the availability of surface water (dam level storage) (Pashkin, 2019). The groundwater storage levels in basic terms are influenced by the recharge (rainfall) [INFLOW] and abstraction (including baseflow) [OUTFLOW]. A sustainable yield for a borehole is typically recommended only one time in a borehole's life (usually after drilling and testing), and the aquifer recharge volume calculations were done with the development of a wellfield or scheme. Water allocations made according to seasonal rainfall and recharge events (DELWP, 2017) prevented unplanned water restrictions and increase water security in Australia.

Climate change will force the relook at the way we interpret pumping test analysis. A more extended period of drought and higher intensity rainfall (DWS, 2013) will affect the recharge mechanism of different types of aquifers (Dennis et al., 2013). The yield recommendation incorporating drought conditions are usually only two years of no recharge (Van Tonder et al., 2002) but can extend to 5 years. The variation of drought patterns in South Africa has changed

from an all wet period in 1950 to the 1970s followed with an all dry period from the 1990s (Abiodun et al., 2018) Various means and method need to be implemented to adaption the challenges like developing and implement schemes to enhance recharge, optimise operating rules, improving monitoring, etc. (DWS, 2013)

2.4.8 Infrastructure

The infrastructure is the link between the aquifer and the user, but if this 'link' is not monitored, operated and maintained, then no water will reach the users. Groundwater (aquifer) is often accused of not being reliable, and thus the failure of the groundwater supply scheme is blamed on groundwater rather than on the infrastructure (pump, power source, valves, pipes, borehole, etc.) used to abstract or delivered the groundwater to the users.

The tasks to monitor the groundwater resource are included into the operational tasks, but both these tasks will be carried out on the same time as the maintenance tasks because all three tasks are interlinked and the success of each task depends on one another (DWA, 2009). For example, when over-abstraction (*operation*) is allowed, it can lead to a drop in water level and a decline in yield (*monitoring*) which can lead to borehole construction failure (*infrastructure*) or fracture closing or clogging (*maintenance*).

The poor planning of the scheme layout and development phase and poor quality material used during the construction phase may also contribute to challenges with the infrastructure during the operational and expansion phases.

Maintenance

Maintenance is described as the activities required to sustain the equipment, infrastructure and supply system in a proper working condition. Davis and Brikké (1995) divided maintenance into three categories:

Preventive maintenance	Servicing to preserve assets; Minimize breakdowns; and Regular inspection.
Corrective maintenance	Replacement of broken and worn out parts to sustain reliable facilities; and Minor repair.

Crisis maintenance	Unplanned responses to user complaints and emergency breakdowns to restore a failed supply.

The maintenance needs to perform as part of the daily tasks of the operator (CDM, 2013). See Table 2.44 below for a list of some recommended daily task to be performed by the borehole operator. Ensuring that maintenance tasks are always carried out requires training of operators, active overall management, and sufficient funds (DWA, 2009). A Maintenance Plan needs to be developed and implemented (DWAF, 2008b) on an annual basis which includes the assessing of the current status of the monitoring network and the identification of areas that require maintenance and upgrade.

Table 2.4: Tasks of an operator of a borehole (adopted from DWA; 2009, Riemann et al., 2010; Cobbing et al. 2014 and CDM, 2013)

Main Tasks	Description
Monitoring	– water levels, – water quality, – pumping rates, – electricity consumption and – water demand
Cleaning and maintaining	– above-ground infrastructure, – submersible pumps, – boreholes, – engine services – treatment facilities and – storage reservoirs
Electrical systems	
Security of installations	
Groundwater protection zone security	– trimming of grass – picking up litter
Reporting	– monitoring – breakages – supplies (fuel, tools, belts, vaults, etc.)

2.4.9 Assessment

Assessment of an aquifer can be defined as the status quo of a geographic extent of an aquifer system. The benefit of characterising (assessing) groundwater resources lays in the economic value of groundwater resources to the national economies through the cost to replace urban and rural water supply should it be lost; the production groundwater underpin; and the 'lost opportunities' of not identify and develop a groundwater resource (Foster et al., 2010).

Foster (2010) indicates that one of the Ostrom Principles – "congruence between resource allocation and the prevailing local conditions and constraints" refers to the balance or sustainability of the need to be found. Assessment of various elements needs to take place and will lead to various methods and approaches to assessment. A groundwater resource can only be sustainable if the amount of water abstracted is less than what enters the system (Margane, 2003). The capture principle optimises this principle (sustainability) in its assessment approach (Seyler et al., 2016).

The main elements of assessment are (Margane, 2003 and DWAF, 2008b):

- Determination of the groundwater system's extent, thicknesses and saturation limits of the aquifers
- Determination of hydrogeological properties and characterisation of groundwater flow
- Identification of the exploitation potential of the aquifer
- Assessment of groundwater quality
- Assessment of groundwater vulnerability to land use, hazards and pollution to groundwater
- Surface water-groundwater interaction (baseflow and ecological requirements) and spring capture
- Evaluation of risks to the groundwater system (such as pollution threats, depletion threats, risks to ecological habitats (groundwater-dependent ecosystems))
- Evaluate existing relevant monitoring networks which may include a risk-based, numerical or analytical model of the aquifer
- Determination of the possibility of the artificial recharge and its possible impact on the quantity and quality of the environment and natural water resources
- Determine water requirement (current and future), needs of water users (all sectors)
- Assessment of existing or planned infrastructure that may be impacted
- Assessment of demographic and socio-economic impacts and changes on groundwater

The aquifer-yield continuum (Pierce et al., 2013) put integrated water resource management back in the groundwater assessment science space by incorporating groundwater science, policy-making and governance (human choice issues) into groundwater management space.

2.4.10 Institutional Arrangements

The failure of the day-to-day groundwater resource management and protection can only be understood if an analysis is done of the existing arrangements and identification of benefits to all the stakeholders (Foster et al., 2010). The analysis can be done through gap analysis, problem-driven analysis or political-economic approach.

The institutions that manage groundwater resources can be divided into three government levels, namely: national, regional and local (DWAF, 2008b; FAO, 2016a and Foster, 2010). The Department of Water and Sanitation (DWS) at the national level have the organisational approach of centralised planning and policy-making but a supporting function to Regional Offices.

At a regional level the DWS Regional Offices, Catchment Management Agencies (CMA) and Aquifer Management Committees (AMC) (for cross/transboundary aquifer) are the institutions that manage groundwater resources (includes monitoring); implementing policies and strategies; and allocating water for use (DWAF, 2008b).

Local-level institutions can include Catchment Management Forums (CMF), Water User Association (WUA), District and Local Municipalities and Water Boards. The responsibilities of the institutions at a local level will include day-to-day management and administration; planning; developing water services and infrastructure; quality protection, monitoring; etc. of the groundwater resources (DWAF, 2008b and FAO, 2016a).

Funding for the operations in the institutions from national to the local level is a challenge. Foster (2010) put the sourcing and allocation of sufficient financial resources at the national level, although the planning and day-to-day management are done on a regional and local level.

In most cases in South Africa, groundwater is still managed by an individual user (farmer, local municipality, mine, etc.) on his property. In intensive groundwater irrigated areas like Dendron and Tosca Irrigation Boards (IB's) were established to manage the groundwater source that is being shared by all the irrigation users. The establishment and conversion to the Water User Associations (WUA's) needed to include all the groundwater users that utilise water or those who have a specific interest in a specific aquifer. Local government, non – governmental organisations and environmental organisations usually are not included or involved in the WUA's (Seward and Van Dyk, 2018). The involvement of all users needs to happen in all aspects of the management of the aquifer and links closely to stakeholder participation (see section 2.4.12). Within the WUA,

there needs to be a group or organisation that takes the responsibility to manage the aquifer on behalf of all the users. The responsibility can be with the municipality, farmers, a utility or users.

The Groundwater Governance: A Global Framework for Action project (FAO, 2016a) explain the ideal institutional arrangement as '*integrate linkages and functions of groundwater management vertically between the national level and the local level, and horizontally at each level with other sectors and agencies impacting on groundwater*'.

Figure 2.13 indicates an ideal institutional arrangement in which groundwater planning, policy and implementation functions are allocated to each appropriate level within a vertically integrated structure, and horizontal linkages at each level provide for coordination, joint management, planning, implementation, etc. (FAO, 2016a).

Regulatory and management or operational functions need to be separated (FAO, 2016a) and performed by different units within a municipality (Riemann et al., 2010). This institutional arrangement is in practice, challenging to achieve in smaller municipalities with limited staff.

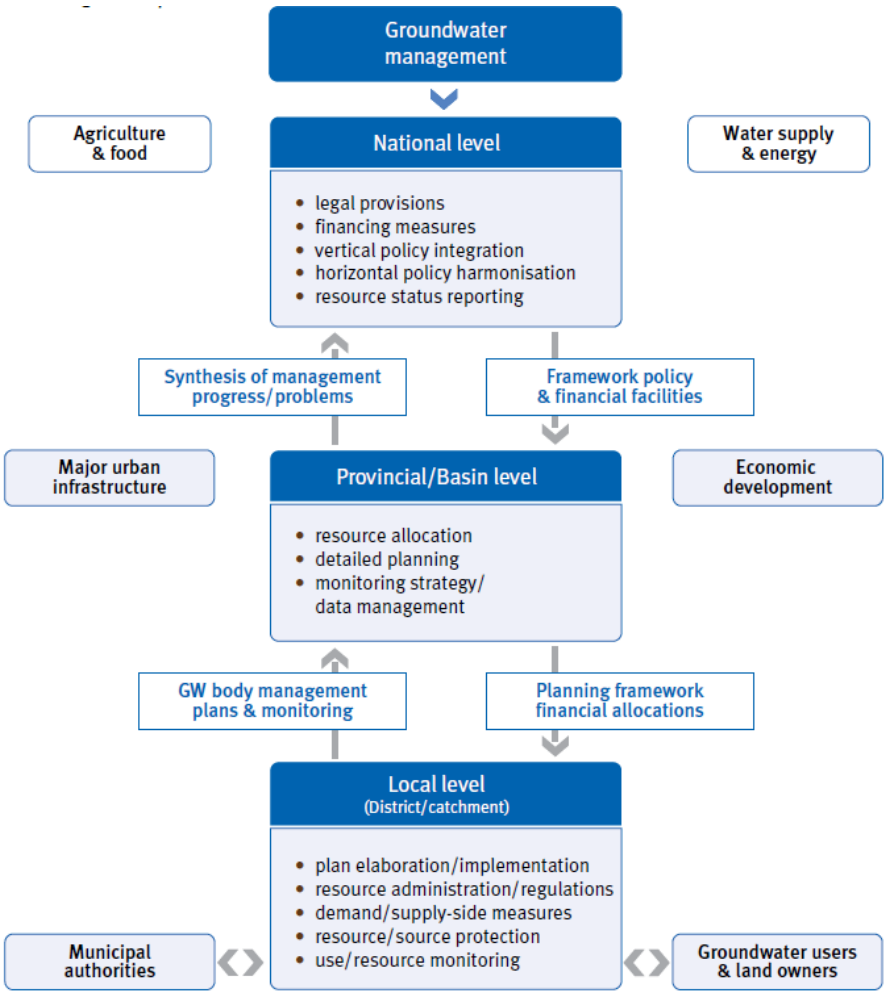


Figure 2.13: Institutional levels of government with horizontal management linkages within the groundwater sphere (FAO, 2016a)

2.4.11 Capacity and Skills

Capacity does not just relate to personnel (or the lack thereof) to manage groundwater at a municipality (Braune et al., 2010) but also includes the capacity of the institution to manage, the stakeholders to participate (see section 2.4.12), groundwater profession to support and government (higher level like CMA and DWS) to lead.

Capacity at the municipality level is in a critical state (NGS, 2017). Sufficient internal capacity needs to be developed to ensure the sustainable management of groundwater at the municipality level (DWA, 2010a). The lack of personnel can be from a high turnover (slow appointment process) (CDM, 2013) or financial constraints to appoint qualified staff (NGS, 2017). A survey in 2005 by MacKay and Koster (Braune et al., 2010) indicate that 74 out of 231 local authorities did not even employ technical experts. The study, and also confirmed by Kotze et al. (2017), show that the skill

to manage groundwater within the municipalities is very limited with none of the local governments having groundwater expertise.

The Groundwater Strategy (2010) advocated the idea of a "Municipal Hydrogeologist" to be appointed at the local municipality or on district municipality level, to support and/or manage the groundwater supply. A hydrogeological background is a necessity for personnel at the municipal level if groundwater is relied upon for municipal water supply. Insourcing of skills from the private sector can help to address skill shortages within a municipality (Braune et al., 2014). The situation from 2005 has since changed with regards to the permanent appointed groundwater personnel at the municipal level. A hydrogeologist was appointed in the Dr Kenneth Kaunda District Municipality, and in 2018 the City of Cape Town appointed a hydrogeologist in the Section: Bulk Water Resource and Infrastructure Planning (C. Lasher-Scheepers, 2018, pers. comm.). Still more needs to be done with in-house training and skills development at the municipal level by the private sector (FAO, 2016a), the academic and research institutions (WRC, CSIR and CGS) (DWA, 2010; Braune et al., 2014 and NGS, 2017).

The support from the government (DWS national, regional) and CMA to the local municipalities are mostly due to a capacity shortage and in some cases, a skill shortage (DWA, 2010).

Management of groundwater cannot be done without the support of the executive management of the municipality. An informed and knowledgeable (capacitated) management can ensure the budget is available, personnel are appointed and the future development planned is approved, (DWS, 2017).

2.4.12 Awareness, Information, Communication and Stakeholder participation

Awareness, Information, Communication and Stakeholder participation are going hand in hand with each other. Through awareness and information sharing (communication), stakeholders will participate more in decision making, management, and taking responsibility for the groundwater resource they use and desirable impacting thereof.

Ostrom suggests that there must be a "collective arrangements for the participation of stakeholders in decision making" which is a principle to follow concerning groundwater governance (Foster et al., 2010). Put in different words: "Is there an opportunity or process for the stakeholders to provide input on how the groundwater is managed?" For example, in public

meetings, in forums, by suggestion or complaint boxes and open-door policy, to mention just a few. By creating an effective communication system, information can flow to and from the users and stakeholders. An effective communication system provides an excellent platform for transparency and accountability for managing groundwater.

Reporting back to stakeholders will not just involve the stakeholders in the management process but will also make the stakeholders aware of the desirable outcome for groundwater management and creating a common goal. This involvement should bring benefits on various levels like social, economic, technical and management levels (Garduño et al., 2010). Although stakeholder participation and influencing the stakeholder behaviour is more linked to groundwater governance process than groundwater management, it still plays a significant role in groundwater management

Exchanges of information are taking place, for example, good land-use practices, regulations and bylaws and changes in land use. The information exchanges will also lead to the capacity building of the stakeholders (Foster et al., 2010).

Linking with the regulatory function of a municipality, the municipality or Aquifer Management Organisation can develop a database of the profiles and all the groundwater users in the municipal area that is using groundwater from a specific aquifer as part of the stakeholder's process. Information like name, location and volume abstracted, uses and use status is essential. However, the database can also be used for more effective networking with the stakeholders (NGS, 2017)

Shultz et al. (2011) identify three positive effects when the users and local inhabitants are involved in decision-making and implementation of management, namely the increases support, increases the livelihood of people, and increases the outcomes.

If an adaptive co-management approach is applied two stakeholder types will participate namely: "the participation of actors with different types of "resource" knowledge (both scientific knowledge and experiential, for example, local, traditional, and indigenous knowledge).; as well as the participation of actors working at different ecological scales and levels of decision-making (e.g., managers of specific habitats and policy-makers at local and national levels)" (Batchelor, 2007; Mays, 2013; Olsson, Folke, & Berkes, 2004; cited in Schultz et al., 2011).

The International Association for Public Participation (cited by Jonker, 2010) in 2000 indicate the increasing levels of public involvement as Inform; Consult; Involve; Collaborate, and Empower. Each stakeholder group will be different, and different approaches will apply. Most of the public

participation processes in the South African water resource management (WRM) setting will most likely be categorised as 'collaborative' (Burt et al., 2006 cited by Jonker, 2010).

2.4.13 Summary

Groundwater management principles are divided into twelve principles:

Protection: Groundwater needs protection from a quality side that include pollution sources that contaminate the groundwater through infiltration and intrusion, and from a quantity side that includes over and excessive abstraction of an aquifer. Preventative measures include protection zones around the aquifer, wellfield or borehole.

Regulation: The National Water Act (1998) regulates the groundwater use through the different types of authorisations and the registration of water use. Different measures support, through the NWA, the comprehensive protection and sustainable groundwater resource management of all resources.

Use: A single abstraction point can not be managed if there are various other abstractions in the same aquifer. The abstraction patents of the different groundwater users need to be taken into account when groundwater assessment and allocations are done.

Planning: The future development of a groundwater resource requires detail planning, knowledge of the groundwater resource and insight into the future water requirements of the users. Planning happens through a predetermined sequence of increasingly detailed phases by scale and level of detail and by increasing the confidence in the yield estimations. The timeous planning and development of additional groundwater resources can prevent water shortages. Planning is divided into the resources investigation, implementation/development and the operational phases.

Monitoring: The management of the groundwater can only be achieved through the gathering of information (data) that influence and impact the groundwater status. The design and setup of a monitoring network need to consider the purpose of the monitoring and aquifer characteristics. A monitoring protocol and network design (Riemann et al., 2010) will determine the different stages of the monitoring; level and purpose of data collection and also the different locations of the monitoring activities. All monitored or collected data need to be captured, stored and processed in

the database system of some sort so that the data can easily be extracted, analysed and reported on.

Conservation: Conservation of groundwater is related to the use of groundwater at the right time and the real purpose of the use. Groundwater can be conserved when other water sources are available. The conjunctive use or rotational operation closely link the in-lieu program. Artificial recharge (or managed aquifer recharge) is an approach to put water back into the aquifer. The value of water use is proportional to the cost and benefit of supply on the one side, and the volume supplied to a community on the other side.

Operation: The sustainability of groundwater are closely linked to the operation of abstraction volumes and activities. Groundwater operating rules can be divided into three groups based on scale, namely borehole, wellfield and aquifer. The water network infrastructure layout in the town determined wellfield and not the aquifer boundaries. Conjunctive use with other water sources like a dam, run-of-river, reclamation, spring, etc. need also be managed because some of these sources are not always available throughout the year (seasonal) and the management can be done through the use of a model for the optimal use of all the water resources.

Infrastructure: The infrastructure is the link between the aquifer and the user, but if this 'link' is not monitored, operated and maintained, then no water will reach the users. Maintenance is described as the activities required to sustain the equipment, infrastructure and supply system in a proper working condition and these tasks are included into the Maintenance Plan.

Assessment: Assessment of an aquifer can be defined as the status quo of a geographic extent of an aquifer system. Assessment of various elements needs to take place and will lead to various methods and approaches to assessment. A groundwater resource can only be sustainable if the amount of water abstracted is less than what enters the system (Margane, 2003).

Institutional Arrangements: The institutions that manage groundwater resources can be divided into three government levels, namely: national, regional and local (DWAF, 2008b; FAO, 2016a and Foster, 2010). Funding for the operations in the institutions from national to the local level is a challenge. Regulatory and management or operational functions need to be separated (FAO, 2016a) and performed by different units within a municipality (Riemann et al., 2010).

Capacity and Skills: Capacity at the municipality level is in a critical state (NGS, 2017). The lack of personnel can be from a high turnover (slow appointment process) (CDM, 2013) or financial constraints to appoint qualified staff (NGS, 2017). The Groundwater Strategy (2010) advocated

the idea of a “Municipal Hydrogeologist” to be appointed at the local municipality or on district municipality level, to support and/or manage the groundwater supply.

Awareness, Information, Communication and Stakeholder participation: Information can flow to and from the users and stakeholders by creating an effective communication system. Through awareness and information sharing (communication), stakeholders will participate more in decision making, management, and taking responsibility for the groundwater resource they use and desirable impacting thereof.

2.5 ‘EXTERNAL DRIVERS’

It is important to remember that some influences sit outside the groundwater sphere and can be referred to as ‘external drivers’. These ‘external drivers’ will influence the behaviour of the users and the managers of the groundwater, the use of the groundwater resource and the pollution pressure that will be placed on the groundwater resource (Foster et al., 2010). This can include the political boundaries that hinder the development of protection around wellfield and recharge zones in urbanised areas, authorisation for mining and industrial development, climate change, the process of urbanisation, and lowering of electricity prices and increased crop prices in the agricultural sector to name a few.

One of the “local ‘external drivers’” at the municipal level is the financial income of the municipality – the ability to pay for the services. This has a direct influence on the money available for operations of the wellfields, maintenance of the infrastructure and new source development (NGS, 2017). Organisational arrangements, national legislation and legal regulation all impact from within the municipality as ‘external drivers’ of the management of groundwater (FAO, 2016a).

Sustainable groundwater management is constrained by the various political and institutional obstacles (Varady et al., 2016) which include “sector fragmentation, poverty, corruption, stagnated budgets, declining levels of development assistance and investment in the water sector, inadequate institutions and limited stakeholder participation” (UNSECO, 2006).

The socio-cultural aspects of groundwater management may be neglected in many instances (Varady et al., 2016a). Religion and cultural beliefs can hamper the development of new developments if consideration is not given to the socio-cultural principles during the community consultation process before a project is planned (Y. Rajkumar, 2006, pers. comm.). Rural

communities have more cultural (traditional) beliefs around water sources, for example, the hot springs with healing powers and “spirits of the ancestors” – Shu Shu hot springs in Eshowe, KZN (D. Molla, 2006, pers. comm.).

Whether the external drivers are on a global scale, at the political front, financial level or socio-cultural level, mitigation around these drivers need to be incorporated into the management of the groundwater.

2.6 LEGISLATION AND REGULATORY FRAMEWORK

The Constitution of the Republic of South Africa (Act No. 108 of 1996) (RSA, 1996) states in Section 24 that: *“Everyone has the right to an environment that is not harmful to their health or well-being” and in Section 27 that “Everyone has the right to have access to sufficient water”.*

2.6.1 Legislation

Water in South Africa is governed through various legislations. The main two legislations that govern water in the Republic of South Africa is the National Water Act (No 36 of 1998) and the Water Services Act (Act No 108 of 1997). The NWA further states in Section 3 that *“As the public trustee of the nation's water resources the National Government, acting through the Minister, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate*” (NWA, 1998).

The Water Act of 1956 (No 54 of 1956) in Section 5 recognise groundwater as ‘private water’ that means *“all water which rises or falls naturally on any land”* and *“is not capable of common use for irrigation purposes”* are the *“sole and exclusive use and enjoyment of“* the *“owner of the land on which such water is found”* (WAct, 1956). The status of groundwater has changed with the promulgation of the National Water Act (No 36 of 1998) when the water resources of South Africa were recognised as a common asset with the National Government, acting through the Minister (NWA, 1998 and NGS, 2017).

The NWA provides a legal framework for the management of the water resource (Riemann et al., 2010). The legal framework that relates to groundwater includes (NWA, 1998):

- Implementation of integrated water resource management (IWRM) principles (Preamble)
- Establishment of Catchment Management Agencies (Sec 77) with Catchment Management Strategies (CMS) (Sec 8)
- The protection of the water resources through a classification system (Sec 13.1(a)) and resource objectives (Sec 13.1(b)) which includes the determination of the Reserve (Sec 16)
- Pollution prevention (Sec 19) and remediation measure (Sec 20)
- The beneficial use and equitable allocation of water through various types of licensed and unlicensed entitlements to use water – authorisation (Sec 21-55)
- Establishment of a national monitoring system through the facilitation and coordination of monitoring of various aspects of water resources by collecting and provide relevant '*information and data*' from '*a variety of sources including water management institutions and water users'* (NWA, 1998) (sec 139-141).

The Water Act of 1956 provides the legislation (Sec 27-32) that declare an area a subterranean Government water control area. The control over the abstraction and use of the water were vested in the Minister (WAct, 1956). This legislation was the forerunner for the countrywide authorisation process that promulgated through the National Water Act in 1998.

The White Paper (DWAF, 1997) indicates that the responsibility for the *"development, apportionment and management of available water resources" to be delegated to a "catchment level, regional level and local authorities in such a manner as to enable interested parties to participate"*. This place the responsibility of managing the (ground) water resources not just at the national level but also at the regional and local municipality levels. The catchment management agencies have o the objective to manage the water resources on behalf of the Minister and to involve the local communities the management (NWA, 1998).

The aim of the Water Service Act (1997) is to provide the rights of access to basic water supply and sanitation which includes "*water services development plans; a regulatory framework for water services institutions; the gathering of information in a national information system and the distribution of that information".* These are the duties of the water service authority (WSA) (Sec 11-21) and the water service provider (WSP) (Sec 22-23). Some of the duties of the WSA that relates to groundwater (Sec 11) include *"11. (1) …. to all consumers or potential consumers in its area of jurisdiction to progressively ensure efficient, affordable, economical and sustainable access to water services."* It also includes the drafting of a water service development plan (Sec 12).

Various regulatory tools exist that help with the regulation of water within municipalities. One example is the Integrated Development Plan (IDP) that combine various development actions into a 5-year overall framework for development in one plan and includes aspects like infrastructure and services are needed, how land/areas are to be used and how the environment will be protected (LGA, 2019).

A Water Services Development Plan (WSDP) was developed to specifically deal with the development of water resource development, water infrastructure and services development (Sec 12) (WSAct, 1997). The current and future water sources, infrastructure development, the operation, maintenance, repair and replacement of existing and future infrastructure, as well as the water conservation, recycling and environmental protection measures to name a few points, are contained in the WSDP (Sec 13) (WSAct, 1997).

The *Local Government: Municipal System Act* (No.32 of 2000) which provide core mechanisms, principles and processes for service delivery; *Regulations relating to compulsory national standards and measures to conserve water* (Regulation 509 of 8 June 2001) defines the minimum standard of services municipalities need to comply to and measurement that needs to be in place to manage water (greywater, effluent water, losses, etc.) within the municipal system. The *National Environmental Management Act* (Act 107 of 1998) relates to the prevention of any pollution, environmental impact assessments, and links with the NWA (1998) on cost recovery – 'polluter-pays' and 'cradle-to-grave' approaches.

2.6.2 Framework and tools

National Water Resource Strategy

The development of the National Water Resource Strategy is a requirement from the NWA (1998) to facilitate the management of water resources in South Africa. It provides a framework for the conservation, development, use, management, control and protection of the water resources for the country as a whole. The NWRS also provides the framework within which water is managed at the catchment or regional level.

National Groundwater Strategy

The 4th generation groundwater strategy for South Africa developed in 2017 was called the National Groundwater Strategy (NGS, 2017). The Groundwater Strategy (2010) provide the groundwater input to the 2nd edition of the NWRS of 2013. The NGS (2017) is built upon the FAO/GEF project "Groundwater Governance" (FAO, 2016a; 2016b, 2016c). The NGS Groundwater Governance Framework is divided into twelve strategy themes which will be implemented at the National, Regional or Basin and Local level (Figure 2.20). The National level strategic actions (Themes 1-11) is mirrored with actions at the Local level (aquifer and municipal level) (Theme 12). One of the main differences between the Groundwater Strategy (2010) and National Groundwater Strategy (2017) is the stakeholder involvement, drive and ownership (leadership – champion) (Themes 1 and 2).

The different strategy themes are highly interlinked and complement each other. The Sustainable Utilisation of groundwater resources (Theme 5) and the Groundwater Protection (Theme 4) will require regulations (Theme 3) to be effective. Local groundwater management will start functioning fully with the support of appropriate monitoring and information (Theme 10) as well as proper capacity, and skilled institutions (Themes 6 & 7) that are in place. The backbone of the institutions is the ability to fund, plan and develop (Themes 8 & 9) sustainable operations.

