Training Manual for Groundwater Resource Management and Groundwater Governance for Municipalities in South Africa

Report to the
Water Research Commission

by

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Module 1: Hydrological Cycle

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1. Learning objectives

To understand and describe the following:

- Processes and components of the hydrological cycle and their purpose;
- Linkages between the hydrological cycle processes;
- Water balance equation; and
- Factors influencing the processes of the hydrological cycle and their interdependence.

1.1 Introduction

It is important to recognize and comprehend the basic concepts of water. The basic concepts can influence the quality and chemical characteristics of water, the amount available and prevent contamination. Water occurs in three phases: solid, liquid, and gas. It forms a distinguished feature of the Earth.

Depending on the environment in which water occurs, water can rapidly change its phase this plays an important role in the climate system. The concept of the hydrological cycle underlines the fact that water is both renewable and limited. With the absence of water there would be no global ecological system otherwise known as the biosphere and Earth would be a lifeless planet (Paisley, 2013).

1.2 Hydrological cycle

The term hydrologic cycle, also known as the water cycle, forms a conceptual model and a fundamental concept in hydrology and refers to the continuous movement and storage of water between the biosphere, atmosphere, lithosphere and hydrosphere (Heath, 1983).

The concept of the hydrologic cycle is critical in understanding the occurrence of water and the development and management of water supplies.

The cycle has no beginning or end and water is typically present in all three phases. This cycle forms one of the greatest natural processes and is vital for sustaining life on earth by providing water to plants, animals and humans. A graphic illustration of the hydrological cycle is given in Figure 1.1.

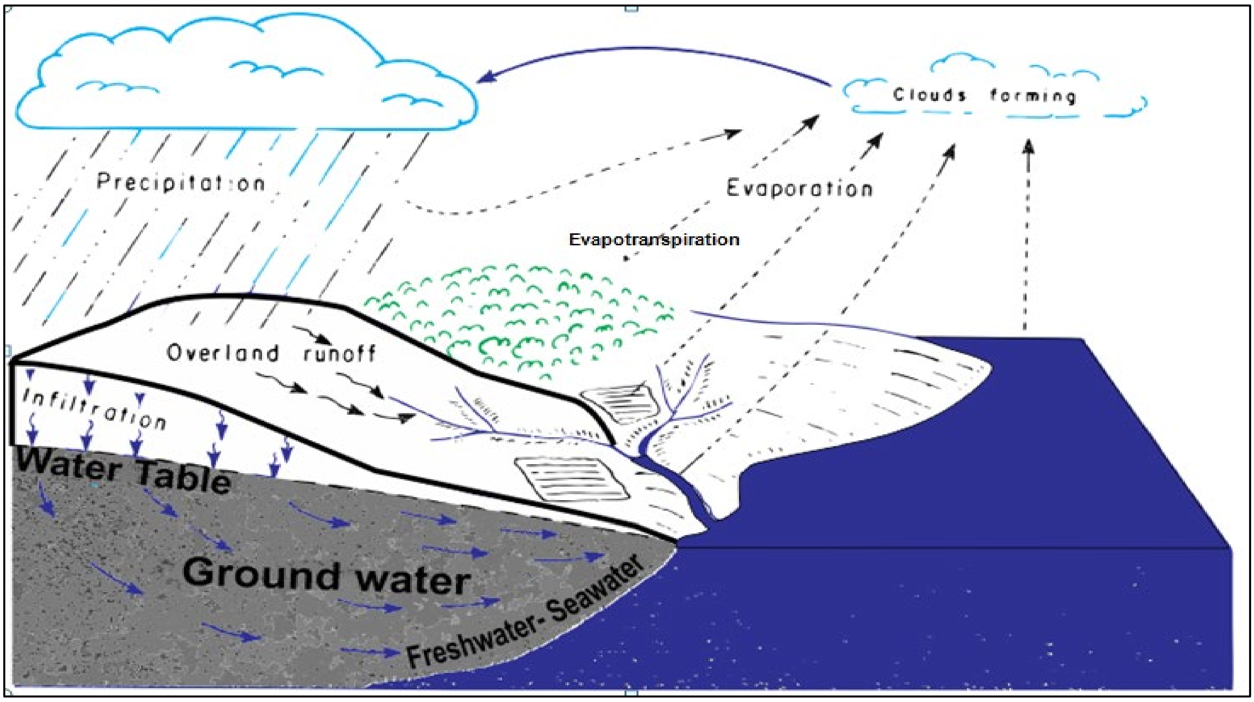

Figure 1.1: The Hydrological Cycle adapted from (Heath, 1983).

1.3 The process of the hydrological cycle

Water in the hydrological cycle is continuously exchanged and moved between the atmosphere and earth as illustrated in Figure 1.1. The driving forces associated with the hydrological cycle include the radiation from the sun. The result of heating of the ocean water by the sun is the key process that keeps the hydrologic cycle in motion. After and in the duration of a precipitation event, water will be typically divided into different portions and stages in the hydrological cycle. A portion of the water normally evaporates and returns directly to the atmosphere, a part of the remaining water will form runoff by water flow over the earth's surface and a percentage infiltrates into the soil (Johnstone *et al.*, 2010).

Once the water percolates into the soil, it may either be taken up by plant roots and some water may return to the atmosphere by transpiration. A certain amount of water also becomes part of our drinking water supply, or seep into lakes, streams, or oceans. Water and moisture in the atmosphere accumulates, and ultimately forms clouds, which return the land surface or oceans in the form of precipitation. Overland flow otherwise known as runoff occurs if the rate of precipitation exceeds the rate of infiltration. The first part of infiltration replaces soil moisture, and thereafter, the excess percolates slowly across the intermediate zone to the zone of saturation (Heath, 1983).

Water in this zone moves downward and laterally and results in ground-water discharge such as springs or seeps in the bottom of streams and lakes or beneath the ocean. The cycle of water by means of precipitation and evaporation or evapotranspiration is called the hydrologic cycle (Jensen, 1999).

1.4 Components of the hydrological cycle

1.4.1 Evaporation

Evaporation is defined as a slow transition of a liquid substance into the gaseous state. As water is heated by the sun, it creates energy that causes surface molecules to become energized and break free from the force binding them together. This normally leads to the transition between liquid substance and gas, where the water evaporates and rise into the atmosphere (Environment and Climate Change Canada, 2013). The majority of evaporation occurs from the oceans, and wind increases the rate of evaporation.

1.4.2 Transpiration

This is the process where plants released water vapour from their leaves and stems by a process called transpiration. Plants only use about 1% of water for growing purposes while the rest is released back to the atmosphere (Csaba & Juhász, 2011).

1.4.3 Condensation

Condensation is the terminology for the transition from water vapour (gaseous form of water) into liquid water. This process occurs in the atmosphere when warm air rises with its water vapour content, cools and loses its capacity to hold water vapour. Water vapour ultimately condenses. When it condenses it becomes a liquid again or turns directly into a solid (ice, hail or snow). The condensing water droplets form the clouds (Environment and Climate Change Canada, 2013).

1.4.4 Precipitation

Precipitation refers to the various forms of atmospheric water falling onto, or condensing on, the Earth's surface for instance rain, snow and hail. In principle, precipitation is caused by condensation of water vapour once the air is cooled to its dew-point. The cooling is generally caused by adiabatic expansion of the uplifted air, due to the decrease in atmospheric pressure with height. Precipitation is a major element of the hydrologic cycle, and is responsible for the fresh water on the planet (International Atomic Energy Agency, 2000).

1.4.5 Runoff

Runoff also known as overland flow or surface runoff is the flow of water that occurs when excess water flows over the Earth's surface. This process occurs because the underlying soil is saturated and reached it full capacity, or because rain precipitates more quickly than soil can absorb it, or because of manmade areas such as roofs, streets and pavements. Runoff is also seen as visible flow of water in rivers, creeks and lakes as the water stored in the basin drains out.

1.4.6 Percolation

Some of the precipitation and snow percolates and infiltrates through cracks, joints and pores in soil and rocks until it reaches the water table where it becomes groundwater.

1.4.7 Groundwater

Groundwater is water that exists in the pore spaces and fractures in rock and sediment beneath the earth’s surface. It is naturally replenished by surface water from precipitation or snow and then moves through the soil into the groundwater system where it recharges the water table. Depending on the geology, the groundwater can support the flow of streams.

1.4.8 Water table

The water table is the upper surface of the saturated zone of an unconfined aquifer at which pore pressure is equal to that of the atmosphere. This is the interface between the unsaturated zone and groundwater and may rise and fall seasonally.

1.5 Factors influencing the processes of the cycle

1.5.1 Runoff

The absence of vegetation or the disturbance on the land surface by factors and activities such as construction, agriculture, logging, or mining often reduce infiltration rates and increase runoff. The result of excessive runoff can typically create erosion and carry sediments or other pollutants into lakes, streams, and wetlands (Johnstone *et al.*, 2010).

1.5.2 Evapotranspiration

The rate of evapotranspiration at any location on the Earth's surface is controlled by several factors (Csaba & Juhász, 2011):

- Energy availability: The more energy available, the greater the rate of evapotranspiration.
- The humidity gradient
- The wind speed
- Water availability: Evapotranspiration cannot occur if water is not available.
- Physical attributes of the vegetation.
- Soil characteristics

1.5.3 Infiltration

Factors that influence and affect infiltration include (U.S. Geological Survey, 2016);

- Precipitation
- Base flow
- Soil characteristics:
- Soil saturation
- Land cover
- Slope of the land
- Evapotranspiration

1.6 Water Balance

A combination of field experiments and water balance modelling can provide us with a better understanding of the components of the hydrological cycle from which to develop appropriate management options.

The term water balance is based on the law of conservation of mass. This law according to Zhang, Walker and Dawes (2002), states that any change in the water content of a specified soil volume during a identified period must be equal to the difference between the amount of water added to the soil volume and the amount of water withdrawn from it.

A water balance can thus be established for any given area of the earth's surface by calculating the total precipitation input and the total of various outputs. The purpose and aim of the water balance is to describe the various ways in which the water supply is expended. The water balance is a method by which we can account for the hydrologic cycle of a specific area, with emphasis on plants and soil moisture.

The water balance is defined by the typical hydrologic equation and can be assessed for any area and for any period of time.

Inflow = Outflow + Change in Storage

The water balance is basically a statement of the law of conservation of mass as applied to the hydrologic cycle.

1.7 Summary

The hydrological cycle is usually described as a recurring effect with a variety of forms of movement of water and changes of its physical state on a given area of the Earth. The main processes of the hydrological cycle consist of: precipitation, infiltration of water into soil, evapotranspiration, recharge of groundwater and ground flow, runoff and movement of water in river channel systems.

1.8 Exercises and tasks

1. Describe the Physical processes which make up the hydrological cycle.
2. Illustrate the water cycle with all of its components.
3. Name and explain two factors that influence the hydrological cycle.
4. Define the water balance and explain the water balance equation.

1.9 Report from student for evaluation and assessment

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Module 2: Water Law

Contents

2. Learning objectives

To understand and describe the following:

- To appreciate the need for legislation of Water
- To understand the key components of water legislation and the Water Act
- Applicable laws and by-laws.

2.1 Introduction

Water Legislation aims to regulate the relationship between persons and between the people and the state administration on water resources. It includes all legal provisions on development, use, protection and management of groundwater resources, which may be either scattered in various enactments or integrated into a comprehensive water law. South Africa is significant in terms of its water law and policy and is the most advanced.

The National Water Act and the Water Services Act should be used within each other side to side in regard to the water management regime in the Republic. The Water Services Act provides the tools and laws to ensure that all South Africans have access to a basic water supply and sanitation.

2.2 Why water legislation

Water legislation is required to regulate water development, limit activities that can compromise water availability, sustainability and quality, concentrate on the increasing competition and associated conflict between water users, and address the threat to water pollution (Eduvie, no date).

According to University of California, 2014 Groundwater Legislation is responsible to:

- Adopts a state definition of “sustainable groundwater management”
- Empowers local agencies to achieve sustainability
- Establishes a uniform framework for local groundwater management planning
- Respects regional differences and provides local agencies flexibility to tailor plans that meet their needs
- Provides state technical assistance
- Improves coordination between land use and groundwater planning

- Provides for state review of groundwater plans and limited state intervention authority when local action has been insufficient
- Protects water rights

Numerous government municipalities have introduced legislation to regulate water and groundwater development and to limit activities that might compromise groundwater availability and quality (Nanni *et al.*, no date).

2.3 Basic Legal Concepts

It is of great magnitude to know and note the difference between the concepts of ‘legislation’ from that of ‘law’.

Legislation is defined as a written law, enacted by a body or person authorised to do so by the Constitution or other legislation. While the term law referred to the complete system of rules that everyone in a country or society must obey. According to the terms stipulated in section 2 of the Interpretation Act 33 of 1975, ‘law’ refers to “…any law, proclamation, ordinance, Act of parliament or other enactment having the force of the law.”

2.4 Components of legislation

Contemporary legislation of groundwater must, be flexible, enforceable and enabling. As a result must basic legislation be limited to fundamental powers and concepts, and the detail associated with regulations and implementation plans.

Some of the specific provisions and components of legislation are discussed below according to (Owen *et al.*, 2010).

2.4.1 Water Abstraction and Use Rights

Water rights along with other factors provide the foundation for abstraction and the right to abstract or divert water. The right to abstract or divert water including groundwater can be granted to individuals, public entities, or private corporations, under certain terms or conditions. Such rights are commonly issued by the water resources authority or by the law courts directly.

2.4.2 Wastewater Discharge Licensing

The licensing of wastewater discharges is designed to protect water against pollution. The ‘polluter-pays principle’ is normally embodied within this area of legislation.

Other components of legislation include:

- Catchment or Aquifer Level Resource Planning
- Conjunctive Use of Groundwater and Surface Water
- Land Surface Zoning for Groundwater Conservation and Protection
- Facilitating Water-User and Stakeholder Participation
- Provisions for Groundwater Monitoring

2.5 Institutional arrangements

Water legislation should ensure the enabling environment is established for effective management of water resources, including groundwater.

2.5.1 Water Boards

Government-owned Water Boards play a key role in South African water sector and resource management. They operate dams, bulk water supply infrastructure, some retail infrastructure and some wastewater systems.

The water boards typically report to the Department of Water Affairs. There are 15 different Water Boards in South Africa.

Any municipality responsible for ensuring access to water service in the Act is defined as the Water Service Authority. This authority may perform the functions of a Water Service Provider, and may also form a joint venture with another water services institution to provide water services.

2.6 Implementation of (ground) water legislation

Successful implementation of (ground)water legislation depends on a number of factors according to Owen *et al.* (2010) and include:

- The administrative set-up and the level of training of water administrators
- A clear understanding of the institutional roles and functions at all relevant levels

- An adequate level of public awareness and acceptance of legal provisions
- Political willingness to promote and attain sustainable groundwater management.

2.7 The National Water Act

2.7.1 Purpose of the Act

According to the National Water Act 36 of 1998, the purpose of the Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account, and include the following factors:

a) meeting the basic human needs of' present and future generations;
b) promoting equitable access to water;
c) redressing the results of past racial and gender discrimination;
d) promoting the efficient, sustainable and beneficial use of water in the public interest;
e) facilitating social and economic development;
f) providing for growing demand for water use;
g) protecting aquatic and associated ecosystems and their biological diversity;
h) reducing and preventing pollution and degradation of water resources;
i) meeting international obligations;
j) promoting darn safely;
k) managing floods and droughts.

The Act provides that national government is the public trustee of the nation's water resources and requires it 'to 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'.

The Ministry of Water Affairs and Forestry is responsible to 'ensure that water is allocated equitably and used beneficially in the public interest, while promoting environmental values'. Catchment management agencies and the water resource classification system act as practises that help to meet the above mentioned objectives.

2.7.2 Water Use

Pending a final determination of the Reserve, the Act provides for a preliminary determination, which is a necessary prerequisite for the authorisation of a water use. The term "Water Use" is widely defined by the Act to not only include the 'use' of water but also activities that could have an adverse impact on water resources.

Water uses identified in terms of section 21 of the National Water Act (Act 36 of 1998) as:

- 21a) taking water from a water resource;
- 21b) storing water;
- 21c) impeding or diverting the flow of water in a watercourse;
- 21d) engaging in a streamflow reduction activity contemplated in Section 36 of the Act;
- 21e) engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1);
- 21f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
- 21g) disposing of waste in a manner which may detrimentally impact on a water resource;
- 21h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;
- 21i) altering the bed, banks, course or characteristics of a watercourse;
- 21j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people;
- 21k) using water for recreational purposes.

The Act provides that a person wishing to use water must be licenced to do so, except in three situations -

1. Uses of water that are likely to have sufficiently insignificant impacts on water resources.
2. Applies if the water use is a continuation of an existing lawful use.
3. Water use permissible in terms of a general authorisation.

2.8 Summary

The National Water Act (No. 36 of 1998) is an Act to provide for fundamental reform of the law relating to water resources. The purpose of this Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled.

The National Government is responsible for the allocation and use of water resources to ensure the sustainable use through the protection of the quality of water resources for the benefit of all water users.

2.9 Exercises and tasks

1. Explain the need for water legislation
2. Define the term Law and Legislation
3. Describe the concept Water boards
4. Name and explain two components of Legislation
5. What is the Purpose for the Water Act and describe the term ‘water use’ in detail

2.10 Report from student for evaluation and assessment.

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Module 3: Groundwater Management

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3. Learning objectives

To understand and describe the following:

- Meaning of groundwater management, and
- Flow-diagram illustrating the groundwater management process at Municipalities for bulk groundwater supply,
- Understanding the functions of management.

3.1 Introduction

Water is our present, past and future and essential to life and may be the most reusable and recyclable commodity on earth (Azad, 1976). The Bill of Rights of The Constitution of South Africa Act (1996) section 27(1)(b), stated that; “Everyone has the right to have access to sufficient food and water...” and section 24(a) stated that; “Everyone has the right to an environment that is not harmful to their health or well-being...”. It’s therefore important to manage and monitor the state of water, in particular groundwater resources and environmental trends, so that it is possible to deal with problems related to sustainability, water scarcity and efficiency.

In South Africa, the term groundwater and groundwater management has been given inadequate attention and is not typically seen as an important and sustainable water resource for bulk supply that can be managed appropriately. Regardless of this, many municipalities is reliant on groundwater resources and manage it successfully.

A generally accepted principle is that “prevention is better that cure” and to manage groundwater resources effectively, it is essential to better understand the quality, quantity and impacts of groundwater use.

3.1.1 Importance of Groundwater for Management

Groundwater is a vital concept worldwide and many nations and various people and many industrial premises depend on it for their water supply. Accelerated development over the past few decades has resulted in great social and economic benefits, by providing low-cost, drought-reliable and (mainly) high-quality water supplies for both the urban and rural population and for irrigation of (potentially high value) crops.

In South Africa’s most water supplies in small towns originate from groundwater sources. These are geographically widespread and almost two-thirds of South Africa’s population depend on them for their domestic water needs, states the Department of

Water Affairs (DWA). Therefore awareness and understanding will assist with the proactive management of groundwater in South Africa (Knüppe, 2010).

3.2 GROUNDWATER MANAGEMENT

3.2.1 Defining Groundwater management

In order to evaluate and better comprehend groundwater management, general terms and concepts need to be discussed, to obtain a broader understanding and perspective of what groundwater management entails.

Daft and Marcic (2012) defined management as:

"The attainment of organizational goals in an effective and efficient manner through planning, organizing, leading, and controlling organizational resources."

Or as Mary Parker Follett (1868-1933) (Barrett, 2003) defined it as:

"Management is the art of getting things done through people"

Management can thus be described as a simple act to coordinate and gather people to achieve a set of objectives and goals.

3.2.2 Management vs governance

Groundwater resources management and groundwater governance are closely related but are two different processes. These two processes normally comes into effect when societies realise that actual conditions urge that human efforts related to groundwater should go beyond plain exploitation.

Governance and management are different processes but not different scales of action. Both processes can take place together at local, regional, national or global scales (Seward and YXU, 2015).

Groundwater management is formerly described as the assessment of hydrologic and environmental aspects in terms of groundwater, and the impacts associated with supply, quality, quantity, sustainability and demands among different consumers and the optimization of exploitation and use (Willis and Yeh, 1987). Groundwater management involves the ability to get and implement results within a short time.

In addition to groundwater management, Moench *et al*. (2012) defined groundwater governance as:

"The process through which groundwater related decisions are taken (whether on the basis of formal management decisions, action within markets, or through informal social relations) and power over groundwater is exercised."

Governance is usually carried out by an authority in power & takes into consideration the requirements of its subjects, though it may fail in many aspects.

Therefore we can agree with Jonker *et al*. (2010) that the process of making decisions is described as water governance, while the process of implementing them is described as water management.

3.2.3 Functions of Management

Management is normally divided and distinguish in four basic management functions and is regarded as the building blocks for management. These "building blocks" is categorized as planning, organising, leading and controlling Figure 1. We can't develop a framework for groundwater management without first discussing and understanding these building blocks. These functions or so called "building blocks" provide valuable steps in the process to achieve organizational goals, and are related and interrelated to each other.

Figure 1: The four basic management functions

3.2.3.1 Planning

Planning is the first foundation phase and the most important component of the four building blocks. It involves the process of selecting certain objectives and determines a sequence of steps and actions that need to be followed to achieve those objectives. Planning requires the process of being conscious about the challenges and encounters facing a business or organisation and to predict future economic and business encounters. Formulation of objectives and steps on how to reach deadlines can then be implemented. After the assessment of various alternatives as conditions change, decisions can be made on the best steps of help allocate resources. Good management consist of good planning and it is always an ongoing process.

3.2.3.2 Organising

Organising is the process of management and can be described as the steps to develop an organising structure and assigning available resources to ensure that all objectives will be accomplished successfully and efficiently. To be able to organise effectively all activities to be accomplished must be identified, classified, assigned to individuals and delegated. Without the organising step, organisations and businesses will have no structure and is likely to fail.

3.2.3.3 Leading

Leading can also be described as guiding or directing and is the process of motivate, influence, communicate and forming effective groups to achieve the business goals and objectives. The most important aspect of leading is good communication skills. This can be accomplished by assessing one another, good and effective problem solving skills and building positive relationships. This building block helps to move the organisation and company towards better goal achievement.

3.2.3.4 Controlling

The last building block of management involves ensuring and measuring achievements in contrast to the previous selected goals and objectives. It can thus be described as process to establish if plans are still being followed and implemented, and track the progress being made. Controlling also requires managers to act fast and be able to identify sources of deviation from successful achievement of goals, and to provide an alternative course of action.

3.2.4 Groundwater management

In evaluating management according to its definitions and functions, a better picture developed about the process of groundwater management.