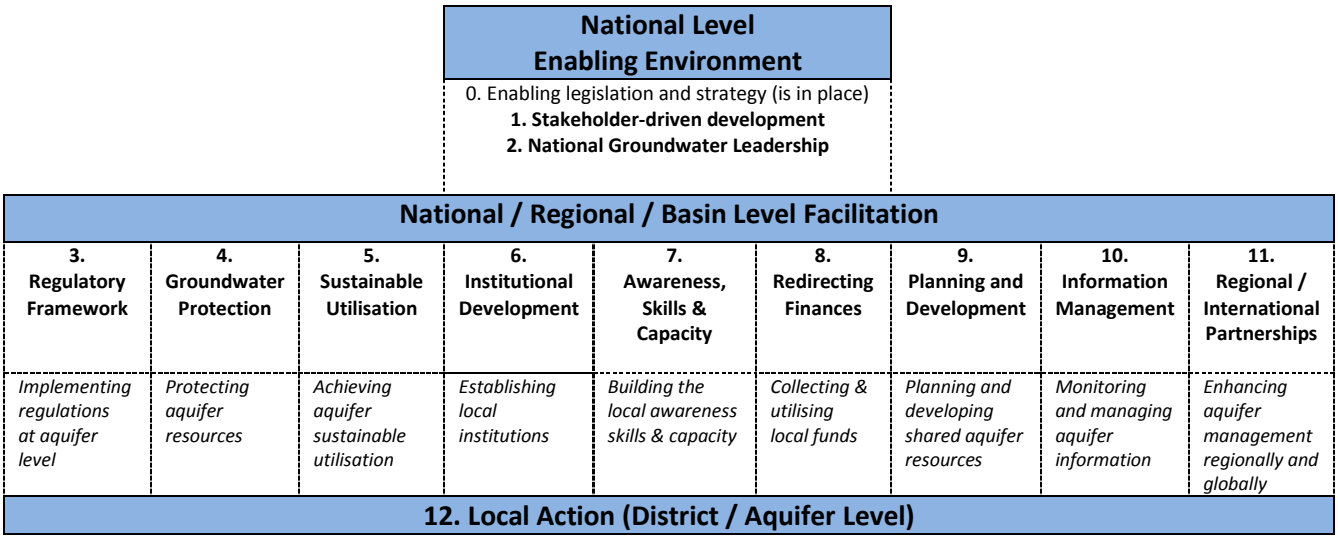


Figure 2.20: NGS Groundwater Governance Framework (NGS, 2017)

Each theme consists of various subheadings, namely, Objectives, Principles, Situation Assessment, Current Challenges, and Strategic Actions. The following Strategic Actions (Table 2.5) are some of the actions relating to groundwater management at the local level and need to be considered in a plan to manage the groundwater resources of the municipality.

Table 2.5: Some groundwater management Strategic Actions from the NGS

• Stakeholder engagement process	• Groundwater awareness-raising
• Valuation of groundwater resources	• Aquifer management
• Groundwater use verification	• By-laws
• Regulation and prohibition of land-based activities	• Protection of groundwater sources for domestic supply
• Sustainable utilisation objectives and plans (Groundwater Management Plans)	• Improve the efficiency of charging for groundwater use
• Local Hydrogeologist	• Capacitating municipalities
• Local participative management institutions	• Stakeholder involvement
• Groundwater technical capacity-building	• Good hydrogeological practice
• Align groundwater finance	• Macro planning
• Harmonisation of databases/information systems	• Groundwater development and management framework
• Groundwater data and information	• Groundwater use information
• Drought risk management	• Integrated information service
• Knowledge sharing	• Monitoring as part of aquifer management

Other regulatory tools

The land use and the changes in land use have a direct influence on both the quality and the rates of recharge. In an urban environment, land-use classification and control is generally the domain of the local municipality (Foster et al., 2010). The *by-laws* or the *Spatial Development Framework* of the municipality can be used to manage development (including protection zones) and land use activities. The *Integrated Waste Management Plan* includes waste handling (minimisation) and management (environmental remediation) (Burke, 2007).

2.6.3 Enforcement

Proper groundwater management can only occur if the above acts, strategies and tools are enforced. Weak enforcement may lead to undesirable land-use practices, over abstraction and pollution. (Foster et al., 2010). The government may promote intensification of agricultural production, rural land-use practices, and mining, but if unregulated, it may negatively impact groundwater resource. There needs to be a process to implement control measure or regulations.

CHAPTER 3:

GROUNDWATER MANAGEMENT PLAN

3.1 INTRODUCTION

The Groundwater Management Plan (GwMP) is the last step in the governance framework (FAO, 2016a). The GwMP is pulling all the twelve groundwater management principles (see section 2.4) into action and present management in an implementable plan of action. The Department of Water Resources in California defines a GwMP as "*planned use of the groundwater basin yield, storage space, transmission capability, and water in storage*" in the Groundwater Management Act (California Assembly Bill 3030) (RAWC, 2007). The GwMP will help to integrate groundwater with surface water, urban wastewater and land management (GWP, 2018a). The more prominent IWRM Framework may consists of the a number of other management plans and the GwMP needs to focus on the groundwater management aspects but still aligned with the other Plans (IUCN BBP, 2017) like environmental management plans (EMPs), integrated development plans (IDPs), integrated waste management plans (IWMPs), water services development plans (WSDPs), catchment management strategy (CMS), etc. (Burke, 2007). In some cases, the GwMP will be a subset of catchment management strategies/plans (Bosman, 2007).

3.1.1 Characteristics

A GwMP should describe detail objectives, timelines, tasks and task owners related to groundwater-related activities and should follow the mitigation hierarchy to align with good practice (IUCN BBP, 2017).

Foster et al. (2010) indicated that 'Groundwater Management Action Plans' need to include the required investment into the development of resource but also the commitment to bringing down the demand for water through various interventions. A clear institutional arrangement or structure is necessary for relation to the different levels of authority and responsibilities in the action plan. (Ostrom Principles - collective mechanisms lay the foundation for the participation of stakeholders in decision making)

Seyler et al. (2016) indicated that there are more elements to consider than just the standard hydrogeological parameters, to determine sustainable groundwater use by referring to "a lack of guidance or discussion relating to the decision as to whether the planned use is socially, environmentally and economically acceptable, and so can be considered sustainable" (Seyler et al., 2016).

Fallding (2000) indicates that the main functions of a management plan are: a) Communication to the people doing the groundworks; b) Summarising or collating data and information relevant to a specific site, activity, issue, etc. in one document, and c) Defining how to manage the resource to achieve policy objectives or to fulfil legal requirements.

The GwMP should be appropriate to a specific situation: baseline; incipient stress; significant stress and unsustainable situation (GWP, 2018a). It may include registration of boreholes and springs; resource mapping, simple management tools for borehole spacing, monitoring, reporting, a regulatory framework, groundwater development policy, resource assessment, legislation and active management mechanisms.

The GwMP of a local authority can also focus on one aquifer instead on all the groundwater resources within the local authority's area of jurisdiction. An 'Aquifer Management Plan' must entail the vision for the aquifer management and clearly defined actions which should link to the Catchment Management Strategy and/or the Water Resource Classification / Reserve determination if available (Riemann et al., 2013). The plan may include an aquifer management plan & annual action plan, groundwater assessment, numerical model and groundwater resource valuation.

Groundwater management will depend upon information about and the interaction between various factors (Table 3.1) (Foster et al., 2009):

Table 3.1: Groundwater management interlinking factors

• Climate conditions and recharge	• Groundwater use (scale, users, rate)
• Groundwater balance	• Vulnerability to degradation (aquifer)
• Groundwater role in environmental services	• Complexity and size of the groundwater resource
• Natural groundwater quality alarms	

Indicators need to be developed, to evaluate performances of the GwMP. The SMART criteria: **S**pecific, **M**easurable, **A**ttainable, **R**elevant and **T**imely can be used to select the indicators (GWP, 2018b).

Planning horizon

One of the first distinctions that are noticeable is that the goals of the GwMPs differ, meaning the planning horizon.

The first group have a statutory goal of achieving in 20 to 45 years with 5 to 10-year short term goals that are written up into plans and is more commonly known as "Management Action Plans" (Gardino and Foster, 2010 and PRAMA, 2017). An example is Prescott in Arizona, USA, with the statutory goal a safe-yield in the year 2025. To achieve the statutory goal four management action plans were already developed (with the 5th in a development phase) with progressively more rigorous management requirements for municipal, agricultural and industrial water users objectives to achieve in 10 year periods started in 1980 till 2025 (PRAMA, 1984, 1995, 1999 and 2017). In the case of the Souss-Chtouka Basin in Morocco, the statutory goal is the groundwater table stabilisation with three management action plans in the periods 2009-2012, 2013-2018 and 2019-2030. The first period's goal was to prevent the growth of the deficit (stop the extension of the irrigated area), the second period's goal was to reduce the deficit noticeably with 'real water savings' and the third period to reduce deficit noticeably by reducing the irrigation area (Gardino and Foster, 2010).

The second group have a 5 to 10-year goal with short term objectives (6-months to 2-years) to achieve the goal (see section 3.3.2 and 3.3.3). This dissertation will focus on the second group because in the South African context, a long term plan is referred to as a strategy and not a plan, although the outcome will be the same. Secondly, the focus the GwMPs is to support the Local Authorities to manage their groundwater resources better in a sustainable manner.

3.2 EXAMPLES OF EXISTING GROUNDWATER MANAGEMENT PLANS

The examples available of the GwMPs are broadly divided into three groups, namely world organisations, international (country, transboundary or aquifer specific) and finally local South African groundwater management plans.

3.2.1 World Organisations

Various international organisations like the World Bank and Food and Agriculture Organisation (FAO) of the United Nations developed a framework or an approach to develop a GwMP (Table 3.2). Each of the approaches differs in detail, focus and responsive audience. Garduño, Foster and Ait-Kadi (2010 and 2012) advocate for '*an adaptive approach … with periodic reviews*' as the '*scientific understanding*' improves through '*continuous monitoring and modelling*' of the groundwater system.

Development Approaches

Most GwMPs describe a process or framework or a planning approach that need to be followed to develop a plan. The final plan is not just a list of actions but a combination of "to-do list" and a "way or process" to do the actions. Foster et al. (2010) describe this process as a "pragmatic framework" that will allow you to elaborate and implement a plan. Fallding (2000) provides four broad approaches to categorised management plans, namely: policy-based; legislation-based; agreement-based; and informal plans.

Table 3.2 below summarises three of the world organisations frameworks or approaches. Each of the approaches is divided into three phases, namely the preparatory phase (data and status), development and stakeholder buy-in phase and finally the implementation and monitoring phase. In the preparatory phase, various data is collected and assessed, as baseline information of the resource, situation assessments and issue to address (purpose of the plan). The development phase consists of the physical development of the GwMP with milestones indicators through a consultative process. The final phase (implementation) involves the implementation of the plan with progress measurement reporting against the indicators and review or updating of plan.

Table 3.2: Aligning GwMP pragmatic frameworks or planning approaches of three Organisations

Phases	World Bank, GW.MATE[1] (4 Steps)	Groundwater Governance Project[2] (3 Steps)	Danish[3] (4 Steps)
Preparation	Assessment of Resource Setting • Hydrogeologic condition • Socio-economic situation Identification of Management Measures • Supply-side engineering • Demand-side interventions • Quality protection Section of Management Instruments • Marco-policy adjustments • Regulatory provisions • Community participation	Identification and prioritisation • Identification of aquifer systems • Assessment of Status • Management Characterization of the System	Action plans - purpose, basis and context
Development		Developing Management Plans for Priority Aquifer Systems • The Consultation Process • Preparation of the Management Plan • Adapting the Plan to the Local Institutions *(base on elements of institutional soundness, incentives and investment)*	Preparation of Action Plans - Content Adoption of action plans
Implementation	Implementation of Action Plan	Implementing and Reviewing Plans • Implementation • Monitoring, Reporting and Evaluation	Implementation of the Action Plan

Notes: 1) Garduño and Foster, 2010; Foster and Ait-Kadi, 2012; Foster et al.,2010 2) FAO, 2016a 3) Miljostyrelsen, 2018

Goals/Objectives

In Table 3.3, the groundwater management objectives of the five world organisation GwMP frameworks are divided into the twelve groundwater management principles as identified and described in Chapter 2.

Table 3.3: List of Management Objectives from GwMPs of five world organisations

Management Principles from Chapter 2	Description	World Bank, GW.MATE[1]	European Union – Water Framework Directive [2]	Mediterranean EU Water Initiative on Groundwater[3]	Groundwater Governance Project[4]	Global Water Partnership: IWRM-Toolbox[5]
Protection	• Vulnerability and risk of aquifer pollution	X			X	
	• Land-use change implications					X
	• Susceptibility to degradation	X			X	
	• Aquifer and source protection zoning	X			X	
	• Pollution prevention measures/controls	X	X			X
	• Accidental pollution incidents		X			
	• Pollution source inventory				X	X
Protection	• Vulnerability and risk of aquifer pollution			X		X
	• Land use change implications				X	
	• Susceptibility to degradation			X		X
	• Aquifer and source protection zoning			X		X
	• Pollution prevention measures/controls	X		X	X	
	• Accidental pollution incidents	X				
	• Pollution source inventory				X	X
Regulation	• Prioritisation of water uses					X
	• Legislation (for protection)	X		X		X
	• Self Regulation					
	• Water use rights (registration/authorisation – water use control)	X		X	X	X
	• Water allocation and quality objectives		X		X	
Use	• Socio-economic evaluation			X		X
	• User profile and use inventory			X	X	X
	• Groundwater use and pollution drivers			X		
	• Water demand/supply balance					X
	• Economic analysis of water use	X				X
Planning	• Alternative sources			X		
	• Future water demands				X	
	• Development scenarios		X		X	
	• Finance of planning interventions				X	
	• Manage Aquifer Recharge/Enhancement	X		X		X
Monitoring	• Monitoring network					X
	• Use measurement					X
	• Quality, quantity (discharge) and levels					X
Conservation	• Use reduction			X		
	• Efficient use					X
	• Conjunctive use			X		X

Operation	• Finance of operations			X	X	X
Infrastructure	• Subsurface infrastructure damage					X
Assessment	• Resource renewability/recharge			X		X
	• Surface water interactions			X		X
	• Resources status/hydrogeological characteristics	X	X	X	X	X
	• Ecosystem needs/status				X	X
	• Land use inventories				X	
	• Vulnerability and risk of aquifer drought				X	X
	• Size of the aquifer system's storage reserve					X
	• Resource and quality trends					X
Institutional Arrangements	• Water-use charging/cost recovery	X		X		
	• Economic incentives					X
	• Transboundary					X
	• Linking with other sectors					X
	• Responsibility /roles					X
	• Stakeholder institutions					X
	• Policy changes					X
	• Conjunctive management					X
Capacity and Skills	• Technical capacity					X
Awareness, Information, Communication and Stakeholder participation	• Policy/political dialogue on land-use			X		X
	• Community/Stakeholder Participation		X	X		X
	• Adaption plan					X
	• Identification of stakeholders				X	
	• Consultation/information with stakeholders					X
	• Permanent stakeholder mechanisms (committee, forum, newsletter, etc.)			X		X
Other issues not covered in Chapter 2	• Reducing pumping energy subsidies			X		
	• Constraining crop guarantee prices			X		
	• Urban distribution efficiency			X		
Operational level	• Fill gaps in information					X
	• A mechanism for Monitoring, Reporting, Evaluation implementation and Updating		X	X	X	X
	• Short- and long-term goals		X		X	
	• Securing investment for management interventions			X		X
	• Mobilising local government/ stakeholder partnership			X		X
	• Identification of priority issues (impact issues or user requirement issues)				X	X
	• Responsibility and schedule			X	X	X

Note 1) Garduño and Foster, 2010; Foster and Ait-Kadi, 2012; Foster et al.,2010 2) EC, 2000 3) MED-EUWI, 2007 4) FAO, 2016a 5) GWP, 2018a,2018b

Some of the elements of the world organisations described in Table 3.3 above related strongly to the Governance or Implementation Governance discussion in Chapter 2.2.5 and not to

Management as defined in Table 2.1. The row listing 'Other issues not covered in Chapter 2' relates to external (other sectorial) impacts on groundwater through policy interventions.

Few of the management principles addressed in Chapter 2 are not mentioned or fully covered in the content of the 'world organisations' GwMP's. Principles like maintenance, operation and skills are practical and are site-specific principles and too much detail principles to consider at the level the world organisations presented their GwMPs but still need to be considered when developing a GwMP.

In the last ten years, more focus is placed on GwMP, and this is clear when the publication dates of the five world organisation's GwMP are compared. The oldest two only provide broad guidance versus the latest three that contain much more detail and direction. The Groundwater Governance Project covered 70% of all the Management Principles.

3.2.2 International

In many countries, GwMPs or action plans for aquifers are a legal requirement and form part of an inclusive way of managing a 'common resource' (Miljøstyrelsen, 2018; CLI, 2019). These countries also provide a detail description of the content or components contained in such plan.

Twenty GwMPs from eight different countries (Table 3.4) is compared to each other in the view of finding a generic structure (Table 3.6) and format (Table 3.7) of a GwMP.

Table 3.4: List of 20 States and Countries with a GwMP's

GwMP	State – Country	
Edwards Aquifer Plum Creek	Texas	United States of America
Santa Rosa Plain Orange County Redding Owens Valley	California	
East King County	Washington	
Prescott	Arizona	
Bolbro Aquifer (Odense)		Denmark
Languedoc-Roussillon		France
Hyderabad Delhi		India
Regina Yorkton	Saskatchewan	Canada
Winkler	Manitoba	
Saq Aquifer		Saudi Arabia

Ipoly Valley		Slovakia-Hungary
Shepparton Warrion	Victoria	Australia
Alice Springs	Northern Territory	

Table 3.4 indicates that most of the GwMPs are from the United States of America (USA). GwMPs is a regulatory requirement in many states in the USA with comprehensive legislation on groundwater management from the 1990s (RAWC, 2007). Australia has a remarkably small number of GwMPs in the list above. The concept of a Management Plan is embedded in several of the natural resources acts of Australia, with management plans such as for bush fires, fisheries, koala, floodplains and coastlines (Fallding, 2000). Most of the States of Australia have a Water Act with specific reference to a management plan for water resources (groundwater resources, surface resources or both) (WAV, 2015). These GwMPs related mostly to specific extraction (operating) rules of an aquifer, water allocation and the statutory requirement according to the Environmental Protection Authority. The statutory requirements relating to the impact on the groundwater resources from mining activities. The water resources are managed in an integrated water resource management (IWRM) approach through policy and legislation (catchment or basin water management plans).

Each of the GwMPs is assessed with regards to the purpose, focus area, validation period, content and structure. Tables 3.5, 3.6 and 3.7 provide summaries of the analysis.

Purpose and Validity Period

The purpose of a GwMP is linked to a specific concern with the management of a groundwater resource. In most cases, multiple issues or concerns are addressed in a single plan. The validity period is also directly linked with the purpose and the timelines associated with milestones achieved in the plan (see Table 3.5).

Table 3.5: Purpose and Validity Period of the various Groundwater Management Plans

GwMP	Main Purpose or Goal	Gw Management Sub Focus	Validity Period (years)		Version
Edwards [1]	Groundwater management	Management, Conservation, Protection	5	2010-2015	3rd
Plum Creek[2]	Groundwater management	Conservation, Management	5	2018-2023	1st
Santa Rosa Plain[3]	Inform and guide local decisions		5	2014-2019	1st

Orange County[4]	Gw Basin management	Declining water table, Seawater intrusion, Artificial recharge	5	2015-2020	6th
Redding[5]	Groundwater management	Planning, Declining water table	10	2007-2017	2nd
Owen Valley[6]	Vegetation management		Once off	1990	1st
East King[7]	Groundwater management	Protection, Safe Yield	5	1998-2003	1st
Prescott[8]	Safe Yield		10	2010-2020	4th
Bolbro[9,22]	Operational, Information and planning		2	2015-2017	1st
Languedoc-Roussillon[10]	Groundwater management	Knowledge Gain, Better administration	5	1997-2002	1st
Hyderabad[11]	Groundwater management	Development, Artificial recharge, Conservation	1	2011-2012	1st
New Delhi[12,13]	Groundwater development and management		-	2006	1st
Regina[14]	Groundwater management	Conservation, Declining water table, Protection	Once-off	1998	1st
Yorkton[15]	Groundwater management	Allocation, Protection	Final	2006	2nd
Winkler[16]	Groundwater management	Public education, Recharge enhancement, Safe Yield	Once-off	1997	1st
Saq[17]	Safe Yield		Once-off	2009	1st
Ipoly Valley[18]	Groundwater management	Better management, Protection	6	2009-2015	1st
Shepparton[19]	Groundwater management	Allocation, Better administration	1	2015	2nd
Warrion[20]	Groundwater management	Knowledge improvement, Risk management, Allocation	5	2010-2015	1st
Alice Springs[21]	Groundwater management	Allocation, Protection	10	2016-2026	1st

Notes: 1) EAA, 2011; 2) PCCD, 2018; 3) SRPW, 2014; 4) OCWD, 2015; 5) RAWC, 2007; 6) OVIC, 1990; 7) EKC, 1998; 8) PAMA, 2017; 9) Bolbro Kildeplads, 2015; 10) GWP, 2013a; 11) Madhnure, et al., 2015; 12) CGB, 2006; 13) Shekhar et al., 2006; 14) Roeper, 1990 15) Maathuis and Simpson, 2006; 16) Winkler, 1997; 17) Al-Salamah et al., 2010; 18) GWP, 2013b; 19) GMW, 2015; 20) WWSPA, 2010; 21) ASWAP, 2013 and 22) Miljøstyrelsen, 2018

The focuses or the goal of the GwMPs vary from safe yield (Prescott), planning (Bolbro), vegetation management (Owen Valley), information and decision support (Santa Rosa Plain) and groundwater management (see Table 3.5). Within the 'Groundwater Management' grouping, the focus also differs with regards to a specific focus on protection, management, public participation, over abstraction, declining water table, conservation, artificial recharge, seawater intrusion, etc. New Delhi's focus was firstly on the development of the groundwater resources before the groundwater resources are managed through artificial recharge and rainwater harvesting (Shekhar et al., 2006).

The period of which the GwMPs was developed varies from the standard five years to the longer ten years and the shorter annual plans. The length is linked mainly to the following factors, namely regulatory requirements and focus or goal objectives. The California Water Code Section 10753 (CLI, 2019), requires local agencies to develop a Groundwater Management Plan and regular update is necessary to comply with the regulatory content requirements. The same is required in the States of Texas, Washington and Arizona. The focus or goal of the plan may have a ten-year achievement objective that links to policy changes or possible infrastructure projects that will make significant investments, public participation and acceptance, land-use change, crop change, education and skills development. The focus of annual or bi-annual plans is quick deliverables in highly dynamic systems. These systems are small, e.g. a wellfield of a town or a compartment and not to an aquifer system that covers a whole county (municipality). Although in Australia, most states do not define the period of validity, amendments to the GwMPs may be identified and considered on an annual base after annual assessments were done (GMW, 2015).

Elements, Structure and Format

Each GwMP's structure can be broken down (see Table 3.6) into elements. Twenty GwMPs are broken down in a broad structure as the pragmatic approach as in Table 3.2. The structure is divided into seven elements with 'Objectives and performance standards' as a sub-section of 'Goals'.

Almost all GwMPs covers in detail the purpose of the plan, the description of the water resources in the area covered with the GwMP as well as the issues of concern, and the goal and objectives that are set with performance indicators or standards to achieve. Only half of the GwMPs has a section on the implementation of the plan that provides direction on who and how the plan needs to be rolled out. The biggest concern is the fact that only twenty-five percent of the plans address the elements of Funding and Tracking of the progress made during the implementation phase of the plan. The lack of addressing these two elements can be from the regulatory format that is provided, or the level of reporting audience does not require any funding or progress commitments. The report of progress and finance can also be through other report channels.

Table 3.6: Elements of the Structure of twenty Groundwater Management Plans: International

Elements	Edwards [1]	Plum Creek[2]	Santa Rosa Plain[3]	Orange County[4]	Redding[5]	Owen Valley[6]	East King[7]	Prescott[8]	Bolbro[9,22]	Languedoc-Roussillon[10]	Hyderabad[11]	New Delhi[12, 13]	Regina[14]	Yorkton[15]	Winkler[16]	Saq[17]	Ipoly Valley[18]	Shepparton[19]	Warrion[20]	Alice Springs[21]
Introduction and purpose	X	X	X	X[A]	X	X	X[B]	X	X	X	X	X	X	X	X	X	X	X	X	X
Water resources	X	X	X	X	X		X[C]	X	X	X	X	X	X	X	X	X	X	X	X	X
Goals	X	X	X	X	X	X	X	X	X				X		X		X			X
Objectives & Performance Standards	X	X	X	X	X	X		X	X	X	X[C]	X	X[D]	X[F]	X[D]	X	X	X	X	X
GwMP Implementa-tion	X		X	X	X		X	X	X				X		X			X	X	X
Funding			X	X			X	X	X											
Track progress	X		X												X			X	X	X
Review plan	X		X		X				X						X			X	X	X

Notes: 1 – 22 (see Notes of Table 3.5) A) History & Governance; B) Overview; C) Area characterisation; D) Plans; and F) Aquifer Systems

The format of each of the GwMPs is different, as seen above, with the elements in Table 3.4. The format is determined by the purpose and context (Fallding, 2000). Six GwMPs were chosen for analyses in Table 3.5 below to demonstrate the different structures that are applied when the GwMPs are developed.

Table 3.7: The Format of 6 Groundwater Management Plans

Name	Winkler[16]	East King[7]	Prescott[8]	Bolbro[9,22]	Saq[17]	Orange County[4]	Shepparton[19]
Intro	Introduction	Introduction	Introduction	Introduction	Introduction	History & Governance Basin Management Goals & Objectives	Introduction Plan Objectives
Resource description	Area Aquifer	Area Characterisa-tion	Overview of Water Resources Water Use Characteris-tics	Hydrogeology Aquifer Area	Ground-water model (scenarios)	Basin Hydrogeology	Overview of aquifer
Tipe of plan & content	Aquifer Issues Options considered Public input Recommended initiatives Plan Implementa-tion (Objectives, Actions)	Quality and Quantity (**specific goals**): Management Objective Performance Standard (Who, Time, Priority) Legislative Authority Funding Implementation Process of Evaluation Revision	Regulatory **Programs:** Conservation Agricultural Municipal Industrial Gw Quality Augmentation & Recharge W Management assistance Plan Implementation Water budget scenarios (use & supply)	**Action** Plan: Implementation Measures Permits Stakeholders Protection Monitoring Inventory of pollution sources	Manage-ment Plan	Water Supply Monitoring Recharge Facilities Seawater intrusion & Barrier W Quality protection Programs Basin management Financial Management	Management **rules**: Aquifer Issues Licenses and use Management Monitoring Implementation
Format	*Public*	*Goals*	*Programs*	*Action*	*Model*	*Projects*	*Rules*

Notes: 4, 7, 8, 16, 17, 19 and 22 (see Notes of Table 3.5)

The *public participation* GwMP (for example, Winkler) involves the public or stakeholders throughout the whole development process. Issues were identified, and public input gathered before recommendations initiated and implementation can take place.

The *goal* GwMP (for example, East King and Edwards) set the main goal with objectives for the groundwater management area. Each of the objectives was turned into management strategies to address the potential threats or issues to groundwater quantity and quality in the planning area. Some of the issues include sand and gravel mining, sewer pipes, pesticides and fertilisers, the burial of human remains, underground storage tanks, bio-solids and effluent, to name a few. Each of the management strategies is turned into a performance standard that provides the responsible

organisation (the *Who?*) with a time frame to complete the strategy (the *Time?*) as well a priority scale (the *Priority?*). The priority scale relates to the impact on groundwater and the method used to address the issue (such as education or regulation). In the case of Texas, the State prescribes to the Counties the goals. The Counties need to develop their management objectives and performance standard according to these set goals.

The *program* GwMP (for example the Prescott) is according to the regulatory framework where management strategies are identified to address the reduction of the total groundwater withdrawals and to replace groundwater use with renewable water supplies. Some of these management strategies consisted of conservation programs for all the major water-using sectors.

The *project* GwMP (for example, Orange County) consists of projects that are deriving from the basin management goals and objectives. The GwMP describes the key issues and factors that are considered during the decision making yearly but does not commit to a particular program.

The *action* GwMP (for example Bolbro) consists of operational action that needs to be performed. The action links very closely to the rules GwMP but provides a more reactive approach with decisions based on a sound knowledge of the aquifer and the pollution risks.

The *rules* GwMP (for example Shepparton) provides simple and clear groundwater licensing rules and management arrangements for the community, licence holders and other stakeholders to ensure the aquifer is managed sustainably and equitably.

Author and Implementation Champion

The institution that developed (meaning that have written) the GwMP for an organisation or area is essential. The GwMPs that were developed was done in-house or where the service provider worked closely with the organisation, a budget or funding, and implementation action or projects included (for example Winkler, East King and Prescott) into the GwMPs. The GwMP that was developed by an external institution or author had no stakeholder input, engagement or buy-in from the organisation it is developing the GwMP for, these GwMPs will just stay a plan, and implementation is doubtful (like for example Saq aquifer). The need to have a champion or a leader in bringing the plan to life (action – implementation) is essential (like Languedoc-Roussillon, Orange and Ipoly Valley). In the case of East King and Shepparton, a 'Groundwater Advisory Committee' or the Water Management Agency was responsible for the development as well as the

implementation. The committee consists of a broad spectrum of groundwater interested groups including federal, state and local agencies, environmental organisations, businesses and citizens.