Groundwater management is generally described as the assessment of hydrologic and environmental aspects in terms of groundwater, and the impacts associated with supply, quality, quantity, sustainability and demands among different consumers and the optimization of exploitation and use (Willis and Yeh, 1987).The management of groundwater resources for beneficial use means the intervention in matters concerning water that could include planning, design and operation of hydraulic works. It assumes that an authority exist that will be influential enough to impose decisions upon individuals or influence people’s behaviour.

Through adapting and understanding the four functions of management mentioned earlier as planning, organising, leading and controlling we can develop a functional flow-diagram for groundwater management. The flow diagram should include the following components:

- Data collection, capturing and monitoring
- Planning
- Data analysis
- Protect
- Awareness
- Legal Framework

3.2.4.1 Data collection, capturing and monitoring

It is impossible to develop an acceptable groundwater management strategy for a certain region without a good knowledge about the resource. Applying groundwater management without successfully collecting, capturing and monitoring groundwater related date would be impractical. A number of basic information is required to be able to manage groundwater effectively, and the more intensive groundwater abstraction become the more data are required for the management thereof.

Data collections must occur over long consistent periods to create a time series to identify variation and trends in data and correlate any change in the groundwater environment. Existing reports may be obtained and used for some data collection, but in most cases additional field work is required. Collection of data includes topographic and geologic data as well as an accurate hydrological survey. Hydrologic survey data includes the groundwater pump and rest levels, borehole locations, water abstraction rates, quantity and quality. A hydrocensus is an excellent example of groundwater data collection and is a task that consists of collecting information on water features, water supply sources and sources of potential. In addition to this, rainfall data are also very valuable.

In the process of monitoring data, an estimation of the amount of water we use and the quality thereof is established. Monitoring is done by testing groundwater quality, recording the amount of groundwater used (abstraction rates) and the levels of groundwater. Monitoring is an essential element of any effort to integrate groundwater science with water-management decisions and is an ongoing process (Holliday, Marin and Vaux, 2007).

3.2.4.2 Legal framework

Effective ways of creating groundwater management is to establish and implement municipal by laws. Municipal By-laws is a kind of law, better described as a form of delegated legislation created by local government and must be distinguished from common law. These by-laws must be approved and authorised by a Municipal Council to regulate the affairs and the services that a municipality provides within its area of jurisdiction. The Constitution of the Republic of South Africa (1996) section B of Schedule 4 and 5, gives specified authority and capabilities to local government, that enable a Municipality to create a by-law. A by-law is thus developed with a purpose and vision to control a situation in an attempt to govern all possibilities.

By-laws are described as a dynamic policy-implementation tool that addresses public interest, enforce standards of conduct and are just like any other laws in the country. Someone who does not act in accordance with the by-law can be charged with a criminal offence, receive a penalty or be challenged in court. Legislation like by-laws allows communities to be more involved in local government affairs, and encourage municipalities to engage more in communities.

3.2.4.2.1 Need for by-laws

By developing by-laws we can manage groundwater resources effectively and place emphasis on the protection of sustainability, conservation and the protection of the environment. By focusing on the need for by-laws one often overlooks other targeted focus points for by-laws in groundwater management such as:

- Polluted sites in regards to Groundwater
- Borehole Construction and Abandonment
- Groundwater Quality and Quantity
- Groundwater Monitoring and Maintenance
- Groundwater Allocation and Access

It is important to remember that by-laws serve no purpose if it is not implemented and enforced.

3.2.5 THE ROLE OF THE GROUNDWATER COORDINATOR

In order to realise the effective protection of groundwater resources, the groundwater coordinator within a management area will need to have a broad understanding of:

• Aquifer importance

• Aquifer vulnerability

• The role of groundwater in the broader environment

• Potentially polluting activities.

• Aquifer protection

A differentiated approach will be needed to make best use of available resources and ensure that least risk is posed to the most important aquifers. The groundwater coordinator will need to understand where groundwater resources are most vulnerable in the catchment, and liaise with land-use planners to ensure that contamination threats are minimised.

Risk assessment and impact assessment provide important tools for prioritising actions where human and financial resources are limited. The effectiveness of these measures in protecting groundwater resources must be measured by appropriate monitoring and assessment, which is used to refine protection programmes.

Effective communication with groundwater users, industry, farmers and other catchment managers will be the key to protecting aquifers. Punitive measures alone will not bring about the desired levels of protection. It will be necessary that a range of important stakeholders in the catchment have an appreciation of groundwater value and vulnerability.

3.3 SUMMARY

For sustainable Groundwater Management, the following actions are necessary:

- Ensure the implementation of existing strategies, regulations and guidelines on groundwater management such as the Artificial Recharge strategy and others.
- Establish a Groundwater Resource Governance Section, which will ensure support to water services institutions in the operation, maintenance and management of groundwater supply schemes. Functions must include the evaluation of artificial recharge potential and conjunctive use schemes.

A key finding has been that groundwater management links to groundwater-dependent sectors like agriculture, rural development, health and environment are not well established in policy or in practice. Internationally, there is a recognition that such a situation, although quite common, can only be addressed through a long-term process through which viable national, regional and local systems can evolve, within a strategic framework in which these intended relationships between diverse sets of interventions or management approaches and the development goals are brought out. Key issues are clarity on the roles and responsibilities of different institutions and the creation of effective co-ordination mechanisms between different agencies.

3.4 Exercises and tasks

1. What is your municipality already doing to manage their groundwater efficiently?
2. What does your Municipality see as the most important Groundwater management issues to take up next?
3. How do politics and socio-economic factors affect the process of managing groundwater in your municipality?
4. In your opinion, please explain the sustainable Groundwater development in terms of the four basic management functions.
5. What is the main difference between groundwater management and governance?
6. Does your municipality have any bylaws which are already implemented? If yes, then please name them, if not please indicate what bylaws you would want at your municipality for effective management.

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Module 4: Groundwater Regulation

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4. Learning objectives

To understand and describe the following:

- Groundwater licensing;
- Groundwater allocation;
- Groundwater protection; and
- Groundwater Institutions.

4.1 Introduction

Groundwater regulation form a fundamental role and is normally required in order to control and regulate groundwater development and activities that might compromise groundwater quality and availability, to address increasing competition and conflict between groundwater users, and to control the increasing threat of groundwater pollution.

Water regulation forms an important groundwater management strategy that is implemented through implementation and development of a licensing and water allocation system.

4.2 Groundwater licensing

4.2.1 Need for a groundwater licensing system

A licensing system for groundwater is aimed to introduce regulating interdependencies among water users and has wider benefits. The main objectives of a groundwater license system are established to (Dinar, Rosegrant and Meinzen-dick, 1997):

- Reduce the interference between abstraction wells,
- Avoid counterproductive conflicts that may arise,
- Resolve emerging disputes between neighbouring abstractors,
- Fostering the participation of water users in groundwater management,
- Improving economic efficiency,
- Implementing demand management programs to reduce groundwater abstraction,
- Systematic collection of abstraction charges to raise revenue for resource management,

- Possible subsequent trading of abstraction rights to promote more efficient water use,
- Developing conjunctive use of surface water and groundwater resources.

4.3 Groundwater allocation

4.3.1 Groundwater allocation defined

Groundwater allocation is the process of determining how water will be shared among the demand of different users and uses. The need for water allocation developed due to the fact of increasing scarcity of the water resource in terms of desirable quality and quantity that need to satisfy all the demands of the different users (Tandi, no date). Water allocation form thus a significant universal function of water management with the main objective to maximise the societal benefits derived from water. These benefits can be classified as economic, social and environmental, each with a corresponding principle such as efficiency, equity and suitability (DINAR *et al*., 1997) .Non-renewable resources such as groundwater need the implementation of a groundwater abstraction rights system. This must be consistent with variable factors such as fluctuating groundwater levels, decreasing well yields and the deterioration of groundwater quality (Owen *et al.*, 2010).

4.3.2 Criteria for allocation

A suitable measure of groundwater resource allocation is necessary to achieve optimal allocation of the resource. Economic, social and environmental factors form the basis for water resource allocations and objectives and should be well-defined to ensure that groundwater is available for human consumption, sanitation, and for food production (Dinar, Rosegrant and Meinzen-dick, 1997).

Howe, Schurmeier and Shaw (1986), described several criteria's used in water allocation (Owen *et al.*, 2010) (Dinar, Rosegrant and Meinzen-dick, 1997):

- Flexibility in the allocation of water, so that the resource can be reallocated from use to use, place to place, for more social benefits, economic and ecological uses through periodic review, and avoiding perpetuity in allocation;
- Security of tenure for established users, so that they will take necessary measures to use the resource efficiently; security does not conflict with flexibility

as long as there is a reserve of the resource available to meet unexpected demands;

- Predictability of the outcome of the allocation process, so that the best allocation can be materialized and uncertainty (especially for transaction costs) is minimized. Equity of the allocation process should be perceived by the prospective users, providing equal opportunity gains from utilizing the resource to every potential user.
- Political and public acceptability, so that the allocation serves values and objectives, and is therefore, accepted by various segments in society.
- Efficacy, so that the form of allocation changes existing undesirable situations such as depletion of groundwater, and water pollution, and moves towards achieving desired policy goals.
- Administrative feasibility and sustainability, to be able to implement the allocation mechanism, and to allow a continuing and growing effect of the policy.

4.3.3 Groundwater allocation

Groundwater needs to be allocated in a manner that will allow activities reliant on water to have access to a sufficient and reasonably reliable supply. Restrictions and limits on the amount of water allocated must be set for sustainability and protection of the resource. Therefore all water users should be identified, registered and monitored for an allocation system to work (Tandi, no date).

Water allocation has usually been provided to meet demand with significant involvement of governments. The allocation by governments, typically described as public allocation, has been used to manage groundwater effectively by laws, policies and registrations (Dinar, Rosegrant and Meinzen-dick, 1997).

According to White Paper on a national water policy for South Africa (1997), under the allocation licensing policy (Section 6.2.2), all existing and new water users will have to apply for registration of their water use within a certain period. The basis of registering and granting a licence to water users will be of beneficial interest to the public and assist in the process of managing the resource.

Applications for licensing procedures and registrations will be evaluated and assessed systematically according to priority areas (Department of Water Affairs and Forestry, 1997). Areas that will be considered first normally include water stress areas, environmental damage areas and competition between users. An assessment of groundwater resources must be conducted before any allocation. Allocations is typically specified in terms of the location of water use, the volume of water to be used, the time at which it is to be abstracted, its quality and reliability areas (Department of Water Affairs and Forestry, 1997).

The allocation system should "promote use which is optimal for the achievement of equitable and sustainable economic and social development" (Levy and Xu, 2011).

For better water allocation the management of monitoring water resources and uses is important. Implementation tools that assist in this process include planning instruments (monitor aquifer quantity/quality, water users and population), managerial guidelines (steps to monitor and evaluate applications), information systems (software to manage applications) and public education (political and public awareness).

4.4 Groundwater protection

Protection of our water resources is critical at this point. South Africa is currently facing a serious drought and the threat of water shortages in major centres. Water resources natural functionality should be preserve if we are to ease the effects of water scarcity. In 1998, the National Water Act was promulgated and places emphasis on the purpose to ensure the optimal and sustainable use and protection of limited water resources.

The National Water Act makes use of two different kinds of processes, for effective resource protection. Resource directed measures (RDM) are the first process that set a number of objectives that will determine the desired level of protection for each resource. The second process is source directed controls. The purpose of source directed controls is to control and manage the impacts in relation to water resources so that the resource protection objectives are achieved.

The National Resource Strategy 2 (2013), developed in South Africa, indicates strategic actions and objections for water resource protection (Corrigan, 2015): Manage for sustainability by using Resource Directed Measures (RDM) to set and approve a management class, and associated reserve and resource quality objectives, for every significant water resource in the country.

- Invest in strategic water resource areas by increasing their protection status.
- Maintain National Freshwater Ecosystem Priority Areas (NFEPAs) in good condition and include them in protected area network expansion plans, where appropriate.
- Invest in the strategic rehabilitation of key catchments to improve water quality and water quantity through Natural Resource Management Programmes (NRM).
- Minimise pollution from wastewater treatment works into surface and groundwater resources.

A balance between water resource protection and the use of a water resource is described as integrated water resource management (IWRM). The protection and management of water resources is important because the lack thereof can be inefficient and expensive.

4.5 Groundwater Institutions

Institutional arrangements on municipal levels are needed such as institutions to have an effective regulatory environment where rules and goals (objectives) can be correctly executed. There is a variety of institutions involved in groundwater management to manage development, regulate changes, conserve, restore and protect groundwater resources.

The National Water Act states that the National Water Resource Strategy must:

- Contain and set a number of objectives for the establishment of institutions to undertake water resource management; and
- Determine the inter-relationship between institutions involved in water resource management.

It is important to note that all water resources management institutions must function in accordance with the National Water Resource Strategy. Therefore it is stipulated that water resource management according to the National Water Act (NWA) is divide into three distinctive institutions (figure 1) specifically catchment management agencies (CMAs), water user associations (WUAs) or international water management bodies (IWMBs).

At the national level, the minister of water affairs is overall responsible for effective water management and the Department of Water Affairs (DWA) role is to provide a "national policy and regulatory framework" for regional and local institutions to conduct the management of water resources (Department of Water Affairs and Forestry, no date).

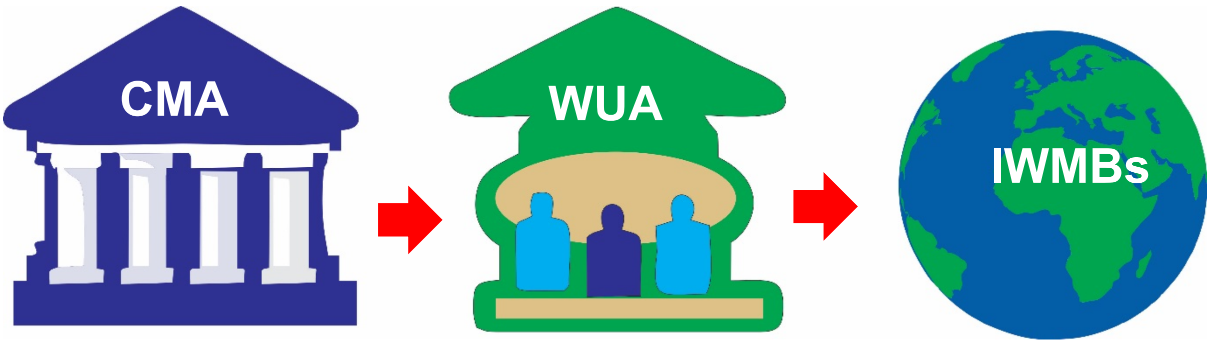

Figure 1: The three distinctive institutions

4.5.1 Catchment Management Agencies (CMAs)

A statutory body established in terms of the National Water Act is referred to as a catchment management agency (CMA). CMAs will be governed by a board, which is appointed by the minister and will begin operating as soon as the governing board has been appointed (DWAF, 2000). The governing board must reflect and represent the interests of all relevant sectors and stakeholders, as well as their interests in the water management area.

The establishment of the 19 water management areas in South Africa from the Catchment management agencies (CMAs) is stipulated by the National Water Act (36 of 1998).

4.5.1.1 Purpose of CMAs

The purpose of a CMA is to delegate water resource management to the regional or catchment level and primarily involve local communities in the process. CMAs form therefore the fundamental course of action for managing water resources at catchment management level (DWAF, 2000). CMAs are also required to seek co-operation between various stakeholders and interested persons on water related matters (Department of Water Affairs and Forestry, no date).

Other important purposes of CMA involved the management of water resources and the development and implementation of a catchment management strategy (CMS) within their water management area. CMA must contribute towards social and economic factors. Note that the National Water Resource Strategy and the catchment management strategy must be in harmony relative to each other (Department of Water Affairs and Forestry, no date).

4.5.1.2 Catchment Management Forums

Catchment forums involve stakeholders in the decision making process about water resources management and are being used significantly by the department of water affairs (DWAF, 2001).

The role of catchment management forums is to assist in facilitating stakeholder consultations. Catchment forums contribute to the representation and assistance of stakeholders in the establishment of CMA and the development of CMS. Catchment forums must promote the integrated planning and cooperative resource management between CMAs and support the water resource management operations of the CMA (DWAF, 2001).

4.5.2 Water User Associations (WUAs)

Water User Associations (WUAs) is a co-operative association of individual water users who wish to undertake water-related activities for their mutual benefit. This association is established by the minister under the National Water Act. Section 92 of the National Water Act, Act no. 36 of 1998 state that the minister may in some cases establish a water user association but it should be ensured that it meets the objectives of the people where national requirements may override local entitlements.

A water user association is an institution that serves its members and is govern by a management committee (Department of Water Affairs and Forestry, no date). It can also provide a method through which the catchment management strategy can be implemented at local level (Department of Water Affairs and Forestry, no date).

4.5.2.1 Purpose of WUAs

WUAs allow people to be more active within a community and to combine their resources and expertise to effectively manage and carry out water-related activities. Some core functions of water user associations include the following (Department of Water Affairs, 2010):

- Act as interface between consumers and management
- Ensure and regulate optimum usage of groundwater and distribution
- Prevent any unlawful act that can reduce the quality
- Prevent groundwater from being waste
- Prevent unlawful use
- Promoting sustainable use
- Protect area of operation
- Provide assistance in the data collection, capture and monitoring process
- Provide general management
- Resolve disagreements between members
- The protection of the environment and ecological balance

4.5.3 International Water Management Bodies (IWMBs)

The term international water management body is described as a corporate body with all the relevant powers and capacity of a regular person. IWMBs are generally established by the Minister during consultation with the cabinet, and will be published as a notice in the Government Gazette. The primary role and function for IWMB is to implement international agreements in terms of management and development of water resources shared with and between neighbouring countries. It also include regional co-operation over water resources.

Other functions in which the IWMBs can assist in include management, training, financial and support services (Department of Water Affairs and Forestry, no date).

4.6 Summary

Groundwater regulation forms an important role in the process to control and regulate groundwater development and activities that might compromise groundwater quality and availability. For an effective monitoring program at municipalities an operational groundwater licensing system and water allocation program need to be developed.

Institutional arrangements on municipal levels play a significant role to have an effective regulatory environment, raise awareness and identify opportunities to collaborate with other agencies.

4.7 Exercises and tasks

1. Why is there a need for groundwater licensing?
2. Define the term allocation and provide the criteria thereof.
3. Describe and name the different groundwater institutions and their purpose.

4.8 Further reading

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Module 5: Groundwater Quality

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5.1 Learning Objectives

To understand and describe the following:

- Indicators of groundwater quality and their measurements;
- National standards;
- Impacts of negative groundwater quality; and
- Drivers/controls of groundwater quality.

5.2 Introduction

Groundwater quality is a hidden issue inside a hidden resource, and as a result far too little attention is given to it. Most groundwater comes out of the earth as good quality potable water that needs almost no treatment before distribution and use (Figure 1). This good quality is a result of the protection that the ground affords the water by filtering out bacteria and protecting the water from pollutants generated at the land surface (Barrett, 2003). In a piped supply system, precautionary disinfection and liming to reduce corrosion in the piping network may be the only treatments required. As a result groundwater is a highly valuable resource for water resources managers. On the negative side, once groundwater has become polluted, it is usually a very long, complex and expensive task to restore the water quality, and in many cases the groundwater resource may be effectively destroyed as a potable water supply it is for these reasons that the monitoring, prevention and remediation of groundwater pollution is a vital management issue. The specific objectives of this module are to:

- Provide guidance on the identification and assessment of threats to groundwater quality
- Introduce management tools and strategies that may be used to either avoid or ameliorate such threats.

According to Groundwater division of GSSA one of the most important natural changes in groundwater chemistry occurs in the soil. Soils contain high concentrations of carbon dioxide which dissolves in the groundwater, creating a weak acid capable of dissolving many silicate minerals. In its passage from recharge to discharge area, groundwater may dissolve substances it encounters or it may deposit some of its constituents along the way. The eventual quality of the groundwater depends on temperature and pressure conditions, on the kinds of rock and soil formations through which the groundwater flows, and possibly on the residence time (www.iwrm.co.za).

Figure 1: Measuring wellhead chemistry/ Groundwater Quality (Adopted from www.infrastructurene.ws)

As a result the groundwater chemistry from various places in South Africa will differ depending on the aquifer in which it is found and may make the water unsuitable for certain uses. For example, water from the Malmesbury shales is unsuitable for most uses due to high total dissolved salts. Groundwater in granites (e.g. in Limpopo) naturally contains fluoride in high concentrations.

It is essential to have the quality of the water from a borehole intended for domestic use tested before consumption. Even natural groundwater may contain substances which can make it unfit for consumption (gwd.org.za).

5.2.1 What is meant by water quality?

Water quality is a term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for an intended purpose. These characteristics are controlled of influenced by substances, which are either dissolved or suspended in water (Owen *et al.*, 2010).

Although scientific measurements are used to define the quality of water, it's not a simple thing to say that “this water is good," or “this water is bad ". The quality of water that is required to wash a car is not the same quality that is required for drinking water. Therefore, when we speak of water quality, we usually want to know if the water is good enough for its intended use, be it for domestic, farming, mining or industrial purposes, or its suitability to maintain a healthy ecosystem.

5.2.2 What is meant by water quality management?

Guidelines for groundwater resources management in water management areas, South Africa: volume 2. 2004 states that water quality is changed and affected by both natural processes and human activities. Generally natural water quality varies from place to place, depending on seasonal changes, climatic changes and with the types of soils, rocks and surfaces through which it moves. A variety of human activities, e.g. agricultural activities, urban and industrial development, mining and recreation, potentially significantly alter the quality of natural waters, and changes the water use potential. The key to sustainable water resources is, therefore to ensure that the quality of water resources are suitable for their intended uses, while at the same allowing them to be used and developed to a certain extent.

Effective management is the tool through which this is achieved. Water quality management, therefore involves the maintenance of the fitness for use of water resources on a sustained basis, by achieving a balance between socio-economic development and environmental protection. From a regulatory point of view the "business" of water quality management entails the ongoing process of planning, development, implementation and administration of water quality management policy, the authorisation of water uses that may have, or may potentially have, an impact on water quality, as well as the monitoring and auditing of the aforementioned (Owen *et al.*, 2010).

5.2.3 Why the need to manage water quality?

The effects of polluted water on human health, on the aquatic ecosystem (aquatic biota, and in-stream and riparian habitats) and on various sectors of the economy, including agriculture, industry and recreation, can be disastrous. Deteriorating water quality leads to increased treatment costs of potable and industrial process water, and decreased agricultural yields due to increased salinity of irrigation water. On the other hand not all health, productivity and ecological problems associated with deteriorating water quality are ascribed to man's activities. Many water quality related problems are inherent in the geological characteristics of the source area. The occurrence, transport and fate in the aquatic environment of numerous persistent and toxic metals and organic compounds (e.g. pesticides) have given cause for serious concern. Contamination of groundwater resources, or of sediments deposited in riverbeds, impoundment's and estuaries by toxic and persistent compounds can cause irreversible pollution, sometimes long after the original release to the environment has ceased (Guidelines for groundwater resources management in water management areas, South Africa: volume 2, 2004).