Preparatory phase information

A GwMP can only be developed if certain basic information and data are available that will help with the Goals and Objectives in the GwMP. The background information can vary from water resource information (like geohydrology and hydrology), water requirements and water supply, other management programs, population projections, etc. Some of this information is data that changes regularly (monthly or yearly). The breakdown of some of the water resources and other data are listed below in Table 3.8 and 3.9:

Table 3.8: Water Resources information

Geography/ physical setting Climate / Precipitation Soils	Water Use Urban water providers and facilities Rural users Non-Consumptive (Environmental, Cultural)
Surface water Systems and water bodies Facilities Streamflow Diversions Imported and Exported water Water quality	Groundwater Regional Geology Hydrogeology Aquifer/s delineation Level movement and trends Faults and groundwater movement Groundwater-surface water interaction Recharge and Discharge Land subsidence Quality/Hydrochemistry
Recycled water	Hydrologic conceptual model
Integrated Surface water/Groundwater Model and Water Budget	Groundwater Dependent Ecosystems (GDE)

Table 3.9: Other additional data/information

Managed Available Groundwater	Annual Groundwater Use
Annual Recharge From Precipitation	Projected Water Supply Needs
Flow Into and Out of the Aquifer	Population Projections
Annual Discharges to Springs and Surface Water Bodies	Regional or other Water Management Strategies
Available Water Supply in the District	Socio-economic activities
Stormwater Management	Water Conservation
Water Reuse	Allocations, Permitting of boreholes (licences)

Goals or Objectives

The Goals and/or Objectives can be presented in different components or groupings. Each of the GwMPs will have a detailed list of goals and/or objectives with performance standards. The components can consist of a format of a *split of goals* between *quality* and *quantity* (e.g. East King); *programs* (e.g. Prescott); *regulatory framework* (e.g. Redding); *strategic plan* (e.g. Edwards); *aquifers* (e.g. Yorkton); *implementation plans* (e.g. Winkler); *prescription plan* (e.g. Warrion); *rules* (e.g. Shepparton); *incentives vs legislation and enforcement* (e.g. Winkler); etc.

The Goal or Objectives and Performance Standards can be carried out as actions or programs or projects. A list (Table 3.10 and the complete table in Appendix A) was compiled from the twenty GwMPs of the management objectives in comparison to the groundwater management principles identified in Chapter 2 above. The list does not contain specific projects or programs, but the core objective that needs to be achieved or addressed through the Goal or Objective.

Table 3.10: List of Management Objectives from twenty international GwMPs

NB: SEE APPENDIX A FOR THE COMPLETE TABLE

Management Principles from Chapter 2	**Description of the Goals/Objectives**
Protection	• Land and water management practice guidelines or education programs (hazardous materials: waste, sites, spills; underground storage and transport of petroleum products [rail, road, pipeline]; on-site sewage treatment and disposal system use; pesticide and fertiliser use; well construction and decommissioning; sewer pipes; solid waste landfills; burial of human remains; sand and gravel mining; sewer effluent; golf course; etc.) • Land use agreements (subsidy – co-funding practices) • Recharge area protection (stormwater management practices, etc.) • Protection zones guideline per zone develop (well-head, recharge • Vulnerability/susceptibility/sensitivity mapping/zones (depth to water, geologic materials, soil permeability and thickness, hydraulic conductivity [K_v], etc.) • Proper borehole construction, abandonment and destruction • Maintain groundwater level (seawater intrusion, land subsidence, restoration) • Remediation/rehabilitation/mitigation (programs [awareness, Emergency Response Plan/Unit (spill or fire), restoration, etc.], project [treatment by wetland, pump-and-treat, removal of invasive plants, buffer strips/zones, etc.]) • Risk assessment of potential impact (lack of stormwater infrastructure, roadway runoff, spillages, vegetation clearing [soil degradation], pesticide and fertiliser use, quantity of aquifer recharge [urbanisation], etc.)
The rest of the Management Principles are in the Complete Table in Appendix A :	

Regulation, Protection, Regulation, Use, Planning, Monitoring, Conservation, Operation, Infrastructure, Assessment, Institutional Arrangements, Capacity and Skills, Awareness, Information, Communication and Stakeholder participation.
NB: THE COMPLETE TABLE IS IN APPENDIX A

Several of the Goals or Objectives overlap with each other and are interlinked. The successful implementation is strongly depended on the implementation of each of the Goals or Objectives. The Goals or Objectives relate strongly to the focus of the GwMPs. The Winkler GwMP has a general focus on most principles to protect and reduce yield, but the Plum Creek GwMP focus only on reducing the abstraction from the aquifer. The Goals or Objectives were also distinguished by the 'level' of the target audience. The local focus, like Redding GwMP, has detail Objectives, but the Ipoly Aquifer GwMP has an administrative and governance focus.

There are four Management Principles that stands out from Table 3.10 that were not been addressed in detail or are addressed by other processes are, namely Planning, Operation, Infrastructure and Capacity or Skills. The reason for the lack of detail Planning and Infrastructure Objectives can be that the time frame of the GwMPs is too short (1 to 10-years) and that the typical planning horizon lean more to 10 to 20-years in the future. The Operations may be too detail on the level of the GwMPs, especially when various users and wellfields are involved and are addressed through an Operational plan. The most significant gap within all the twenty GwMPs was the lack of capacity and enhancing the skills of the employees of the organisation that manage the groundwater. Only two GwMPs mention the recruitment of personnel and the training it takes to perform. The lack of Capacity or Skills, Infrastructure and Operation, were also mentioned by the World Organisations in Table 3.3. One reason can be that the reviewed GwMP is from developed countries with well-functioning municipalities and catchment agencies with enough skilled personnel to manage and implement the GwMP.

3.2.3 Local

Groundwater Management Plans are not commonly used in South Africa. Groundwater is managed through various means but mostly not with a set plan. Only seven "GwMPs" were discovered in South Africa by the author, and the GwMPs vary from a framework, a draft proposal of a plan, recommendation to manage groundwater to a full groundwater management plan. Table 3.7 below provide the areas where the GwMP is located and the status of each of the document (see Note 1 below Table 3.7).

Table 3.11: List of seven South African GwMPs with Status and Purpose

GwMP	Province	Status	Purpose
Polokwane[1]	Limpopo	Draft project Inception	
Delmas[2,3]	Mpumalanga	Final	Resource protection
Baviaans[4]	Eastern Cape	Final	
Graaff-Reinet[5]		Final (draft)	Optimal aquifer use Groundwater quality protection Optimal abstraction vs equipment efficiency Controlling, monitoring and reporting
Bredasdorp[6]	Western Cape	Final	Water security Resource monitoring
West Coast[7]		Draft action plan	Scientific understanding
Hermanus[8]		Final (summary)	Aquifer protection Groundwater assessment Wellfield development Wellfield operation and management Stakeholder participation

Note: 1) Naicker et al., 2019; 2) Zhang, 2006; 3) Bertram, 2008 4) De Kock and Welman, 2010; 5) Rudolph and Hough, 2012; 6) Myburgh and Prinsloo, 2018; 7) Vermaak, 2018; and 8) Riemann et al., 2010

The GwMP for Polokwane is an inception report (draft) with the GwMP development approach (Naicker et al., 2019). The Delmas, Baviaans and Graaff-Reinet GwMPs are fully developed and detailed (Zhang, 2006; De Kock and Welman, 2010; Rudolph and Hough, 2012) It consists of an additional summary for the Delmas GwMP (Bertram, 2008). The Graaff-Reinet GwMP is presented as a final document, but the scope of work for the project indicates that only a draft must be prepared (Rudolph and Hough, 2012). Myburgh and Prinsloo (2018) provide a wellfield operational plan to manage and monitor the Bredasdorp wellfield in a sustainable manner. Vermaak (2018) developed an action plan (draft) to provide a better scientific understanding of the four West Coast aquifers that need to be managed as one aquifer system. Riemann et al. (2010) provides an example with an excellent framework where groundwater can be managed in, as well as a summary of a GwMP for Hermanus Municipality but fell short of a detail GwMP.

The purpose of the different GwMP vary from protecting the aquifer or resource, optimal use from the aquifer with efficient equipment, monitoring, development of wellfield, expanding the scientific knowledge through assessment, operations and finally the stakeholder participation. Skill and capacity, institutional arrangements, maintenance and regulation are some of the issues that are lacking when the purposes of the above GwMP are compared with the principles in chapter 2.

Development Approaches

The development approaches are different between the Polokwane, Delmas, Baviaans and Graaff-Reinet GwMPs. The above mentioned four GwMPs are the only local GwMPs that provide a development approach within the GwMP itself. Table 3.12 below offer a breakdown of the three phases and the steps followed in the development process of each of the GwMP.

The first visible distinction between the four GwMPs is the involvement of the stakeholders or client. The four GwMPs can be divided into three groups: a) Stakeholder engagement after Development; b) Development after Stakeholder engagement; and c) Stakeholder engagement throughout development. None of the approaches is wrong, but the stakeholder involvement is such a critical part of the success to the implementation of the GwMP that the continuous engagement and buy-in of stakeholders cannot be stressed enough (Foster et al., 2010; Garduño et al., 2010).

The second distinction is the lack of the implementation and review phases in the GwMPs except for the "one-liners-mention" in the Delmas GwMP (see also Table 3.13). The Delmas GwMP only proposes that additional investigations are necessary to optimise the draft GwMP. The GwMP needs to be revised and enhanced with extra information available (Zhang, 2006). The reason for this phenomenon can be that all the GwMPs were developed as part of a once-off project. There was, and there is still no long term plan with a 10-year goal to address the update or tracking the progress of implementation of the GwMPs. A second reason can be that the GwMPs are developed by external organisations such as Professional Service Providers (PSP) or the Department of Water and Sanitation (as in the case of Polokwane GwMP) and not in-house by the municipality themselves. It is challenging for the municipalities to update internally if the municipality does not have the skills or capacity to update documents like the bigger water utilities in the US, Canada or Australia. These external organisations (PSP or DWS) cannot commit to funding any of the actions recommended by the GwMP.

The continuation of the GwMP can thirdly be hampered due to a lack of finances within the municipality to pay / budget for the revision / next GwMP in a five-year / 10-year period. These reasons bring about a lack of commitment from the municipality side as well as dedicated programs with budget, personnel and timeframes.

Table 3.12: The development approaches from four Local GwMPs

Phases	Polokwane[1] (five Steps)	Delmas[2] (four Steps)	Baviaans[4] & Graaff-Reinet[5] (four Steps)
Preparation	Inception Phase • Desktop Assessment Groundwater Resource Appraisal: • Hydrogeological setting • Socio-economic development and ecosystem dependency assessment • Groundwater Resource Status	Project initiation • identification of stakeholders • identification of data sources Collection of information and assessing requirements: • Groundwater status • Environmental impact • Risk/Hazard Assessment	Familiarisation • Project, area, Stakeholders. Information gathering • Gaps • Risks Assessment • Recommendations • Stakeholder engagement – content
Development	Developing Aquifer Management Plan (draft) Stakeholder Engagement • Capacity Building Programme Hydrogeological Reporting • Final Aquifer Management Plan • Implementation and Monitoring Plan	Develop Draft Groundwater Management Plans	Draft Groundwater Management Plan • Stakeholder engagement *(Only Baviaans GwMP)* Final Groundwater Management Plan • Stakeholder engagement sign-off
Implement ation		Revised and Update Plan • Additional studies - information	

Notes: 1, 2, 4 and 5 (see Notes of Table 3.11)

The Delmas GwMP is the only GwMP between the four GwMPs in Table 3.12 (as well in Table 3.13) with the risk or hazard assessment. The risk assessment has a significant impact on the purpose of the goals and objectives in the GwMP to identify possible negative impacts associated with the abstraction of groundwater, the vulnerability and protection of the resource, and the use and management of groundwater resources (Zhang, 2006). Zhang (2006) identified nine hazards with groundwater use and groundwater abstraction that relates to the existing municipal groundwater abstraction schemes, historical data, and the underlying karst geology.

Elements, Structure and Validity Period

The West Coast Action Plan has a validity period of three years with detailed actions, partners and resources, timeframes, the status of the action and critical barriers (see Table 3.13 below) (Vermaak, 2018). The funding and resources to implement the actions were identified with partners and the Department as the key champion as a driver for implementation which relate to the water utilities of other countries (as mention above in Section 3.2.2.3).

According to Table 3.13, there are no goals or objectives in the Hermanus GwMP. Two reasons can explain this: a) Riemann et al. (2010) only provided a non-comprehensive GwMP for Hermanus and a comprehensive GwMP still need to be developed (K. Riemann, 2017, pers. comm.); and b) that the municipality is already busy with activities and projects to manage the groundwater resources. The municipality is implementing the recommendations from the monitoring reports and provide regulary feedback on progress at the project and stakeholder meetings. Riemann et al. (2010) describe management actions and recommendations that were implemented over eight years (since 2002). These management recommendations were analysed as part of the compilation of Table 3.14. One of the issues that are discussed with the Hermanus GwMP is the Administrative and Organisational Structure of the municipality. Each municipality has a different administrative structure, and each position or post has a different responsibility and authority. Many municipalities do not have dedicated or skilled staff that manage or coordinate all the aspects of groundwater in a municipality (Kotzé et al. 2019).

None of the GwMPs provides any measurement of progress or milestone to achieve during the validation period. The GwMPs provide only a list of actions to be done without evaluating the progress and the report back to authorities or stakeholders.

Table 3.13: Elements of the Structure from 6 Groundwater Management Plans from South Africa

Elements	Delmas[2,3]	Baviaans[4]	Graafff-Reinet[5]	Bredasdorp[6]	West Coast[7]	Hermanus[8]
Introduction and purpose	X	X	X	X	X	X[B]
Water resources	X[A]	X	X	X	X	X
Goals	X	X				
Objectives & Performance Standards	X	X	X	X	X	
GwMP Implementation					X	
Funding					X	
Track progress						

Review plan	X					
Validity Period (years)					3	

Notes: 2 – 8 (see Notes of Table 3.11); A) Risk Assessment included and B) Administrative and Organisational Structure

The GwMP of Polokwane was let out during this analyse in Table 3.13 because the development of the Polokwane GwMP was still in the early stages of the development, and the plan or structure of the plan was not yet developed. However, the report was included in Table 3.14 – Management Objectives – because the intentions of the inception report to address certain management objectives in the final GwMP.

Management Objectives

The 'Goal' and 'Objectives' in the South African GwMPs is called 'Management Recommendations'. The author proposes the term 'Management Objectives' as a way forward. Most of the recommendations are a guideline for good groundwater management but do not provide a specific list with points of action, responsible person/organisation, timelines, and milestone/performance standard.

Table 3.10 provides a list of Objectives from the international GwMPs assessment, and Table 3.14 (see complete table in Appendix A) provides a list from the South African GwMPs but only the Management Objectives that are not listed in Table 3.10 – unique to South Africa. This will be saved on the duplication of Management Objectives, but Table 3.15 (in Appendix A) provides a complete list of all the Management Objectives from South African GwMPs.

Table 3.14: List of Management Objectives from seven South African GwMPs that appear <u>ONLY</u> in the South African GwMPs

<u>NB: SEE THE COMPLETE TABLE IN APPENDIX A</u>

Management Principles from Chapter 2	Description of the Management Recommendations from South African GwMPs that appears <u>ONLY</u> in the South African GwMPs
Protection	• Land and water management practice guidelines (closure / decommissioning of waste sites; stormwater; mining: tailings, acid mine drainage; informal settlements)[8,5] • Protection zones (springs, develop/ delineation of zones and implement areas of protection [BPZONE], protection plan develop and updated)[5,4,2,1] • Proper borehole construction, abandonment and destruction (program to seal, plug unused bh's)[2] • Maintain groundwater level (volume vs Iron Reducing Bacteria[6,5,4], sinkhole

	formation[3,2]) • Remediation/rehabilitation/mitigation (project [sewer discharge in recharge zone][2]) • Risk assessment of potential impact (pit latrines [sanitation], Environmental Impact Assessment [EIA report], Hazard identification – Over abstraction [decline water levels, yields, ground instability], point and non-point source contamination, insufficient supply, treatment problems, reticulation infrastructure, prolonged drought, recharge from poor quality surface water)[8,5,2] • Mapping pollution sources[8], census[2]
The rest of the Management Principles are in the Complete Table in Appendix A : Regulation, Protection, Regulation, Use, Planning, Monitoring, Conservation, Operation, Infrastructure, Assessment, Institutional Arrangements, Capacity and Skills, Awareness, Information, Communication and Stakeholder participation. **NB: THE COMPLETE TABLE IS IN APPENDIX A**	

(see Notes of Table 3.11)

Table 3.15: List of ALL the Management Objectives from South African GwMPs that appear ONLY in the South African GwMPs AND that appear BOTH in the international and South African GwMPs

See table in Appendix A

The South African GwMPs as the international GwMPs are focusing a lot on the protection and monitoring. The difference is thou the level of detail the South Africa GwMP's are describing the objectives. The regulation, assessment and planning objectives are extensively expanded because of the South African water regulations and Department of Water and Sanitation's detail planning projects in throughout South Africa. The operational side of groundwater management is greatly described in the operation and infrastructure. The softer issues around institutional arrangements, skill and capacity as well as awareness, information and communication are more expanded because the current groundwater management is much lacking these aspects.

3.2.4 Summary

The focus of each of the GwMPs is different from the World GwMPs focusing on the protection, use, assessment and institutional arrangement principles of groundwater management. Furthermore, the international and South African GwMPs focus on the protection, regulation, planning, monitoring, conservation, operation, infrastructure, skills and awareness of groundwater management. The reason for the focus difference between the GwMPs in the amount of detail is the level at which the different GwMPs is implemented. The world GwMPs focus on the high-level issues in the principles versus the international and South African GwMPs, which also focus on the

practical side of the principles. The South African GwMPs have an environment versus use element through the Reserve Determination and Classification compliance regulatory framework.

The focus difference between the international and South African GwMPs can be noted in the broader terms from the international side on the regulation, use and conservation of groundwater management while the South African GwMPs focus more on the planning, operations and capacity or skills of groundwater management. The reason for that is the better regulatory framework in the international GwMPs versus the capacity or skill and operational shortages at local government in South Africa.

A combined table of all the Management Objectives from the world, international and local GwMPs provide a summary of all the elements that need to be considered or addressed per Principle in a Groundwater Management Plan (see Table 3.16).

A combined table provides a detail description of all the elements to address within a GwMP, but some of the Management Objectives are closely related and can be combined or similar. The reasons for the difference between the international and local GwMP are:

- The terminology differs from the international to the South African GwMPs. The understanding of various terminologies or the meaning of a specific action can be different or misunderstood.
- Some of the activities or tasks are fragmented. For example, the same task appears at different principles.
- The scale of which the GwMPs were developed will differ between a district municipality area, system of aquifers and wellfield.

3.3 DEVELOPMENT OF AN GWMP FRAMEWORK

The physical development of a GwMP is influenced by the development approach that is followed with the preparation, development and implementation phases (see Table 3.2 and 3.8). The format, structure and elements within the GwMP will be determined by the goal or purpose to be achieved by the organisation that manages the groundwater resource (see Tables 3.5 - 3.7; 3.11 – 3.13). The actions to be performed by the various role players to achieve the goal or purpose of the GwMP will be determined by the groundwater management principles that are required (see the summary Tables 3.17).

3.3.1 Development Approach

One of the main factors determining the successful implementation of a GwMP is the approach followed during the development of the GwMP. The preparation, development and implementation phases need to be addressed to ensure the process is transparent, in content and evidence-based that involves stakeholders (FAO, 2016a). The "pragmatic framework" approach of the World Bank GW-MATE (Garduño and Foster, 2010; Foster and Ait-Kadi, 2012; Foster et al., 2010) and the planning process of the Groundwater Governance Project (FAO, 2016a) provided a clear description of the three approach phases. Most of the elements of the GW-MATE approach were incorporated into the Groundwater Governance Project approach (FAO, 2016a). Table 3.16 provide an adapted summary description of the approach in three phases.

Table 3.16: The three-phase approach to prepare, develop and implement a GwMP (adapted from FAO, 2016a).

Phases	Steps	Description
Preparation *(Identification and prioritisation)*	Identification of aquifer systems (Desktop level – prioritisition)	Physical delineation of the system: • Mapping the groundwater flow regime • Human-made perturbations Socio-economic evaluation of system: • Evaluating the importance of the system • Critical role to water supply, agriculture, industry and ecosystems Assessment of pressures on system: • Susceptibility & vulnerability to irreversible degradation or groundwater flooding • Identify opportunity for new/enhanced underground reservoirs Strategic importance of aquifer Lowest spatial scale + stakeholder engagement Aquifer crossing administrative boundaries
	Assessment of Status (Detail level of top priority))	Assessment (see also Table 3.8 and 3.9): • Current Groundwater abstraction & Use, and Pollution pressures • Direct data: groundwater levels, aquifer discharge and quality • Indirect data: ecosystem condition, pollution pressures, and aquifer degradation susceptibility and pollution vulnerability Identify information gaps & minimum level of confidence

	Management Characterization of the System (Including external factors)	"*which will determine how it can best be managed*"- include: • geographical scale of the aquifer system and size of storage reserve, • degree of connectivity with surface water • level of contemporary recharge • aquifer susceptibility to irreversible degradation and groundwater vulnerability to pollution Authority and Stakeholder owned
Development *(Developing GwMPs for Priority Aquifer Systems)*	The Consultation Process *(Based on permanent stakeholder mechanisms)*	Reach consensus on aquifer services Information communicate – preparatory phase info: • Current groundwater resource and quality status • Groundwater status trends • Potential risks • Costs of 'no-management-action' • Options for management measures
	Preparation of the Management Plan *(Base on elements of institutional soundness, incentives and investment)*	The elements are summarised in Table 3.17 according to the twelve Principles of groundwater management
	Adapting the Plan to the Local Institutions - *socio-economy, institutional set-up and capacity*	Aspects to consider: • Number and special extent of groundwater abstraction points or potential polluters • State of institutional development • Proportion of population abstracting groundwater directly • Economic significance of groundwater resource use
	Adoption of Plan	Agreed GwMP: • Stakeholder engagement sign-off • Groundwater Management implementing organisation/ authority sign-off
Implementation *(Implementing and Reviewing Plans)*	Implementation *(To annual programmes and budgets, with stakeholder involvement and fixed reporting for accountability)*	Aspects to consider: • Implement on a structured periodic basis • Stakeholder involvement – continuous • Awareness-raising and information sharing • Operational time-frame and management monitoring framework endorsement • Flexibility with changes in groundwater knowledge and in external drivers • Adaptive management approach
	Monitoring, Reporting and Evaluation	Monitor performance Assess performance and results against plan targets and indicators Regular reporting through permanent organisational and stakeholder mechanisms Revised and Update Plan periodically

3.3.2 Table of Content

The Table of Content can also be called a Table of Elements because each GwMP will have a different goal or purpose, format, structure and actions, but the elements will stay the same. The elements can act as the chapter headings with more descriptive sub-headings to address the different goals or purpose, format, structure and actions (CLI, 2019).

Elements or Chapters

According to the elements in the international and South African GwMPs (see Tables 3.6 and 3.13) the Table of Content needs to contain the following elements (Table 3.17).

Table 3.17: Element of a generic GwMP Table of Content

Elements/Chapters	Description
Introduction and purpose Institutional issues	Purpose of the GwMP; Historical overview of the groundwater management issues; Organisational management of the aquifer; Institutional coordination; Adoption of the plan; Stakeholder engagement
Water resources Regulatory Socio-economic	Planning area; Groundwater resources; Other water resources; Water use; Water requirements; Protection; Groundwater dependent ecosystems; Regulatory/licence/allocations; Socio-economic; Conservation
Goals Objectives & Performance Standards	Main goals, Management objectives and performance standards to address the principles (see Table 3.16)
GwMP Implementation	Roles and responsibilities; Procedure; Time frames
Funding	Funding for objectives
Track progress	Reporting; Milestones; Audit
Review plan	Validity period, Updating/review schedule

Management Objectives

The Goals or Objectives and Management recommendations are central in the GwMP. The various formats of the GwMPs will influence the way the objectives and recommendations are presented in the GwMPs, but the management principles will all be the same. Table 3.18 provides a detailed list of various recommendations and objectives under each of the twelve groundwater management principles described in chapter 2. Each GwMP will differ from each other because each GwMP will only use objectives and recommendations from Table 3.18 that apply to the goal it wants to address. The final GwMP can consist of other plans (WAMP, 1997 and Riemann et al., 2010) that focus on specific principles.

Table 3.18: Management Objectives of GwMPs.