5.2.3.1 Salinisation

A persistent water quality problem is salinisation, which has two major causes, natural and anthropogenic. The origin of natural salinisation of river water is geological. Man-made causes are multiple. A wide variety of man's activities are associated with increased releases of salts, some in the short and others in the long term. Immediate increases in salt concentrations result from point sources of pollution, such as the discharging of water containing waste by industries. Diffuse pollution, resulting inter alia from poorly managed urban settlements, waste disposal on land and mine residue deposits pose even a bigger problem, as it impacts over a larger area on the water resource. The effect of diffuse pollution on groundwater is also often problematic in terms of remediation (Barrett, 2003).

5.2.3.2 Eutrophication

Another major water quality problem is eutrophication which is the enrichment of water with the plant nutrients nitrate and phosphate. This encourages the growth of microscopic green plants termed algae. As nutrients are present in sewage effluent, the problem is accentuated wherever there is a concentration of humans or animals. The algae cause problems in water purification, e.g. undesirable tastes and odours, and the possible production of trihalomethanes or other potentially carcinogenic products in water that is treated with chlorine for potable purposes.

5.2.3.3 Micro-pollutants

A water quality issue which is receiving increasing attention among industrialised nations is pollution by metals and man-made organic compounds, such as pesticides.

Serious incidents of health impacts to man and animals have occurred at places throughout the world through uncontrolled exposure to these micro-pollutants. Pollution of this type tends to be highly localised and associated with specific industries or activities. Mining activities often expose pyrite containing rock formations to air and water to produce acid rock drainage. Due to the low pH of acid rock drainage heavy metals are mobilised. The Department of Water Affairs and Forestry has recently established a water pollution control works in the Brugspruit catchment, at huge cost, to treat acid rock drainage emanating from abandoned coal mines.

5.2.3.4 Microbiological pollutants

Water contamination by faecal matter is the medium for the spread of diseases such as dysentery, cholera and typhoid.

5.2.3.5 Erosion and sedimentation

Average sediment yields for South African catchments range from less than 10 to more than 1 000 tonnes/km^2/annum. In some parts of the country erosion has increased by as much as tenfold as a result of human impacts. Apart from the loss of fertile agricultural soil, off-site damage like loss of valuable reservoir storage, sediment damage during floods and increased water treatment costs, have been largely ignored even though these are estimated to be in excess of R 100 million per year.

5.2.4 Who is water quality being managed for?

Being the public trustee of the Nation's water resources, the Minister of Water Affairs and Forestry and his Department, the Department of Water Affairs and Forestry, has to manage South Africa's water resources to ensure continued adequate water supplies of acceptable quality to all recognised users. From a water quality management point of view these recognised users consist of, five water user sectors; these being the domestic, agricultural, industrial and recreational water user sectors , as well as the aquatic ecosystem, also constituting the water resource base (Owen *et al.*, 2010).

5.2.5 The underlying principles of groundwater quality management

According to Meyer (2002) and Riemann *et al*. (2011) sustainability, equity and efficiency are recognised as the central guiding principles in the protection, use, development, conservation, management and control of water resources. These guiding principles are inherent to the management of water quality. Water resources must therefore be judiciously managed and equitably shared by all water users in the most optional manner. In water quality management, sustainability means that the protection of water resources must be balanced with its development and use. This "balance" is attained through a process of resource classification, the determination of an associated Reserve and the determination of Resource Quality Objectives. Resource Quality Objectives, inter alia, stipulate in-stream water quality objectives aimed at meeting the water quality requirements of the five water user sectors, and are aimed at ensuring fitness for use of South Africa's surface water, groundwater and coastal estuaries. The concepts of Resource Quality Objectives and Resource Quality that were introduced by the National Water Act, 1998 (Act No. 36 of 1998), necessitate that water quality management, now, also takes responsibility for the management of the aquatic ecosystem quality (in-stream and riparian habitat, and aquatic biota quality).

The following prominent principles form the basis of water quality management policies and practices in South Africa.

- The management of water quality must be carried out in an integrated and holistic manner, acknowledging that all elements of the environment are interrelated.
- Decision-making must ensure that the best practicable environmental option is adopted by taking account of all aspects of the environment including all the people in the environment.
- The precautionary approach to water quality management applies, in which active measures are taken to avert or minimise potential risk of undesirable impacts on the environment.
- In general the principle of Polluter Pays, applies. In accordance with this principle, the cost of remedying pollution, degradation of resource quality and consequent adverse health effects, and of preventing, minimising or controlling pollution is the responsibility of the polluter.
- Participative management in the management of water quality must be advocated, ensuring that all interested and affected parties, and previously disadvantaged persons have an equal opportunity to participate.

- Transparency and openness must underlie all decision-making processes, and all information must be made accessible in accordance with the law.

5.2.6 Approaches to groundwater quality management

According to Riemann *et al*. (2011) water quality management, in South Africa, has evolved from a pollution control approach, which essentially concentrated on source directed management measures, to the current approach where water quality management consists of an integrated source, remediation and resource directed management approach which recognises the receiving water users', as well as the aquatic ecosystem's water quality requirements. This water quality management approach is actualised through a combination of measures and arrangements provided for in the National Water Act, 1998 (Act No. 36 of 1998); these provisions including:

- The protection of water resources;
- the establishment of Water Management Strategies and Water Management Institutions;
- the licensing of water use. (Which includes the licensing of discharges through coastal marine out-fall pipelines to the marine environment);
- the implementation of a National Pricing Strategy containing a system of Waste Discharge Charges; and
- the establishment of a National monitoring system and a National information system.

5.2.6.1 Resource directed water quality management

Meyer (2002) further opines that in order to counter the continuing deterioration of water quality and to meet the challenges of the future, the Department of Water Affairs and Forestry has adopted a Receiving Water Quality Objectives approach, consisting of a Receiving Water Quality Objectives approach for non-hazardous substances and a Pollution Minimisation and Prevention approach for hazardous substances (Figure 2).

The Receiving Water Quality Objectives approach for non-hazardous substances accepts that the receiving water environment has a certain, usually quantifiable, capacity to assimilate waste without serious detriment to the quality requirements of its recognised users. However, if applied without the necessary precaution, the Receiving Water Quality Objectives approach for non-hazardous substances will inevitably lead to the deterioration of water resources to the point where they will be less fit for use by the recognised water user sectors. To counter the limitations of this approach, a precautionary approach was accepted to avert danger and minimise uncertainty and potential risk of undesirable impacts on the environment (Guidelines for groundwater resources management in water management areas, South Africa: volume 2. 2004).

Figure 2: Resource directed water quality management (adopted from gwd.org.za).

For those wastes that are hazardous and a threat to the environment due of their toxicity, persistence and extent of bio-accumulation, a precautionary approach aimed at minimising or preventing their entry into the water environment, was adopted.

5.2.6.2 Hierarchy of water quality management decision-taking

Decisions in regard to water quality management are made in terms of a hierarchy of principles, which is specifically aimed at marrying the protection, and use and development of water resources. The hierarchy of decision-taking is as observed from Figure 3 below:

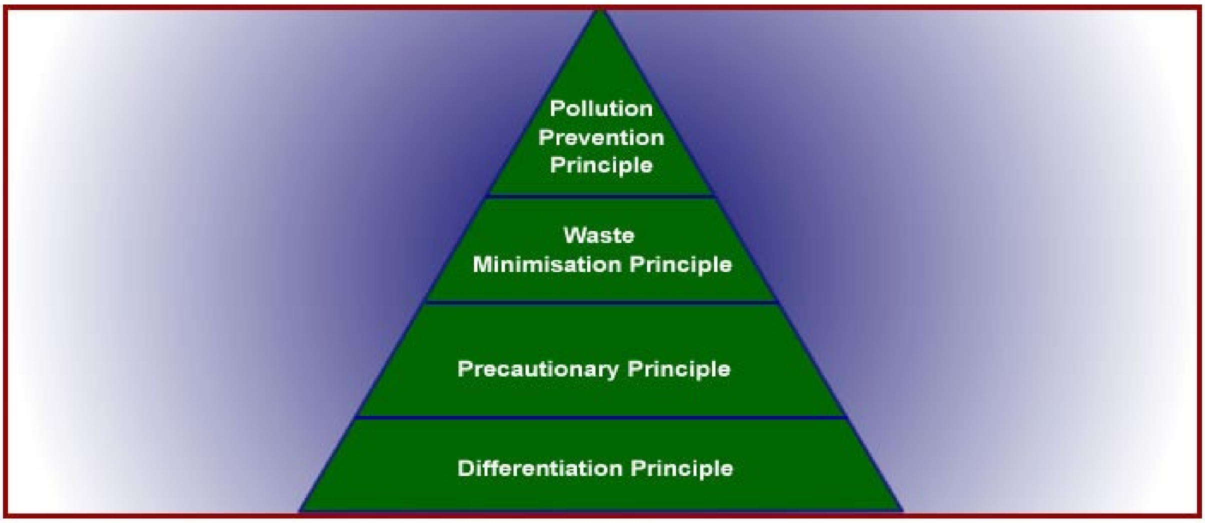

Figure 3: Hierarchy of water quality management decision-taking (adopted from www.dwa.gov.za)

5.2.6.3 Source directed water quality management

Without efficient and effective source directed controls, the water quality objectives set through resource directed water quality management will, in most cases, not be met. Prior to authorising a license application for a water use that may potentially impact on water quality, the applicant must conduct an impact assessment. Such an impact assessment has to demonstrate that the source directed controls proposed (Figure 4), are sufficient to ensure that the water resource remain fit for use by the recognised water user sectors, in accordance with the Receiving Water Quality Objectives approach. Impact assessments must also consider the cumulative effects of actions that in itself may not be significant, but may be significant when added to the impact of other similar actions (Riemann *et al*., 2011).

Figure 4: Source directed water quality management (adopted from gwd.org.za).

5.3 Why do groundwater supplies merit protection?

www.dwa.gov.za opines that groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both the urban and rural environment. For municipal water supply, high and stable raw-water quality is a prerequisite, and one best met by protected groundwater sources. Too often those exploiting groundwater for the provision of potable water supply have taken no action to protect water quality. Aquifers worldwide are experiencing an increasing threat of pollution from urbanization, industrial development, agricultural activities and mining enterprises. It may take many years or decades before the impact of a pollution episode by a persistent contaminant becomes fully apparent in groundwater supplies abstracted from deeper wells and take even longer to clean up.

- Groundwater supplies merit protection because they are a vital resource for the supply of potable water in both rural and urban environments.
- Water managers need to initiate proactive campaigns and practical actions to protect the natural quality of groundwater.

5.3.1 Natural groundwater quality

Groundwater is usually safe to drink without treatment, unlike surface water. This is because harmful microbiological pathogens such as bacteria and viruses usually cannot survive for long in aquifers. However, it is normal for chlorination to be carried out as a precaution for most public groundwater supplies.

Monitoring of the microbiological quality of a groundwater source gives important information about the groundwater system, and early warning of problems. Groundwater contains dissolved “minerals” such as chloride, sodium, iron and others, in the same way as surface water. The natural dissolved mineral content of groundwater depends on a number of factors, including the aquifer material and the groundwater residence time. Figure 5 indicates natural groundwater electrical conductivity (mS/m) in RSA. In some cases, high levels of dissolved minerals cause groundwater to be brackish or even saline. In some (relatively rare) cases, naturally high levels of dissolved constituents like fluoride, arsenic or nitrate render groundwater unfit to drink, even though it may taste perfectly fresh (Riemann *et al*., 2011).

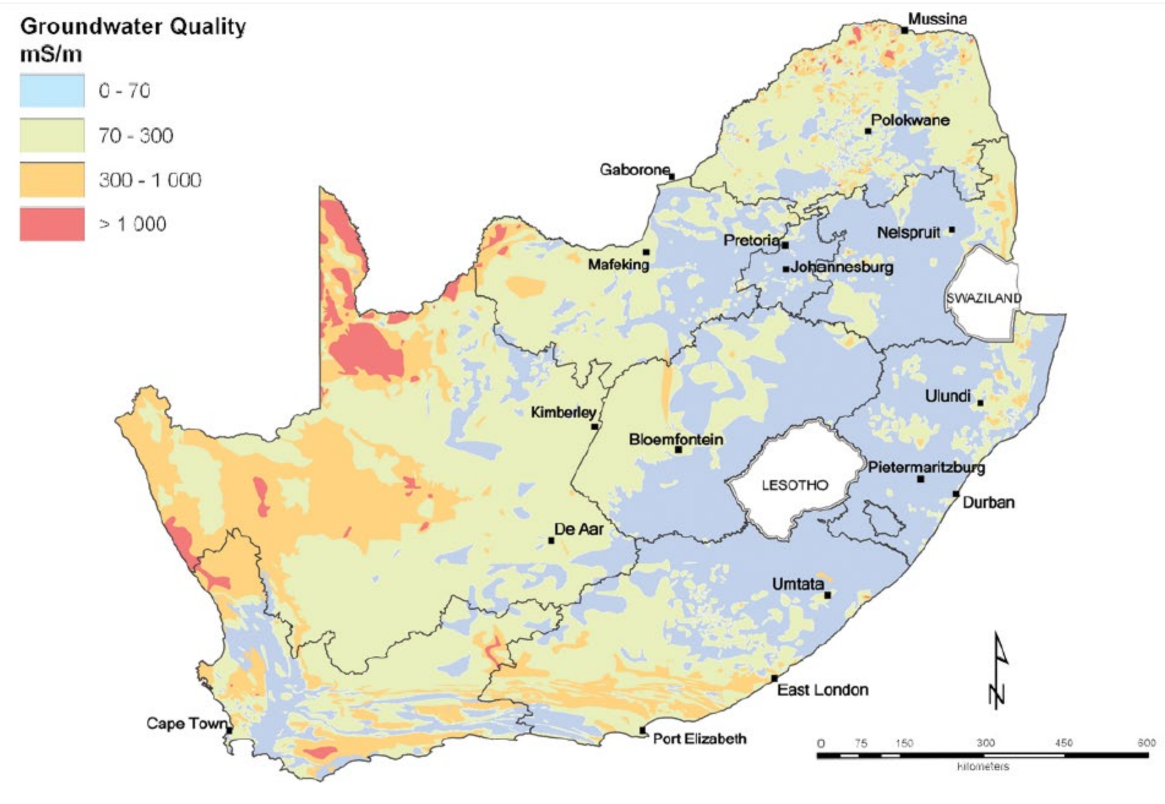

Figure 5: Electrical conductivity map of groundwater in RSA. (Adopted from www.dwa.gov.za).

The map in Figure 6 shows nitrate concentrations in groundwater across South Africa, based on available data. In areas where nitrate is higher than allowable limits, groundwater will need to be treated or blended.

Monitoring is the key to understanding natural groundwater quality variations. Groundwater is normally less susceptible to pollution compared to surface water, since an overlying unsaturated zone generally protects it. However, once polluted, groundwater is difficult and expensive to clean up. Groundwater pollution can come from a variety of sources, and in the worst cases can make groundwater unsafe to drink and uneconomical to treat (www.iwrm.co.za).

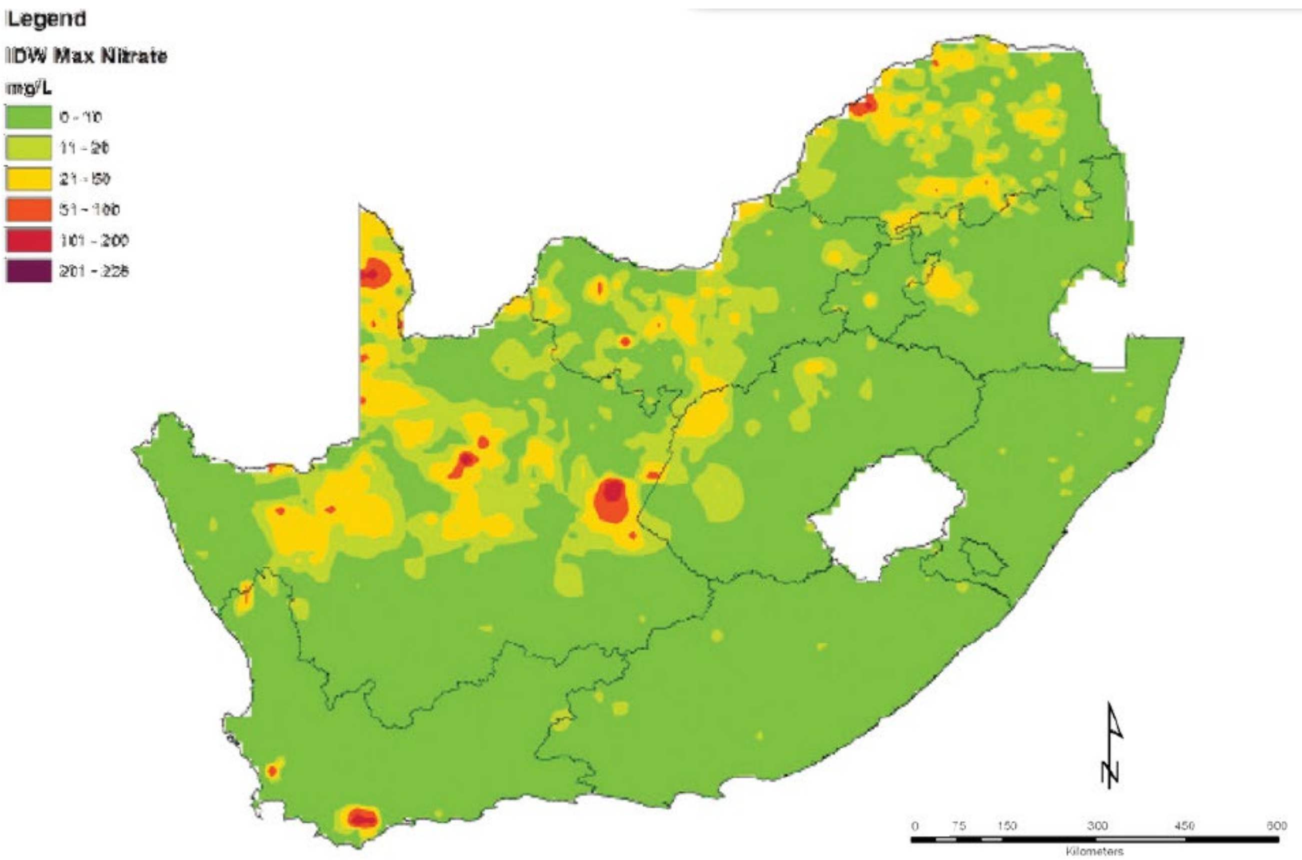

Figure 6: Map of nitrate levels in groundwater in South Africa. (Adopted from www.dwa.gov.za).

5.3.2 Protection zone policy in South Africa

A common method that is used world-wide to help protect groundwater quality is to establish areas or “protection zones” around groundwater abstraction points (and sometimes well fields and even whole aquifers) within which activities that may pollute groundwater are controlled. It is also obviously not enough merely to define a protection zone – of equal importance are the restrictions or rules that are made for activities within the protection zone, and the enforcement of these.

Riemann *et al*. (2011) states that groundwater source protection zones are commonly used in many European countries and in the United States (where they are known as wellhead protection zones) to protect major or vulnerable groundwater sources (See Figure 7) for the groundwater levels of RSA).

There are various documents that cover groundwater protection in South Africa, including protecting single groundwater sources from point-source pollution. The specific legal requirement that will adequately protect groundwater, through protection zoning, is through the recently assented classification of water resources. However, it is usually much easier, quicker and cheaper to protect groundwater from pollution or the effect of over-abstraction than it is to try to reverse the damage at a later date. Groundwater protection is therefore an economic as well as an environmental imperative, and groundwater protection measures and policy will save money in the long term. The cost of dealing with polluted or contaminated groundwater can also involve considerable hardship to people and the environment.

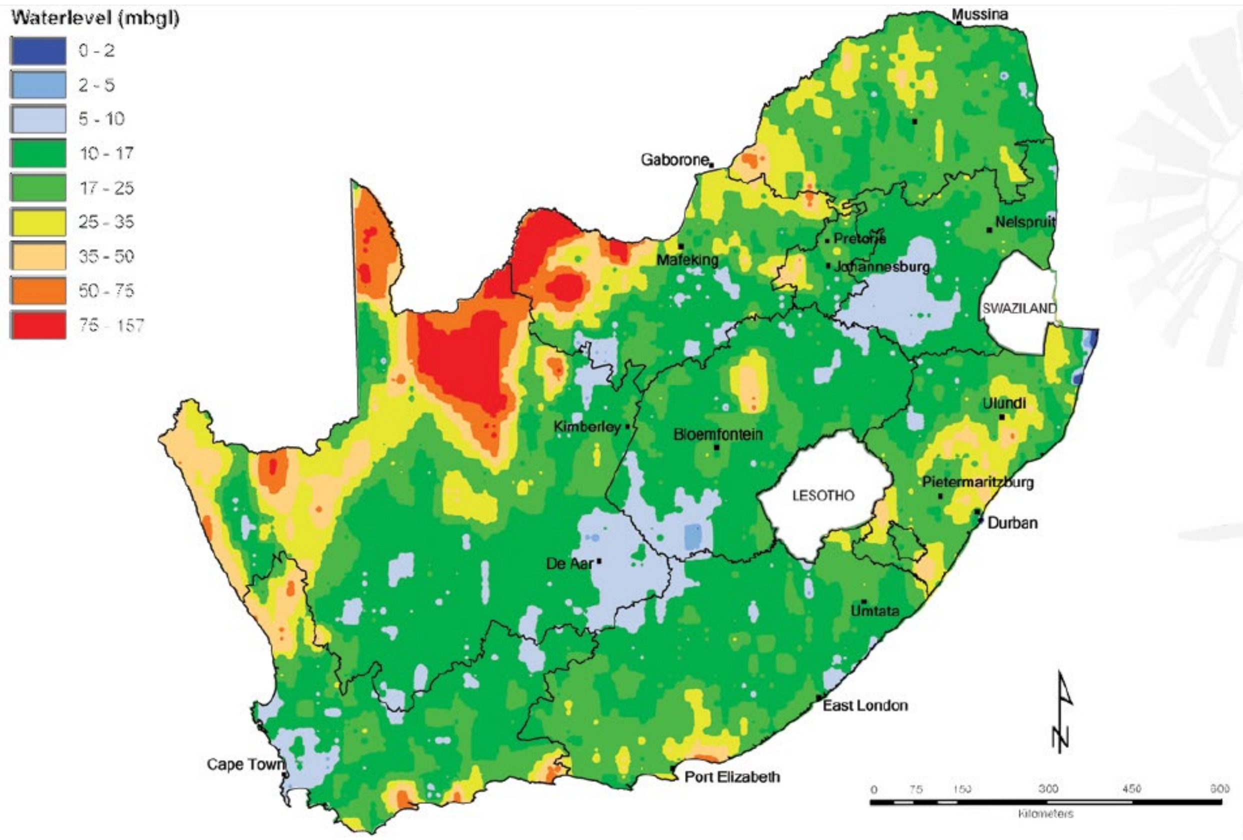

Figure 7: Groundwater levels map of RSA. (Adopted from www.dwa.gov.za).