Management Principles from Chapter 2	Management Objectives of the world, international and local GwMPs	World	International	Local
Protection	**Land and water management practice guidelines/ education programs** (hazardous materials: waste, waste sites, spills; underground storage and transport of petroleum products [rail, road, pipeline]; on-site sewage treatment and disposal system use; pesticide and fertiliser use; well construction and decommissioning; sewer pipes; solid waste landfills; burial of human remains; sand and gravel mining; sewer effluent; golf course; closure / decommissioning of waste sites; stormwater; mining: tailings, acid mine drainage; informal settlements; etc.)		X	X
	Protection zones guideline developed per zone (well-head, recharge, springs, develop/ delineation of zones and implement areas of protection [BPZONE], protection plan develop and updated)	X	X	X
	Land use agreements (subsidy – co-funding practices)		X	
	Recharge area protection (stormwater management practices, etc.)		X	X
	Vulnerability/susceptibility/sensitivity **mapping/zones** (depth to water, geologic materials, soil permeability and thickness, hydraulic conductivity [Kv], etc.)	X	X	X
	Pollution source **inventory** and **Mapping** pollution sources, census	X	X	X
	Proper **borehole construction, abandonment and destruction** (program to seal, plug unused bh's)		X	X
	Maintain groundwater level head (seawater intrusion, land subsidence, restoration, volume vs Iron Reducing Bacteria, sinkhole formation)		X	X
	Remediation/rehabilitation/mitigation (programs [awareness, Emergency Response Plan/Unit (spill or fire), restoration, etc.], project [treatment by wetland, pump-and-treat, removal of invasive plants, buffer strips/zones, sewer discharge in recharge zone, etc.])	X	X	X
	Risk assessment of potential impact and Susceptibility to degradation (lack of stormwater infrastructure, roadway runoff, spillages, vegetation clearing [soil degradation], pesticide and fertiliser use, quantity of aquifer recharge [urbanisation], pit latrines [sanitation], Environmental Impact Assessment [EIA	X	X	X

	report], Hazard identification – Over abstraction [decline water levels, yields, ground instability], point and non-point source contamination, insufficient supply, treatment problems, reticulation infrastructure, prolonged drought, recharge from poor quality surface water)			
	Land-use change implications	X		
Regulation	**Effective legislation/policy**	X	X	
	Sustainable development (economical and social benefit)		X	
	Prioritisation of water uses	X		
	Water use rights (registration/authorisation – water use control and waste disposal)	X	X	X
	Water use license and environment (Resource Directed Measures determination, Compliance to license conditions) and Water allocation and quality objectives	X		X
	Enforcement / legal action (non-compliance or unauthorised use)		X	
	Water **metering**		X	
	Registry of water use (census)			X
	Borehole (all) **registration program**		X	X
	Abandoned borehole **closure program**		X	
	Setting of limits (groundwater level decline [m below ground level]; nitrate use, etc.)		X	
	Transfer of water permits (allocations) and Water Use Agreements (access, compensation, servitudes)		X	
	Compliance Audits (municipality and government)			X
	By-Laws, Guidelines and standards (Best-practice-guidelines, sanitation, design standards, underground fuel tanks, borehole construction, - abandonment, registration of boreholes and water use, reducing the use of fertilisers, effluent irrigation, etc.)		X	X
	Link with **Other Regulatory Plans**			X
	Drought restriction regulation			X
	Report water use volumes/licences vs availability		X	
	Environmental impact assessment		X	
	Self Regulation	X		
Use	Water demand/supply **balance**	X		
	Socio-economic evaluation and Economic analysis of water use	X		
	Abstraction **strategy**			X
	User profile and use **inventory and Registry** of water use allocations/license/entitlements	X	X	X
	Use **reduction by sectors** (water-use efficiency, conservation, Water demand management programs)		X	X
	Increase **water reuse** (agriculture, landscape irrigation, greywater)			
	Use **non-domestic quality** standard water for other uses (brackish – industrial, dual toilet system, etc.)		X	
	Groundwater use and pollution **drivers**	X		
	Best Management Practice (BMP)		X	
Planning	**Future water requirement** scenario's	X	X	X
	Water budget (recharge vs use)		X	X
	Long-term **hydrological condition** scenarios		X	X
	Climate Change Plan for and adapt (interventions)		X	X
	Investigate **alternative supply** (feasibility studies - underdeveloped groundwater, desalination, reuse, rainwater harvesting, artificial recharge, stormwater, surface water, back-up resources in case of emergency [drought, bh collapse/failure, toxic spill], agreement with other WSP, replacement of polluted wellfield, augmentation sources)	X	X	X

	Manage Aquifer Recharge/Enhancement	X		
	Options analysis between sources			X
	Reconnaissance investigation, future interventions			X
	Exploration drilling and testing			X
	Wellfield design			X
	Additional **infrastructure**			X
	Finance of planning interventions	X		
	Future **spacial development impacts** –Land-use planning	X	X	X
	Coordination between surface and groundwater planning initiatives/projects		X	
	Drought management plan – operations, local/short-term sources		X	
Monitoring	**Coordinate** all monitoring activities + redesign (focus driven)		X	
	Collect, collate and interpretation = knowledge (database - capture, edit, audit, analyse, amend monitoring and operation actions)	X	X	X
	Monitor (groundwater levels, -quality, -use; land subsidence; hydrometeorological conditions, pollution sources, contaminants, surface water quality, groundwater-dependent ecosystems, current and closed waste sites [pollution sources], ecological indicators, pumping rate [flow meter], pumping hours, infrastructure [contamanation entering reticulation system/infrastructure], sinkholes, water quality includes [turbidity, E. coli, free chlorine], surface water discharges, visual inspection of potential risks)	X	X	X
	Databases – store data		X	X
	Manage and analyse data (involve specialists- air, water quality, data capture, data analysing tool/software)		X	X
	Reporting and publication of data		X	X
	Monitoring data (municipality, government, users [license conditions], NGO's/environmental groups, private boreholes in the wellfield/aquifer)		X	X
	Monitoring programs (aquifer management, compliance, project/research, Protocol/plan development intervals/frequency, baseline/ background)		X	X
	Monitoring network assess, design, setup and amended (density, spatial extent, location, purpose and level [aquifer and sub-aquifer/wellfield level], include regional aquifer)	X	X	X
	Inventory/database of monitoring points information (borehole name, -owner, -type, -depth, screened interval, etc.), pollution sources (land use, fuel tanks, irrigation, piggery, cemeteries, industries, surface water, etc.)		X	X
	Early warning systems installation (including subsidence)		X	X
	Seawater intrusion/saline water table		X	
	Monitoring **Equipment** (manual dip meter and level logger, water quality sampling)			X
	Installation of meters/monitoring equipment (level loggers, quality, flow meters, hour meters [pump time], rainfall, dip tubes, water sampling taps)		X	X
	Water quality sampling, analyses (field measurements, sites specific analysing constituents, accredited laboratories, audit, duplicate samples)			X
	Standard of monitoring – according to Guidelines, SABS, procedures			X
	Organisations performing/ensuring the monitoring is carried out		X	X
Conservation	Use **reduction**	X		
	Efficient use	X		
	Conjunctive use (use other sources additionally)	X	X	X
	Conservation **program** – alien vegetation clearing			X
	Artificial recharge (stormwater, ASR and groundwater banking)		X	X
	Recharge enhancement (precipitation, low-risk agriculture, shelterbelts, contour cultivation and dyking)		X	
	In-lieu recharge program (other water in-place of groundwater)		X	
	Low Impact Development (LID) in new construction		X	

	Economic value of groundwater establish		X	X
Operation	**Operational rules** (conjunctive use of sources, optimise efficiency, aquifer response [stable water level, reducing energy cost, maintaining/improving water quality], Manual – operator, technical specifications [borehole and wellfield], amendments after assessment [quantity and quality])		X	X
	Annual groundwater pumping rule/allocations (runoff, water use, pumping, groundwater level and recharge, summer/winter pumping rates or wet/dry periods - assessment)		X	X
	Environmental rules aquifer monitoring		X	
	Emergency procedures develop – sinkhole and subsidence, insufficient water supply, water contamination, reticulation system and infrastructure breakdown			X
	Reporting			X
	Regional operators		X	
	Finance for operations	X		
	Wellfield guide – managers			X
	Monitoring **field forms**/sheets and records			X
Infrastructure	Maintenance / Subsurface **infrastructure damage** (breakages, wear, leaks, pollution, etc.)	X	X	
	Maintenance **program** (including monitoring equipment, reticulation system)			X
	Infrastructure **Plan** (monitoring, maintenance, operation, planning, development)			X
	Asset register (develop and update including photos)			X
	Layout of scheme		X	
	Modernisation and **upgrading** technologies/ infrastructure - efficiency and integration (plastic fittings, anti-theft mechanisms)		X	X
	Guideline on construction of boreholes		X	
	Borehole **rehabilitation** (preformance optimatoin)			X
	Recharge enhancement structure (built, maintain)		X	
Assessment	Resources status/**hydrogeological characteristics**	X		
	Resource renewability/**recharge**	X		
	Size of the aquifer system's storage reserve	X		
	Mapping aquifers (recharge, discharge areas)		X	
	Climate factors (wind, temperature, humidity, evapotranspiration, rainfall), climate models)			X
	Ecosystem needs/status	X		
	Resource and quality **trends**	X		
	Land use **impacts**		X	
	Land use **inventories**	X		
	Surface water interactions	X		
	Groundwater use **impacts** (cumulative/interference, groundwater-dependent ecosystems, domestic/stock [Schedule1])		X	
	Manage and analyse data		X	
	Assessment of **aquifers** and **Regional** assessment			X
	Maintain & Update **model** and Regional aquifer model		X	X
	Vulnerability and risk of aquifer **drought**	X		
	Long-term safe **yield**		X	
	Long term **monitoring**			X
Institutional Arrangements	**Conjunctive** resource management (Other institutions, Aquifer Management Committee)	X	X	X
	Collaboration with **other authorities** using the **same aquifer**		X	
	Collaboration with Government (District, Dept of Water, - Environment, - Agriculture, etc.), NGO's, research institutions, other Sectors, Others (Parks, Farmers Union, CMA, Forums, other expert organisations, etc.)	X	X	X

	Water Services **Authority vs** Water Services **Provider** institutional structure, roles and responsibility	X		X
	Transboundary	X		
	Administration and Organisational structure			X
	Staff Responsibilities			X
	Financial management (cost recovery, maintenance, development, operations, rehabilitation, monitoring resources, tools and equipment, etc.)		X	X
	Water-use charging/cost recovery	X		
	Economic incentives	X		
	Off-the-grid vs bulk water supply and wastewater interventions		X	
	Pricing plan and cost analysis (development, infrastructure, treatment, environment, etc.)			X
	Stakeholder institutions	X		
	Policy changes	X		
Capacity and Skills	**Technical capacity**	X		
	Recruiting a qualified hydrogeologist and a Gw technician		X	X
	Skills and qualification **requirement**			X
	Skills and Capacity **plan**			X
	Training (operations, sampling, monitoring [quantity and quality], procurement of external services, capturing and recording of data, maintenance, basic geohydrological and water quality knowledge, audits)		X	X
	Knowledge transfer/**succession planning**			X
Awareness, Information, Communication and Stakeholder participation	**Identification** of stakeholders and Stakeholder contact list	X		X
	Permanent stakeholder **mechanisms** (committee, forum, newsletter, etc.)	X		
	Consultation/information with stakeholders and Stakeholder engagement (authorities/regulators, users, etc.)	X		X
	Stakeholder **participation** in regulatory processes (licensing, EIA), assessment, planning and management			X
	Monitoring **oversight committees**			X
	Annual or bi-annual aquifer **status report** (monitoring data, recharge, allocations, management programs, etc.)		X	
	Partnerships & Coordinate programs		X	
	Policy/political **dialogue** on land-use	X		
	Public awareness / Education programs (protection, use, rainwater harvesting, brush control [flood control], landscaping, link to existing education programs or develop new education programs for not addressed elements, identify conditions - lead to the formation of sinkholes)		X	X
	Educational leadership to citizens (printed publication, public speaking, guidelines, signposts, etc.)		X	
	Stewardship plan – user, owner, manager		X	
	Citizen science			X
	Adaption plan	X		
	Guidelines (constructions of boreholes, placement/ location of minimum impact)		X	
	Research study – increase knowledge, efficiency, technology, long term impacts		X	
Other issues not covered in Chapter 2	Issues related to financial management influences - Reducing pumping energy subsidies; Constraining crop guarantee prices; Urban distribution efficiency	X		
Operational level	A **mechanism** for Monitoring, Reporting, Evaluation, Implementation, Updating and Report on a bi-annual or annual basis – a continual improvement on GwMP with updated and new information	X	X	X
	Identification of **priority issues** (impact issues or user requirement issues) and	X		

	Short- and Long-term **goals**			
	Responsibility and schedule	X		
	Development of plan **in close co-operation** with the municipality			X
	Municipal Council **buy-in/adopting** GwMP		X	
	Mobilising local government/ stakeholder partnership	X		
	Securing investment for management interventions	X		
	Treatment and Distribution of water – treatment of water at Water Treatment Works (WTW), training of staff at WTW and reticulation system, reticulation infrastructure monitoring and maintenance, seal old piping, sufficient spares, monitoring of water quality at the end-user			X

3.3.3 Implementation Approach

In the medical profession, a management plan will have two components, namely, a short-term plan and a long-term plan (Free Dictionary, 2018). A short-term plan assesses and analyse to resolve the present condition/gaps (thus immediate action "not to let the patient die on the table" scenario). This will relate – in the case of groundwater – to the setting up of the monitoring network, baseline water quality, install monitoring infrastructure, etc. within a month. The long-term plan entail to treat the patient till a full heathy state. And for groundwater this is frequent monitoring, reporting, monitoring committee meetings, six-monthly aquifer assessment, infrastructure maintenance, etc. A groundwater management plan can be divided into four time periods that implementation needs to acquire, namely: immediate action, short term, medium-term and long term goals.

The **Immediate action** will entail actions that are within the current abilities (material, funds, skills and capacity) without spending 'new' funds of a municipality and can be done within one month. This may include fixing of leaks, repairing borehole enclosure (fences and pump houses), removing surface pollution sources near boreholes (domestic litter waste), measuring of volume, abstraction rate, pumping hour readings at functional flow meters, logging borehole operations, etc.

The **Short-term implementation** will entail actions or activities that are within the current abilities (material, funds, skills and capacity) by spending funds of a municipality and can be done within a period of 3 – 6 months. Table 3.19 capture some of these actions.

Table 3.19: Posible Short term implementation actions

• Replacing broken pumps and motors	• Replace and or installing flowmeters
• Installing borehole level and water quality monitoring equipment (dipper tubes/conduit pipe, pressure probes, sampling tap)	• Identify boreholes to monitor for background groundwater levels within the wellfield and start monitoring these boreholes

• Take water quality samples and analyse the samples at a laboratory	• Implement operational rules for borehole and wellfield
• Develop a database for the monitoring data and analyse data	• Develop a reporting mechanism must be developed to report to the council and well to the water users (community)
• The source of all boreholes, wellfields, infrastructure reports and data from archives must to be placed in a central database	• Reporting and communication also need to be from the users in the form of a reporting of leaks, broken pipes, taps and pollution spills)
• Develop a library or holding place for like reports and quick referencing	• Fencing off the wellfield and prevention of pollution near wellfield
• Source the authorisation or mandated requirements (groundwater use license requirements – data to be supplied to DWS, abstraction limits, etc.) and start obtaining the required information	

The **Medium-term implementation** will entail action that may require additional external sources above the current abilities of the municipality (material, funds, skills and capacity) or the municipality need time to budget or request funding for the planned action. These activities may involve activities that were started in the short term phase to continue and expanded; contractors and tender procedures and can be done within a period of 1 – 2 years. Include analyses of the groundwater information (monitoring data, borehole/wellfield development report, etc.) as part of a groundwater assessment report; develop groundwater operating rules (borehole, wellfield and aquifer); manuals or guidelines; develop groundwater protection zones; training of staff; comply to all authorisations (water use license, environmental, etc.) to name a few.

The **Long-term implementation** will entail action that involves activities that need long term planning, budget and intervention from outside the municipality like the Provincial or National Government. The time frame for long term actions is within three to 5-years. This may include rezoning areas as no-development (protection) zones, implementing bylaws to reduce water use, monitoring, prevent pollution; amend regulation, plan and develop new wellfields, policy changes and organisational rearrangements (structure, personnel, budgets).

Figure 3.1 illustrates the implementation timelines with some actions or tasks associated with the different implementation terms.

All the phases need to be committed to and placed against a specific time frame. The best way is in an organogram with specific dates. This can be audited and monitored by the Council as well as the water users. Figure 3.2 is an example of such an implementation schedule.

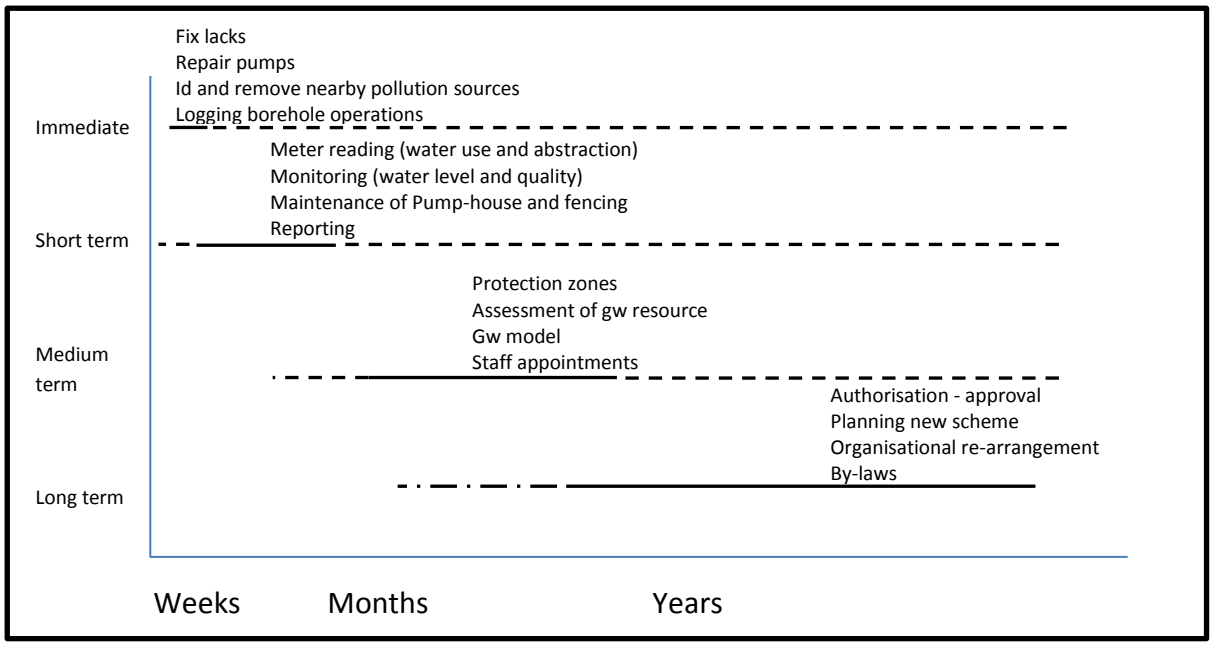


Figure 3.1: Examples of tasks, timelines and actions

List of tasks/actions (Time frame)	Y1 Q1		Y1 Q2		Y1 Q3	Y1 Q4	Y2 Q1-2	Y2 Q3-4	Y3	Y4
Immediate action (1 month)										
Fix lacks	■	■								
Repair pumps	■	■	■							
Id and remove nearby pollution sources	■	■								
Logging borehole operations	■									
And and and …….										
Short term (3 - 6 months)										
Meter reading (water use and abstraction)	■	■	■	■	■	■	■	■	■	■
Monitoring (water level and quality)		■	■	■	■	■	■	■	■	■
Maintenance of Pump-house and fencing			■	■	■			■		■
Reporting		■		■		■		■	■	■
Stakeholder meeting			■			■	■	■	■	■
And and and ……										
Medium-term (1-2 Years)										
Protection zones					■			■	■	
Assessment of gw resource							■	■	■	
Gw model								■	■	
Staff appointments								■		
And and and ……										
Long term (3-5years)										
Authorisation – approval									■	
Planning new scheme										■
Organisational re-arrangement									■	■
By-laws										■
And and and ……										

Figure 3.2: Example of an Implementation Schedule

The immediate- and short-term actions consist of activities that can be implemented as well as the preferred management and protection measures within the existing municipal framework. The medium- and long-term actions are defined by activities that will take a longer time, for example, local organisational (municipality) arrangements and the legal reform (Foster et al., 2010).

Operations and maintenance plan

Some of the immediate, short and medium-term actions can be incorporated in an operations and maintenance plan (CDM, 2013) which provide a detailed description of **routine** functions or tasks and roles of the personnel. The management tasks can be divided into daily, two weekly, quarterly and yearly tasks (Murray, 2007). The tasks list needs to contain the following per task:

- Task
- Who (the person that need to perform the task)
- A detailed description of what the task entails
- Existing Challenge or Impediment and
- Who should remove challenge or impediment

The tasks can be divided into four categories: general; operational; monitoring; and human resources (Swart et al., 2009).

3.3.4 Summary Template

A GwMP needs to consist of detailed information and description of all the elements described in Table 3.13, but the GwMP can become a bulky and not a very practical working document for everyday use. The East King GwMP consists of three volumes and 428 pages in total; the Orange County GwMP and Graaff-Reinet GwMPs comprised of 395 and 125 pages respectively. The detailed GwMP needs to be used and consulted on a regular basis, but not all of the information is relevant to all users (L. Fourie, 2012, pers. comm.). A summarised version with selective extracted portions from the full GwMP is needed for operational purposes (Martiz et al., 2012; and Myburgh and Prinsloo, 2018).

Generic GwMP Summary Template

The Summary format in Figure 3.3 is recommended to be used that incorporate all the elements of the GwMP and the more detail operational principles to manage the groundwater resources on a daily basis (see Figure 3.3 and the A3 size version in Appendix B).

The Management Objectives are prioritised, and only the highest priority Objectives are presented in the Summary. The limiting of the number of Objectives presented can be overcome by merely showing Objectives applicable for a specific year and thus developing an annual GwMP Summary.

The Summary steers itself to an operational plan, but precaution needs to be taken to incorporate all twelve groundwater management elements, and a separate Operational and Maintenance (O&M) Plan must be developed to address the O&M issues.

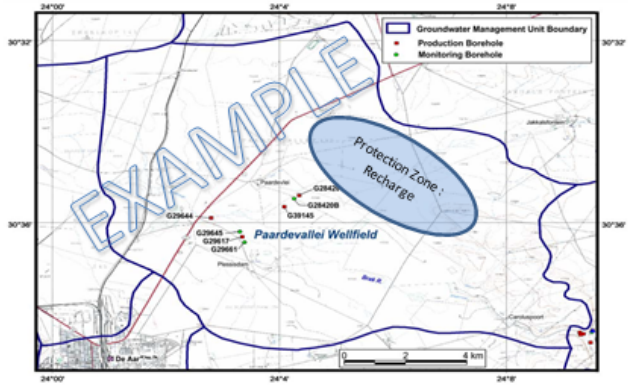
Separate Summary Templates for just the short-term, medium-term, operational and maintenance activitives can also be develop and hence change can be addressed and updated without changing the overall document.

Groundwater Management Plan
Name of Municipality
2019 – 2024

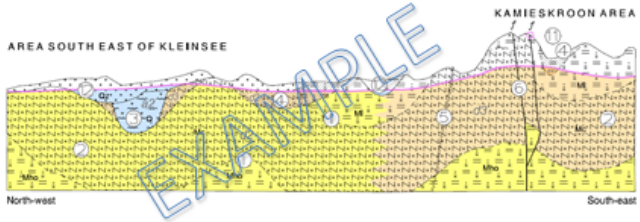
Municipality LOGO

Organisational management of the aquifer;
Institutional coordination;

Planning area;



Groundwater resources:



Water use:
Water requirements:
Protection:
Groundwater dependent ecosystems:

Regulatory/licence/allocations Conditions:

HIGH PRIORITY Groundwater Management Objectives (detail list of Objectives in GWMP)

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time Frame
Protection			
Regulation			

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time Frame
Use			
Planning			
Monitoring			
Conservation			
Operation			
Infrastructure			
Assessment			
Institutional Arrangements			
Capacity and Skills			
Awareness, Information, Communication and Stakeholder participation			

Operational Production Boreholes and Management Specifications

Wellfield / Groundwater Unit	Borehole		Pump			Maximum Monthly Abstraction (m³)	Maximum Permissible Drawdown below collar (m)
	name/ number	Depth (m)	Intake (m)	Capacity (l/s)	Duty cycle		

Funding for objectives:

Operational Tasks (more detail in the Operational and Maintenance Plan

Task	Who	Detail description of what the task entails	Existing Impediment	Who should remove impediment
DAILY				
WEEKLY				
2-WEEKLY				
MONTHLY				
QUARTERLY				
ANNUALLY				

List of tasks/actions (Time frame)	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1-2	Y2 Q3-4	Y3	Y4
Immediate action (1 month)								
Short term (3 - 6 months)								
Medium-term (1-2 Years)								
Long term (3-5years)								

EXAMPLE

Reporting:

Audit:

Signed-off:
Municipal Manager : _____ Date: _____
Director: Engineering Services : _____ Date: _____
Manager: WSA/WSP : _____ Date: _____

Figure 3.3: Generic format of a GwMP Summary

3.4 IMPLEMENTATION CHALLENGES

The implementation of the GwMP can be challenging if a phased approach (see section 3.3.3) is not followed because through the implementation of the GwMP issues including staff shortages, funding, institutional arrangement, regulation will be resolved.

The adoption of buy-in of the GwMP by the institutional authority and the stakeholder (FAO, 2003) is identified as one of the first steps in agreeing on the way forward to manage groundwater. The support from all departments within the municipality can hamper the procurement of parts to fix pumps, clearing of pollution sources, inform users, health and safety or appointment of personnel.

The socio-economic and environmental situation of a municipality or so-called 'soft' issues (FAO, 2003) need to be identified early in the implementation phase because the 'softer' issues may prevent the implementation of technical intervention which includes the development of new wellfields, restricting land use activities, protection zones and water use rate increases.

Technical challenges that can be faced by the implementing section or organisation may include lack of transport, unskilled operators (training), budgeting (no funds available for paying suppliers), lack of equipment for maintenance and lack of administrative support (Swart et al., 2009).

3.4.1 Leadership, institutional or organisational arrangements

Leadership is needed to go from isolated measures to a coordinated plan; this will ensure improved continuity and coordination. This 'champion' will need to play a leading role in the coordinating and directing financing of groundwater development and management (Foster et al., 2010 and NGS, 2017).

Aquifer or groundwater management units are not linked to political and administrative boundaries. A GwMP by a municipality does not work in isolation as it needs to fit into the catchment management strategy (if it exsit) and management actions by the CMA or DWS. It also need to consider other users and their needs and operational requirements. The delineation of appropriate boundaries of a groundwater resource planning, management area or unit can be challenging to determine. The socio-economic and political factors in a municipality may overrule the management approaches. Other challenges to overcome may include limited funds available, lack of institutional capacity or politics (GWP, 2018a).

CHAPTER 4 :
APPLICABILITY OF GROUNDWATER MANAGEMENT PLANS AT DIFFERENT AQUIFER TYPES

4.1 INTRODUCTION

The applicability of the GwMP methodology is applied through the three case studies with different aquifer types and scales are present. A *primary aquifer* near Yzerfontein (Grootwater aquifer – coastal primary aquifer), *karoo aquifer* at Beaufort West (Main Karoo Basin) and the West Coast *Aquifer System* consisting of the Langebaan-, Adamboerskraal- and Elandsfontein Aquifers were selected for this purposes.

A GwMP Summary was developed for each of the case studies to illustrate the differences in aquifer development stages, institutional arrangements, the spatial distribution of the wellfields or aquifers.

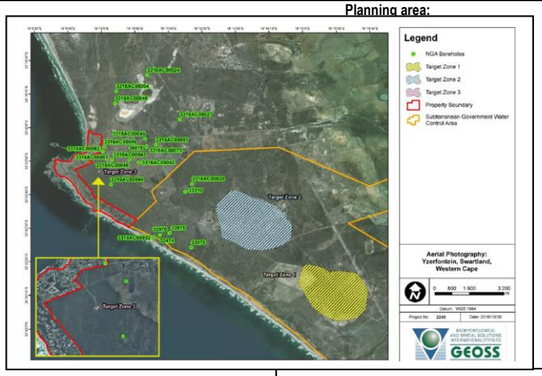
The groundwater management principles provide the backbone of the development and the implementability of the GwMPs. The understanding the principles of groundwater management with the local or municipality's current situation will ensure a practical GwMP.

4.2 APPLY GWMP FRAMEWORK AT AN ALLUVIAL AQUIFER: GROOTWATER AQUIFER

Groundwater Management Plan
Swartland Municipality – Grootwater Aquifer
2019 – 2024

Organisational management of the aquifer: West Coast District Municipality (WCDM) is responsible for the management of the water supply as WSP to Yzerfontein and surrounding towns from surface water – Voelvlei dam in the Swartland Municipality (SLM) (WSA). No groundwater is been supplied to the bulk supply system[1].SLM is investigating developing a wellfield on a farm in the Grootwater aquifer[2] (GwA). A large portion of the GwA is covered with the Subterranean Water Control Area namely Yzerfontein SWCA[3].
Institutional coordination: Service Level Agreement between WCDM and SLM need to be set up regards Swartland Regional Water Supply Scheme[1]. The new groundwater supply need also be negotiated between the two parties and the private landowners regarding the servitudes and operation.

Planning area:



Hydrologeology[4]: Aquifer Units in the Quartzose Sand Member (QSM) of the Varswater Formation and The Bredasdorp Formation: Grootwater Aquifer.
Unconfined – semi-confined aquifer: Bredasdorp Formation – peaty sand;
Aquiclude: Duynefontyn Member of Varswater F – clay, silty sand.
Semi-confined aquifer: Varswater Formation – sand and gravel.

Water resources[1]: Groundwater = 0 hm and Surface water (Voelvlei Dam/ SRWSS) = 0.367hm. Total = 0.367hm
Additional developed groundwater resources: Uitkoms wellfield: 1.0 hm/a[4]
Water consumption[1]: Summer = 1691 ML/d and Avg = 1012 ML/d

Future Water requirements[1]: 2030 = 0.633 hm/a

Protection: No protection is currently in place the SWCA do not allow large scale abstraction. Farm activities are limited. The farmstall with fual station at Jackelsfontein and R27 road present the biggest pollution risk.

Groundwater dependent ecosystems: The only areas with shallow water table are location across the aquifers. Various springs are associated with deep laying fault systems and depressions

Regulatory/licence/allocations Conditions:
Registered: Wellfield: Jackelsfontein – 260 000m³/a is registered with DWS WARMS under Jakkelsfontein Homeowners Ass (WSService). Farm Jackels Fontein 572 is been underplayed by the Vygefontein portion of the Grootwater aquifer.
Not registered: Swartland Municipality.
In the process of registration: Uitkoms wellfield[5,4] – 0.569 hm

HIGH PRIORITY Groundwater Management Objectives (detail list of Objectives in GwMP)

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time
Protection			
Develop protection zones with the allowed land use activity list.	Protection zones map and land use activity list	WCDM:Tech Man + SLM + CMA	'21
Develop protection buffer zones (2km) from the sea for abstract	Buffer zones map	WCDM:TechMan+CMA	'22
Develop Remediation/rehabilitation/mitigation (programs [awareness, Emergency Response Plan/Unit (spill or fire).] especially along the R27 road,	ERP/unit + program linked to the DM	SLM: EnviroOff + WCDM	'22
Assess risks of potential impacts on the quality, quantity and environment of the GwA	Potential impact risks	SLM:EnviroOff+WCDM	'20
Regulation			
Apply for Water use rights (registration/authorisation) Register Uitkoms wellfield	Water Use Licences	SLM: TechMan + CMA	'20
Develop Bylaws, mitigations, plans and procedures to implement Drought restriction regulation (DRR)	DRR Bylaws, mitigations, plans and procedures	SLM: TechMan + DWS	'23
Develop water and land use agreements with landowners	Landowner agreements	WCDM:TechMan+SLM	'19
Develop a program to promote the use of non-domestic quality std water for other uses (brackish – industrial, dual toilet system))	Non-domestic quality water use program	SLM:TechMan+Comms	'22
Report water use volumes/licences vs availability	Annual report+WULcondit	SBM:TechMan+WCDM	'21
Use			
Compile a User inventory of water use and monitor use	Database Monitoring rep	SLM: TechMan + CMA	'19

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time
Planning			
Develop a Climate Change Plan and long-term hydrological condition scenarios with interventions, and implementation framework include Managed Aquifer Recharge	Climate Change Plan and long-term hydrological condition scenarios	WCDM: TechMan+ DWS + CMA	'24
Investigate Managed Aquifer Recharge as a seawater intrusion prevention method (stormwater or wastewater).	Seawater intrusion prevention through AR report	SLM: TechM + Geohydrologist	'23
Water budget comparing water use and recharge values	Water budget	WCDM: TechMan + SLM + Geohydrologist	'20
Exploration drilling and testing of Uitkoms wellfield	New wellfield added to bulk	WCDM +SLM	'20
Wellfield design for new wellfield	New wellfield design plans	SLM Engineering serv	'20
Drought management plan– operations, local/short-term sources	Drought management plan	SLM:TechMan+WCDM	'22
Monitoring			
Develop a comprehensive monitoring program which includes all water sources, infrastructure, land use, pollution sources, etc.	Monitoring programs	WCDM: TechMan	'19
Develop an inventory of all the monitoring points information, pollution sources	Monitoring Inventory	SLM: TechM + WCDM	'19
Develop a monitoring network to include DWS mon. boreholes at Uitkoms wellfield and the Greater GwA for quantity and quality	New routes	WCDM: Water Tech+DWS	'19
Develop a specific seawater intrusion monitoring network	Seawater intrusion		'20
Capture all monitoring data on a database	Updated monitoring database	WCDM: TechMan; Admin	'19
6 monthly analysis on monitoring data with adjustment actions	6 Monthly monitoring rep	WCDM: TechMan	'19
Develop an inventory of all the monitoring points information, pollution sources	Monitoring Inventory	SLM: TechM + WCDM	'20
Report and publish monitoring data public, DWS/CMA	Reporting and publication of data	WCDM + SLM: Council	'20
Conservation			
Develop artificial recharge scheme in the GwA	Artificial recharge scheme in GwA	WCDM: TechMan	'23
A Conservation program through consultation with landowners to clear vegetation like the Port Jackson tree to reduce gw use	Clearing alien vegetation program	SLM: Environment Officer	'22
Develop guidelines for Low Impact Development (LID) in the construction of new developments	LID Guideline	SLM: TechM Environment Officer	'22
Conjunctive use schedule developed to use other water sources at the right time	Conjunctive use schedule	WCDM: TechMan	'23
Operation			
Develop Operational rules for each borehole, wellfield + aquifer	Operational rules	Geohydrologist + WCDM: TechMan	'20
Implement wellfields	Sustainable groundwater supply	WCDM	'20
Emergency procedures develop for infrastructure failure, spillage	Emergency procedures rules	WCDM:TechMan + SLM	'21
Infrastructure			
Equip all newly drilled boreholes with dipper tube and water sampling tap	Monitoring infrastructure install	WCDM: Water Tech	'20
Assess bulk infrastructure capacity and the incorporation of the new wellfield to meet the future water requirement	Infrastructure Assessment Report with augmentation and operational rules	WCDM: Engineering Services	'19
Update infrastructure design plans/layout with the new scheme	Upd. infrastructure plan	WCDM: Eng Serv	'21
Develop Maintenance program/schedule which includes monitoring equipment, reticulation system	Maintenance program/schedule	WCDM: Water Tech	'20
Assessment			
Re-assess the Long-term safe yield of all the boreholes/ wellfields with climate variability influences	Long-term safe yield	WCDM: TechMan	'22
Assess the actual recharge volume from the Darling Hills run-off to the Grootwater Aquifer	Quantified volume recharge	Geohydrologist + WCDM: TechMan	'20
Develop and Upd numerical model with monitoring data of GwA	Developed and Upd model	WCDM + DWS	'23
Institutional Arrangements			
Establish an Aquifer Management Committee (AMC) with land-owners, NGOs like West Coast Biosphere(WCB)(GwA)	Aquifer Management Committee	CMA + SLM+WCDM	'19
A subcommittee of the AMC: Collaboration with other users in GwA: Vyge Valley Estate, Jakkalsfontein NR, Tygerfontein	User agreements	WCDM	'19
A subcommittee of the AMC: Monitoring committee evaluating monitoring data, quantity, quality, environment	Independent representative monitoring structure/comm	CMA + WCDM West Coast Biosphere	'19
Define WSA and WSP roles and responsibilities for new wellfield	WSA/WSP Agreement	WCDM and SLM	'19
Assess the total cost of water supply including maintenance, development, operations, rehabilitation, monitoring resources, tools and equipment, etc. to link the water use tariff	Water budget	WCDM: Finance + SCM + SLM:TechMan + Council	'19
Capacity and Skills			
Training of key personnel in data capturing software/database	Training	WCDM: TechMan	'20
Awareness, Information, Communication and Stakeholder participation			
Develop news/information bits to info/educate users of the water status in aquifers (with monthly accounts and WCB)	Monthly news bits	WCDM : TechMan; Admin	'20
Monthly report back to WSA on Status of water infrastructure, water use, resources level	WSP water status report	WCDM: TechMan + CMA	'19
Research study to increase the knowledge of aquifer behaviour	More effective management	DWS+WCDM	'23

Operational Production Boreholes and Management Specifications

Aquifer/ Ground-water Unit	Wellfield	Borehole name/ number	Borehole Depth (m)	Pump Intake (m)	Pump Capacity (l/s)	Pump Duty cycle (h/d)	Max Abstraction Daily (ML/d)	Max Abstraction Month ML/m	Max Permissible Drawdown (mbgl)	No pump days /yr
Grootwater	Uitkoms 1A	G33332	59	29*	5*	24*	0.432*	13.14*	27*	365
		Bh1	60*	30*	10*	24*	0.864	26.28*	28*	365
		Bh2	60*	30*	7*	24*	0.605	18.39*	28*	365
	Phase 2*	Bh3	60*	30*	10*	24*	0.864	26.28*	28*	365

* Not yet implemented – recommended values

Funding for objectives: Water sales. Council approval

Operational Tasks (more detail in the Operational and Maintenance Plan

Task	Who	Detail description of what the task entails	Existing Impediment	Who should remove impediment
DAILY				
Respond to telemetry alarms	Tech	Carry the telemetry cell phone at all times. Receive + respond to alarms	Automate system to send 2-hourly SMS	WCDM:TechM
Respond to leak report	Foreman	Carry out leak prepare to pipeline, pumps	No Report book	WCDM:TechM
WEEKLY				
Water team meeting	TechM	Meet water team: tasks, HR, feedback		
2-WEEKLY				
Physical check all bh	Foreman	Drive to all bhs, inspect, rectify, repair, report as necessary		
Read bulk meters	Tech	Physical reading of bulk meter + balance		
MONTHLY				
Water level monitoring	Tech + Office	Monitor each bh (prod +mon) water level, flowmeter, capture data and report	Dipmeter in poor condition	WCDM:TechM
Data to hydrogeologist	TechM	Captured data - email		WCDM:TechM
QUARTERLY				
Review data/balance	TechM	Review data, supply/demand- report to SLM	Budget	WCDM:MM
Report to council	TechM	Report: incidence, use, level, recommend		
ANNUALLY				
Sample of all prod bh	Tech	Sample, analysis and report	Field equipment	TechM
SLM: Report to DWS	TechM	Report to DWS as per WUL conditions		

List of tasks/actions (Time frame)	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1-2	Y2 Q3-4	Y3	Y4
Immediate action (1 month)								
Develop water and land use agreements with landowners	■	■	■	■	■	■	■	■
Capture all monitoring data on a database	■	■	■	■	■	■	■	■
Short term (3 - 6 months)								
Develop a monitoring network to include Uitkoms wellfield and take over DWS monitoring bhs		■	■	■	■	■	■	■
6 Monthly monitoring assessment report				■	■	■	■	■
Service-level agreement between SLM and WCDM					■	■		
Establish an Aquifer Management Committee					■	■	■	■
Medium-term (1-2 Years)								
Assess report on aquifer behaviour on full production –upd model						■	■	■
Appoint Gw Technician					■	■	■	
Apply for water use rights from DWS					■	■		
Long term (3-5years)								
Investigate possible extension of wellfield (phase 2)							■	■
Develop an Artificial Recharge Scheme in Grootwater Aquifer								■

Reporting: Monthly reporting by Technical Manager to Municipal Manager; Quarterly reporting to Council

Audit: Yearly evaluation and update of action; the Year 2024 review; develop/update GwMP

Signed-off:
Municipal Manager : _____ Date: _____
Director: Engineering Services : _____ Date: _____
Manager: WSA/WSP :_____ Date: _____

1) DWS, 2016; 2) Aartsma, 2019; 3) Vermaak, 2015; 4) Timmerman GH3372, 1985; 5) Barron, 1998; 6) Muller, 2018

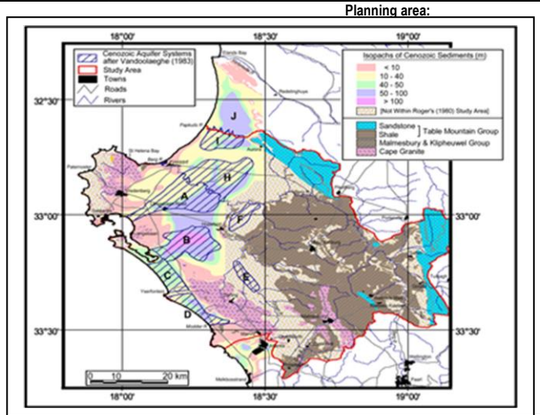
4.3 APPLY GWMP FRAMEWORK AT AN ALLUVIAL AQUIFER SYSTEM: WEST COAST AQUIFER SYSTEM

Groundwater Management Plan
West Coast District Municipality
2019 – 2024

Organisational management of the aquifer: West Coast District Municipality is responsible for the management of the water supply as WSP to Saldanha, Vredenburg, Veldrif, Langebaan and surrounding towns from surface water – Misverstand dam and groundwater – Langebaan Road (borehole-, wellfield-, pipeline- and electricity infrastructure; and aquifer management)[1]. Other users on the 3 aquifers include farmer –agriculture, Elandsfontein mine – mining. A large portion of the aquifers is covered with the Subterranean Water Control Areas namely Saldanha SWCA. The Lower Berg River Valley SWCA was never formally declared (in the Government Gazette) but were managed as a SWCA[2].

Institutional coordination: Agreements with private landowners, servitudes are in place. Meetings with other stakeholders (West Coast District Municipality,Saldanha Bay Municipality, NGOs, industry and domestic – water users) are held on an ad-hoc basis.

Planning area:



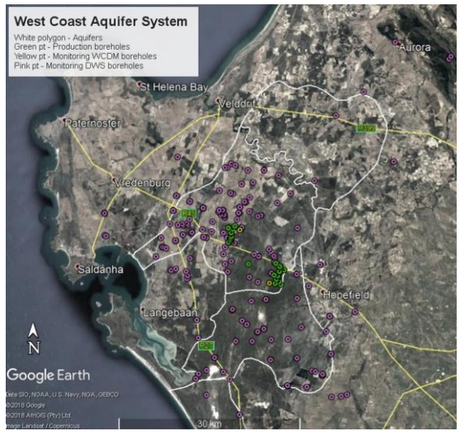
Hydrologeology[3]: Aquifer Units in the Elandsfontyn Formation: Langebaan Road, Elandsfortein and Adamsboerskraal Aquifers.
Unconfined aquifer: Bredasdorp and Varswater Formations. Aquiclude: Elandsfontyn Formation – clay. *Confined aquifer:* Elandsfontyn Formation – sand and gravel.

Water resources[1]: Groundwater = 1.35 hm and Surface water (Misverstand Dam/ Withoogte WTW) = 13.166 hm. Total = 14.516 hm
Additional developed groundwater resources: Langebaan Road 1A + 1B: 4.0 hm[4] and Hopefield B: 1.6 hm[5] Total: 5.6hm/a

Water consumption[1]: Summer = 55.4 ML/d and Avg = 41.0 ML/d
Future Water requirements[1]: 2030 = 27.5 hm/a

Protection: Only borehole protection – sanitation seal, security gate fence alarm system and pump housing around borehole. Land use management agreement with farmer and servitude.

Groundwater dependent ecosystems: The only areas with shallow water table are location across the 3 aquifers. Various springs are associated with deep laying fault systems and depressions



Regulatory/licence/allocations Conditions:
Registered: Total: 0.148hm/a; Wellfield: Hopefield A 147 000m³/a is registered with DWS WARMS under Saldanha Bay Municipality (WSA).
Not registered: wellfield: existing Langebaan Road 1A - 1.5hm/a.
In the process of registration: *Langebaan Road: Extension (1B)*[6] – 2.416 hm and *Existing (1A)* existing abstraction[3] – 1.5 hm and the additional volume[6] – 1.614 hm; *Langebaan Road Total*[4] – 5.53 hm. *Hopefield B*[7] – 1.6 hm.

HIGH PRIORITY Groundwater Management Objectives (detail list of Objectives in GwMP)

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time
Protection			
Id Recharge area; develop protection zones with allowed land use activity list (stormwater management practices, etc.)	Zones map and land use activity list	WCDM:Tech Man + CMA	'22
Id + develop a program for abandonment boreholes to prevent leaking through clay layer (program to seal, plug unused bh's)	Project to seal/plug unused bh's	WCDM: H&SafetyOff; Tech Man	'22
Ensure pump intake is above the clay layer (confined aquifer) to prevent unconfined conditions	Maintain gw level head above the clay layer	WCDM: WaterTech	'20
Develop Remediation/rehabilitation/mitigation (programs [aware-ness, Emergency Response Plan/Unit (spill or fire).] along R45	ERP/unit + program linked to the DM	SBM: EnviroOff + WCDM	'22
Regulation			
Finalise Water use rights (registration/authorisation) Register Langebaan Road 1A and 1B; and Hopefield B wellfields	Water Use Licences	SBM: TechMan + CMA	'20
Develop Bylaws, mitigations, plans and procedures to implement Drought restriction regulation (DRR)	DRR Bylaws, mitigations, plans and procedures	SBM: TechMan + DWS	'22
Review the SWCA and GA limits to ensure sustainable development	Sustainable development	WCDM: TechMan + CMA + DWS	'21
Report water use volumes/licences vs availability	Annual report + WUL conditions	SBM: TechMan + WCDM	'19

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time Frame
Use			
Investigate the increase in water reuse (agriculture, landscape irrigation, greywater)	Potential reclamation plant expansion, other sector use	SBM: TechMan	'23
Develop a program to promote the use of non-domestic quality standard water for other uses (brackish – industrial, dual toilet)	Non-domestic quality water use program	SBM: TechMan + Comms	'24
Planning			
Develop a Climate Change Plan with interventions and implementation framework include Managed Aquifer Recharge	Climate Change Plan	WCDM: TechMan+ DWS + CMA	'23
Exploration drilling and testing of Langebaan Road 2 and 3 wellf	New wellfields add to bulk syst	WCDM +SBM	'21
Drought management plan – operations, short-term sources	Drought management plan	SBM:TechMan+WCDM	'21
Monitoring			
Develop a comprehensive monitoring program which includes all water sources, infrastructure, land use, pollution sources, etc.	Monitoring programs	WCDM: TechMan	'20
Develop a monitoring network to include DWS mon. boreholes at Langebaan Road and Hopefield for quantity and quality	New routes	WCDM: Water Tech+ DWS	'19
Capture all monitoring data on a database	Updated monitoring database	WCDM: TechMan; Admin	'19
6 monthly analysis on monitoring data with adjustment actions	6 Monthly monitoring report	WCDM: TechMan	'19
Report and publish monitoring data public, DWS/CMA	Reporting and publish of data	WCDM+SBM:Counc	'19
Conservation			
Develop artificial recharge scheme in the LbR Aquifer	AR scheme in LbRA	WCDM: TechMan	'20
Conjunctive use schedule developed to use other water sources at the right time	Conjunctive use schedule	WCDM: TechMan	'19
Operation			
Develop Operational rules for each borehole, wellfield + aquifer	Operational rules	WCDM: TechMan	'19
Implement wellfields	Sustainable gw supply	WCDM	'19
Emergency procedures develop for infrastructure failure, spillage	Emergency procedures rules	WCDM:TechMan+SBM	'19
Infrastructure			
Equip all newly drilled boreholes (dipper tube, w sampling tap)	Monitoring infrastructure install	WCDM: Water Tech	'19
Develop an Asset register and update including photos	Asset Register	WCDM: SCM	'20
Assess bulk infrastructure capacity from Withoogte, the incorpor- ation of the new + future wellfield to meet future requirement	Infrastructure Assessment Report with augmentations	WCDM: Engineering Services	'20
Update infrastructure design plans/layout with new schemes	Updated infrastructure plan	WCDM: Eng Serv	'20
Develop Maintenance program/schedule which includes monitoring equipment, reticulation system	Maintenance program/schedule	WCDM: Water Tech	'20
Put the existing 5 boreholes of Hopefield A in operation	0.147hm extra water to system	WCDM	'20
Assessment			
Re-assess the Long-term safe yield of all the boreholes/ wellfields with climate variability influences	Long-term safe yield	WCDM: TechMan	'23
Update the numerical model with monitoring data of Langebaan Road Aquifer and West Coast Aquifer System	Updated model	WCDM + DWS	'22
Institutional Arrangements			
Re-establish an Aquifer Management Committee (AMC) with land-owners, NGOs around Langebaan Road and Hopefield Aq	Aquifer Management Committee	CMA + SBM+WCDM	'19
A subcommittee of the AMC: Collaboration with other users in LbRAS like Kropz mine, Irrigation, SAAF	User agreements	WCDM	'19
A subcommittee of the AMC: Monitoring committee evaluating monitoring data, quantity, quality, environment	Independent representative monitoring structure/committee	CMA + WCDM	'19
Define WSA and WSP roles and responsibilities	WSA/WSP Agreement	WCDM and SBM	'19
Assess the total cost of water supply including maintenance, development, operations, rehabilitation, monitoring resources, tools and equipment, etc. to link the water use tariff	Water budget	WCDM:Finance+SCM + SBM:TechMan + Council	'20
Capacity and Skills			
Training of key personnel in data capturing software/database	Training	WCDM: TechMan	'20
Appoint Gw Technician	Gw Technician	WCDM: HR	'20
Awareness, Information, Communication and Stakeholder participation			
Develop news/information bits to info/educate users of the water status in aquifers (with monthly accounts + Saldanha Bay Water Quality Forum Trust + West Coast Biosphere)	Monthly news bits	WCDM : TechMan; SBM: Admin	'20
Monthly report back to WSA on Status of water infrastructure, water use, resources level	WSP water status report	WCDM: TechMan + CMA	'19
A research study to increase the knowledge of AR, recharge	More effective management	DWS+WCDM	'24

Operational Production Boreholes and Management Specifications

Aquifer / Groundwater Unit	Wellfield	Borehole name/ number	Borehole Depth (m)	Pump In take (m)	Pump Capacity (l/s)	Pump Duty cycle (h/d)	Max Abstraction Daily (ML/d)	Max Abstraction Monthly (ML/m)	Max Permissible Drawdown (mbgl)	No pump days / yr
Langebaan Road	1A[3]	G45632	87	35	25	24	2.160	65.70	21	365
		G45633	74	35	25	24	2.160	65.70	21	365
		G45634	82	35	25	24	2.160	65.70	23	365
		G45636	78	50	20	24	1.728	52.56	37	365
	1B[6]	LRA-1B1	78	46	25	23	2.070	62.96	40	365
		LRA-1B2	43	30	14	16	0.806	24.53	30	365
		LRA-1B3	72	55	6	23	0.496	15.11	43	365
		LRA-1B4	72	53	41	22	3.247	98.77	38	365
Langebaan Road	Hopefield B[5]	HPF2-2			3.4	24	0.30	9.13		365
		HPF2-5			6.5	24	0.56	17.03		365
		HPF2-6			5.8	24	0.50	15.21		365
		HPF2-7			5.5	24	0.47	14.30		365
		T2-540			3.7	24	0.32	9.73		365
		T2-1190			3.6	24	0.31	9.43		365
		T3W-1510			4.5	24	0.38	11.56		365
		T4-2240			10	24	0.86	26.16		365
		TB-2150			2.18	24	0.19	5.78		365
		TA-1850			5.75	24	0.50	15.21		365
Hopefield	Hopefield A						0.40	12.25		

Funding for objectives: Water sales. Council approval

Operational Tasks (more detail in the Operational and Maintenance Plan

Task	Who	Detail description of what the task entails	Existing Impediment	Who should remove impediment
DAILY				
Respond to telemetry alarms	Tech	Carry the telemetry cell phone at all times. Receive + respond to alarms	Automate system to send 2-hourly SMS	WCDM:TechM
Respond to leak report	Foreman	Carry out leak prepare to pipeline, pumps	No Report book	WCDM:TechM
WEEKLY				
Water team meeting	TechM	Meet water team: tasks, HR, feedback		
2-WEEKLY				
Physical check all bh	Foreman	Drive to all bhs, inspect, rectify, repair, report as necessary		
Read bulk meters	Tech	Physical reading of bulk meter + balance		
MONTHLY				
Water level monitoring	Tech + Office	Monitor each bh (prod +mon) water level, flowmeter, capture data and report	Dipmeter in poor condition	WCDM:TechM
Data to hydrogeologist	TechM	Captured data - email		WCDM:TechM
QUARTERLY				
Review data/balance	TechM	Review data, supply/demand- report to SBM	Budget	WCDM:MM
Report to council	TechM	Report: incidence, use, level, recommend		
ANNUALLY				
Sample of all prod bh	Tech	Sample, analysis and report	Field equipment	TechM
SBM: Report to DWS	TechM	Report to DWS as per WUL conditions		

List of tasks/actions (Time frame)	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1-2	Y2 Q3-4	Y3	Y4
Immediate action (1 month)								
Expand monitoring network to include Langebaan Road 1B and Hopefield B wellfields	■	■	■	■	■	■	■	■
Equip all newly drilled boreholes with dipper tube and water sampling tap	■							
Short term (3 - 6 months)								
Take over DWS monitoring bhs		■	■	■	■	■		
6 Monthly monitoring assessment report				■			■	■
Re-establish an Aquifer Management Committee						■	■	■
Medium-term (1-2 Years)								
Assess report on aquifer behaviour on full production –upd model							■	■
Appoint Gw Technician					■	■	■	
Water use rights and conditions are received from DWS			■	■				
Long term (3-5years)								
Development of phases 3 and 4 wellfields							■	■
Develop a Artificial Recharge Scheme in LangebaanRoad Aquifer								■

Reporting: Monthly reporting by Technical Manager to Municipal Manager; Quarterly reporting to Council
Audit: Yearly evaluation and update of action; the Year 2024 review; develop/update GwMP

Signed-off:
Municipal Manager : _____ Date: _____
Director: Engineering Services : _____ Date: _____
Manager: WSA/WSP :_____ Date: _____

1) DWS, 2016; 2) Vermaak, 2015; 3) Weaver, 1998; 4) Nel, 2018a; 5) Nel, 2019; 6) Conrad, 2018; 7) Nel, 2018b

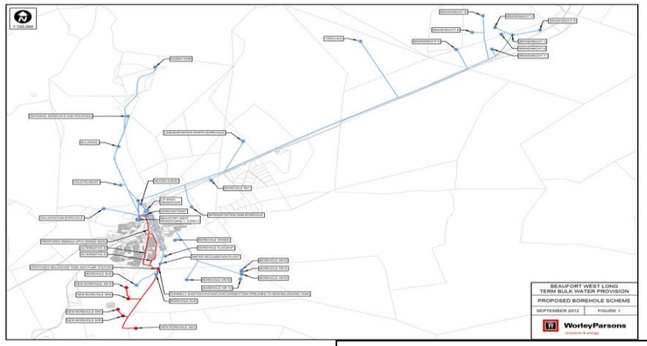
4.4 APPLY ON FRACTURE ROCK AQUIFER: BEAUFORT WEST LM

SA Groundwater

Groundwater Management Plan
Beaufort West Municipality
2019 – 2024

Organisational management of the aquifer: Beaufort West Municipality is responsible for the management of the water supply to Beaufort West (borehole-, wellfield-, pipeline- and electricity infrastructure; and aquifer management) although most boreholes are located on private land.
Institutional coordination: Agreements with private landowners, servitudes are in place. Meetings with other stakeholders (Central Karoo District Municipality, industry and domestic – water users) are held on an ad-hoc basis.

Planning area:



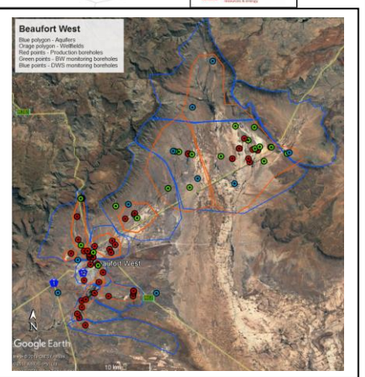
Hydrologeology[1]: Mostly associated with dolorite intrustion, the main recharge zone and area with deep alluvial cover.
Water resources[3]: Groundwater = 3.832 hm; Surface water (Gamka Dam) = 0.373 hm and Reclamation = 0.442 hm; Total = 4.647 hm

Water consumption[2]: Summer = 7.3 ML/d, Avg = 6.7 ML/d and Drought = 4.0 ML/d

Future Water requirements[3]: 2030 = 8.1 ML/d

Protection: Only borehole protection – sanitation seal, fence and pump housing around borehole for boreholes in and near town. Boreholes outside town on farms no pump housing or fencing, only sanitation seal and land use management agreement with farmer.

Groundwater dependent ecosystems: The only areas with shallow water table are location in the Gamka Valley north of town and in town downstream of the Beaufort West Dam.