5.4 Risk assessment

5.4.1 How do aquifers become polluted?

According to Riemann *et al*. (2011) aquifers may become polluted by specific point sources, such as waste ponds or effluent discharge from factories and mines, or they become polluted from diffuse pollution such as the application of agricultural fertilizers and pesticides. Groundwater may also become polluted through well head contamination from poorly constructed/designed boreholes.

According to www.dwa.gov.za when subsurface contamination is inadequately controlled, and exceeds the natural attenuation capacity of the underlying soils and strata, then the groundwater system becomes contaminated by this waste. In the vadose (unsaturated) zone, natural subsoil profiles actively and effectively attenuate many water pollutants especially human excreta and domestic wastewater by biochemical degradation and chemical reaction. Concern about groundwater pollution relates primarily to the phreatic (water table) aquifers, especially where the unsaturated zone is thin and the water-table is shallow. Deeper and confined aquifers are afforded much greater natural protection by the overlying ground. The threats to groundwater arise from a variety of different sources (Fig 8.1) and many of these are quite different from sources that typically pollute surface water bodies, due to differences in the mobility and persistence of contaminants in the subsurface as compared to surface water bodies. What is clear is that if the source, nature and pathways of the pollutant(s) are properly understood, then sharply-focused pollution control measures can produce major benefits for relatively modest cost if correctly targeted at key point sources.

In summary:

- Aquifers may be polluted by point source discharges or from diffuse pollutants.
- Typically aquifers become polluted when pollution is inadequately controlled and exceeds the natural attenuation capacity of the ground.
- Groundwater quality management requires the assessment of pollution hazard and risk to groundwater, delineation of groundwater vulnerability zones, control of effluent discharges (e.g. by a system of permits), as well as the construction of containment structures (e.g. lined waste ponds) in order to avoid or reduce groundwater pollution.

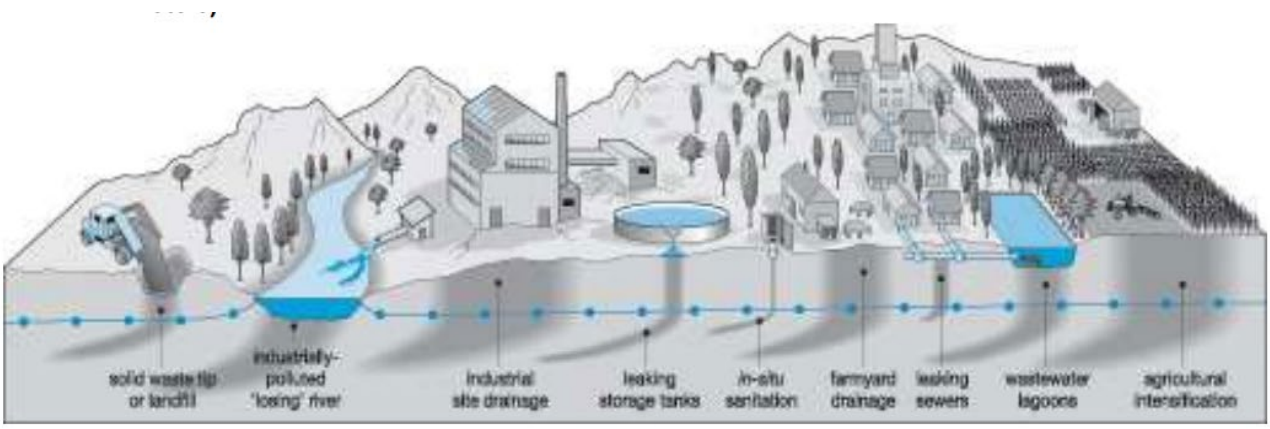

Figure 8: Land use activities commonly generating a groundwater pollution threat. (Adopted from www.agw-net.org)

5.4.2 Groundwater pollution

Just because water is underground does not mean that it cannot be polluted. Groundwater can be contaminated in many ways (See Figure 9). Groundwater associated with coal deposits often contains dissolved minerals poisonous to plants and animals. Pollutants dumped in the ground, in landfills and at sites of animal husbandry or pollutants introduced below ground such as in unlined latrines and burial sites, may leak into the soil and work their way down into aquifers.

Pollutants include substances that occur as liquids like petroleum products, dissolved in water like nitrates or are small enough to pass through the pores in soil like bacteria. Movement of water within the aquifer is then likely to spread these pollutants over a wide area, making the groundwater unusable and spreading disease.

Figure 9: Sources of Groundwater Pollution. (Adopted from gwd.org.za.)

5.4.3 How is groundwater quality measured and monitored

A key aspect for management of groundwater quality is the application of water quality monitoring at selected boreholes, especially in areas considered to be at risk. Groundwater quality may be measured by sampling and analysing the groundwater from selected wells. Monitoring (Figure 10) may be pro-active with monitoring wells installed prior to a planned activity that may generate pollution (Figure 6), so that changes to the groundwater condition can be measured as they occur. Alternatively monitoring may be reactive with monitoring wells installed to monitor possible pollution from an already existing facility/activity. This subject is dealt with more fully in the Module (7) on Groundwater Monitoring.

Meyer (2002) believes that there are several issues involved in groundwater quality monitoring that need to be considered, adding considerable complexity to the task. The cost of chemical analyses may be very high, depending on the parameters analysed. In many instances, especially for organic agro-chemicals and industrial reagents, local laboratories may not be equipped to carry out the required analyses. Where possible, cheap indicator parameters should be identified and measured as an alternative to a full chemical analysis. Sampling wells, if not in regular daily use, need to be thoroughly flushed before sampling. Sampling points need to be carefully selected, which requires a clear understanding of the groundwater flow patterns and knowledge of the location of the sources of pollution. Sampling frequency needs to also be considered and will be based on the sensitivity of the pollution problem, and the frequency of flow inducing or flushing events such as groundwater recharge.

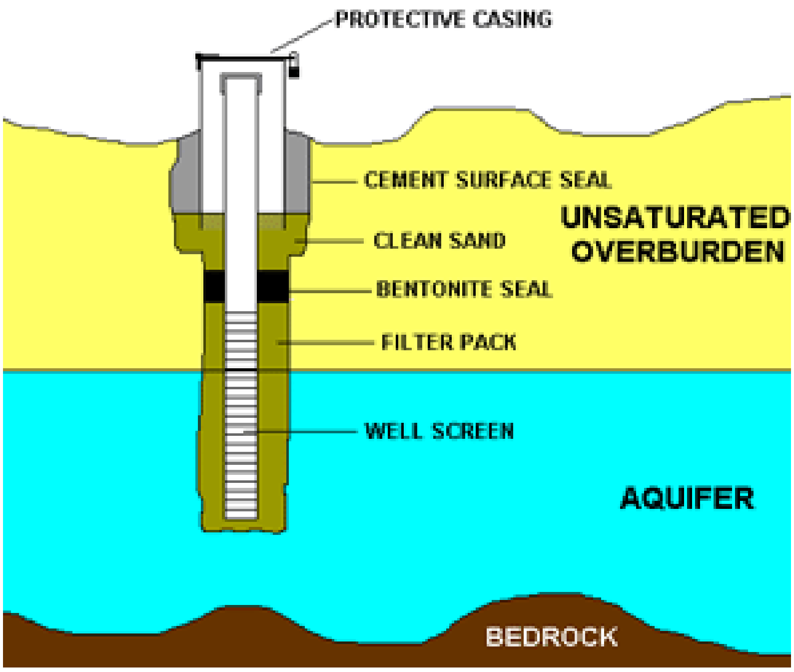

Figure 10: Monitoring Well. (Adopted from www.geologicresources.com).

5.4.4 Protecting groundwater from pollution

Management of groundwater quality requires both the protection of aquifers and groundwater from ingress of pollutants and also the remediation/treatment of polluted resources. It should be noted that treatment of polluted groundwater is complex, expensive, often only partially successful and it may take many years of treatment before groundwater quality can be restored. Groundwater quality can range from high quality potable water to something that is entirely toxic, with a full range of water qualities in between. In addition to protection and remediation, groundwater quality management may include the matching of different water qualities to different uses and blending of different water qualities to provide a larger groundwater resource of intermediate but still acceptable quality for a particular use requirement (Guidelines for groundwater resources management in water management areas, South Africa: volume 2. 2004).

Groundwater quality management should be pro-active and attempt to prevent the contamination of groundwater resources, and thus avoid the lengthy, expensive and often ineffective remediation of contaminated aquifers. Groundwater protection initially involves two key aspects.

These are:

1. assessment of aquifer pollution vulnerability and
2. mapping of groundwater pollution hazards.

Together these two factors may be then used to generate a groundwater pollution risk map. Such maps may be used to guide the location of proposed new developments such that the risk of groundwater contamination is reduced in sensitive area and they can be used in already developed areas to assess probable zones already at risk or polluted from ongoing activities. Once the risk has been identified and assessed, then certain groundwater quality management practices may be introduced. These may include:

- groundwater quality monitoring to assess actual groundwater quality status and changes to quality over time
- prohibition of certain activities in sensitive or vulnerable areas
- prohibiting the disposal of certain levels of waste except in sealed facilities
- management of both the quality and quantity of effluent and waste disposal by a series of permits
- monitoring of compliance with regulations/perm.

5.4.5 What does groundwater pollution protection involve?

As we have seen, to protect aquifers against pollution it is essential to constrain land-use, effluent discharge and waste disposal practices.

One widely used strategy has been the establishment of groundwater protection zones (Figure 11). Simple and robust zones may be established with indications of which activities are permissible/possible. Such zones need to be incorporated into the town/city planning maps and legislation and used to guide various developments. Such zones have a key role in setting priorities for groundwater quality monitoring, environmental auditing, etc. and can help to reduce the costs involved in producing groundwater quality maps.

There is need for sensible balances between protecting aquifers and boreholes, but aquifer oriented strategies are more acceptable. It may not be cost-effective to protect all parts of an aquifer equally. This will depend on the groundwater use, the contaminant loads, flow paths, etc. (Riemann *et al.*, 2011).

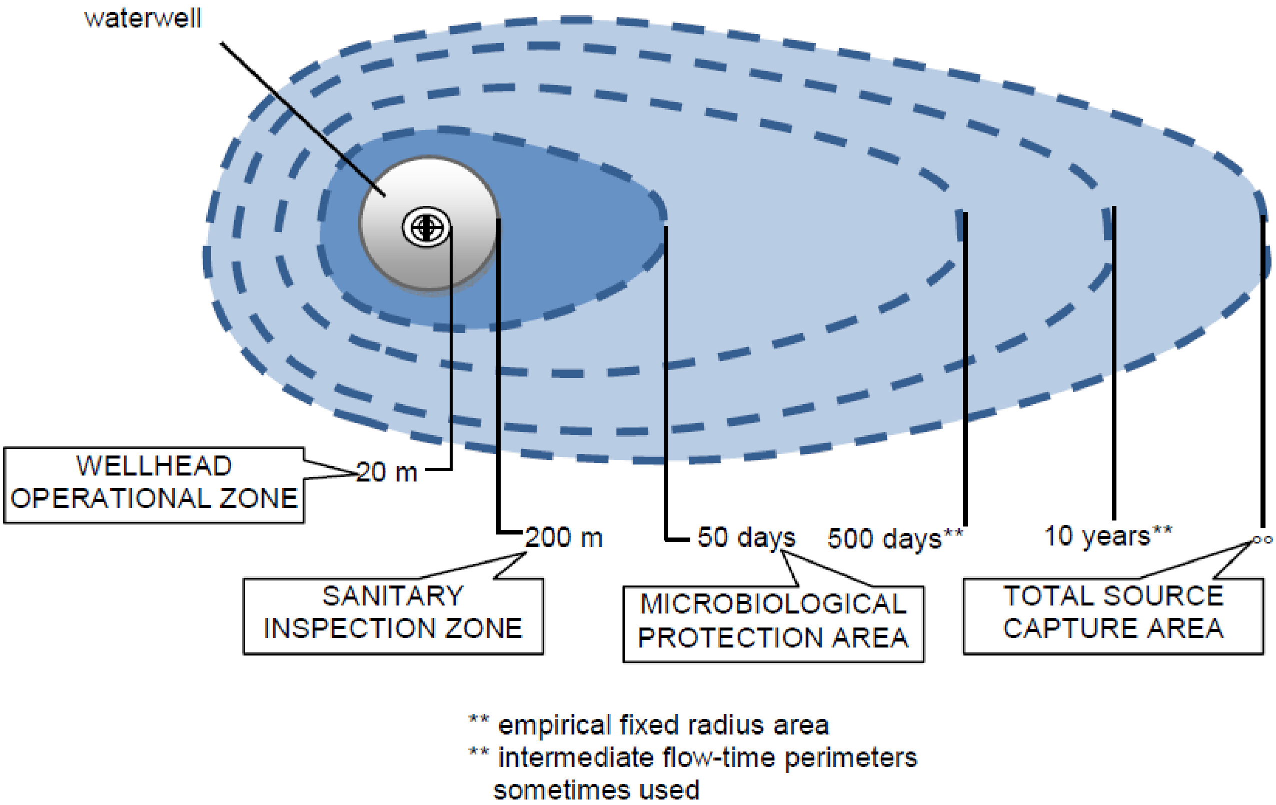

Figure 11: Groundwater protection zones are a simple but powerful tool for protecting important groundwater sources. Restrictions on various activities are imposed, depending on the zone, typically based on the flow time to the abstraction point (www.dwa.gov.za).

In summary:

Land-use, effluent discharge and waste disposal practices must all be managed in order to protect aquifers against pollution. Simple and robust zones need to be established with indications of which activities are permissible/possible.

5.4.6 Who should promote groundwater pollution protection?

The principle that the “polluter pays” should be applied in cases of groundwater pollution. However the source of pollution may be difficult to definitively ascertain in cases of diffuse pollution and in urban/industrial environments where there are multiple point sources causing pollution. The ultimate responsibility or groundwater pollution protection must lie with the relevant agency of national or local government. Nevertheless, an obligation also exists on water-service companies to be proactive in undertaking pollution hazard assessments for their groundwater sources.

5.4.7 Urban wastewater and groundwater quality

Urban wastewater may be considered as a special case for groundwater quality management. This is because urban wastewater generation is unavoidable, ubiquitous and growing in volume all the time as cities grow. In addition, there are very real benefits that can be realized from urban wastewater such as groundwater recharge and the provision of irrigation water for certain crops. Alongside such benefits, urban wastewater also contains real hazards in terms of bacterial pathogens and industrial wastes with a wide range of organic and inorganic substances.

5.4.8 How does urban wastewater relate to groundwater?

There is steadily-increasing wastewater generation by most growing cites and the management of this wastewater is a significant problem for cities, especially in developing countries. Unfortunately many sewerage systems discharge directly to surface watercourses with minimal treatment and little dilution in the dry season. The rather rudimentary and common wastewater handling and reuse practices in developing nations tend to generate high rates of infiltration to underlying aquifers especially in the more arid climates. Infiltration through the ground improves the wastewater quality and stores it for future use, but can also pollute groundwater.

5.4.9 Groundwater quality management

Historically emphasis was placed on the protection of the quality of South Africa's surface and marine water resources, while policies and strategies to deal with groundwater pollution were scarce. Under the National Water Act, the status of groundwater has now been changed from private water to public water and new efforts are being made to afford groundwater the same protection enjoyed by surface water resources. Policies and strategies for groundwater quality management in South Africa are now being developed by DWAF with the stated mission:

"To manage groundwater quality in an integrated and sustainable manner within the context of the National Water Resource Strategy1and thereby to provide an adequate level of protection to groundwater resources and secure the supply of water of acceptable quality."

The protection of water quality in South Africa is to be achieved by the combination of three core strategies:

- Resource-directed strategies (chapter 3 of NWA)
- Source-directed strategies (mainly chapter 4 of NWA)
- Remediation strategies (chapter 3 of NWA)

The relationship between these strategies is illustrated in Figure 12.

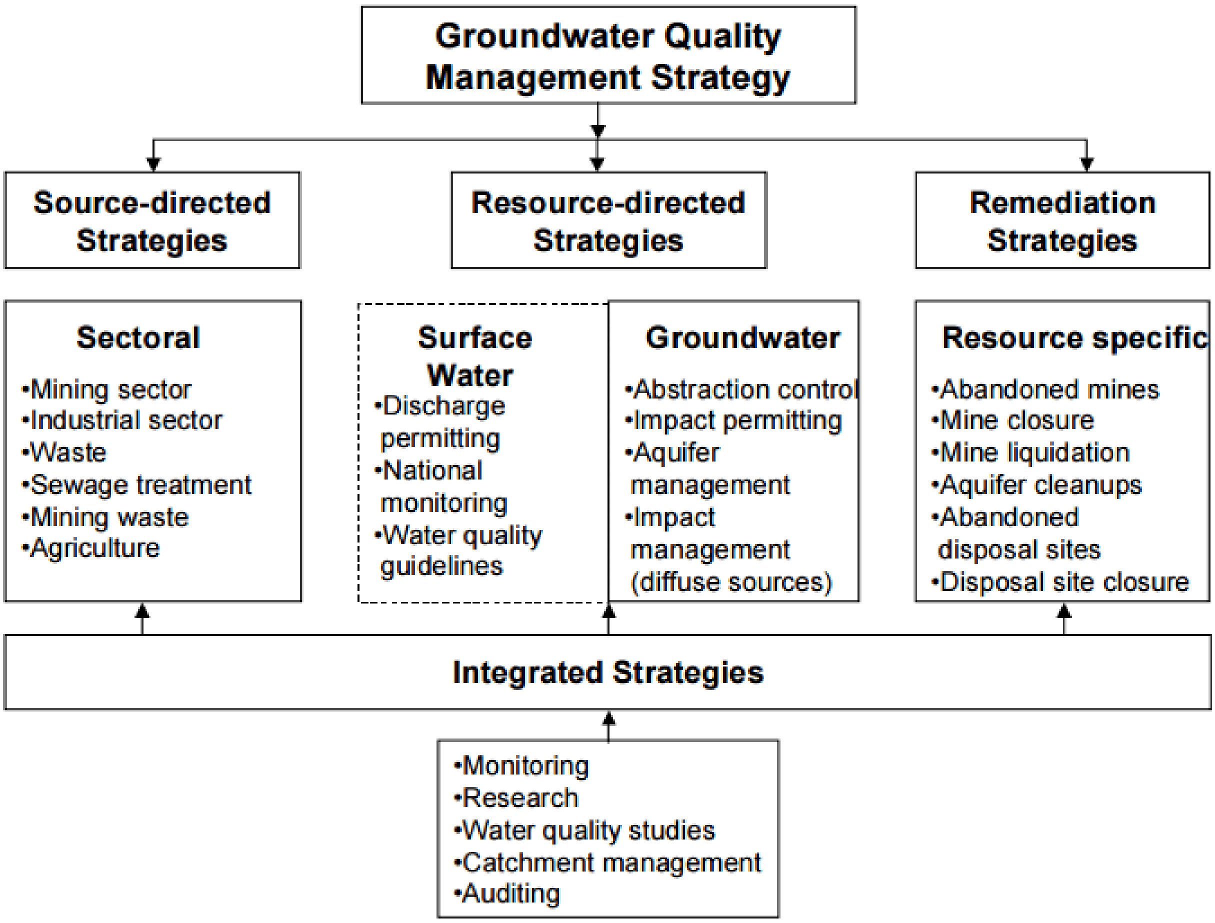

Figure 12: Integrated strategies to manage groundwater quality in South Africa (adopted from DWA, 2000).

5.4.9.1 Resource-directed strategies

Resource-directed strategies are aimed at understanding the inherent characteristics and current and potential future use of the water resource itself.

These are then used to determine the required level of protection. The measures implemented under this strategy are directed at managing such impacts as do inevitably occur in such a manner as to protect the reserve and ensure suitability for the beneficial uses of the resource. Examples of resource-directed measures include:

• Resource classification.

• Determination of resource management classes.

• Reserve determination.

• Setting of resource quality objectives.

5.4.9.2 Source-directed strategies

Source-directed strategies are aimed at minimising, or preventing at source possible, the impact of developments or activities on groundwater quality. Source directed controls have, in the past, been principally targeted at point sources of pollution to surface waters and coastal marine waters. Examples of source directed controls include:

• Licences and general authorisations.

• Standards to regulate the quality of waste discharges.

• Minimum requirements for on-site management practices.

• Requirements for minimising water use impacts.

• Requirements for remediation of polluted water resources.

5.4.9.3 Remediation strategies

Remediation strategies are aimed at remediating historical groundwater pollution, where practicable, to protect the reserve and ensure at least fitness for the purpose served by the remediation. Under Chapter 4 of NWA, the clean-up of contaminated groundwater is the responsibility of the polluter, who must also bear the costs of remediation. In the case where the responsible person(s) cannot be identified or has failed to comply with the law, remedial action may be undertaken directly by the Catchment Management Agency (CMA). Remedial measures for which the CMA is accountable include:

• Setting and evaluating priorities for remedial action

• Clean-up of abandoned sites

• Emergency action plans or procedures for accidental spills.

Recognising that groundwater management will have limited resources; actions taken by the groundwater coordinator to implement groundwater protection need to be prioritised according to:

• The value of the groundwater resource

• The vulnerability of the resource and

• The risk of adverse impacts on human health and ecosystems.

5.5 The National Water Act (1998)

According to www.dwa.gov.za the National Water Act provides the framework within which the Department can manage the protection, use, development, conservation and control of South Africa's water resources.

The eleven uses of water specified by the National Water Act (Section 2) are:

- taking water from a water resource
- storing of water
- impeding or diverting the flow of water in a watercourse
- engaging in a stream flow reduction activity
- engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1)
- discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit
- disposing of waste in a manner which may detrimentally impact on a water resource
- disposing in any manner of water which contains
- waste from, or which has been heated in, an industrial or power generation process
- altering the bed, banks, course or characteristics of a watercourse removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people, and
- using of water for recreational purposes.

The eleven uses are not rights and may generally take place only in terms of an authorisation or licence.