Regulatory/licence/allocations Conditions:
Registered: Total: 3 258 985m³/a; Wellfields: Brandwag (not incl. Tweeling) 347 862m³/a; Hansrivier 1 218 297m³/a; Lemoenfontein 156 660 m³/a; Town (incl. Gamkavallei) 1 241 830m³/a ; Steenrotsfontein 294 336m³/a.
Not registered wellfield/boreholes: Tweeling – 286 824m³/a; GoG – 122 400 m³/a and CGS – 406 734m³/a

HIGH PRIORITY Groundwater Management Objectives (detail list of Objectives in GwMP)

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time
Protection			
Id Recharge area; develop protection zones with allowed land use activity list (stormwater management practices, etc.)	Zones map and land use activity list	BWM:Tech Man + CMA	'20
Develop a Pollution source inventory and Mapping pollution sources, census	Database with spatial reference/ map and mitigation actions	BWM: EnviroOfficer	'21
Develop Land use agreements (subsidy – co-funding practices)	All land-use agreement in place	BWM:Legal Service	'20
Id + develop a program for abandonment and destruction boreholes (program to seal, plug unused bh's)	Project to seal/plug unused bh's	BWM: H&SafetyOff; Tech Man	'23
Develop Remediation/rehabilitation/mitigation (programs [awareness, Emergency Response Plan/Unit (spill or fire), etc.],	ERP/unit + program linked to the DM	BWM: EnviroOff + DistrictM	'20
Regulation			
Verify Water use rights and conditions (registration/authorisation) Register Tweeling; GoG and CGS boreholes	Verified Water Use Licences	BWM: TechMan + CMA	'19
Develop Bylaws, mitigations, plans and procedures to implement Drought restriction regulation (DRR)	DRR Bylaws, mitigations, plans and procedures	BWM: TechMan + DWS	'20
Develop a Registry of water use (census) – develop a registry	Registry of water use	BWM: TechMan	'21
Report water use volumes/licences vs availability	Annual report according to WUL conditions	BWM: TechMan + DWS + CMA	'21
Use			
Develop a program to reduce water use by sectors (water-use efficiency, conservation, Water demand management programs)	Multi-Sector water use reduction program	BWM: TechMan + Comms+Community Off	'20
Use continue			
Investigate the increase in water reuse (agriculture, landscape irrigation, greywater, bigger reclamation plant)	Potential reclamation plant expansion, other sector use	BWM: TechMan	'22
Develop a program to promote the use of non-domestic quality standard water for other uses (brackish – industrial, dual toilet)	Non-domestic quality water use program	BWM:TechMan+Comm	'23
Planning			
Develop a Climate Change Plan with interventions and implementation framework	Climate Change Plan	BWM: TechMan	'24
Investigate alternative supply through feasibility studies which include Manage Aquifer Recharge/Enhancement	Manage Aquifer Recharge/Enhancement	BWM: TechMan + DWS + CMA	'23
Drought management plan – operations, local/short-term source	Drought management plan	BWM:TechMan+CKDM	'20
Monitoring			
Develop a comprehensive monitoring program which includes all water sources, infrastructure, land use, pollution sources, etc.	Monitoring programs	BWM: TechMan	'20
Expand monitoring network to include Springfontein, Hansrivier, Kleinhansrivier and Kwaggafontein.	New route	BWM: Water Tech	'19
Capture all monitoring data on a database	Upd monitoring database	BWM:TechMan; Admin	'19
6 monthly analysis on monitoring data with adjustment actions	6 Monthly monitoring assessment report	BWM: TechMan	'19
Report and publish monitoring data public, DWS/CMA	Report and publish of data	BWM TechMan;Counci	'20
Conservation			
In-lieu recharge program	In-lieu recharge program	BWM: TechMan	'21
Conjunctive use schedule developed to use other water sources at the right time	Conjunctive use schedule	BWM: TechMan	'20
Investigate a Recharge enhancement project (including AR)	Recharge enhancement proj	BWM: TechMan	'20
Operation			
Develop Operational rules for each borehole, wellfield + aquifer	Operational rules	BWM: TechMan	'19
Emergency procedures develop for infrastructure failure, spillage	Emergency procedures rules	BWM:TechMan + CKDM	'19
Infrastructure			
Equip all newly drilled boreholes with dipper tube and water sampling tap	Monitoring infrastructure install	BWM: Water Tech	'19
Develop an Asset register and update including photos	Asset Register	BWM: SCM	'20
Develop Maintenance program/schedule which includes monitoring equipment, reticulation system	Maintenance program/schedule	BWM: Water Tech	'19
Assessment			
Re-assess the Long-term safe yield of all the boreholes/ wellfields with climate variability influences	Long-term safe yield	BWM: TechMan	'21
Mapping of the recharge and discharge areas of the aquifers	Recharge + discharge map	BWM: TechMan	'22
Institutional Arrangements			
Establish an Aquifer Management Committee with landowners	Aquifer Management Committee	CMA+BWM:TechMan	'20
Assess total cost of water supply including maintenance, development, operations, rehabilitation, monitoring resources, tools and equipment, etc. to link the water use tariff	Water budget	BWM: Finance + SCM + TechMan + Council	'21
Capacity and Skills			
Training of key personnel in data capturing software/database	Training	BWM: TechMan	'20
Appoint Gw Technician	Gw Technician	BWM: HR	'21
Develop a succession plan or knowledge transfer program for technical staff	Secession Plan	BWM: TechMan	'20
Awareness, Information, Communication and Stakeholder participation			
Develop news/information bits to info/educate users of the water status in aquifers (with monthly accounts)	Monthly news bits	BWM : TechMan; Admin	'19
Monthly report back to Council on Status of water infrastructure, water use, resources level	Council water status report	BWM: TechMan + CMA	'19

Operational Production Boreholes and Management Specifications

Aquifer / Groundwater Unit	Wellfield	Borehole		Pump			Max Monthly Abstraction (m³)	Max Permissible Drawdown below collar (m)	No pump days /yr
		Name/ number	Depth (m)	Intake (m)	Capacity (l/s)	Duty cycle (h/d)			
Brandwacht	Brandwacht	Brandwacht 1	85		10	20	21 600		121
		Brandwacht 2	58		4	20	8 640		121
		Brandwacht 4	78		4	20	8 640		121
		Brandwacht 5			6	20	12 960		121
		Brandwacht 6	74		8	20	17 280		121
		Brandwacht 8	85		4	20	8 640		121
		Brandwacht 9	79		4	20	8 640		121
		Brandwacht 11			10	20			
	Tweeling	Kuilspoort			9	24	23 328		365
Lemoen-fontein	Lemoenfontein	Lemoenftn N	61		10	20	21 600		218
		Lemoenftn W							
Gamka-vallei	Gamkavallei N	Bulkraal	85		8	20	17 280		228
		Volstruisgat S	79		3	20	6 480		228
		GoG4			2.98	16	5 200		
		GoG5			2.87	16	5 000		
		Waterval	91.44		5	20	10 800		228

Aquifer/ Ground-water Unit	Wellfield	Borehole		Pump			Max Monthly Abstraction (m³)	Max Permissible Drawdown below collar (m)	No pump days /yr
		name/ number	Depth (m)	Intake (m)	Capacity (l/s)	Duty cycle (h/d)			
Gamka-valley	Walkerdam	Walkerdam	55		2.5	20	5 400		365
	Gamkavallei S	Noord Einde N			7	20	15 120		365
		Noord Einde S	85.79		7	20	15 120		365
Springftn	Springfontein	Springfontein	78		5	20	10 800		109
Hansrivier	Hansrivier	Hansrivier 10	80		17	12	22 032		365
		Hansrivier 15	108		2.5	20	5 400		292
Dorp		Hoenderplaas	74		6.6	12	8 554		365
	Rioolwerke	Flagship			4	20	8 640		365
Kleinhans-rivier		Klein Hansriv 3			7	20	15 120		365
	Steenrotsfontn	SR4			3.6	20	7 776		365
		SR10			4	20	8 640		365
Kwaggaftn		QA2			2.4	20	5 184		365

Funding for objectives: Water sales. Council approval

Operational Tasks (more detail in the Operational and Maintenance Plan

Task	Who	Detail description of what the task entails	Existing Impediment	Who should remove impediment
DAILY				
Respond to telemetry alarms	Tech	Carry the telemetry cell phone at all times. Receive + respond to alarms	Automate system to send 2-hourly SMS	TechM
Respond to leak report	Foreman	Carry out leak prepare to pipeline, pumps	No Report book	TechM
WEEKLY				
Water team meeting	TechM	Meet water team: tasks, HR, feedback		
2-WEEKLY				
Physical check all bh	Foreman	Drive to all bhs, inspect, rectify, repair, report as necessary		
Read bulk meters	Tech	Physical reading of bulk meter + balance		
MONTHLY				
Water level monitoring	Tech + Office	Monitor each bh (prod +mon) water level, flowmeter, capture data and report	Dipmeter in poor condition	TechM
Data to hydrogeologist	TechM	Captured data - email		
QUARTERLY				
Review data/balance	TechM	Review data and supply/demand- report	Budget	MM
Report to council	TechM	Report: incidence, use, level, recommend		
ANNUALLY				
Sample of all prod bh	Tech	Sample, analysis and report	Field equipment	TechM
Report to DWS	TechM	Report to DWS as per WUL conditions		

List of tasks/actions (Time frame)[4]	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1-2	Y2 Q3-4	Y3	Y4
Immediate action (1 month)								
Develop news/information bits to info/educate users of the water status	■	■	■	■	■	■	■	■
Equip all newly drilled boreholes with dipper tube and water sampling tap	■	■	■					
Short term (3 - 6 months)								
Expand monitoring network to include Springfontein, Hansrivier, Kleinhansrivier and Kwaggafontein		■	■	■	■	■		
6 Monthly monitoring assessment report				■			■	■
Medium-term (1-2 Years)								
Map the recharge and discharge areas of the aquifers					■		■	■
Appoint Gw Technician						■	■	
Verify Water use rights and conditions				■		■		
Long term (3-5years)								
Establish an Aquifer Management Committee with landowners							■	■

Reporting: Monthly reporting by Technical Manager to Municipal Manager; Quarterly reporting to Council

Audit: Yearly evaluation and update of action; the Year 2024 review; develop/update GwMP

Signed-off:
Municipal Manager : _____ Date: _____
Director: Engineering Services : _____ Date: _____
Manager: WSA/WSP :_____ Date: _____

Notes: 1) Campbell, 1977; 2) Haarhoff, 2019; 3) DWS, 2016; 4) Lasher, 2011

4.5 DISCUSSION

The Summary provides a shorter version of the full GwMP and only contains an abstract of information and highlights just the critical management objectives.

The Grootwater aquifer is not developed as a water source for the Swartland Municipality, but that are already users tapping into the aquifer that rely on the aquifer as their domestic water resource. The protection, assessment and planning elements are essential for a new wellfield development with the monitoring and institutional arrangements elements that need to take the lead in the first two years.

The aquifer type plays an essential role in the institutional arrangements, assessment and protection because the alluvial aquifer is vast in surface area with many users tapping into and having an impact on all the users. The fact that the wellfield need to be developed, all the agreements, committees, monitoring and assessment can be in place before abstract starts at the new wellfield.

The focus of the Langebaan Road Aquifer System is on the implementation, operation, monitoring and institutional arrangement aspects of the newly developed wellfields. The protection and future developments are not currently the priority of the municipality.

The three aquifers need to be managed as one single aquifer system. In the past Langebaan Road aquifer was manage on its own, but in the last few years, the research indicates that the three aquifers react as an aquifer system. The aquifer connectivity (communication) of the alluvium aquifer type system was only scientifically proven after detail studies and comprehensive monitoring analysis. The new information brings forth the importance of the more comprehensive focus on the institutional arrangements with all stakeholders in the “new extended area of influence“.

The fracture rock (Karoo) type aquifer system around Beaufort West is manage very well throughout the last few decades because of the close involvement of the Department and the experience personnel at the municipality. Regular expert advices from geohydrological consultants in the last few years optimise the management of the groundwater resources around Beaufort West. Very good relationships between landowners and municipality exist and new land agreements are establish once new source development are planned.

The Karoo type aquifers are ‘localised aquifers’. The aquifer system around Beaufort West consists of 7 aquifers. The some of the wellfields are located across two or three aquifers that make the

management and operational aspects challenging. The conjunctive use of different water sources add an additional challenge, but also add positives to the water security and availability question.

Because the Beaufort West aquifer system is so long in operation, the knowledge build-up over years needs to be capture. One of the challenges is not to lose the old report and information (borehole logs, construction, etc.).

The 3 sites that were selected had more or less the same institutional arrangement that provide a very good platform to evaluate the 3 sites. The next step would be to do a comparison between different GwMPs of different institutional arrangements as the institutional arrangement came out as the biggest influencing element on the management of groundwater.

CHAPTER 5 :

CONCLUSIONS

The main aim of the study was to investigate whether existing groundwater management plan methodologies can be standardised and applied on different types of aquifers for the South African context.

To achieve the main aim, different objectives were identified for the study namely to:

- Evaluate the principles groundwater is manage at the municipality level
- Evaluate the methodologies of various international and local groundwater management plans
- Propose a generic groundwater management plan framework by evaluating various existing plans and
- Assess the generic groundwater management plan framework if applied on different levels of scale and aquifer types in South Africa.

Understanding the difference between groundwater governance and groundwater management provides a clear direction towards the management functions, what a local municipality needs to do to manage their groundwater resources sustainably. Various relationships between governance and management can be experienced at different levels, that explain the different ways groundwater management is dealt with at various levels.

The concept of groundwater management has various elements that influence the management of groundwater resources. Groundwater management can be divided into twelve principles which can be grouped into two broad categories. The first category is the quantity and quality science side that includes planning, assessment, protection, monitoring, conservation, operation, use and infrastructure principles. The second category consists of the softer principles side that includes regulation, institutional arrangements, capacity and skills, and the awareness, information sharing, and stakeholder participation.

The world organisations provide a generic approach with a broad and high-level action to the GwMPs, where international and local GwMPs a more detail-focused like operations, monitoring and conservation. The broad structure of all the GwMPs are the same, but the approaches,

elements addressed in the structure, as well as the format of each GwMP differ. The purpose or goal of the GwMPs, as well as the validity period, is mainly linked to the regulatory requirements and goal objectives. The development of a GwMP cannot be done without a thorough preparatory phase of information gathering. The biggest shortcoming of all the GwMPs is the implementation phase which is the ultimate reason why a GwMP is developed. The lack of tracking the progress of implementation, funding to implement the action or objectives, the reporting or feedback, and finally, the evaluation and update of the GwMP often result in uptake of GwMPs.

An adapted approach to develop a GwMP for South Africa is recommended to address the preparation, development and implementation phases with a generic table of content that contain all the elements of the GwMP. The management objectives are central to the GwMP and are provided as a list of over 150 objectives in the twelve management principle categories to be selected from for site-specific requirement. A summary template provides a quick overview of the most relevant and often used information of the GwMP.

Although the summaries were successfully developed for the three different aquifer types, the real differences were not the type of aquifer but rather the different institutional arrangements of the three aquifers. The management objectives are in many ways the same with a site-specific difference, but the responsibilities and roles of the institution differ significantly.

The GwMP methodology can still be expanded further to be more practical and widely used. This can be done through:

- Full development of a GwMP with the three-phased approach
- Compare the GwMP's of different institutionalal arrangements
- The development of a user-friendly software interface
- Updating the methodology to be more practical
- Awareness on the use-of and buy-in of GwMPs with the local municipalities which include articles in journals (technical) and magazines (laymen); and add GwMPs to all new groundwater development project's scope of work
- A guideline for municipalities on the use of the GwMPs and
- The development of the above action and distribution of the guideline through a WRC project.

REFERENCES

Aartsma, H. 2019. Desktop Feasibility Study into Water Supply to Yzerfontein from Grootwater Aquifer. Draft - Bigen Africa Report No 3251-00-00. Bigen Africa Services, Bellville, South Africa. pp1-83.

Abiodun, B.H., Ujeneza, E.L., Meque, A., Naik, M., Omar, S.A., Lawal, S., Nguvava, M., Gore, M., Molepo, K., Maoyi, M., Mukwenha, P., New, M., Rouault, M., Engelbrecht, F. and Abatan, A.A. 2018. *Regionally Extensive Droughts and Climate Change in Southern Africa: Mechanisms, Reliability and Projections*. WRC Report No 2317/1/18. ISBN 978-1-4312-0973-6. Water Research Commission, Pretoria, South Africa. pp 1-164.

Academies Council of Canada (ACC). 2009. *The Sustainable Management of Groundwater in Canada: Expert Panel on Groundwater*. The Council of Canadian Academies. Ottawa, ON Canada. ISBN 978-1-926558-11-0. pp: 1-270.

Al-Salamah, B.S., Ghazaw, Y.M. and Ghumman, A.R. 2010. *Groundwater modeling of Saq Aquifer Buraydah Al Qassim for better water management strategies*. · Environmental Monitoring and Assessment (2011) 173:851–860. DOI 10.1007/s10661-010-1428-1. https://www.researchgate.net/publication/42976159_Groundwater_modeling_of_Saq_Aquifer_Buraydah_Al_Qassim_for_better_water_management_strategies [Assessed 12 March 2018].

Alice Springs Water Allocation Plan (ASWAP). 2013. *Alice Springs Water Allocation Plan 2016-2026*. Water Resources Branch, Department of Land Resources Management, Alice Springs, Northern Territory of Australia. Water Resources Branch, Department of Land Resource Management. Report No. 01/2016A. Alice Springs, Northern Territory, Australia. ISBN 978-1-921937-47-7. https://denr.nt.gov.au/__data/assets/pdf_file/0020/271415/FINAL-ASWAP-AS-DECLARED-BY-MINISTER-IN-2016-.pdf. pp 1-58. [Assessed 27 April 2019].

Baron, J.H. 1990. *Aquifer Characteristics and Recommended Water Allocations in the Grootwater Aquifer Unit, Yzerfontein Subterranean Government Water Control Area*. DWA Technical Report No GH 3715. Directorate of Geohydrology, Cape Town, Departement of Water Affairs, South Africa. pp1-43.

Batchelor, C. 2007. *Water governance literature assessment.* International Institute for Environment and Development. IIED code G02523. Available at http://pubs.iied.org/pdfs/G02523.pdf. Assessed 6 April 2018.

Bertram, E. 2008. Groundwater Management Plan for Delmas Municipality. DWS internal document. Directorate: Hydrological Services, Department of Water Affairs, Pretoria, South Africa. pp 1-2.

Bolbro Kildeplads. 2015. *Bolbro Kildeplads – Handleplan Maj 2015*. Dated May 2015. VandCenter Syd as, Odense, Denmark. www.vandcenter.dk. pp: 1-33 https://www.vandcenter.dk/-/media/vandcenter/om-os/filer/bolbro-kildeplads-handleplan-maj-2015.pdf?la=da&hash=E1E04D96CE40C4B4648187B86902B7828FF1FC78

Bosman, C. 2007. *Beyond the buzzwords – what does "sustainable groundwater management" really mean?* Paper presented to the 10th Groundwater Conference; Bloemfontein, 8 -10 October 2006. https://www.academia.edu/40631562/BEYOND_THE_BUZZWORDS_-_WHAT_DOES_SUSTAINABLE_GROUNDWATER_MANAGEMENT_REALLY_MEAN. pp1-9.

Braune, E. 2000. *Towards comprehensive groundwater resource management in South Africa*, in Sililo, O. et al. (eds.) *Groundwater: Past Achievements and Future Challenges*. Proceedings of the XXX IAH Congress, Cape Town, South Africa, 26 November – 1 December 2000. ISBN 9058091597. Publish by AA Balkema, Rotterdam, Netherlands. pp 1-1144.

Braune, E., Adams, S and Fourie, F. 2014. *20 Years of Groundwater Research, Development and Implementation in South Africa.* Water Research Commission Report No SP78/14. WRC, Pretoria, South Africa. pp 1-82.

Braune, E., Adams, S. and Xu, Y. 2010. *Assessing the impact of research funded by the Water Research Commission on capacity building on the groundwater sector*. Water Research Commission Report No KV232/09. WRC, Pretoria, South Africa. pp 1-62.

Braune, E., Hollingworth, B., Xu, Y., Nel, M., Mahed, G and Solomon, H. 2008. *Protocol for the Assessment of the Status of Sustainable Utilization and Management of Groundwater Resources with Special Reference to Southern Africa*. Water Research Commission Report No TT318/08. WRC, Pretoria, South Africa. pp 1-72.

Braune, E.G. and du Plessis, J.A. 2019. Stochastic daily time-step conjunctive water use model for local municipalities. Unpublished M.Sc. thesis. University of Stellenbosch, South Africa.

Burke, J. 2007. *Integrated Water Resource Management Plan Guidelines for Local Authorities*. WRC Report No TT304/07. Water Research Commission, Pretoria, South Africa. pp 1-167.

California Legislative Information (CLI). 2019. Chapter 3. Groundwater Management Plans [10753 – 10753.11]. Water Code, Division 6. Conservation, Development, and Utilization of State Water Resources [10000 – 12999], Part 2.75. Groundwater Management [10750 – 10755.4]. http://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=WAT&division=6.&title=&part=2.75.&chapter=3.&article=. [Assessed 13 March 2019].

Calow, R.C., Macdonald, D.M.J. and Orpen, W.R.G. 1996. *Groundwater management in drought-prone areas of Africa: South Africa*. British Geological Survey, Overseas Geology Series, Technical Report WC/96/56. British Geological Survey, Keyworth, Nottingham, United Kingdom. http://resources.bgs.ac.uk/sadcreports/rsa1996calowwc9656.pdf [Asccessed 13 August 2019]. pp 1-49.

Cambridge Dictionary. 2018. In: 1st ed. [online] Available at: https://dictionary.cambridge.org/dictionary/. [Assessed 2 April 2018].

Campbell, G.D.M. 1977. *Beaufort West Groundwater Investigation (April 1975 – December 1977).* DWA Technical Report No GH 3135. Directorate Geohydrology, Pretoria, South Africa. pp1-216.

Capricorn District Municipality (CDM). 2013. Operations and Maintenance, Draft Plan. Unit: Operations and Maintenance, Infrastructure Department, Capricorn District Municipality, Polokwane, South Africa. pp 1-90.

Central Groundwater Board (CGB). 2006. *Hydrogeological Framework and Groundwater Management Plan of NCT Delhi.* Dated February 2006. Central Groundwater Board, State Unit Office, New Delhi, India. pp. 1-10. https://www.researchgate.net/publication/266947830_Hydrogeological_frame_work_and_groundwater_management_plan_of_NCT_Delhi [Assessed 5 October 2017].

Chave, P., Howard, G., Schijen, J., Appleyard, S., Fladere, F. and Schimon, W. 2006. Chapter 17: *Groundwater protection zones*, in Schmoll, O., Howard, G., Chilton, J. and Chorus, I. (eds.) *Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources*. World Health Organization. ISBN: 1843390795. Published by IWA Publishing, London, UK. pp. 465-492.

Cobbing, J., Eales, K., Gibson, J., Lenkoe, K and Rossouw, T. 2014. *An appraisal of diverse factors influencing long-term success of groundwater schemes for domestic water supplies, focusing on priority areas in South Africa*. WRC Report No 2158/1/14. Water Research Commission, Pretoria, South Africa. pp 1-177.

Conrad, J. 2018. *Yield and Quality testing of the Langebaan Road Aquifer (1b). Western Cape.* GEOSS Report No: 2018/05-61. GEOSS, Stellenbosch, South Africa. pp1-59.

DANCED. 2004. *Groundwater Management Strategy: Full Guideline*. Integrated Water Resource Management Project - DANIDA. Department of Water Affairs and Forestry, Pretoria, South Africa. pp. 1-44.

Davis, J. and Brikke, F. 1995. *Making your water supply work: Operation and Maintenance of small water supply systems*. Occasional Paper Series 29, IRC International Water and Sanitation Centre, The Hague, the Netherlands. pp. 1-119. Available at https://www.ircwash.org/sites/default/files/Davis-1995-Making.pdf [Assess 24 July 2019].

Davies, J., Robins, N.S., Farr, J., Sorensen, J., Beetlestone, P. and Cobbing, J.E. 2013. *Identifying transboundary aquifers in need of international resource management in the Southern African Development Community region.* HJ 2013, 21, 321–330; DOI 10.1007/s10040-012-0903-x. Available online: https://www.researchgate.net/publication/257471386_Identifying_transboundary_aquifers_in_need_of_international_resource_management_in_the_Southern_African_Development_Community_region/citations (assessed 31 August 2019).

De Kock, A.S. and Welman, P.I. 2010. *Baviaans Municipality: Groundwater Management Plan*. Uhambiso Consult, Report no 8285AG. Uhambiso Consult, Port Elizabeth, South Africa. pp1-40.

De Lange, S.S. 1999. Environmental impact of point pollution sources. Unpublished M.Sc.thesis, University of the Free State, Bloemfontein, South Africa.

DELWP. 2017. *Annual Water Outlook for Victoria.* The State of Victoria Department of Environment, Land, Water and Planning. ISBN 978-1-76047-880-3 (pdf/online). DELWP, Melbourne, Australia. Available at https://www.water.vic.gov.au/__data/assets/pdf_file/0025/91690/DELWP0067_StateAnnualWaterOutlook_2017_v22_weba03.pdf. [Access 6 February 2019].

Dennis, R., Dennis, I., Rantlhomela, P. and Hogan, C. 2013. *Potential Climate Change Impacts on Karoo Aquifers*. WRC Report No KV 308/12. Water Research Commission, Pretoria, South Africa. pp 1-178.

Dillon, P., Escalante, E.F. and Tuinhof, A. 2016. *Thematic Paper No. 4: Management of Aquifer Recharge and Discharge Processes and Aquifer Storage Equilibrium.* Groundwater Thematic Papers, Groundwater Governance: A Global Framework for Country Action project. Available at: http://www.groundwatergovernance.org or http://www.fao.org/3/a-i6040e.pdf. Accessed 6 April 2018. pp. 223-274.

Dogramaci, S. 2004. *A Review of groundwater pumping to manage dryland salinity in Western Australia.* Department of Environment, Salinity and Land Use Impacts Series Report No.

SLUI 25. https://www.water.wa.gov.au/__data/assets/pdf_file/0015/5541/42412.pdf [Accessed 6 November 2019]. pp 1-40.

Dogramaci, S., De Silva, J. & Brooks, T. 2009. *Groundwater pumping to control the watertable at Tammin*, Salinity and land use impacts series, Report no. SLUI 41, Department of Water, Perth. https://www.researchgate.net/publication/265015296_Groundwater_pumping_to_control_the_watertable_at_Tammin [Accessed 7 November 2019]. pp 1-56.

DWA. 2009. Review of groundwater management examples in South Africa. Strategy and Guideline Development for National Groundwater Planning Requirements Project - National Groundwater Strategy. DWA Report No. P RSA C000/00/11909/2, Activity NGS02 Marketing and Communication. Unpublished report. Department of Water Affairs, Pretoria, South Africa.

DWA. 2010a. *Groundwater Strategy*. Department of Water Affairs, Pretoria, South Africa. pp 1-64.

DWA. 2010b. *Technical Series 3: Primary Aquifers of South Africa*. Main Report: Guideline for the assessment, planning and management of groundwater in South Africa. Department of Water Affairs, Pretoria, South Africa.

DWAF. 1995. *A Guideline for Groundwater Protection for the Community Water Supply and Sanitation Programme*. Department of Water Affairs and Forestry, Pretoria, South Africa. pp 1-54.

DWAF. 1997. *White Paper on National Water Policy of South Africa*. Department of Water Affairs and Forestry, Pretoria, South Africa. pp 1-64.

DWAF. 2004. *A Framework for Groundwater Management of Community Water Supply*. NORAD: Toolkit for Water Services. Report number 1.1. Department of Water Affairs and Forestry, Pretoria, South Africa. pp 1-41.

DWAF. 2008a. *Feasibility Study towards the Policy Development on Aquifer Protection Zoning*. Internal Report. ISBN 978-0-621-38235-8. Water Resources Information Programme, Department of Water Affairs and Forestry, Pretoria, South Africa. pp 1-71.

DWAF. 2008b. *Guideline for the assessment, planning and management of groundwater in South Africa*. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWS. 2013. Climate Change Adaptation Strategy for Water. Draft. Department of Water Affairs, Pretoria, South Africa. pp 1-83.

DWS. 2016. Reconciliation Strategies – All Towns. Directorate National Water Resource Planning, Department of Water and Sanitation, Pretoria, South Africa http://www6.dwa.gov.za/DocPortal/Default.aspx

DWS. 2017. Groundwater Promotional Booklet of Councillors. Department of Water and Sanitation, Pretoria, South Africa. Draft. pp 1-22.

East King County (EKC). 1998. *East King County Groundwater Management Plan – Management Strategies 1998 – 1995*. Dated December 1998. Seattle, Washington, United States of America. pp. 1-52. https://your.kingcounty.gov/dnrp/library/1998/kcr143/kcr143_Mgmt-Plan.pdf [Assessed 23 May 2017].

Economic Commission for Europe (ECE). 1989. *Charter on Groundwater Management*. Economic Commission for Europe. 1989 E/ECE/1197. United Nations, New York. pp 1-24.

Edwards Aquifer Authority (EAA). 2011. *Groundwater Management Plan 2010 - 2015*. Edwards Aquifer Authority, Texas, United States of America. pp. 1-52. https://www.edwardsaquifer.org/eaa [Assessed 1 September 2017].

Environment Agency (EA). 2012. *Groundwater protection: Principles and practice (GP3)*. Version 1. Environment Agency, Bristol, England. pp 1-215.

European Communities (EC). 2000. *Water Framework Directive 2000/60/EC*. No L 327, Official Journal of the European Communities. Publish date 22.12.2000. pp. 1-72. https://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF. [Assessed 25 January 2019].

Fallding, M. 2000. *What makes a good natural resource management plan?* Ecological Management & Restoration, Vol 1, No 3, December 2000. pp. 185-194. https://onlinelibrary.wiley.com/doi/abs/10.1046/j.1442-8903.2000.00031.x. [Assess 23 April 2019].

FAO. 2003. *Groundwater Management- The Search for Practical Approaches*. Water Reports No 25, Food and Agriculture Organisation of the United Nations, Rome, Italy. pp. 1-50. http://www.fao.org/tempref/agl/AGLW/ESPIM/CD-ROM/documents/5E_e.pdf [Assessed 13 December 2018].

FAO. 2016a. *Global Framework for Action to achieve the vision on Groundwater Governance.* Groundwater Governance: A Global Framework for Action project. http://www.groundwatergovernance.org, or http://www.fao.org/3/a-i5705e.pdf. [Accessed November 2017].

FAO. 2016b. *Synthesis Report*. Groundwater Thematic Papers, Groundwater Governance: A Global Framework for Action project. pp. 5-46. Available at: http://www.groundwatergovernance.org or http://www.fao.org/3/a-i6040e.pdf. [Accessed 6 April 2018].

FAO. 2016c. *Global Diagnostic on Groundwater Governance.* Groundwater Governance: A Global Framework for Action project. http://www.groundwatergovernance.org, or http://www.fao.org/3/a-i5705e.pdf. [Accessed November 2017].

Free Dictionary. 2018. In: 1st ed. [online] Available at: https://medical-dictionary.thefreedictionary.com/management+plan. [Assessed 2 April 2018].

Foster, S. and Ait-Kadi, M. 2012. *Integrated Water Resources Management (IWRM): How does groundwater fit in?* Hydrogeology Journal (2012) 20: 415–418.

Foster, S., Evans, R and Escolero, O. 2015. *The groundwater management plan: in praise of a neglected 'tool of our trade'*. Hydrogeology Journal (2015) 23: 847–850.

Foster, S. and Garduño, H. 2013. *Groundwater-resource governance: Are governments and stakeholders responding to the challenge?* Hydrogeology Journal. March 2013, Volume 21, Issue 2, pp 317–320.