In implementation of the Act the Department must take into account the following (section 2 of the Act):

a) basic human needs of present and future generations

b) the need for equitable access to water

c) redressing the results of past racial and gender discrimination

d) promoting the efficient, sustainable and beneficial use of water in the public interest

e) facilitating social and economic development

f) providing for growing demand for water use

g) protecting aquatic and associated ecosystems and their biological diversity

h) reducing and preventing pollution and degradation of water resources

i) meeting international obligation

j) promoting dam safety

k) managing exposure to, and effects of, floods and droughts.

National government is empowered through the Act to establish suitable institutions and to ensure that they have appropriate community, racial and gender representation.

The Act will enable the Department to effectively implement its new policies regarding groundwater quality management. The following will be important:

- groundwater no longer enjoys the status of private water and is now subject to the same control measures as surface water;
- powers to monitor, assess, plan and audit performance of all water users have been provided for in the Act;
- the Department can within its available resources provide extension and support services and play a role in building capacity at community level; and
- the Department will be able to influence land-use planning decisions, to regulate or prohibit land-based activities, to develop and implement Best Practice standards and to implement source controls where necessary. Implementation of Best Practice standards as conditions of authorisation managed by other organs of state will be particularly important (www.dwa.gov.za).

5.6 Summary

Groundwater occurs as part of the natural water cycle. Groundwater is formed by precipitation, such as rain water, that infiltrates down into the soil layer, but is not utilised by plants, and then percolates deeper underground. Groundwater is thus water that is found in the spaces between sand and soil particles or within the cracks in hard rock underground. Access to groundwater is done by means of drilling boreholes or utilising springs. In South Africa users of groundwater include municipal, rural, agricultural and mining. A large number of the population in rural areas depend on boreholes for the provision of drinking water. Agriculture also utilises a large percentage of groundwater for crop irrigation practices (Meyer, 2002).

According to Barrett (2003) the quality of groundwater is normally safe to drink, but could be affected by its underground environment in that it may dissolve some of the minerals in the rock with which it comes in contact. The monitoring of groundwater quality and quantity is thus important to ensure that it is utilised sustainably. Groundwater quality monitoring is done through taking water samples from monitoring boreholes and analysing the water quality at a SANAS accredited laboratory (www.aquatico.co.za). Groundwater is a merchandise which is proposed to be utilized wisely whilst ensuring its serenity and sacredness as far as quality and amount. Universal usage in segments, for example, streamlined, metropolitan, commercial, agricultural and private makes groundwater polluted and changing over it as a powerless element.

Groundwater pollution and over-abstraction are serious problems in certain parts of South Africa. Poor and deteriorating groundwater quality is widespread and can be attributed to diverse sources in various sectors such as mining, industrial activities, effluent from municipal wastewater treatment works, storm water runoff from urban and especially informal settlements (where adequate sanitation facilities are often lacking), return flows from irrigated areas, effluent discharge from industries, etc.

The mining footprints undoubtedly impact on water sources whether it is surface or groundwater. Poor and deteriorating groundwater quality is widespread and can be attributed to diverse sources in various sectors such as mining. The discharge or decant of contaminated water and highly saline effluents from mining activities and/or abandoned mines (commonly referred to as acid mine drainage) is a serious environmental threat and social concern (www.aquatico.co.za).

5.7 Exercises and tasks

1. Are you aware of any significant groundwater quality issues in your region in either the urban or rural?

2. Give examples of groundwater pollution in your municipality. How can it be avoided in future environment?

3. What controls over groundwater pollution do you have? Are they effective?

4. Who manages/ maintains groundwater protection zones in your region? Are there any reforms that you would recommend?

5. What happens to waste water from your city?

6. Identify a common groundwater quality problem in one of your countries.

7. What would you change to improve the management of the problem?

8. Please share your experience of groundwater quality problems in your municipality.

9. According to the National Water Act, how many uses of water specified by the National Water Act (Section 2) are there? Name these uses.

10. What do you think of natural groundwater quality? Do you think it should/not be treated before consumption? Please state your reasons.

5.8 Report from student for evaluation and assessment.

5.9 References

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Module 6: Groundwater Quantity

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6. Learning objectives

To understand and describe the following:

- Meaning of groundwater quantity;
- Factors influencing groundwater quantity; and
- Measures and indicators of groundwater quantity;
- To appreciate the importance of protecting groundwater quality;
- To understand the role of risk assessment and vulnerability mapping in managing groundwater quality;
- To examine the specific case of Urban Wastewater and Groundwater Quality.

6.1 Introduction

South Africa is a relatively dry and drought prone country. The rainfall is generally low and erratic with a mean annual precipitation in the order of 500 mm compared to the world average of 860 mm. Some 21% of South Africa receives less than 200 mm/a. The country has limited water resources and is ranked globally amongst the twenty most water-scarce countries. The distribution of these resources has, to a large degree, dictated the establishment of settlements, routes of migration and man's mode of living. The historic importance of the water resources can be gauged by the hundreds of town and farm names relating to water, i.e. Bloemfontein, De Aar.

In terms of South Africa's overall water consumption, groundwater contributes only some 15% of the total volume consumed (DWAF, 2002). This percentage belies the fact that over 300 towns and 65% of the population are entirely dependent upon this resource for their water supply. Lack of reliable hydrogeological information has been identified as one of the reasons why groundwater has generally not been developed to its full potential. It is estimated that some 12 million people are still without an adequate supply of water to meet their basic needs. Over 80% of South Africa is underlain by relatively low yielding, shallow, weathered and/or fractured-rock aquifer systems. By contrast, appreciable quantities of groundwater can be abstracted at relatively high-rates from dolomitic and quartzitic aquifer systems located in the northern and southern parts of the country, respectively, as well as from a number of primary aquifers situated along the coastline (Figure 1).

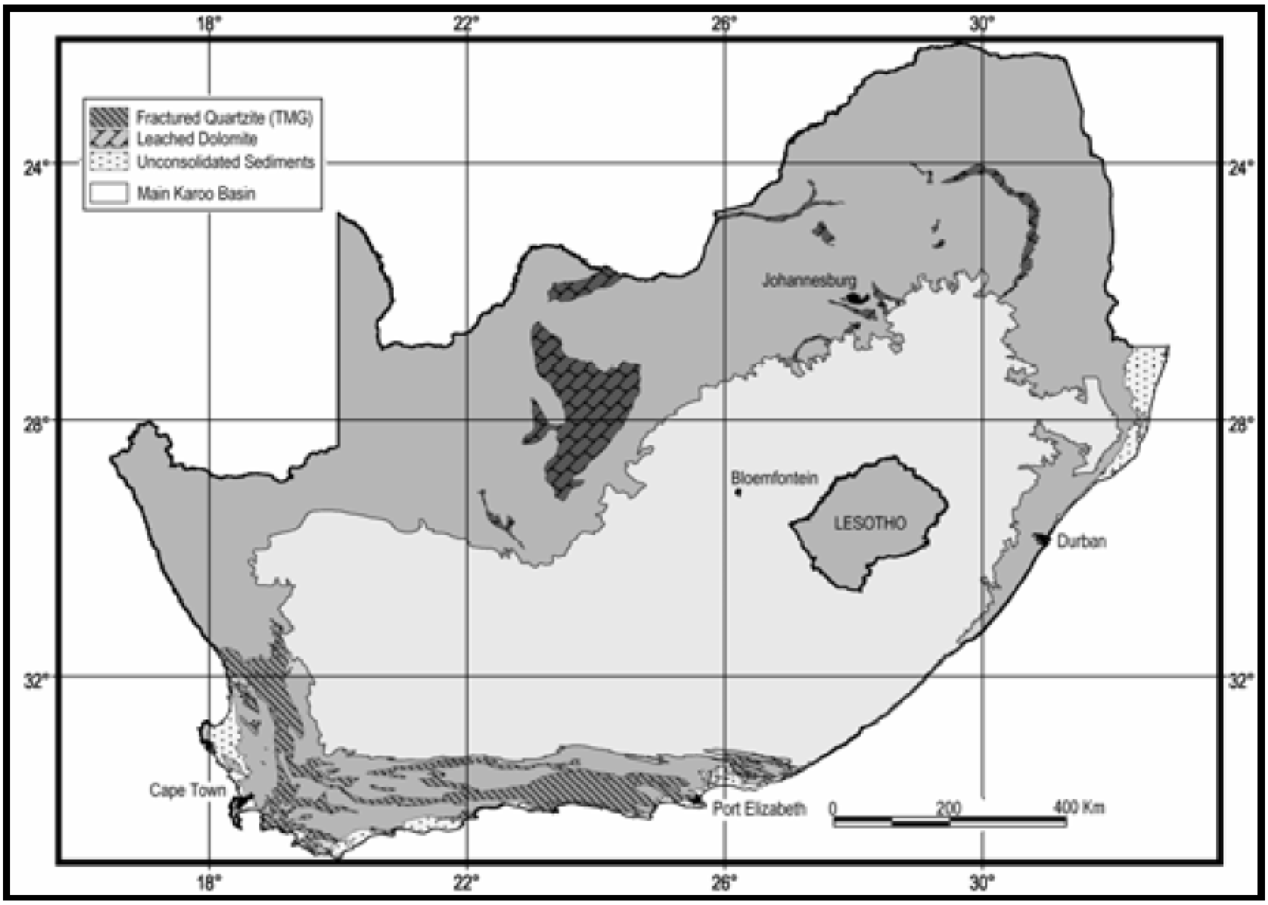

Figure 1: Distribution of significant secondary and primary aquifer systems in South Africa (Groundwater strategy, 2016).

This module highlights and summarizes the results of the Department of Water and Sanitation's Groundwater Resources Assessment Phase 2 (GRA2) project which aimed at quantifying the recharge, storage and sustainable yield of the aquifer systems in South Africa.

In late 2003, the Department of Water and Sanitation (DWS) initiated the Groundwater Phase 2 Project, which is aimed at the quantification of the groundwater resources of South Africa on a national scale. The project has been carried out by key DWS personnel and other consultants, i.e. SRK consulting, and was completed in June 2005. Algorithms have been developed for the estimation of aquifer storage, recharge, baseflow and the groundwater reserve. The quantities derived for the key aspects of recharge, aquifer storage and extractable groundwater are 30,520, 235,500 and 19,000 Mm^3/a, respectively.

6.2 Previous work

The question as to the total amount of groundwater available for development in South Africa could not, until recently, be answered by hydrogeologists, much to the frustration of water resource engineers and planners, not to mention the hydrogeologists themselves. Whilst the 'Surface Water Resources of South Africa' publication is in its third edition, no similar such body of work is available for groundwater. Early attempts at quantifying the groundwater resources of South Africa, e.g. Enslin (1970), Vegter (1995), were largely educated guesses. Estimates of the sustainable groundwater yield as derived by these pioneers of hydrogeology in the country were 2,500 and 5,400 Mm^3/a, respectively. Concern about the lack of systematic country-wide groundwater data collection and interpretation led the Directorate of Geohydrology in Department of Water and Sanitation (DWS) to launch in mid-1990 a programme to compile a series of 21 hydrogeological maps of South Africa at a scale of 1:500 000, each of which has an accompanying explanatory booklet. This was basically an aquifer classification project and was completed in 2005 (Figure 2).

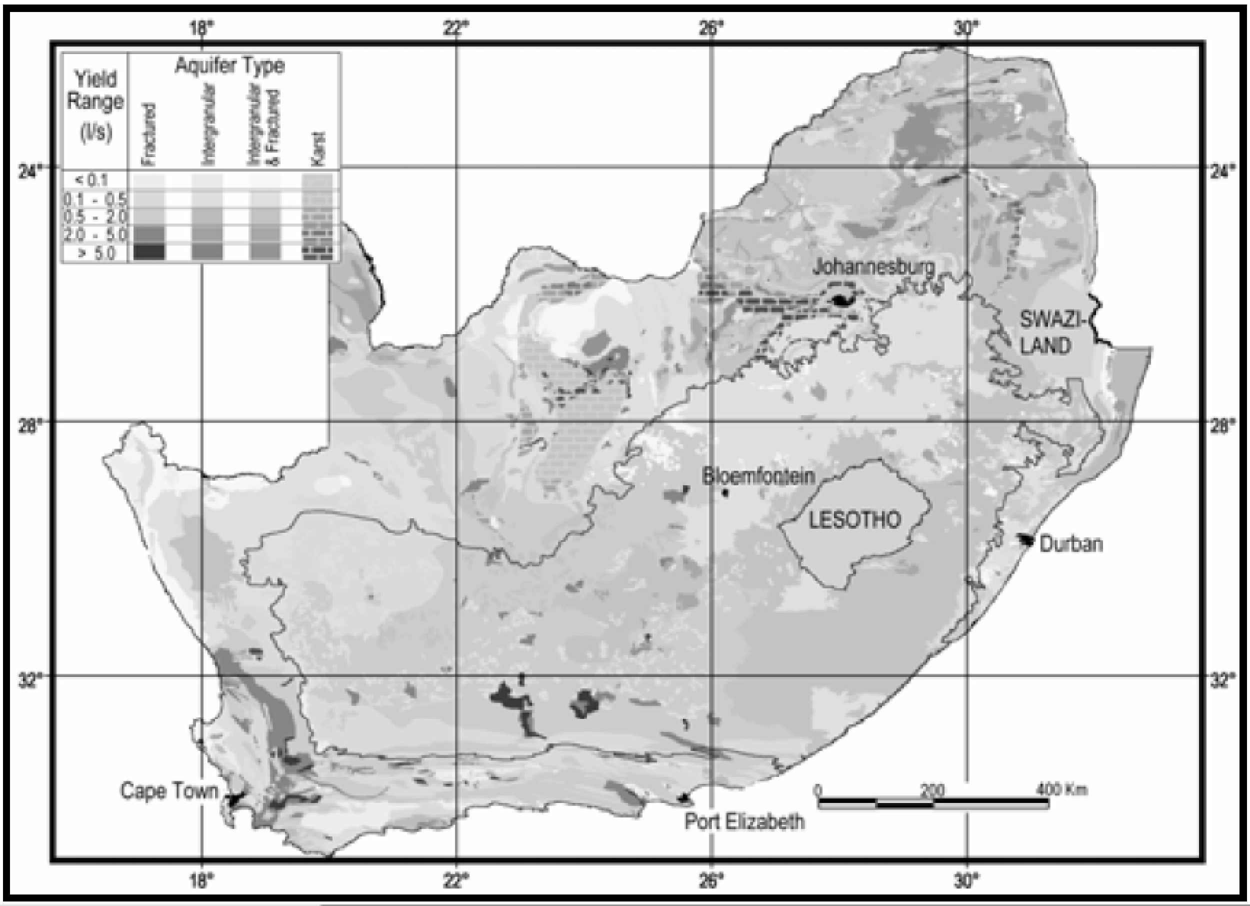

Figure 2: Composite of DWAF's 21 1/500,000 scale aquifer yield maps of South Africa (Groundwater strategy, 2016).

In 1995, Vegter however produced the first synoptic and visual representation of the groundwater resources of South Africa. The work was published in a set of seven maps and an explanation booklet. It provided a valuable indication of availability of groundwater on a regional scale. The series of maps depict borehole yield probabilities, depth to groundwater-level, groundwater quality / hydrochemical type, mean annual recharge and groundwater contributions to baseflow on a national scale. The main maps basically represent a statistical analysis of information stored in DWS's National Groundwater Data Base.

This work was built-on by Baron, Seward and Seymour (1998) with production of the so-called 'Groundwater Harvest Potential' map of South Africa. Regional estimates of aquifer storage and recharge were used to provide a sustainable groundwater yield in $m^3/km^2/a$, which the authors defined as 'the maximum volume of groundwater that could be abstracted per annum without depleting the particular aquifer'. Their estimate was 19 000 Mm^3/a. Haupt (2001) further refined the Harvest Potential map by recognizing that in many cases aquifer permeability would be the main factor limiting the utilisation of the so-called harvest potential. He applied a factor to the harvest potential based on country-wide borehole yield analyses and came up with an estimate of groundwater availability of 10 000 Mm^3/a.

6.3 Groundwater occurrence

Water not only covers three quarters of the Earth's surface: it is also present almost everywhere below ground surface, down to considerable depth and in continuous motion. It represents an invisible component of the hydrosphere and of the water cycle. This groundwater represents by far the biggest portion of all liquid (not frozen) freshwater on earth – about 96% (see figure below). In comparison, the global volume of freshwater in lakes is less than 1% of the total fresh groundwater volume (see Figure 3).

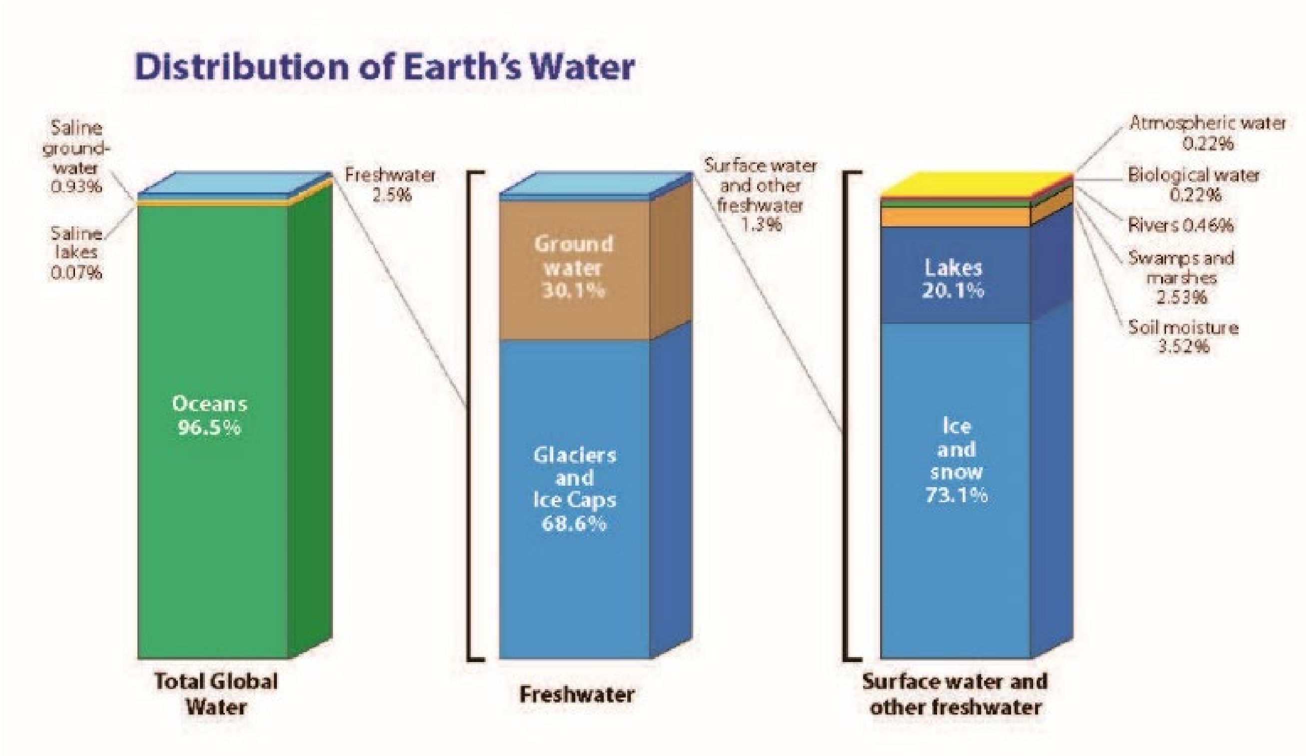

Figure 3: The groundwater portion of the earth's freshwater (Murray *et al.*, 2010).

6.4 Groundwater occurrence in South Africa

South Africa's aquifer systems have received their water-bearing properties, in particular the permeability, through the region's historical geological and hydrological development and as a result of the physical and chemical composition of the different rock types. Figure 4 illustrates the main types of permeability found in different rock types. Permeability is termed primary if it is formed as the rock is formed (intergranular) and secondary if it is formed in the rock formation itself (fissures and caverns, fractures, joints and faults).

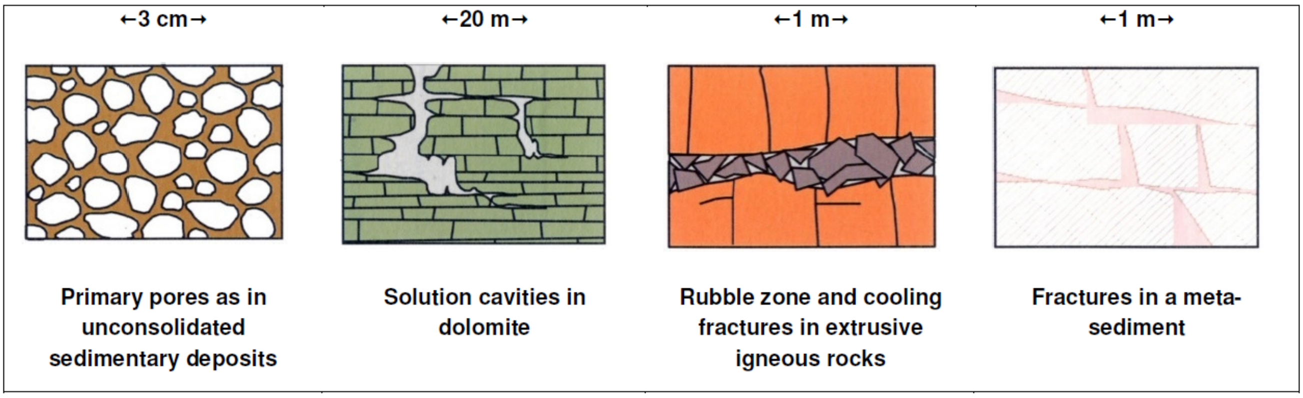

Figure 4: Different aquifer permeability types (Murray *et al*., 2010).

The simplified geology map in Figure 5 enables a national-scale view of the main aquifer types in South Africa based on the aquifer properties of the main lithology (rock type) of the different rock strata.