Foster, S., Garduño, H., Tuinhof, A. & Tovey, C. 2009. *Series Overview*. GW.MATE Briefing Note Series Note 0. Washington, DC: World Bank. Available at www.worldbank.org/gwmate or GW-MATE cd.

Foster, S., Garduño, H., Tuinhof, A. & Tovey, C. 2010. *Groundwater Governance – conceptual framework for assessment of provisions and needs*. GW.MATE Strategic Overview Series No. 1. Washington, DC: World Bank. Available at www.worldbank.org/gwmate or GW-MATE cd.

Foster, S., Hirata, R., Gomes, D., D'Elia, M. and Paris, M. 2002. *Groundwater Quality Protection*. GW-MATE, Washington, DC: World Bank. pp 1-114.

Foster, S., Perry, C., Hirata, R. and Garduno, H. 2009. *Groundwater resource accounting: critical for effective management in a 'changing world'*. GW Mate briefing note series, Note 16. Washington, DC: World Bank. Available at: http://documents.worldbank.org/curated/en/733281468337470805/Groundwater-resource-accounting-critical-for-effective-management-in-a-changing-world. Accessed: 31 March 2018.

Fourie, F., Vermaak, N., Hohne, D, and Murray, R. 2016. Authorising MAR projects within the context of South Africa's National Water Act, paper presented to the 9th International Symposium on Managed Aquifer Recharge (ISMAR9); Mexico City, 20 -24 June 2016.

Fourie, S.A. 2017. Groundwater Use: The Planning Perspective. Lecture notes distributed in the unit. GEOH6865 Groundwater Management module. University of the Free State, Bloemfontein on 19 September 2017.

Garduño, H. and Foster, S. 2010. *Sustainable Groundwater Irrigation – approaches to reconciling demand with resources*. GW.MATE Strategic Overview Series No. 4. Washington, DC: World Bank. Available at www.worldbank.org/gwmate or GW.MATE cd.

Garduño, H., Van Steenbergen, F. and Foster, S. 2010. *Stakeholder Participation in Groundwater Management enabling and nurturing engagement*. 2nd edn, rev 2002.GW.MATE Briefing Note Series No. 6. Washington, DC: World Bank. Available at www.worldbank.org/gwmate or GW-MATE cd.

Gerlak, A.K., Medgal, S.B., Varady, R.G. and Richards, H. 2013. *Groundwater Governance in the U.S. Summary of Initial Survey Results.* University of Arizona, Tucson, AZ. https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/GroundwaterGovernanceReport-FINALMay2013.pdf. Accessed: 18 December 2018. pp.1-27.

Global Water Partnership (GWP). 2000. *Integrated Water Resource Management*. Global Water Partnership, TAC Background Papers No.4. Stockholm, Sweden. GWP. pp.1-71.

Global Water Partnership (GWP). 2013a. France – Management Plan for the Astian Aquifer #20. Knowledge Resources: Case Studies: Europe https://www.gwp.org/en/learn/KNOWLEDGE_RESOURCES/Case_Studies/Europe/France-Management-plan-for-the-astian-aquifer-20/ Viewed 13 April 2018.

Global Water Partnership (GWP). 2013b. Transboundary Water Management Plans for Slovakian-Hungarian Transboundary Groundwater Bodies #421. Knowledge Resources: Case Studies: Europe. https://www.gwp.org/globalassets/global/toolbox/case-studies/europe/Transboundary_Water_Management_Plans_for_Slovakian-Hungarian_Transboundary_Groundwater_Bodies_421.pdf [Assessed 13 April 2018]

Global Water Partnership (GWP). 2018a. Groundwater Management Plans. Integrated Water Resource Management (IWRM) Toolbox Series C4.03. https://www.gwp.org/en/learn/iwrm-toolbox/Management-Instruments/Planning_for_IWRM/Groundwater_management_plans/. Viewed 13 April 2018.

Global Water Partnership (GWP). 2018b. Monitoring and evaluation systems. Integrated Water Resource Management (IWRM) Toolbox Series C1.03. https://www.gwp.org/en/learn/iwrm-toolbox/Management-

Instruments/Understanding_Water_Endowments/Monitoring_and_evaluation_systems/. Viewed 13 April 2018.

Goulburn-Murray Water (GMW). 2015. *Shepparton Irrigation Region Water Supply Protection Area Groundwater Management Plan*. Goulburn-Murray Water, Tatura, Victoria, Australia. Report no. DM 3786511. https://www.g-mwater.com.au/downloads/gmw/Groundwater/Shepparton_Irrigation_Region_WSPA/29022016_-_3786511-v25-SHEPPARTON_IRRIGATION_REGION_GROUNDWATER_LOCAL_MANAGEMENT_PLAN.pdf. [Accessed 27 April 2019]. pp. 1-39.

Graham, J., Amos, B. and Plumptre, T. 2003 *Principles for Good Governance in the 21st Century*. Policy Brief No. 15 – August 2003. Institute on Governance, Ottawa, Canada. Pp.1-9. https://iog.ca/

Haarhoff, K. 2019. Water Status of Beaufort West, presentation presented at MIG Project Appraisal meeting in Cape Town, South Africa, 25 January 2019.

IUCN Business and Biodiversity Programme (IUCN BBP). (2017). *IUCN Review Protocol for Biodiversity Net Gain: A guide for undertaking independent reviews of progress towards a net gain for biodiversity.* Business and Biodiversity Programme, International Union for Conservation of Nature. Gland, Switzerland: IUCN. 32pp.

Jensen, M.M. 2017. *Stakeholder involvement*. Workshop notes distributed in the unit. Danish Groundwater Mapping and Assessment, Aalborg, Environmental Protection Agency, Ministry of Environment and Food of Denmark on 18 August 2017.

Jonker, L.E., Swatuk, L.A., Matiwane, M., Mila, U., Ntloko, M. and Simataa, F. 2010. *Exploring the Lowest Appropriate Level of Water Governance in South Africa.* Water Research Commission, Report No. 1837/1/10. Pretoria, South Africa. pp. 1-85.

Jørgensen, L.F. and Stockmarr, J. 2008. *Groundwater monitoring in Denmark: characteristics, perspectives and comparison with other countries*. Hydrogeology Journal (2009) 17: 827–842. DOI 10.1007/s10040-008-0398-7

Klein, W.A., Manda, A.K. and Griffin, M.T. 2014. *Refining management strategies for groundwater resources*. Hydrogeology Journal (2014) 22: 1727–1730.

Kotzé, Y.L., Van der Merwe, J., Gomo, M, Molaolwa, G.G., De Lange, J., Esterhuizen, L., Olifant, P.W. and Mantyeane, A.W. 2019. *Training Manual on Groundwater Resource Management and Groundwater Governance for Municipalities.* Water Research Commission, Report No. 2447/1/19. Pretoria, South Africa. pp. 1-50.

Lasher, C. and Conrad, J. 2011. *Geohydrological assessment (October 2011) – Beaufort West*. GEOSS Report No: G2011/10-03. GEOSS, Stellenbosch, South Africa. pp.1-90.

Lazarus, P. 1997. *Towards a Regulatory Framework for the Management of Groundwater in South Africa.* Water Research Commission, Report No. 789/1/98. Pretoria, South Africa. pp. 1-66.

Local Government Action (LGA). 2019. http://localgovernmentaction.org.dedi6.cpt3.host-h.net/xh/content/integrated-development-plan. Viewed 11 February 2019.

Maathuis, H. and Simpson, M. 2006. *Groundwater Resources in the Yorkton Aquifer Management Plan Area: Final Report.* Date June 2006. Report number SRC Pub No. 10419-1E06. Saskatchewan Research Council, Saskatoon, Saskatchewan, Canada. pp. 1-140.

Madhnure, P., Rao, P.N. and Rao, A.D. 2015. *Establishing Strategies for Sustainable Groundwater Management Plan for Typical Granitic Aquifers-A Pilot Study near Hyderabad, India.* Aquatic Procedia 4 (2015) 1307 – 1314. https://www.sciencedirect.com/science/article/pii/S2214241X15001716. [Accessed 24 March 2018].

Margane, A. 2003. *Guideline for Sustainable Groundwater Resources Management.* ACSAD-BGR Technical Cooperation Project: Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region, Project No.: 1996.2189.7, Vol 6. Damascus, Syria. 235pp.

Maritz, G., Fourie, L., Cumming, C., Steynberg, M., Wegelen, W., Naidoo, J. and Smit, P. 2012. *Camdeboo Municipality Water Services Provider Business Plan*. Prepared by: Rapid Response Unit of the Department of Water Affairs, February 2012, Camdeboo Municipality, Graaff-Reinet, South Africa.

Mays, L.M. 2013. *Groundwater Resources Sustainability: Past, Present, and Future*. Water Resour Manage (2013) 27:4409–4424; DOI 10.1007/s11269-013-0436-7

Mediterranean Groundwater Working Group (MED-EUWI). 2007. *Mediterranean Groundwater Report.* Technical report on groundwater management in the Mediterranean and the European Union Water Framework Directive http://www.semide.net/topics/groundwater/Mediterranean_Groundwater_Report_final_150207.pdf. pp. 1-125. [Assessed 19 March 2018].

Meyer, R. 2002. *Guideline for the monitoring and management of groundwater in the rural water supply schemes*. Water Research Commission, Report No. 861/1/02a. Pretoria, South Africa. pp. 1-105.

Miljøstyrelsen. 2000. *Zonering (Zoning)*. Vejledning nr 3, 2000. Miljøstyrelsen, København. pp 1-153.

Miljøstyrelsen. 2018. *Vejledning om indsatsplaner* (*Guidance on action plans)*. Vejledning nr 27, Februar 2018. Miljøstyrelsen, København. 54p.

Moench, M., Kulkarni, H. and Burke, J. 2016. *Thematic Paper No. 7: Trends in Local Groundwater Management Institutions*. Groundwater Thematic Papers, Groundwater Governance: A Global Framework for Country Action project. Available at: http://www.groundwatergovernance.org or http://www.fao.org/3/a-i6040e.pdf. Accessed 6 April 2018. pp. 373-419.

Muller, C. 2018. *Geohydrological assessment and borehole siting at Yzerfontein, Swartland, Western Cape*. GEOSS Report No: 2018/10-41. GEOSS, Stellenbosch, South Africa. pp1-16.

Murray, K. Du Preez, M and Meyer, R. 2007. *National Microbial Monitoring Programme for Groundwater – Implementation Manual*. Water Research Commission, Report No. TT312/07. Pretoria, South Africa. pp. 1-113.

Murray, R. 2007. *Prince Albert Municipality: Groundwater Management and Artificial Recharge – Feasibility Study*. Groundwater Africa, Stellenbosch, South Africa. pp1-152.

Murray, R. and Harris, J. 2010. *Water Banking: A practical guide to using Artificial Groundwater Recharge.* Strategy and Guideline Development for National Groundwater Planning Requirements. Department of Water Affairs, P RSA 000/00/13510, dated October 2010. Pretoria, South Africa. pp. 1-105.

Myburgh, J.A. and Prinsloo, J. 2018. *Western Cape Department of Local Government: Bredasdorp – Borehole Re-Drilling and Groundwater Management Plan*. AGES Report No 2018/06/15/GWSD. AGES Omega, East London, South Africa. pp1-41.

Naicker, S., Magingi, A. and Bengeza, T. 2019. Development of the Polokwane Urban Complex Aquifer Management Plan: Inception Report (Draft). Directorate Water Resource Planning Systems, Department of Water and Sanitation, Pretoria, South Africa. pp 1-27.

National Groundwater Strategy (NGS). 2017. *National Groundwater Strategy*. WRC Report No TT714/17. WRC, Pretoria, South Africa. pp 1-125.

National Water Act (NWA). 1998. *South African National Water Act*, Act No. 36 of 1998. Volume 398, No Government Gazette, Volume 390, No 18522. Pretoria: Government Gazette.

Nel, J.M. 2018a. *Hydrogeological report for Langebaan Road Aquifer: Support document for Water Use License application*. UWC, Report Version 1, 20 February 2018. Institute for Water Studies, University of the Western Cape, Bellville, South Africa. pp1-33.

Nel, J.M. 2018b. Results of aquifer testing at LRA 1B wellfield. UWC, Internal Memo, 11 April 2018. Institute for Water Studies, University of the Western Cape, Bellville, South Africa. pp1-21.

Nel, J.M. 2019. *Hopefield Wellfield: Geophysical Survey, Borehole Locations, Construction and Yields*. UWC, Report Version 1, 16 April 2019. Institute for Water Studies, University of the Western Cape, Bellville, South Africa. pp1-70.

Nielsen, A.M. 2017. *Groundwater Management*. Workshop notes distributed in the unit. Danish Groundwater Mapping and Assessment, Aalborg, Environmental Protection Agency, Ministry of Environment and Food of Denmark on 18 August 2017.

Orange County Water District (OCWD). 2015. *Groundwater Management Plan 2015 Update*. Dated 17 June 2015. Orange County Water District, California, United States of America. pp. 1-395. https://www.ocwd.com/media/3503/groundwatermanagementplan2015update_20150624.pdf [Assessed 1 September 2017].

Owens Valley and Inyo County (OVIC). 1990. *Green Book for the Long-term Groundwater Management Plan for the Owens Valley and Inyo County*. Dated June 1990. Inyo County, California, United States of America. pp. 1-66. https://www.researchgate.net/publication/238762955_GREEN_BOOK_FOR_THE_LONG-TERM_GROUNDWATER_MANAGEMENT_PLAN_FOR_THE [Assessed 1 September 2017].

Oxford Dictionary. 2018. In: 1st ed. [online] Available at: https://en.oxforddictionaries.com/. [Assessed 2 April 2018].

Pashkin, P. 2019. *Western Cape Stand Alone Dams Monitoring Report. Western Cape Stand Alone Dams and Schemes – Dec 2018*. Directorate Water Resource Planning Systems, Department of Water and Sanitation, Pretoria, South Africa. pp 1-31.

Pierce, S.A., Sharp, J.M. Jr., Guillaume, J.H.A., Mace, R.E. and Eaton, D.J. 2013. *Aquifer-yield continuum as a guide and typology for science-based groundwater management*. Hydrogeology Journal (2013) 21: 331–340.

Pietersen, K., Beekman, H.E. and Holland, M. 2011. *South African Groundwater Governance Case Study*. A World Bank report. Water Research Commission Report No KV 273/11. WRC, Pretoria South Africa. pp. 1-101.

Plum Creek Conservation District (PCCD). 2018. *Plum Creek Conservation District Groundwater Management Plan - 2018*. Lockhart, Texas, USA. pp. 1-127. http://pccd.org/wp-content/uploads/2019/01/PCCD-Management-Plan-ADOPTED-for-website.pdf [Accessed 19 March 2019].

Prescott Active Management Area (PAMA). 1984. *Prescott Active Management Area Management Plan for First Management Period 1980 - 1990.* Arizona Department of Water Resources, Phoenix, Arizona, United States of America. Pp. 1-108. http://infoshare.azwater.gov/docushare/dsweb/Get/Document-10091/PRAMA_1MP.pdf [Assessed 28 June 2018].

Prescott Active Management Area (PAMA). 1995. *Prescott Active Management Area Modifications to the Second Management Period 1990 - 2000.* Arizona Department of Water Resources, Phoenix, Arizona, United States of America. Pp. 1-91. http://infoshare.azwater.gov/docushare/dsweb/Get/Document-10059/PRAMA%202MP%20MODIFICATIONS_July1995_full.pdf [Assessed 28 June 2018].

Prescott Active Management Area (PAMA). 1999. *Third Management Plan for the Prescott Active Management Area 2000-2010.* Arizona Department of Water Resources, Phoenix, Arizona, United States of America. Pp. 1-394. http://infoshare.azwater.gov/docushare/dsweb/Get/Document-10009/PrescottAMA_3MP.pdf [Assessed 18 March 2019].

Prescott Active Management Area (PAMA). 2017. *Fourth Management Plan for the Prescott Active Management Area 2010-2020.* Arizona Department of Water Resources, Phoenix, Arizona, United States of America. Pp. 1-292. http://infoshare.azwater.gov/docushare/dsweb/Get/Document-10037/PrescottFourthManagementPlan.pdf [Assessed 18 March 2019].

Rebelo, A. and Morris, C. 2019. 'Financial incentives could spur cities and land owners to protect wetlands , in *The Conversation*, viewed 7 August 2019, from http://theconversation.com/financial-incentives-could-spur-cities-and-land-owners-to-protect-wetlands-118277

Redding Area Water Council (RAWC). 2007. *AB 3030 Groundwater Management Plan for the Redding Groundwater Basin – 2007*. Redding Area Water Council, Shasta County, California, United States of America. pp. 1-25. https://www.co.shasta.ca.us/docs/libraries/public-works-docs/docs/AB3030_May2007.pdf?sfvrsn=61f32bb8_0 [Assessed 13 March 2019]

Republic of South Africa. 1996. *The Constitution of the Republic of South Africa, Act 108 of 1996*. Pretoria: Government Gazette. ISBN 978-0-621-39063-6. pp. 1-182.

Riemann, K., Louw, D., Chimbaza, N. and Fubesis, M. 2010. *Groundwater management framework*. WRC Report No 1917/1/10. Water Research Commission, Pretoria South Africa. pp. 1-149.

Riemann, K., Fubesis, M. and Chimbaza, N. 2013. *Development of a 'Blue Drop' type Scoring System for Groundwater Management at Municipal Level*. WRC Report No KV 311/1/12. Water Research Commission, Pretoria South Africa. pp. 1-38.

Riemann, K., Rust, J., Hoosain, M., Jack, S. 2016. *Deliverable 6 – Water Governance Framework and Action Plan for Conjunctive Use*. Project: Water Governance of Groundwater and Surface Water Resources in South Africa. WRC Report No K5/2332. Water Research Commission, Pretoria. 118p.

Robins, N.S., Calow, R.C., MacDonald, A.M., Macdonald, D.M.J., Gibbs, B.R., Orpen, W.R.G., Mtembezeka, P., A J Andrews, A.J., Appiah, S.O., and Banda, K. 1997. *Final ReportGroundwater management in drought-prone areas of Africa.* British Geological Survey, Overseas Geology Series, Technical Report WC/97/57. British Geological Survey, Keyworth, Nottingham, United Kingdom. http://resources.bgs.ac.uk/sadcreports/malawi1997robinsddroughtwc9757.pdf [Asccessed 13 August 2019]. pp 1-38.

Rodgers, P. and Hall, A.W. 2003. *Effective Water Governance.* Global Water Partnership, Technical Committee, Background Paper No 7. Hantverkargatan 5, SE-112 21 Stockholm. 1-49p.

Roeper, U.V.R. 1990. *Development of an aquifer management plan in a complex glacial setting, Regina, Canada*. In Groundwater management, Book 1, Proceedings of the 1990 Cluster of Conferences, February 20 - 21, 1990, Kansas City, NWWA, pp. 685 - 693.

Rotz, R.R. and Milewski, A.M. 2019 *Physical modeling of inland freshwater lens formation and evolution in drylands.* Hydrogeology Journal (2019) 27: 1597 - 1610. https://doi.org/10.1007/s10040-019-01940-1. [Accessed 28 August 2019].

Rudolph, D. and Hough, J. 2012. *Groundwater Management Plan for Graaff-Reinet*. VELA VKE, Report No A0000-W1C-01. VELA VKE, South Africa. pp1-125.

Russo, T., Alfredo, K. and Fisher, J. 2014. *Sustainable Water Management in Urban, Agricultural, and Natural Systems*. Water (2014), 6, 3934-3956 www.mdpi.com/2073-4441/6/12/3934/pdf [Accessed 28 July 2018].

Sami, K., Neumann, I., Gqiba, D., de Kock, G. and Grantham, G. 2002. *Groundwater exploration in geologically complex and problematic terrain - Guidelines (volume 1)*. Water Research Commission, Report No. 966/1/02. Pretoria, South Africa. pp. 1-70.

Santa Rosa Plain Watershed (SRPW). 2014. *The Santa Rosa Plain Groundwater Management Plan - 2014.* County of Sonoma, Santa Rosa, California. pp: 1-335.

Schultz, L., Duit, A and Folke, C. 2011. *Participation, Adaptive Co-management, and Management Performance in the World Network of Biosphere Reserves*. World Development, Elsevier, vol. 39(4), pages 662-671, April. http://www.pik-potsdam.de/~fournet/AfriBiRds/Literature%20review/Files/Schultz%20et%20al.%20-%202011%20-%20Participation,%20Adaptive%20Co-management,%20and%20Managem.pdf [Assessed 5 November 2018].

Seward, P. and Van Dyk, G.S.d.T. 2018. Chapter 25: *Turning the tide – curbing groundwater over-abstraction in the Tosca-Molopo area, South Africa*, in Villholth, K.G., López-Gunn, E., Conti, K.I., Garrido, A. and Van der Gun, J. (eds.) *Advances in Groundwater Governance*. CRC Press. Leiden, The Netherlands. pp. 511-525.

Seward, P. and Xu, Y. 2015. *Key Interventions to Improve Local Groundwater Governance*. WRC Report No 2238/1/15. Water Research Commission Pretoria, South Africa. pp. 1-160.

Seyler, H. and Holland, M. 2016. *Assessment and Update of Groundwater Scheme Operating Rules - Sedgefield.* WP10778: Operating Rules for Water Supply and Drought Management for Stand-alone Dams and Schemes – January 2016. Directorate Water Resource Planning Systems, Department of Water and Sanitation, Pretoria, South Africa. pp 1-70.

Seyler, H., Witthüser, K. and Holland, M. 2016. *The Capture Principle Approach to Sustainable Groundwater Use.* WRC, Report No. 2311/1/17. Water Research Commission Pretoria, South Africa. pp. 1-163.

Shekhar, S., Purohit, R. R. and Kaushik, Y.B. 2006. *Groundwater Management in NCT Delhi. Conference:* 5th Asian Regional Conference of Indian National Committee on Irrigation and Drainage (INCID) At Vigyan Bhawan, New Delhi 6-11 December 2006. Volume: Proceedings https://www.researchgate.net/publication/238708371_Groundwater_Management_in_NCT_Delhi. [Assessed 19 March 2019].

Sililo, O.T.N. and Saayman, I.C. 2001 *Groundwater Vulnerability To Pollution in Urban Catchments*. WRC Project No 1008/1/01 Water Research Commission, Pretoria, South Africa. pp. 1-70.

Swart, C.D., Mwiinga, G., Marler, M., Meyer, V., Hlophe, M., Rajagopaul, R. and Charles, K. 2009. *Guideline and training aids for the sustainable Operation and Maintenance of small water treatment plants*. WRC, Report No. 1599/1/09. Water Research Commission, Pretoria, South Africa. pp. 1-70.

Timmerman, L.R.A. 1985. *Preliminary Report on the Geohydrology of the Grootwater Primary Aquifer Unit between Yzerfontein and the Modder River*. DWA, Technical Report No GH 3372. Department of Water Affairs, Bellville, South Africa. pp1-78.

Tuinhof, A., Dumars, C., Foster, S., Kemper, K., Garduño, H., & Nanni, M. 2002. *Groundwater Resource Management – an introduction to its scope and practice*. GW.MATE Briefing Note Series, No. 1. Washington, DC: World Bank. Available at www.worldbank.org/gwmate or GW-MATE cd.

United Nations Educational, Scientific and Cultural Organization (UNESCO). 2006. *Water – a shared responsibility. The United Nations World Water Development Report 2.* 7, UNESCO, 7, place de Fontenoy, 75007 Paris, France. https://unesdoc.unesco.org/ark:/48223/pf0000145405 [Access 1 February 2019]. pp 1-601.

Van Tonder, G., Bardenhagen, I., Riemann, K., van Bosch, J., Dzanga, P. and Xu, Y. 2002. *Manual on Pumping Test Analysis in Fractured-rock Aquifers.* WRC, Report No. 1116/1/02. Water Research Commission, Pretoria, South Africa. pp. 1-231.

Varady, R.G., Van Weert, F., Megdal, S.B., Gerlak, A., Iskandar, C.A., House-Peters, L. 2016. *Thematic Paper No. 5: Groundwater Policy and Governance*. Groundwater Thematic Papers, Groundwater Governance: A Global Framework for Country Action project. Available at: http://www.groundwatergovernance.org or http://www.fao.org/3/a-i6040e.pdf. Accessed 6 April 2018. pp. 279-324.

Vermaak, N. 2015. Western Cape Groundwater Control Areas. Internal Document – DWS. Directorate Planning and Information, Western Cape, Department of Water and Sanitation, Bellville, South Africa. pp1-81.

Vermaak, N. 2018. Action Plan on Sustainable Groundwater Management for the West Coast Aquifer System. Draft report – Water Sector Governance and Operations –The Danish Model, DFC Scholarship Programme, Copenhagen, Denmark. pp1-19.

Villholth, K.G. 2005. *Groundwater assessment and management: implications and opportunities of globalization*. Hydrogeology Journal (2006) 14: 330–339.

Villholth, K. G and Conti, K.I., 2018. Chapter 1: *Groundwater governance: rationale, definition, current state and heuristic framework*, in Villholth, K.G., López-Gunn, E., Conti, K.I., Garrido, A. and Van der Gun, J. (eds.) *Advances in Groundwater Governance*. CRC Press. Leiden, The Netherlands. pp. 3-31.

Warrion Water Supply Protection Area Groundwater Management Plan (WWSPA). 2010. Warrion Water Supply Protection Area Groundwater Management. Southern Rural Water

Corporation, Maffra, Victoria, Australia. http://www.srw.com.au/files/Technical_reports/Warrion_Groundwater_Management_Plan.pdf. [Accessed 27 April 2019]. Pp. 1-26.

Water Act (WAct), 1956. *Water Act*, Act No. 54 of 1956, Statutes of the Republic of South Africa - Water. Issue no 28, 1956, Government Gazette, . Pretoria: Government Gazette. pp 1201 – 1399.

Water Act (WAV). 2015. *Water Act* 1989. No. 80 of 1989, Authorised Version No. 113 incorporating amendments as at 1 March 2015. Parliament of Victoria, Australia. http://www.legislation.vic.gov.au/Domino/Web_Notes/LDMS/LTObject_Store/LTObjSt9.nsf/DDE300B846EED9C7CA257616000A3571/AB07E1293846B175CA257DF9000051A0/$FILE/89-80aa113%20authorised.pdf. [Accessed 27 April 2019]. pp. 1-833.

Water Services Act (WSAct). 1997. *South African Water Services Act*. Act No. 108 of 1997. Government Gazette, Volume 390, No 18522. Pretoria: Government Gazette.

Weaver, J.M.C. and Fraser, L. 1998. *Langebaan Road Aquifer Drilling and Testing of New Wellfield*. CSIR Report No ENV/S-C 98042. Division of Water, Environment and Forestry Technology, CSIR, Stellenbosch, South Africa. pp1-98.

Wijnen, M., Augeard, B., Hiller, B., Ward, C., Huntjens, P. 2016. *Thematic Paper No. 11: Managing the invisible: understanding and improving groundwater governance*. Groundwater Thematic Papers, Groundwater Governance: A Global Framework for Country Action project. Available at: http://www.groundwatergovernance.org or http://www.fao.org/3/a-i6040e.pdf. [Accessed 6 April 2018]. pp. 575-704.

Winkler. 1997. *Winkler Aquifer Management* Plan. Winkler, Manitoba, Canada. pp. 1-24. https://www.gov.mb.ca/waterstewardship/reports/acquifer/winkler_aquifer_mp.pdf [Assessed 3 February 2012].

Zhang, J. 2006. *Groundwater Management Plan for Delmas Municipal* Council. GCS, Report no: 2005.08.399 - Draft. GCS (Pty) Ltd, Woodmead, South Africa. pp1-122.

OPSOMMING

Die volhoubaarheid van grondwater as 'n huishoudelike bron van water word soms bevraagteken vanweë die gereelde mislukking van watervoorsiening vanaf grondwater na gemeenskappe. Die volhoubaarheid van die toevoer van grondwaterbronne kan nie net gekoppel word aan die hoeveelheid grondwater wat uit die akwifeer onttrek word nie, maar is direk gekoppel aan die bestuur van die eksterne omgewing rondom die akwifeer of welveld. Die doel van hierdie studie is die basiese begrip en die kompleksiteit van grondwaterbestuur, die verskillende aspekte van grondwaterbestuur wat in 'n bestuursplan geïdentifiseer en aangespreek kan word, en wat binne 'n spesifieke tydsbestek geïmplementeer kan word. Die konsep 'bestuur' en 'n 'plan', insluitend die verskil tussen bestuur en beheer en hoe die verskil op 'n plaaslike skaal bestuur word, bied 'n duidelike begrip vir watter grondwaterbestuur die plaaslike owerheid verantwoordelik is. Die konsep van grondwaterbestuur is in twaalf beginsels verdeel en word breedvoerig beskryf om die idee van elke beginsel vir die bestuur van die bestuursdoelwitte tydens die plan te verduidelik. Die eksterne drywers en wetlike raamwerk wat grondwaterbestuur beïnvloed, word ook ondersoek. Die kenmerke van grondwaterbestuursplanne (GwBP'e) is ontleed aan die hand van 32 GwBP'e van wêreldorganisasies, internasionaal (buite RSA), wat oorgrensende akwifere en owerhede in Suid-Afrika ingesluit het. Die vyf wêreldorganisasies GwBP'e is spesifiek ontleed vir die ontwikkelingsbenadering: voorbereidings-, ontwikkelings- en implementeringsfases. Die twintig internasionale en plaaslike plaaslike GwBP's bied die geleentheid om die wetlike / regulatoriese agtergrond, die doel, die geldigheidstydperk, die elemente, struktuur en formaat van elke GwBP te beoordeel. Die bestuursdoelwitte van al die GwBP's is volgens die twaalf grondwaterbeginsels voorgelê en geklassifiseer. Die resultaat van die gedetailleerde assessering was 'n generiese driefase-benadering om 'n GwBP op te stel, te ontwikkel en te implementeer. 'n Inhoudsopgawe met elemente of hoofstukke wat gebruik kan word om die GwBP te ontwikkel om te verseker dat alle aspekte aangespreek en implementering uitvoerbaar is. 'n Finale lys van 150+ bestuursdoelwitte is om die mees moontlike aksies vir die bestuur van die grondwater by 'n plaaslike owerheid aan te spreek. Die uitdagings met die implementering van 'n GwBP kan meestal aangespreek word deur leierskap en institusionele reëlings. 'n Samevattende templaat is ontwikkel om die operasionele inligting uit die GwBP vir daaglikse gebruik te onttrek. Uiteindelik is hierdie studie afgesluit met die toepaslikheid van die opsommende templaat by drie verskillende akwifeer tipes.

APPENDIX A: COMPLETE TABLES OF CHAPTER 3

This Section contains the **COMPLETE** Tables in Chapter 3:

Table 3.10: List of Management Objectives from twenty international GwMPs.

Table 3.14: List of Management Objectives from seven South African GwMPs that appear ONLY in the South African GwMPs.

Table 3.15: List of ALL the Management Objectives from South African GwMPs that appear ONLY in the South African GwMPs AND that appear BOTH in the international and South African GwMPs.

Table 3.10: List of Management Objectives from twenty international GwMPs

Management Principles from Chapter 2	Description of the Goals/Objectives
Protection	• Land and water management practice guidelines/ education programs (hazardous materials: waste, sites, spills; underground storage and transport of petroleum products [rail, road, pipeline]; on-site sewage treatment and disposal system use; pesticide and fertiliser use; well construction and decommissioning; sewer pipes; solid waste landfills; burial of human remains; sand and gravel mining; sewer effluent; golf course; etc.) • Land use agreements (subsidy – co-funding practices) • Recharge area protection (stormwater management practices, etc.) • Protection zones guideline per zone develop (well-head, recharge… • Vulnerability/susceptibility/sensitivity mapping/zones (depth to water, geologic materials, soil permeability and thickness, hydraulic conductivity [K_v], etc.) • Proper borehole construction, abandonment and destruction • Maintain groundwater level (seawater intrusion, land subsidence, restoration) • Remediation/rehabilitation/mitigation (programs [awareness, Emergency Response Plan/Unit (spill or fire), restoration, etc.], project [treatment by wetland, pump-and-treat, removal of invasive plants, buffer strips/zones, etc.]) • Risk assessment of potential impact (lack of stormwater infrastructure, roadway runoff, spillages, vegetation clearing [soil degradation], pesticide and fertiliser use, quantity of aquifer recharge [urbanisation], etc.)
Regulation	• Effective legislation/policy • Sustainable development (economic and social benefit) • Enforcement / legal action (non-compliance or unauthorised use) • Water use license and waste disposal • Water metering • Setting of limits (groundwater level decline [m below ground level]; nitrate use, etc.) • Transfer of water permits (allocations)??? • Report water use volumes/licences vs availability • Borehole (all) registration program • Abandoned borehole closure program • Environmental impact assessment • By-Laws, Guidelines and standards (Best-practice-guidelines, sanitation, design standards, underground fuel tanks,

	borehole construction, - abandonment, etc.)
Use	• Increase water reuse (agriculture, landscape irrigation, greywater) • Use non-domestic quality standard water for other uses (brackish – industrial, dual toilet system, etc.) • Use reduction by sectors (water-use efficiency, conservation) • Best Management Practice (BMP) • Registry of water use allocations/license/entitlements
Planning	• Future water requirement scenario's • Plan for and adapt to Climate Change • Water budget (recharge vs use) • Drought management plan – operations, local/short-term sources • Investigate alternative supply (feasibility studies - underdevelop groundwater, desalination, reuse, rainwater harvesting, artificial recharge) • Long-term hydrological condition scenarios • Coordination between surface and groundwater planning initiatives/projects • Future spacial development impacts
Monitoring	• Coordinate all monitoring activities + redesign (focus driven) • Collect, collate and interpretation = knowledge • Monitoring data (municipality, government, users [license conditions], NGO's/environmental groups) • Databases – store data • Inventory/database of monitoring points information (borehole name, -owner, -type, -depth, screened interval, etc.), pollution sources (land use, fuel tanks, irrigation, piggery, cemeteries, industries, etc.) • Reporting and publication of data • Monitor (groundwater levels, -quality, -use; land subsidence; hydrometeorological conditions, pollution sources, contaminants, surface water quality, groundwater depending ecosystems, etc.) • Monitoring programs (aquifer management, compliance, project/research) • Manage and analyse data • Monitoring network assess, design , setup and amended (density, spatial extent, location, purpose and level [aquifer and sub-aquifer/wellfield level]) • Seawater intrusion / saline water table • Early warning systems installation • Installation of meters (quantity, quality)

	• Organisations performing/ensuring the monitoring or is carried out
Conservation	• Artificial recharge (stormwater, ASR and groundwater banking) • Recharge enhancement (precipitation, low-risk agriculture, shelterbelts, contour cultivation and dyking) • Conjunctive use (use other sources additionally) • In-lieu recharge program (other water in-place of groundwater) • Low Impact Development (LID) in new construction • Economic value of groundwater establish
Operation	• Environmental aquifer monitoring rules • Annual groundwater pumping rule/allocations (runoff, water use, pumping, groundwater level and recharge) • Operational rules (conjunctive use of sources, optimise efficiency, aquifer response [stable water level, reduces in energy, maintaining/improving water quality]) • Regional operators
Infrastructure	• Maintenance (breakages, wear, leaks, pollution, etc.) • Layout of scheme • Recharge enhancement structure (built, maintain) • Guideline on construction of boreholes • Modernisation and upgrading technologies/ infrastructure - efficiency and integration
Assessment	• Mapping aquifers (recharge, discharge areas) • Manage and analyse data • Maintain & Update model • Long-term safe yield • Land use impacts • Groundwater use impacts (cumulative/interference, groundwater-dependent ecosystems, domestic/stock [Schedule1])
Institutional Arrangements	• Conjunctive resource management – other institutions • Collaboration with other authorities using the same aquifer • Collaboration with Government (District, DWS, Environment, Agriculture, etc.), NGO's, Research institutions, Others (Parks, Farmers Union, CMA, Forums, other expert organisations, etc.) • Financial management (cost recovery, maintenance, development, operations, rehabilitation, etc.) • Off-the-grid vs bulk water supply and wastewater interventions
Capacity and Skills	• Recruiting a hydrogeologist and a Gw technician • Training – operations, sampling, monitoring (quantity and quality), procuration of external services)

Awareness, Information, Communication and Stakeholder participation	• Stewardship plan – user, owner, manager • Research study – increase knowledge, efficiency, technology, long term impacts • Partnerships & Coordinate programs • Public awareness / Education programs (protection, use, rainwater harvesting, brush control (flood control), landscaping, link to existing education programs or develop new education programs for not addressed elements, • Educational leadership to citizens – printed publication, public speaking, guidelines, signposts, etc. • Guidelines (constructions of boreholes, placement/location of minimum impact, • Annual or bi-annual aquifer status report (monitoring data, recharge, allocations, management programs, etc.)
Other issues not covered in Chapter 2	•
Operational level	• Municipal Council buy-in/adopting GwMP • Review, implementation and report on a bi-annual basis

Table 3.14: List of Management Objectives from seven South African GwMPs that appear ONLY in the South African GwMPs

Management Principles from Chapter 2	Description of the Management Recommendations from South African GwMPs that appears ONLY in the South African GwMPs
Protection	• Land and water management practice guidelines (closure / decommissioning of waste sites; stormwater; mining: tailings, acid mine drainage; informal settlements)[8,5] • Protection zones (springs, develop/ delineation of zones and implement areas of protection [BPZONE], protection plan develop and updated)[5,4,2,1] • Proper borehole construction, abandonment and destruction (program to seal, plug unused bhs)[2] • Maintain groundwater level (volume vs Iron Reducing Bacteria[6,5,4], sinkhole formation[3,2]) • Remediation/rehabilitation/mitigation (project [sewer discharge in recharge zone][2]) • Risk assessment of potential impact (pit latrines [sanitation], Environmental Impact Assessment [EIA report], Hazard identification – Over abstraction [decline water levels, yields, ground instability], point and non-point source contamination, insufficient supply, treatment problems, reticulation infrastructure, prolonged drought, recharge from poor quality surface water)[8,5,2] • Mapping pollution sources[8], census[2]
Regulation	• Water use license (Resource Directed Measures determination, Compliance to license conditions)[5,4,2,1] • By-Laws (registration of boreholes and water use, reducing the use of fertilisers, effluent irrigation,)[8,2] • Link with Other Regulatory Plans[8] • Drought restriction regulation[6] • Registry of water use (census)[2] • Compliance Audits (municipality and government)[2]
Use	• Use reduction by sectors (Water demand management programs)[7] • Abstraction strategy[7]
Planning	• Future spacial development impacts –Land-use planning[5] • Investigate alternative supply (stormwater, surface water, back-up resources in case of emergency [drought, bh collapse/failure, toxic spill][7], agreement with other WSP[2], replacement of polluted wellfield[2], augmentation sources[2]) • Options analysis between sources[8]

	• Reconnaissance investigation[8], future interventions[2] • Exploration drilling and testing[8] • Wellfield design[8] • Climate Change interventions[7] • Additional infrastructure[2]
Monitoring	• Collect, collate and interpretation (database - capture, edit, audit, analyse)[2] • Monitoring data (private boreholes in the wellfield/aquifer)[8,2] • Inventory/database of monitoring points information (surface water)[2] • Monitor (current and closed waste sites [pollution sources], ecological indicators, pumping rate [flow meter], pumping hours, infrastructure [contamanation entering reticulation system/infrastructure], sinkholes, water quality includes [turbidity, E. coli, free chlorine], surface water discharges, visual inspection of potential risks)[8,5,4,3,2] • Monitoring Programs (Protocol/plan development intervals/frequency, baseline/ background)[8,7,6,5,2,1] • Manage and analyse data (involve specialists- air, water quality, data capture, data analysing tool/software)[2] • Monitoring network (include regional aquifer)[4] • Early warning systems installation (subsidence)[2] • Installation of meters/monitoring equipment (level loggers, quality, flow meters, hour meters [pump time], rainfall, dip tubes, water sampling taps)[6,5,4] • Monitoring, Equipment (manual dip meter and level logger, water quality sampling)[6,5] • Water quality sampling, analyses (field measurements, sites specific analysing constituents, accredited laboratories, audit, duplicate samples)[6,5,2] • Standard of monitoring – according to Guidelines, SABS, procedures[2]
Conservation	• Conservation program – alien vegetation clearing
Operation	• Annual groundwater pumping rule (summer/winter pumping rates or wet/dry periods - assessment)[2] • Operational rules (Manual – operator, technical specifications [borehole and wellfield], amendments after assessment [quantity and quality])[8,5,4,2] • Emergency procedures develop – sinkhole and subsidence, insufficient water supply, water contamination, reticulation system and infrastructure breakdown[2] • Wellfield guide – managers[8]

	• Monitoring field forms/sheets and records[2] • Reporting[5]
Infrastructure	• Modernisation and upgrading technologies/ infrastructure (plastic fittings, anti-theft mechanisms)[2] • Asset register (develop and update including photos)[8,5,2] • Maintenance program (including monitoring equipment, reticulation system)[8,2] • Borehole rehabilitation (performance optimisation)[8] • Infrastructure Plan (monitoring, maintenance, operation, planning, development)[7,3]
Assessment	• Climate factors (wind, temperature, humidity, evapotranspiration, rainfall), climate models)[7,2] • Assessment of aquifers[7, 5,4], Regional assessment[4] • Regional aquifer model[2] • Long term monitoring[2]
Institutional Arrangements	• Conjunctive resource management (Aquifer Management Committee)[4] • Financial management (monitoring resources, tools and equipment)[5] • Administration and Organisational structure[8,7,5,4,2] • Pricing plan and cost analysis (development, infrastructure, treatment, environment, etc.)[7] • Water Services Authority vs Water Services Provider institutional structure, roles and reponsibility[5,4] • Staff Responsibilities[2]
Capacity and Skills	• Training (capturing and recording of data, maintenance, basic geohydrological and water quality knowledge, audits)[6,5,2] • Skills and qualification requirement[5] • Skills and Capacity plan[7] • Knowledge transfer/succession planning[7] • Appoint qualified hydrogeologist[2]
Awareness, Information, Communication and Stakeholder participation	• Public awareness / Education programs (identify conditions - lead to the formation of sinkholes)[2] • Stakeholder engagement (authorities/regulators, users, etc.)[8,1] • Monitoring oversight committees[8] • Stakeholder participation in regulatory processes (licensing, EIA)[7,8], assessment, planning and management[4]

	• Citizen science[7] • Stakeholder contact list[2]
Other issues not covered in Chapter 2	•
Operational level	• Review, implementation and report on a bi-annual basis – a continual improvement on GwMP with updated and new information • Development of plan in close co-operation with municipality[3] • Treatment and Distribution of water – treatment of water at Water Treatment Works (WTW), training of staff at WTW and reticulation system, reticulation infrastructure monitoring and maintenance, seal old piping, sufficient spares, monitoring of water quality at end user[2]

1) Naicker et al, 2019; 2) Zhang, 2006; 3) Bertram, 2008 4) De Kock and Welman, 2010; 5) Rudolph and Hough, 2012; 6) Myburgh and Prinsloo, 2018; 7) Vermaak,2018; and 8) Riemann et al., 2010

Table 3.15 List of ALL the Management Principals and examples of Management Recommendations from South African GwMPs that appear in the international and South African GwMPs.

Management Principles from Chapter 2	Description of the Management Recommendations from South African GwMPs that <u>match</u> the Goals/Objectives from international GwMPs	Description of the Management Recommendations from South African GwMPs that <u>only</u> reside in the South African GwMPs
Protection	• Land and water management practice guidelines/ education programs (hazardous materials: waste, sites, spills; underground storage and transport of petroleum products [rail, road, pipeline]; on-site sewage treatment and disposal system use; pesticide and fertiliser use; well construction and decommissioning; sewer pipes; solid waste landfills; burial of human remains; sand and gravel mining; sewer effluent; golf course; etc.)[8,7,5,2] • Recharge area protection (stormwater management practices, etc.)[7,8] • Protection zones guideline per zone develop (well-head, recharge…[7,5] • Vulnerability/susceptibility/sensitivity mapping/zones (depth to water, geologic materials, soil permeability and thickness, hydraulic conductivity [K_v], etc.)[2] • Maintain groundwater level (seawater intrusion, land subsidence[3,2], restoration[2]) • Remediation/rehabilitation/mitigation (programs [awareness, Emergency Response Plan/Unit (spill or fire), restoration, etc.], project [treatment by wetland, pump-and-treat, removal of invasive plants, buffer strips/zones, etc.])[5,4,2,1] • Risk assessment of potential impact (lack of stormwater infrastructure, roadway runoff, spillages, vegetation clearing [soil degradation], pesticide and	• Land and water management practice guidelines (closure / decommissioning of waste sites; stormwater; mining: tailings, acid mine drainage; informal settlements)[8,5] • Protection zones (springs, develop/ delineation of zones and implement areas of protection [BPZONE], protection plan develop and updated)[5,4,2,1] • Proper borehole construction, abandonment and destruction (program to seal, plug unused bhs)[2] • Maintain groundwater level (volume vs Iron Reducing Bacteria[6,5,4], sinkhole formation[3,2]) • Remediation/rehabilitation/mitigation (project [sewer discharge in recharge zone][2]) • Risk assessment of potential impact (pit latrines [sanitation], Environmental Impact Assessment [EIA report], Hazard identification – Over abstraction [decline water levels, yields, ground instability], point and non-point source contamination, insufficient supply, treatment problems, reticulation infrastructure, prolonged drought, recharge from poor quality surface water)[8,5,2] • Mapping pollution sources[8], census[2]

	fertiliser use, quantity of aquifer recharge [urbanisation], etc.)[8,7,2]	
Regulation	• Water use license and waste disposal[8,5] • Borehole (all) registration program[2] • By-Laws, Guidelines and standards (Best-practice-guidelines, sanitation, design standards, underground fuel tanks, borehole construction, - abandonment, etc.)[5,2]	• Water use license (Resource Directed Measures determination, Compliance to license conditions)[5,4,2,1] • By-Laws (registration of boreholes and water use, reducing the use of fertilisers, effluent irrigation,)[8,2] • Link with Other Regulatory Plans[8] • Drought restriction regulation[6] • Registry of water use (census)[2] • Compliance Audits (municipality and government)[2]
Use	• Registry of water use allocations/license/entitlements[2]	• Use reduction by sectors (Water demand management programs)[7] • Abstraction strategy[7]
Planning	• Plan for and adapt to Climate Change[7] • Water budget (recharge vs use)[6,5,4,1] • Investigate alternative supply (feasibility studies - underdevelop groundwater, desalination, reuse, rainwater harvesting, artificial recharge)[7, 5,4,2,1] • Long-term hydrological condition scenarios[7,2]	• Future spacial development impacts –Land-use planning[5] • Investigate alternative supply (stormwater, surface water, back-up resources in case of emergency [drought, bh collapse/failure, toxic spill][7], agreement with other WSP[2], replacement of polluted wellfield[2], augmentation sources[2]) • Options analysis between sources[8] • Reconnaissance investigation[8], future interventions[2] • Exploration drilling and testing[8] • Wellfield design[8] • Climate Change interventions[7] • Additional infrastructure[2]
Monitoring	• Collect, collate and interpretation = knowledge[4,2] • Monitoring data (municipality, government, users [license conditions], NGO's/environmental groups)[2] • Databases – store data[2] • Inventory/database of monitoring points information (borehole name, -owner, -type, -depth, screened interval, etc.)[2], pollution sources (land use, fuel tanks, irrigation, piggery, cemeteries, industries, etc.)[5,2]	• Collect, collate and interpretation (database - capture, edit, audit, analyse)[2] • Monitoring data (private boreholes in the wellfield/aquifer)[8,2] • Inventory/database of monitoring points information (surface water)[2] • Monitor (current and closed waste sites [pollution sources], ecological indicators, pumping rate [flow meter], pumping hours, infrastructure [contamanation entering reticulation

	• Reporting and publication of data[5,2] • Monitor (groundwater levels, -quality, -use; land subsidence; hydrometeorological conditions, pollution sources, contaminants, surface water quality, groundwater depending ecosystems, etc.)[8, 5,4,3,2] • Monitoring programs (aquifer management, compliance, project/research)[7, 6] • Manage and analyse data[5,4,2] • Monitoring network assess, design, setup and amended (density, spatial extent, location, purpose and level [aquifer and sub-aquifer/wellfield level])[5,3] • Early warning systems installation[2] • Installation of meters (quantity, quality)[6,5] • Organisations performing/ensuring the monitoring is carried out[8, 5]	system/infrastructure], sinkholes, water quality includes [turbidity, E. coli, free chlorine], surface water discharges, visual inspection of potential risks)[8,5,4,3,2] • Monitoring Programs (Protocol/plan development intervals/frequency, baseline/ background)[8,7,6,5,2,1] • Manage and analyse data (involve specialists- air, water quality, data capture, data analysing tool/software)[2] • Monitoring network (include regional aquifer)[4] • Early warning systems installation (subsidence)[2] • Installation of meters/monitoring equipment (level loggers, quality, flow meters, hour meters [pump time], rainfall, dip tubes, water sampling taps)[6,5,4] • Monitoring, Equipment (manual dip meter and level logger, water quality sampling)[6,5] • Water quality sampling, analyses (field measurements, sites specific analysing constituents, accredited laboratories, audit, duplicate samples)[6,5,2] • Standard of monitoring – according to Guidelines, SABS, procedures[2]
Conservation	• Artificial recharge (stormwater, ASR and groundwater banking)[7,2] • Conjunctive use (use other sources additionally)[4] • Economic value of groundwater establish[7]	• Conservation program – alien vegetation clearing
Operation	• Annual groundwater pumping rule/allocations (runoff, water use, pumping, groundwater level and recharge)[6,2] • Operational rules (conjunctive use of sources, optimise efficiency, aquifer response [stable water level, reduces in energy, maintaining/improving water quality])[5,4,2]	• Annual groundwater pumping rule (summer/winter pumping rates or wet/dry periods - assessment)[2] • Operational rules (Manual – operator, technical specifications [borehole and wellfield], amendments after assessment [quantity and quality])[8,5,4,2] • Emergency procedures develop – sinkhole and subsidence, insufficient water supply, water contamination, reticulation system and infrastructure breakdown[2] • Wellfield guide – managers[8] • Monitoring field forms/sheets and records[2]

		• Reporting[5]
Infrastructure	• Modernisation and upgrading technologies/ infrastructure - efficiency and integration[3,2]	• Modernisation and upgrading technologies/ infrastructure (plastic fittings, anti-theft mechanisms)[2] • Asset register (develop and update including photos)[8,5,2] • Maintenance program (including monitoring equipment, reticulation system)[8,2] • Borehole rehabilitation (performance optimisation)[8] • Infrastructure Plan (monitoring, maintenance, operation, planning, development)[7,3]
Assessment	• Maintain & Update model[4,2]	• Climate factors (wind, temperature, humidity, evapotranspiration, rainfall), climate models)[7,2] • Assessment of aquifers[7, 5,4], Regional assessment[4] • Regional aquifer model[2] • Long term monitoring[2]
Institutional Arrangements	• Conjunctive resource management – other institutions[4] • Collaboration with Government (District, Dept of Water, - Environment, - Agriculture, etc.), NGO's, Research institutions, Others (Parks, Farmers Union, CMA, Forums, other expert organisations, etc.)[4,3,2] • Financial management (cost recovery, maintenance, development, operations, rehabilitation, etc.)[5]	• Conjunctive resource management (Aquifer Management Committee)[4] • Financial management (monitoring resources, tools and equipment)[5] • Administration and Organisational structure[8,7,5,4,2] • Pricing plan and costing analysis (development, infrastructure, treatment, environment, etc.)[7] • Water Services Authority vs Water Services Provider institutional structure, roles and reponsibility[5,4] • Staff Responsibilities[2]
Capacity and Skills	• Training (operations, sampling, monitoring [quantity and quality], procurement of external services)[7, 6, 5]	• Training (capturing and recording of data, maintenance, basic geohydrological and water quality knowledge, audits)[6,5,2] • Skills and qualification requirement[5] • Skills and Capacity plan[7] • Knowledge transfer/succession planning[7] • Appoint qualified hydrogeologist[2]
Awareness, Information,	• Public awareness / Education programs (protection, use, rainwater harvesting, brush control [flood	• Public awareness / Education programs (identify conditions - lead to the formation of sinkholes)[2]

Communication and Stakeholder participation	control], landscaping, link to existing education programs or develop new education programs for not addressed elements)[7,2] • Educational leadership to citizens – printed publication, public speaking, guidelines, signposts, etc.[7]	• Stakeholder engagement (authorities/regulators, users, etc.)[8,1] • Monitoring oversight committees[8] • Stakeholder participation in regulatory processes (licensing, EIA)[7,8], assessment, planning and management[4] • Citizen science[7] • Stakeholder contact list[2]
Other issues not covered in Chapter 2	•	•
Operational level	• Review, implementation and report on a bi-annual basis[2]	• Review, implementation and report on a bi-annual basis – a continual improvement on GwMP with updated and new information • Development of plan in close co-operation with municipality[3] • Treatment and Distribution of water – treatment of water at Water Treatment Works (WTW), training of staff at WTW and reticulation system, reticulation infrastructure monitoring and maintenance, seal old piping, sufficient spares, monitoring of water quality at end user[2]

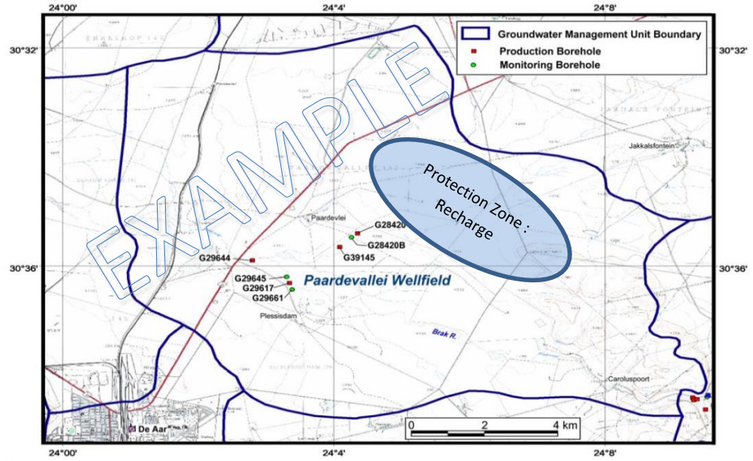
1) Naicker et al., 2019; 2) Zhang, 2006; 3) Bertram, 2008 4) De Kock and Welman, 2010; 5) Rudolph and Hough, 2012; 6) Myburgh and Prinsloo, 2018; 7) Vermaak,2018; and 8) Riemann et al., 2010

APPENDIX B: GENERIC FORMAT OF A GWMP SUMMARY (A3 SIZE)

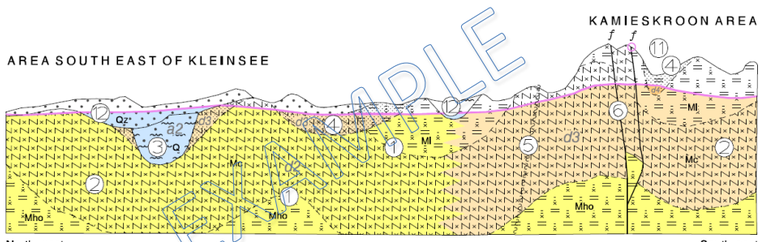
SA Groundwater	**Groundwater Management Plan Name of Municipality 2019 – 2024**	**Municipality LOGO**

Organisational management of the aquifer;
Institutional coordination;

Planning area;



Groundwater resources:



Water use:
Water requirements:
Protection:
Groundwater dependent ecosystems:

Regulatory/licence/allocations Conditions:

HIGH PRIORITY Groundwater Management Objectives (detail list of Objectives in GwMP)

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time Frame
Protection			
Regulation			

Management Objectives	Performance Standards / Milestones	Responsible person / Organisation	Time Frame
Use			
Planning			
Monitoring			
Conservation			
Operation			
Infrastructure			
Assessment			
Institutional Arrangements			
Capacity and Skills			
Awareness, Information, Communication and Stakeholder participation			

Operational Production Boreholes and Management Specifications

Wellfield / Groundwater Unit	Borehole		Pump			Maximum Monthly Abstraction (m^3)	Maximum Permissible Drawdown below collar (m)
	name/ number	Depth (m)	Intake (m)	Capacity (l/s)	Duty cycle		

Funding for objectives:

Operational Tasks (more detail in the Operational and Maintenance Plan

Task	Who	Detail description of what the task entails	Existing Impediment	Who should remove impediment
DAILY				
WEEKLY				
2-WEEKLY				
MONTHLY				
QUARTERLY				
ANNUALLY				

List of tasks/actions (Time frame)	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1-2	Y2 Q3-4	Y3	Y4
Immediate action (1 month)								
Short term (3 - 6 months)								
Medium-term (1-2 Years)								
Long term (3-5years)								

Reporting:

Audit:

Signed-off:
Municipal Manager : _____ Date: _____
Director: Engineering Services : _____ Date: _____
Manager: WSA/WSP : _____ Date: _____

EXAMPLE