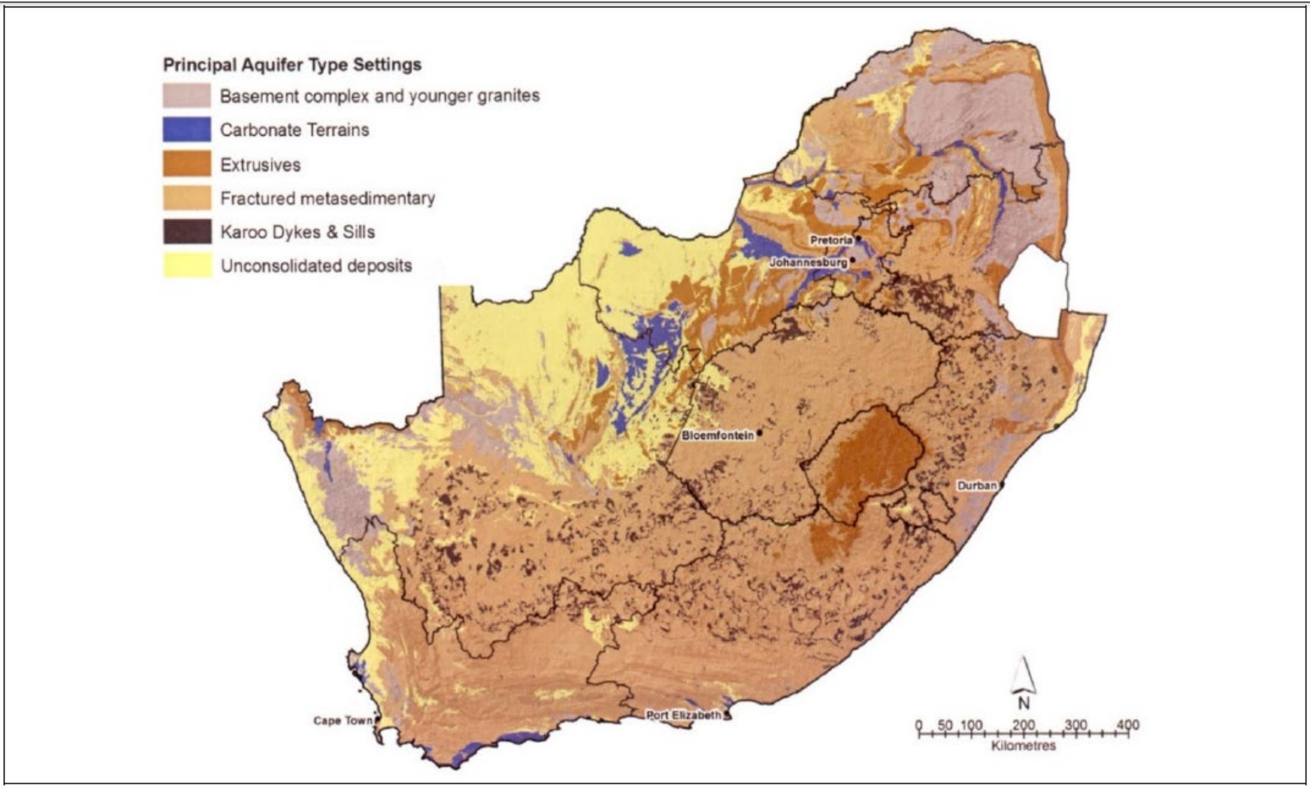

Figure 5: Main aquifer types in South Africa (Colvin *et al.*, 2007).

More than 90% of South Africa is underlain by hard-rock, or secondary, aquifers controlled by secondary faulting and jointing. Primary (sandy) aquifers generally are restricted to the coast, alluvial valley deposits and the Kalahari.

A very pragmatic aquifer classification was already developed in 1995 to support the regulatory system developed by the then Department of Water and Sanitation – see (Parsons, 1995).

Table 1.1: Aquifer Systems in South Africa (after Parsons, 1995)

AQUIFER SYSTEM CLASSIFICATION	COVERAGE OF COUNTRY (%)	GENERAL LOCATION
MAJOR AQUIFERS	18	Primary aquifer systems along the coast; Dolomitic systems in parts of Gauteng, Mpumalanga, the Northern Cape and North West Province; Rocks of the Table Mountain Group bordering the Cape coast; Parts of the Karoo Supergroup; Cities and towns receiving water from major aquifer systems are Pretoria, Mmabatho, Atlantis, St. Francis Bay and Beaufort West.
MINOR AQUIFERS	67	Minor aquifers occur widely across South Africa with variable borehole yield and water quality. They supply many smaller settlements, e.g. Nylstroom, Williston, Carnarvon and Richmond.
POOR AQUIFERS	15	Poor aquifers occur mainly in the dry northern and western parts of the country. The generally low borehole yields of poorer quality are, however, still of critical importance to small rural communities.

A map showing the spatial distribution of major, minor and poor aquifers is shown in Figure 6.The map also shows locations where groundwater sources are used, either as sole source or in combination with surface water sources.

A critical characteristic in terms of groundwater's exploitation is the depth that has to be drilled to encounter groundwater. This is expressed as the depth to the first water strike and the country-wide situation is shown in the map, Figure 7. This depth ranges between 30-60 m for large parts of the country, to over 120 m, in particular under the deep sand cover in the Kalahari.

The thickness of the water-saturated formation determines the storage of an aquifer. This is particularly important in times of drought. However, the sustainable utilization of an aquifer is dependent on its natural replenishment or recharge, just as in the case of river flow. The management task is to ensure that utilisation stays within the limits imposed by rainfall and recharge. Groundwater differs from rivers in that the response to rainfall is not "flashy", but reflects over a period of months or even years. The response to droughts is also much slower, with groundwater therefore a far more buffered resource than surface water. Surface characteristics and geology can result in 'preferential recharge areas' and it is important to know and understand these. A project supported by the WRC is presently underway to map these areas, so that they can be better protected (Nel *et al*., 2013; Nel *et al*., 2015).

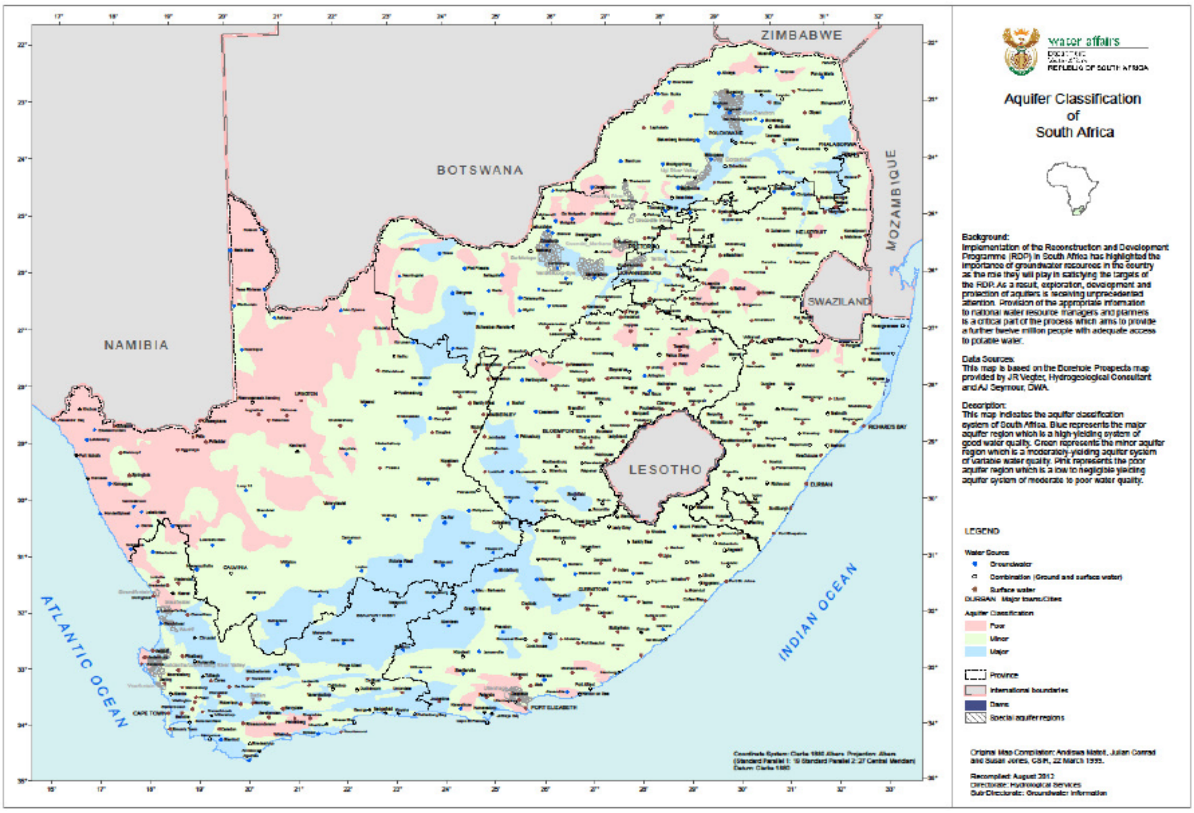

Figure 6: Aquifer classification in South Africa (Groundwater strategy, 2016).

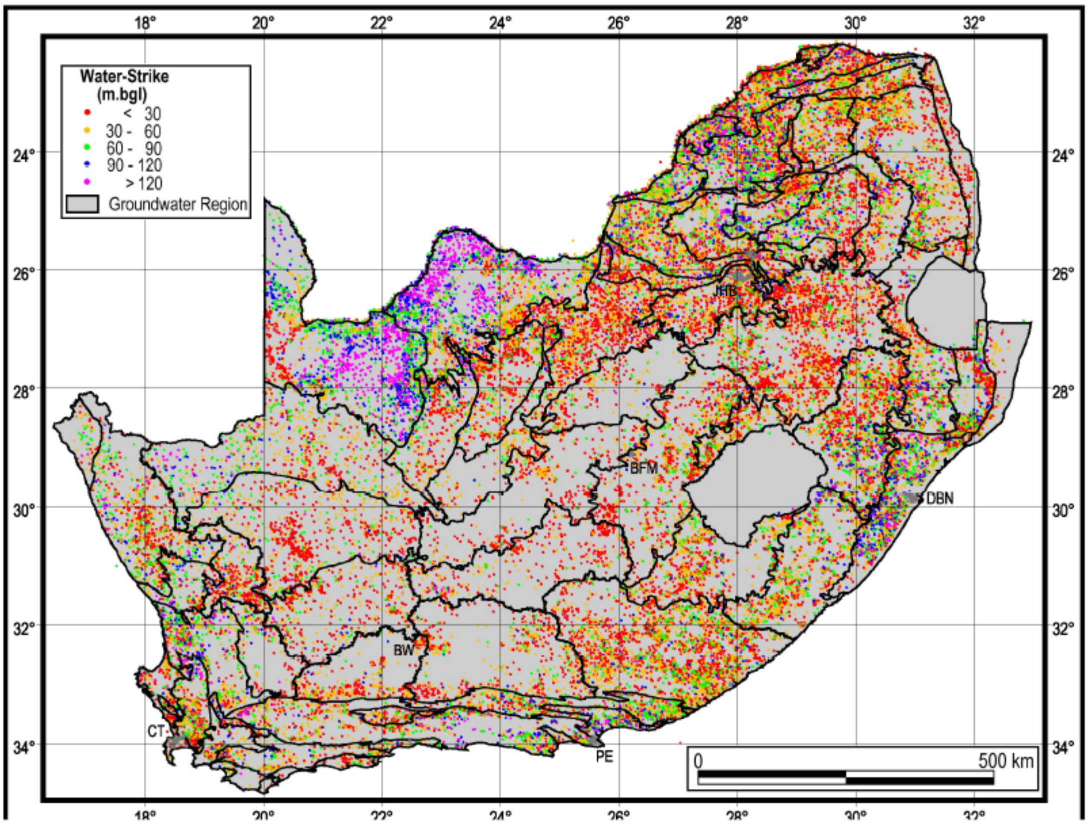

Figure 7: Depth to Water Strike in South Africa (Groundwater strategy, 2016).

6.5 Groundwater – environment linkages

An aquifer – literally a 'water carrier' – is both a reservoir and a transport channel. Groundwater flow in an aquifer is governed by the aquifer's intrinsic characteristics (shape, size, permeability, etc.) but also by its recharge, largely produced by infiltration of precipitation. Most of the groundwater flow eventually ends up in springs and streams. In coastal areas there may be a significant outflow into the sea. Groundwater recharge and groundwater discharge are thus the links between groundwater and the other components of the water cycle. This is illustrated in the water cycle diagram (Figure 8) below (Colvin *et al*., 2007).

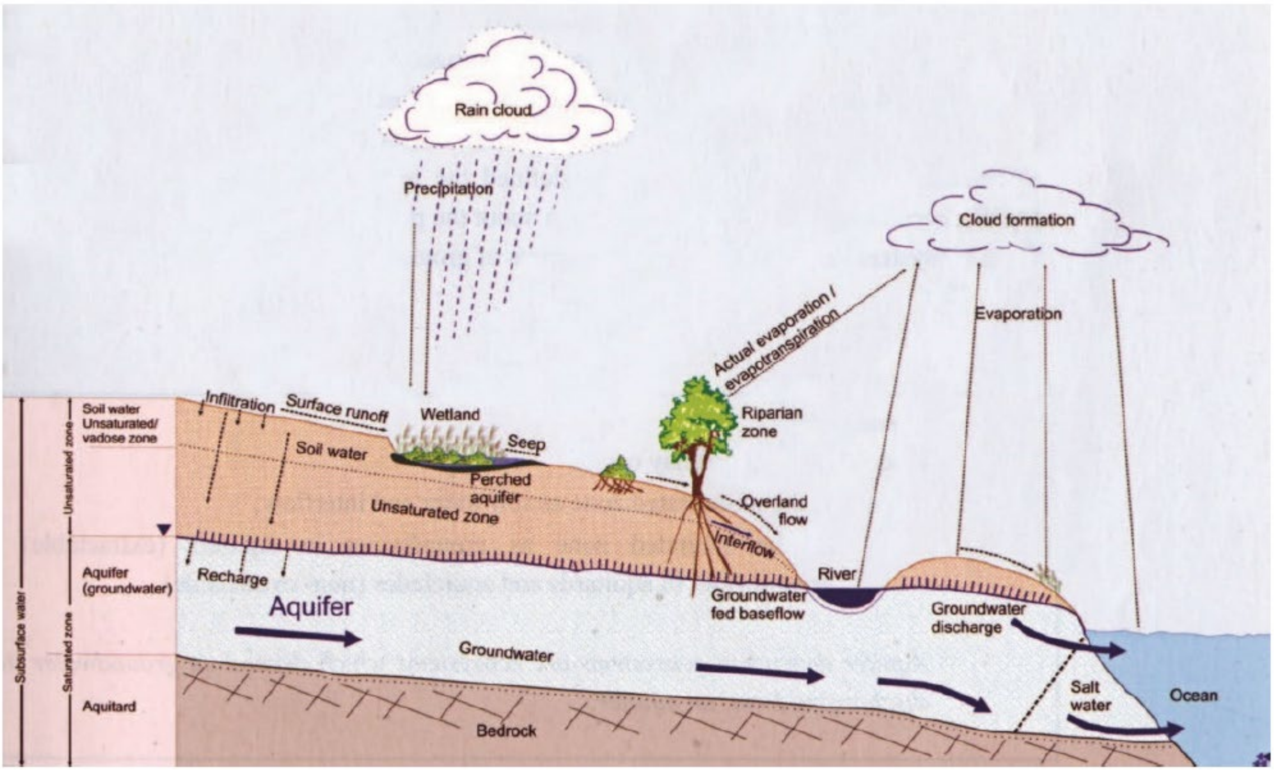

Figure 8: Subsurface and surface flows of water in the environment (Colvin *et al*., 2007).

Wherever groundwater flows or discharges to the surface, Aquifer-Dependent Ecosystems (ADEs) can occur. Their identification is often difficult, but a type-setting and identification study has been undertaken to guide groundwater management and allocation (Colvin *et al*., 2007). Examples of known South African Aquifer-Dependent Ecosystems include:

- in-aquifer ecosystems in the dolomites (North West Province);
- springs and seeps in the TMG sandstone (Western Cape);

- terrestrial keystone species such as Acacia erioloba in the Kalahari;
- lakes and punctuated estuaries on the shallow sand aquifers of the east and south coast;
- riparian zones in the seasonal alluvial systems of the Limpopo;
- seeps on the Karoo dolerite sills.

6.6 Groundwater use

To put the quantification of groundwater resources into perspective, a brief discussion on its use in South Africa is given. Groundwater contributes 15% of all the water resources been used in South Africa. Figure 9 below provides a breakdown of groundwater use for different economic sectors and Figure 10 indicates how this is further broken down into different Water Management Areas. Large volumes of groundwater are used for irrigation in the drier, more sparsely populated west of the country. Such a volumetric aggregate is however not always a good reflection of the importance of groundwater for a specific sector.

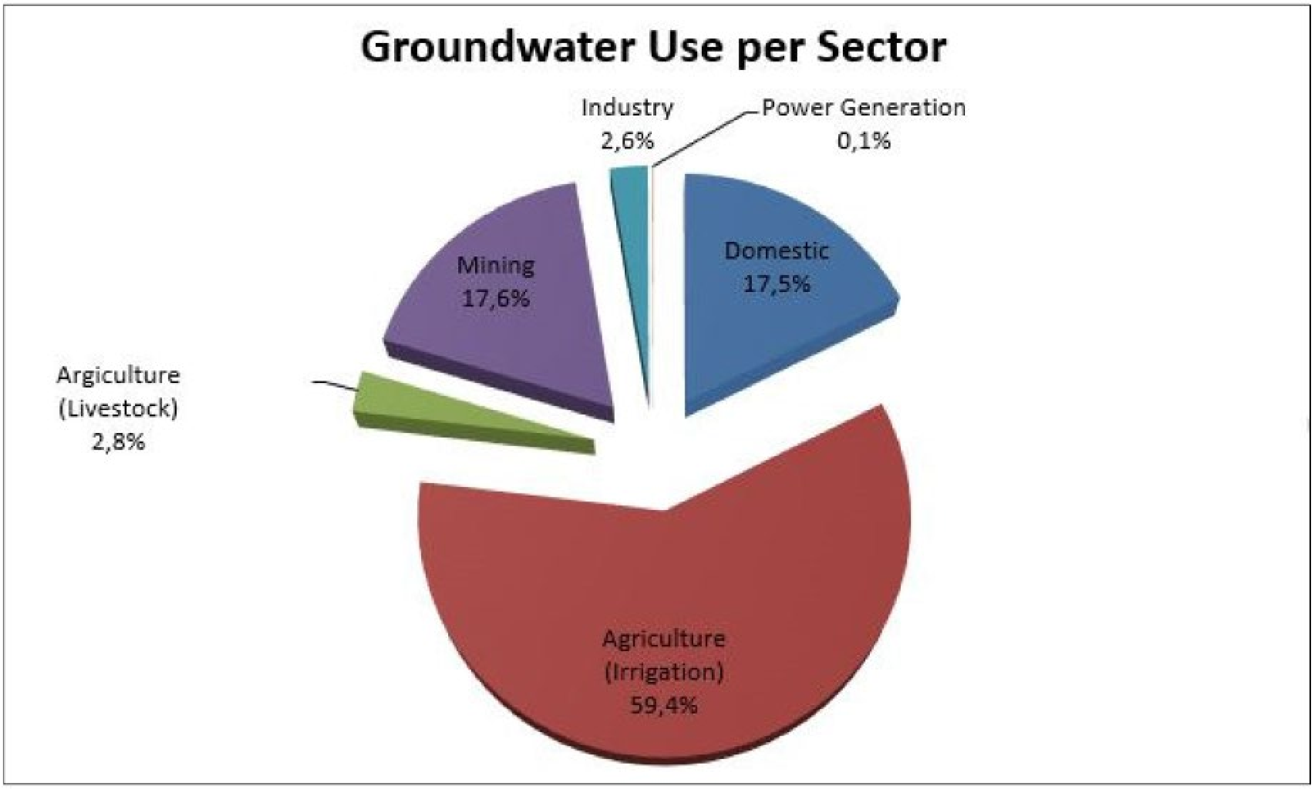

Figure 9: Breakdown of groundwater use for different economic sectors (Colvin *et al*., 2007).

Groundwater is widely but variably used across the whole of the country. A more detailed breakdown of the sectoral use of groundwater in the major surface water catchments is provided by Colvin *et al*. (2007) and is in Figure 10. This study the most up to date estimate of total groundwater use in South Africa, deriving a figure of 1,770 Mm^3/a. Sixty four percent of all groundwater abstracted is used for irrigation.

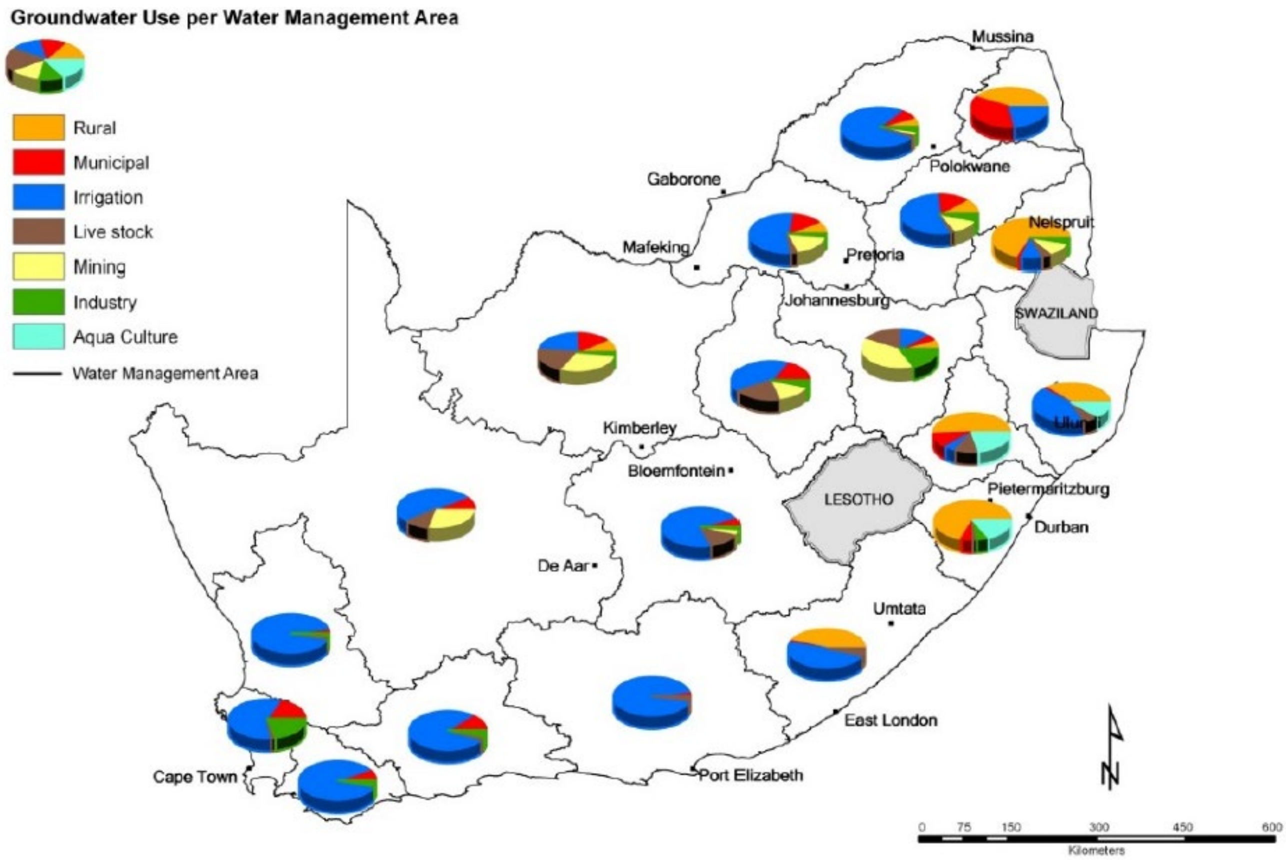

Figure 10: Groundwater use per Water Management Area (Groundwater strategy, 2016).

The Reconstruction and Development Programme (RDP) and subsequent plans and strategies have enabled major progress in supplying our citizens with an improved water supply since 1994. According to the 2010 Millennium Development Goal (MDG) Report (UNDP, 2010) in 1996 only 61% of the national population was using an improved drinking water source. In 2013 that figure stands at 95% (DWA, 2013), meaning that South African has easily achieved its MDG obligation in relation to water. This achievement would not have been possible without groundwater becoming an important source. In 5 of the 9 provinces more than 50% of settlements now have a groundwater supply, Limpopo leading with 84% followed by North West and Northern Cape Provinces, both with more than 65% of communities supplied from groundwater.

In terms of volumes, it represents a very small portion of the overall water supplied, but in terms of the national objective of development and the elimination of poverty and inequality, it represents major progress.

Groundwater is becoming increasingly important for urban water supply. 22% of towns use groundwater as sole source and another 34% in combination with surface water. Water sources of domestic water supply (urban & rural) are shown in Figure 11.

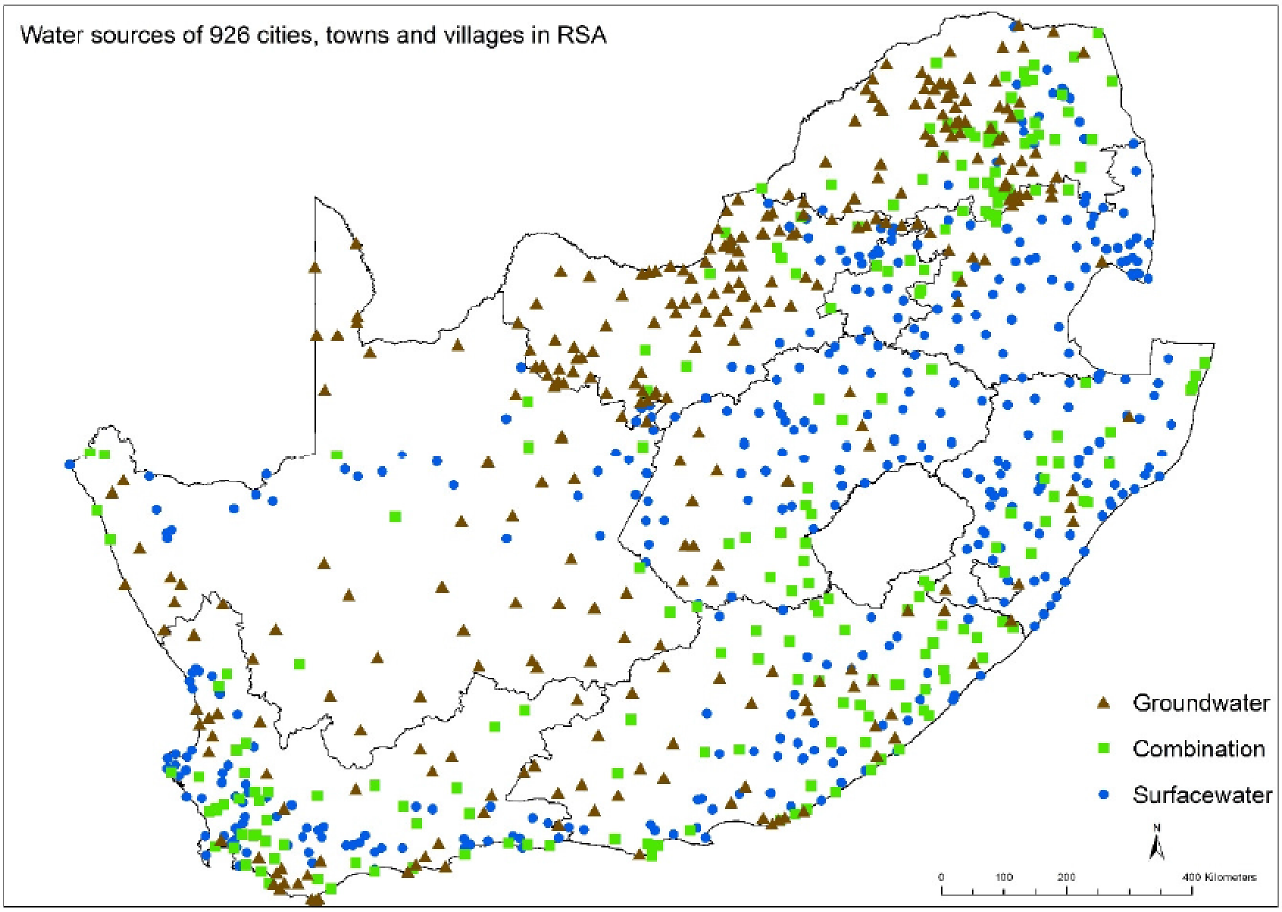

Figure 11: Water sources of domestic water supply (urban & rural) (Groundwater strategy, 2016).

6.7 Quantification of groundwater resources

Whilst the 'Surface Water Resources of South Africa' publication is currently undergoing its fourth revision, no similar such body of work is available for groundwater. In late 2003, the Department of Water and Sanitation initiated the so-called Phase 2 Groundwater Resources Assessment (GRA2) project, the main aim of which is to quantify South Africa's groundwater resources. The project also required that GIS-based algorithms be developed that would enable DWS to easily update the groundwater resource potential estimates in the years ahead as new and more detailed geohydrological information became available. A raster or grid based GIS model was developed and all and outputs were produced at a cell size of 1x1km. The following key outputs from the project will be discussed (1) aquifer storage, (2) recharge and (3) yield.

6.7.1 Aquifer storativity

GIS layers were developed for various levels within a conceptual aquifer system (Figure 12). These aquifer levels are grouped into two broad zones; namely (i) 'static' storage zone, which is the volume of groundwater available in the permeable portion of the aquifer below the zone of natural water level fluctuation (level 2), and (ii) 'dynamic' storage zone, which is the volume of groundwater available in the zone of natural water level fluctuation. The levels are listed below:

Level 1 – base of the aquifer

Static

Level 2 – base of the natural dynamic groundwater elevation

Level 3 – current groundwater elevation

Level 4 – average groundwater elevation

Dynamic storage

Level 5 – top of the aquifer

A sixth level, a management water level restriction, was introduced to take into account any possible environmental, legal or other constraints placed on the volumes of water that may safely be abstracted from an aquifer system, e.g. restrictions to ensure that DWAF's 'Reserve' requirements are met, restrictions on maximum water level drawdown in dolomitic aquifers due to the hazard of sinkhole formation or avoiding intrusion of saline water.

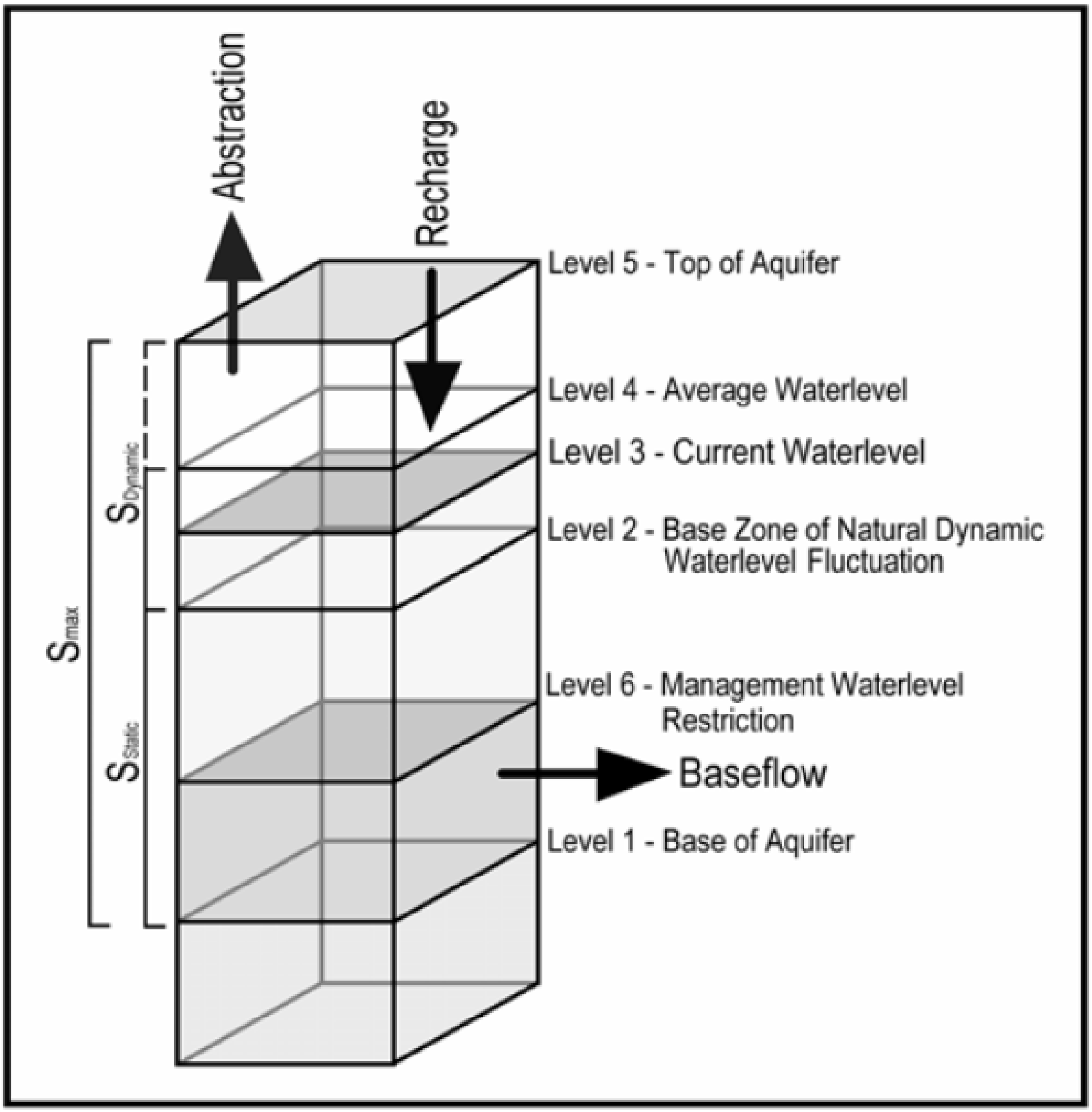

Figure 12: Six Levels in Aquifer System used to assess volumes of Groundwater held in storage (Colvin *et al*., 2007).

The volume of water stored between any two aquifer levels or zones is estimated as the volume of aquifer material reduced by an appropriate storage-coefficient or specific yield. The GIS model makes use of a number of these potential storage volumes (levels) together with parameters such as rainfall recharge and base-flow to determine the annual volumes of groundwater available for use on a sustainable basis.

The approach involved defining the thickness and storativity of two aquifer zones, (i) the upper 'weathered-jointed' or WZ and (ii) the underlying 'fractured' zone or FZ. It is estimated that 79% of this water is stored in the WZ which is on average only 33 m thick, as opposed to an average FZ thickness of 121 m – providing a mean aquifer thickness of 154 m. The mean storativity of the WZ and FZ is estimated at 2.62×10^{-3} and 1.52×10^{-4}, respectively. The distribution of storage is shown in Figure 13 which indicates that some 235,500 Mm^3 of groundwater may be stored in aquifer systems in South Africa.

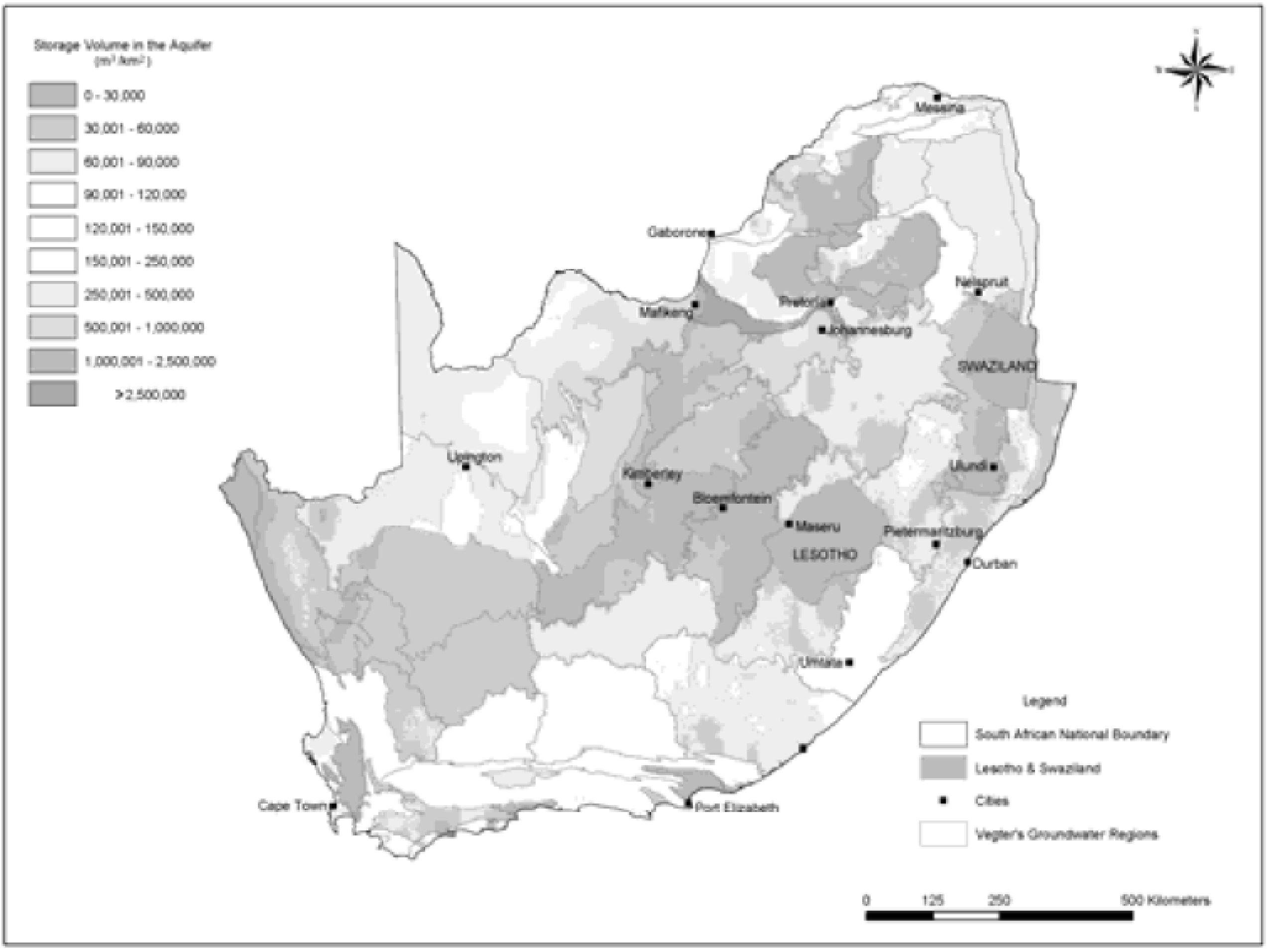

Figure 13: Estimated total volume (m^3/km^2) of groundwater stored in South African Aquifers (Groundwater strategy, 2016).

6.7.2 Aquifer recharge

The annual groundwater recharge from rainfall was estimated using the chloride-mass-balance and a GIS based modelling approach using various empirical rainfall versus recharge relationships. This was followed by cross calibration of results with field measurements and detailed catchment studies. A mean annual recharge volume of 30,520 Mm^3 was thus calculated.

6.7.3 Groundwater resource yield estimates

The methodology developed to estimate the sustainable yield of the groundwater resources during the GRA2 project employs a basic water-balance approach, where the change in storage in a system is equal to all inputs to, less all outputs from the system.

Over long periods of time and where the groundwater system is in its natural state (i.e. without any abstraction), the natural inputs will be in balance with the natural outputs, such that the change in storage will be zero. This means that the groundwater component of the hydrological system is in a quasi steady-state, which implies that the averaged values of the variables have not changed over the time period over which the averaging took place. However, if groundwater is abstracted from the system, this balance is disturbed and the system is no longer in steady-state and water levels will decline in response to withdrawals from groundwater storage.

A new steady-state will be established, in theory, if abstraction does not exceed recharge. If abstraction exceeds recharge the system will remain in a dynamic (transient) or unsteady-state. Groundwater is now removed mainly from storage, as well as a proportion from river systems.

A GIS based raster-modelling approach was used to apply these basic water-balance equations to each cell in the study domain for both steady and unsteady-state conditions. The steady-state algorithms are applied to produce information relating the 'average' groundwater conditions using 'averaged' input datasets (i.e. mean annual recharge, average water level, etc.). These averaged outputs will only require updating should more accurate input datasets be acquired or if the algorithm is enhanced. The transient-state algorithms need to be applied at regular time intervals, in this case yearly, to produce outputs about the current status of the groundwater resource, and will be required as input information generated during the previous time step (i.e. antecedent conditions such as aquifer storage and water levels). The algorithms are developed in a hierarchical system whereby the output from one lower-order algorithm is required as input into the next higher-level algorithm, where an additional refinement or management restriction is applied and so on.

6.7.3.1 Groundwater resource potential

The Groundwater Resource Potential (GRP) is defined as the maximum volume (m^3) of groundwater that can be abstracted per unit area per annum without causing any long-term 'mining' of the aquifer system (i.e. without continued long-term declining water levels). The GRP is based purely on physical inputs / outputs and aquifer storage. It is therefore not equivalent to the 'sustainable' or 'optimal' yield of the system, which normally takes into account factors such as intrusion of poor quality water, variable aquifer permeability, practical and cost issues relating to extracting the water, etc.

Two basic algorithms have been developed to determine the GRP based on the (i) average or steady-state (AGRP) and (ii) dynamic or transient-state aquifer conditions. The steady-state Groundwater Resource Potential dataset is similar to DWAF's Harvest Potential map in that they both provide estimates of the maximum volumes of groundwater that are potentially available for abstraction on a sustainable basis, and only take into consideration the volumes of water held in aquifer storage and the recharge from rainfall. The feasibility of abstracting this water is limited by many factors due mainly to the physical attributes of a particular aquifer system, economic and/or environmental considerations. One of the most important of these is the inability to establish a network of suitably spaced production boreholes to 'capture' all the available water in an aquifer system or on a more regional scale (Water Systems Management, 2001). The factors limiting the ability to develop such a network of production boreholes, include, inter alia, the low permeability or transmissivity of certain aquifer units, accessibility of terrain to drilling rigs, unknown aquifer boundary conditions.

The Average Groundwater Resource Potential or AGRP of aquifers in South Africa (Figure 14 and 15) is estimated under normal rainfall conditions at 49,249 Mm^3/a, which decreases to 41,553 Mm^3/a during a drought. These estimates are regarded as the maximum volumes that could be abstracted on a sustainable basis, if and only if, an adequate and even distribution of production boreholes could be developed over the entire catchment or aquifer system – which is impractical both physically an economically.

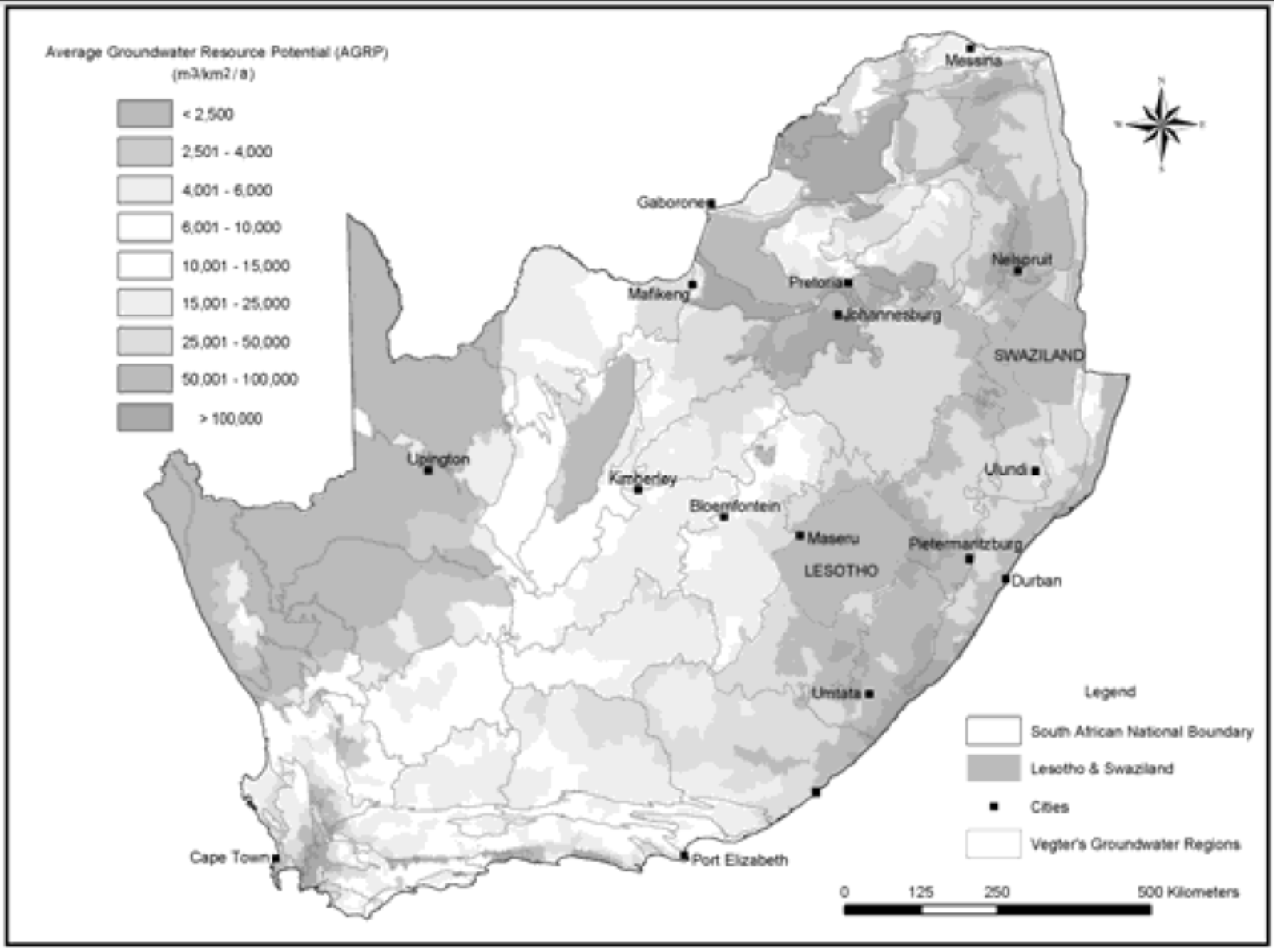

Figure 14: Average Groundwater Resource Potential for South Africa (Groundwater strategy, 2016).

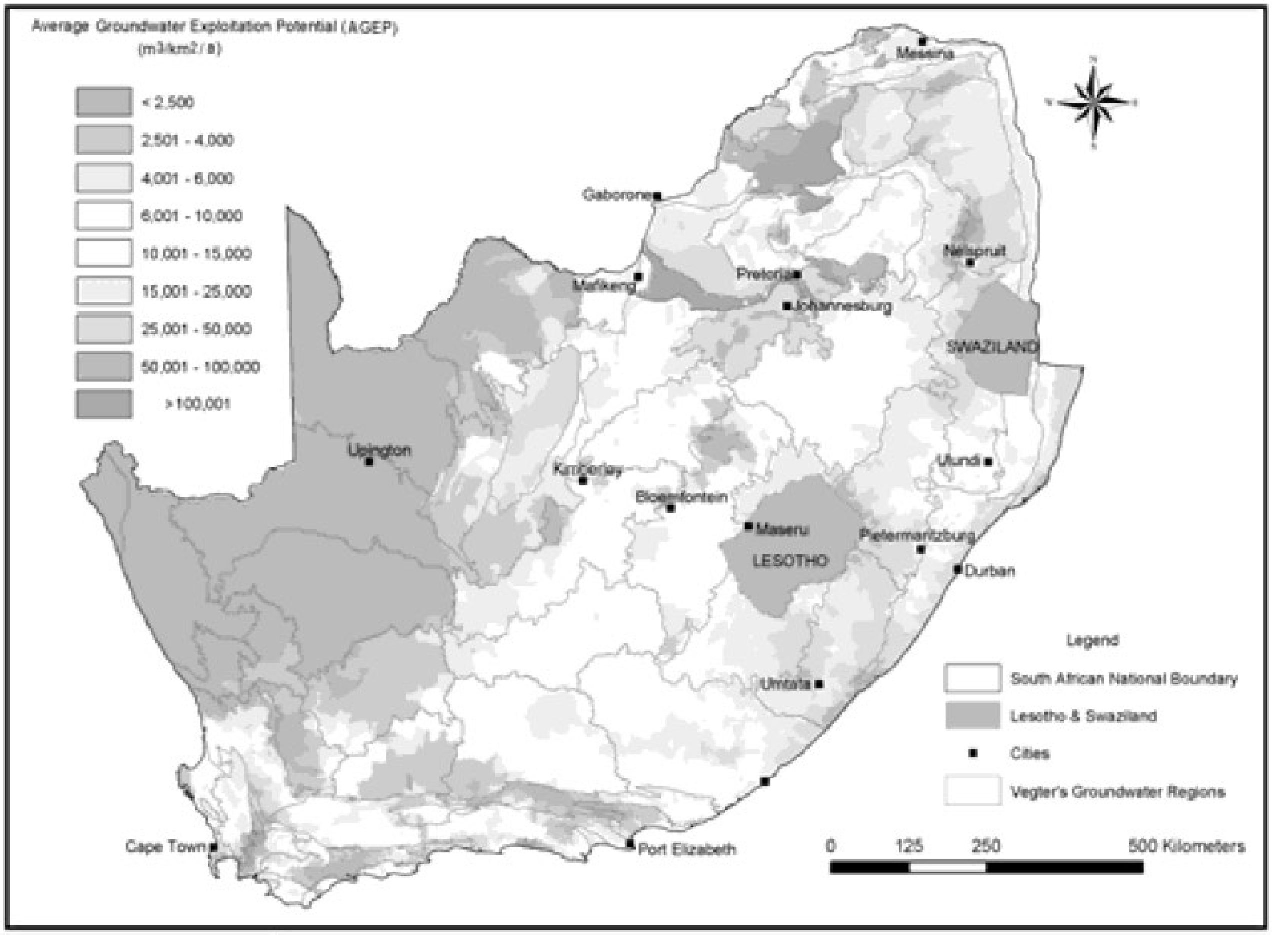

Figure 15: Average Groundwater Resource Potential for South Africa (Groundwater strategy, 2016).

6.7.3.2 Groundwater exploitation potential

In order to account for the pumping limitations discussed above, the GRA2 project made use of Haupt's (2001) concept of an 'Exploitability Factor' or EF and Vegter's (1995) national 'Borehole Prospects' coverage to generate a 1x1km EF grid for the country. Vegter stated that the prospects of obtaining a groundwater supply from a particular lithological unit may be judged by analysis of the yield distribution of an adequate number of randomly spaced boreholes drilled into this unit. He classified the lithostratigraphic units of the country into 16 water-bearing categories and analysed the yield information from 120,000 boreholes obtained from DWAF's NGDB. The Borehole Prospects coverage is therefore an indication of the extent to which various lithological units are able to act as aquifers.

The EF factor was applied to the AGRP grid to produce the so-called 'Average Groundwater Exploitation Potential' or AGEP coverage. The total AGEP of aquifers in South Africa is estimated at 19,073 Mm^3/a, which declines to 16,253 Mm^3/a during a drought. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be annually abstracted on a sustainable basis.

Groundwater quality is one of the main factors restricting the development of available groundwater resources. Although there are numerous problems associated with groundwater quality, some of which are relatively easily remediated, high concentration of total dissolved solids, nitrates and fluoride are considered to be the most common and serious problems associated with water quality on a regional scale.

6.7.3.3 Potable groundwater exploitation potential

The Potable Groundwater Exploitation Potential (PGEP) of aquifers in South Africa (Figure 16) is estimated at 14,802 Mm^3/a, which declines to 12,626 Mm^3/a during a drought. Nationally, this represents almost a 30% reduction in the annual volumes of available groundwater for domestic supply due to water quality constraints.

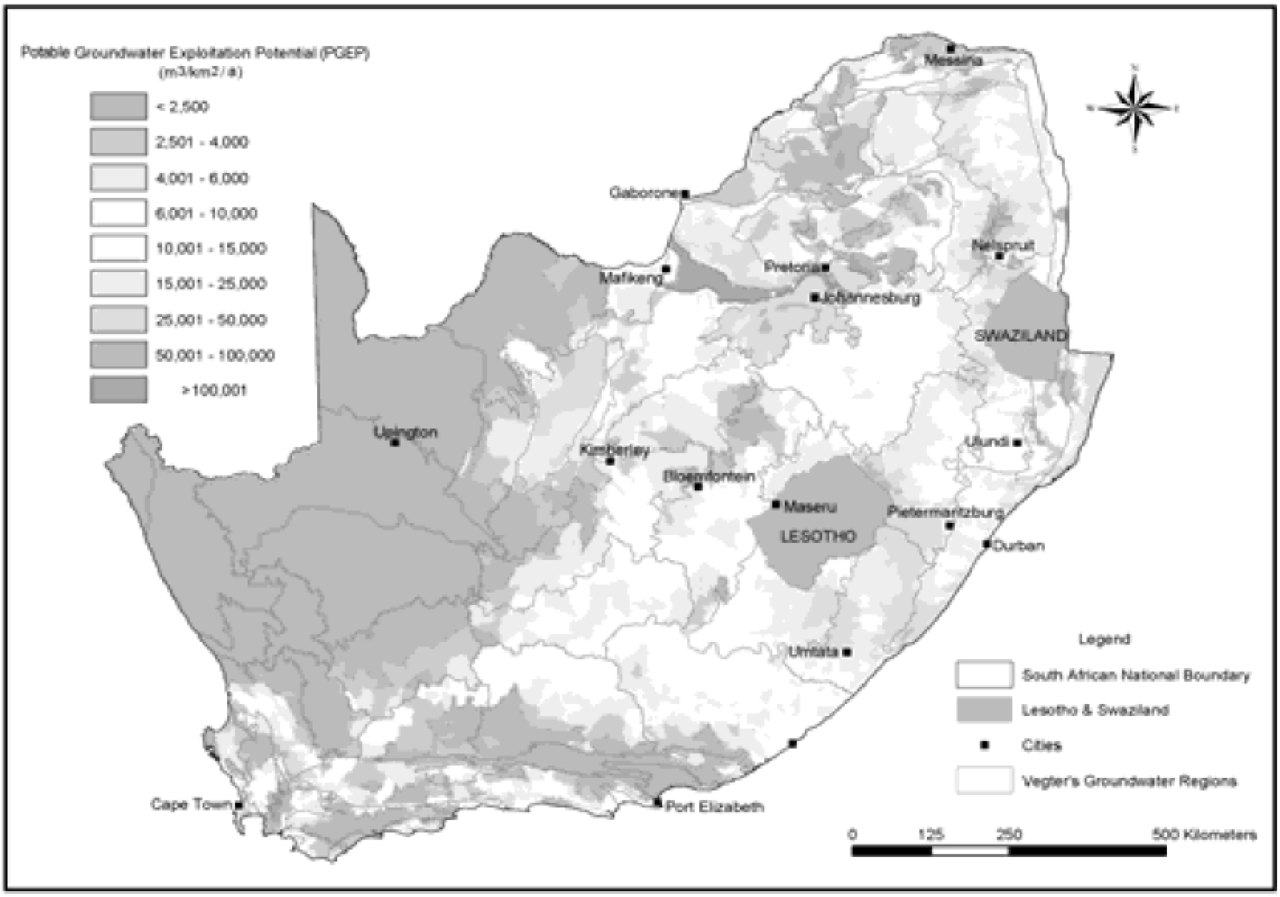

Figure 16: Potable Groundwater Exploitation Potential of South Africa (Groundwater strategy, 2016).

6.7.3.4 Utilisable groundwater exploitation potential

The volume of water that may be abstracted from a groundwater resource may ultimately be limited by anthropogenic, ecological and/or legislative considerations, which ultimately is a management decision that will reduce the total volume of groundwater available for development – referred in the GRA2 project as the Utilisable Groundwater Exploitation Potential (UGEP). This includes the important legislative restriction imposed on the volumes of groundwater available for utilisation by the requirements of the 'Groundwater Component' of the Reserve as stipulated in the South African National Water Act of 1998. Other aspects such as protection against the hazards of saline intrusion or sinkhole formation, conserving important groundwater dependant ecosystems, maintaining baseflow to rivers, etc. can all be factored in using this approach.

The Utilisable Groundwater Exploitation Potential (UGEP) under normal rainfall conditions and under drought conditions is estimated at 10,353 and 7,536 Mm^3/a, respectively (Figure 17). The UGEP represents a management restriction on the volumes that may be abstracted based on the defined 'maximum allowable water level drawdown' and therefore it is always less than or equal the AGEP. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be annually abstracted on a sustainable basis.

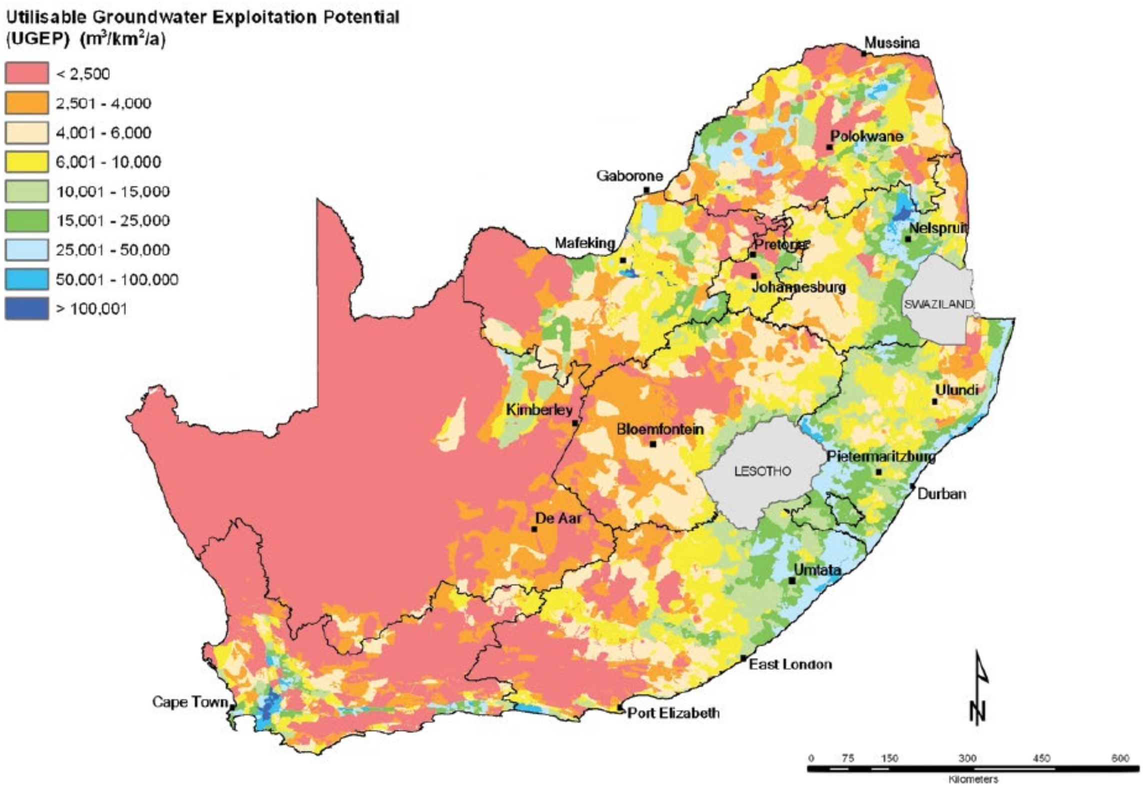

Figure 17: Utilisable Groundwater Exploitation Potential for South Africa (Groundwater strategy, 2016).

6.8 How much groundwater does South Africa have?

One of the most important questions that is frequently asked is "how much groundwater do we have in South Africa?" This question is more complex than it might first seem, because using groundwater in a sustainable way for water supplies, without harming the environment, depends on sufficient data and on factors including recharge (i.e. what proportion of rainfall percolates into the ground to become groundwater), the quality of the groundwater, and the properties of the aquifer (i.e. an aquifer that supports only very low yielding bore holes may contain a lot of groundwater, but still not be very useful for water supply). The most recent scientific estimates place groundwater in South Africa in the same league, volumetrically, as our storedsurface water resources: The total volume of available, renewable groundwater in South Africa (the Utilisable Groundwater Exploitation Potential, or UGEP) is 10 343 million m³/a (or 7 500 million m³/a under drought conditions. (See Table 6.1 below for a breakdown of groundwater availability per Water Management Area)

Table 1.2: Groundwater Availability per Water Management Area (WMA) modified after Colvin *et al*. (2007).

Number	**Water Management Area**	**UGEP (Million m^3/a)**
1	Limpopo	644.3
2	Luvuvhu and Letaba	308.9
3	Crocodile West and Marico	447.8
4	Olifants	619.2
5	Inkomati	667.8
6	Usutu to Mhlatuze (including Swaziland)	862.0
7	Thukela	512.6
8	Upper Vaal	564.0
9	Middle Vaal	398.1
10	Lower Vaal	645.1
11	Mvoti to Umzimkulu	704.9
12	Mzimvubu to Keiskamma	1 385.9
13	Upper Orange(including Lesotho)	673.0
14	Lower Orange	318.0
15	Fish to Tsitsikamma	542.4
16	Gouritz	279.9
17	Olifants/Doring	157.5
18	Breede	362.9
19	Berge	249.0
Total		10 343.4

We currently use between 2 000 and 4 000 million m³/a of this groundwater. Therefore there is the potential to considerably increase groundwater supplies in South Africa. In contrast, the assured yield of South Africa's surface water resources is approximately 12 000 million m³/a, but more than 80% of this is already allocated. Although most (but not all) large-volume water users rely on surface water, the majority of small water supplies, which are critical to livelihoods and health, depend on groundwater (See figure 10 for the groundwater use per sector in WMA).

6.9 Groundwater and drought / climate change

Groundwater's resilience to drought is well known – often one of the first responses in times of serious drought is to drill boreholes. The southern African region is already prone to droughts, and climate change scientists predict that this may get worse – climate change forecasts for southern Africa anticipate hotter, drier weather, particularly in the west. Rainfall events may be more intense, but less frequent. With surface water resources already stretched in South Africa, groundwater should form a very important part of our climate change adaptation strategy in terms of assuring continuity of water supplies. Much work still needs to be done regarding the effects of climate change on technical issues such as groundwater recharge.

However, the seriousness of the issue is not in doubt – as a recent UNEP publication on climate change in southern Africa puts it: "…climate change may bring about a new set of weather patterns and extremes that are well beyond what the local communities in southern Africa are capable of dealing with.

The advantages of groundwater (much lower evaporation/evapotranspiration and slower declines in drought years, because the volumes stored underground are so much higher compared with surface water) mean that it should form a key part of our strategy to adapt to climate change. Groundwater will be less directly and more slowly impacted by climate change, as compared to, e.g. rivers (surface water). This is because rivers get replenished more quickly, and droughts and floods are quickly reflected in river water levels. Only after prolonged droughts will groundwater levels show declining trends. Groundwater is also closely linked to the issue of food security through irrigation of crops and maintenance of environmental flows.

The replenishment of groundwater is controlled by long-term climatic conditions. Since rainfall is the main source of recharge to aquifers, climate change may have a considerable impact on groundwater resources. Under predicted climate change conditions, groundwater has to be used and managed in a sustainable way in order to maintain its buffering and contingency supply capabilities, as well as maintain adequate water quality for human consumption.

Land-use planning has to consider groundwater resources as a precious and finite resource, and take all necessary measures to protect groundwater resources and their recharge mechanisms in the long run. Other impacts of climate change on groundwater include possible salinisation of coastal aquifers as sea levels rise, higher annual temperatures increasing rates of evapotranspiration (and therefore reducing recharge), and more intense storm events which can destroy small alluvial aquifers associated with river channels.

Our understanding of the impact of climate changes on groundwater in South Africa is limited and further research need to be conducted on various aspects of groundwater (quality and quantity) to quantify the impact on groundwater and on the communities that are dependent on groundwater.

Recommendations made elsewhere in this document on topics such as artificial recharge, groundwater data collection and groundwater research all form part of our strategy for meeting climate change.

6.10 Summary

Estimates of the available groundwater resource potential of South Africa range from a maximum of 47,727 Mm^3/a to as low as 7,536 Mm^3/a. For general water resource planning purposes, it is recommended that the so-called ‘Average Groundwater Exploitation Potential’ or AGEP be adopted where the total volume of groundwater available for abstraction under normal rainfall conditions is estimated at 19,073 Mm^3/a and which declines to 16,253 Mm^3/a during a drought. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be annually abstracted on a sustainable basis. Only approximately 6% by volume of the AGEP is currently being abstracted on an annual basis.

6.11 Exercises and tasks

1. Explain and illustrate with diagrams how Groundwater occurs in South Africa.

2. How much Groundwater does South Africa have? Support your answer with the use of Groundwater use per sector.

3. Based on the content of this module and your observations, how does the use of groundwater have an effect on the following?

- Drought in South Africa
- Overall Hydrological Cycle

4. Summarize the Groundwater Quantity “Concept” based on your opinion and/or experience

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6.12 Report from student for evaluation and assessment.

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Module 7: Groundwater monitoring

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7. Learning Objectives

To understand and describe the following:

- Objectives and purpose of groundwater monitoring;
- Quality and quantity monitoring, their indicator parameters;
- Monitoring programme design.

7.1 Introduction

Scarcity of water and the increasing concern of groundwater contamination have led to the implementation of monitoring networks and is a pre-requisite for effective management (Zhou, 1994).

Research and knowledge about groundwater resources and the increasing development in population, industrial and agricultural water demand, has indicated that groundwater resources need to be managed and monitored effectively to prevent the deterioration of groundwater quality and quantity (Zhou, 1994).

According to Makeig (1991), the need for the regulation and management of activities that indicates a threat to groundwater quality has become more important over the years.

A balance between supply and demand can be seen in groundwater resources and as a result there is a narrow link between the quantity of useable groundwater and the quality of that water. The effective management and protection of groundwater resources depends on the knowledge and understanding of basic principles, as well as the availability of information on factors affecting the quantity and quality (Zhou, 1994).

Monitoring provides and includes data on groundwater quantity and quality of the resource itself and is an integral aspect of groundwater management (Sundaram *et al.*, 2009). In the absence of monitoring, groundwater quality deterioration, groundwater abstraction and contamination takes place without any safeguard for this resource (Owen *et al.*, 2010).

A groundwater monitoring system operation, programme and design needs careful planning in which significant and useful information can be achieved in a sustainable, cost effective manner (Owen *et al.*, 2010).

7.2 What is monitoring

7.2.1 Monitoring Defined

Groundwater monitoring is impractical without a clear and distinct definition.
Bosman (2014) defined monitoring as the process of collecting data in a systematic manner that is used for a specific purpose. In other words it is data that is collected at a certain suitable frequency, location and on specific features of the water resource, to ensure that date recorded in regard to the resource status is complete, accurate and cost effectively.

The organisation of such data into information which is to be used in improving the decision-making process,

- Directly as a management tool for the company and
- Indirectly to inform government the public and other parties.

Monitoring of groundwater is an important component in groundwater management and is also described in general terms as the ongoing process of collecting data and the organising and assessment of data into information to improve decision making and determine performance progress and trends (*Basic Information*, 2016 and Jha, 2010).

7.2.2 Monitoring Information

Appreciation of the importance of reliable data (values collected by measurement) and information (data which had been evaluated and interpreted to indicate the state of conditions) is lacking regardless that monitoring is a vital and integral component of all hydrogeological studies. In groundwater management the collection of data and the interpretation of information on groundwater resources play an important role and form the foundation for management.

The absence of accurate and reliable groundwater data can compromise the accurate assessment and status of groundwater supply of the resource (Department of Water Affairs, 2013).

"A reliable dataset can only be achieved through approved, standardized, capturing procedures of quality approved data" (Department of Water Affairs, 2010).
Monitoring is thus necessary for precise and sufficient data collection to inform decision making, and reduce and manage risks. The ultimate objective is to provide information that can be used for planning, decision making and operational water management (Department of Water Affairs, 2013).

According to Bosman (2014), management decisions must be based on information, not on data. A lack of data and skills results in inadequate information for decision support and poor management of the resource. The hierarchy of monitoring information can be seen in figure 1.

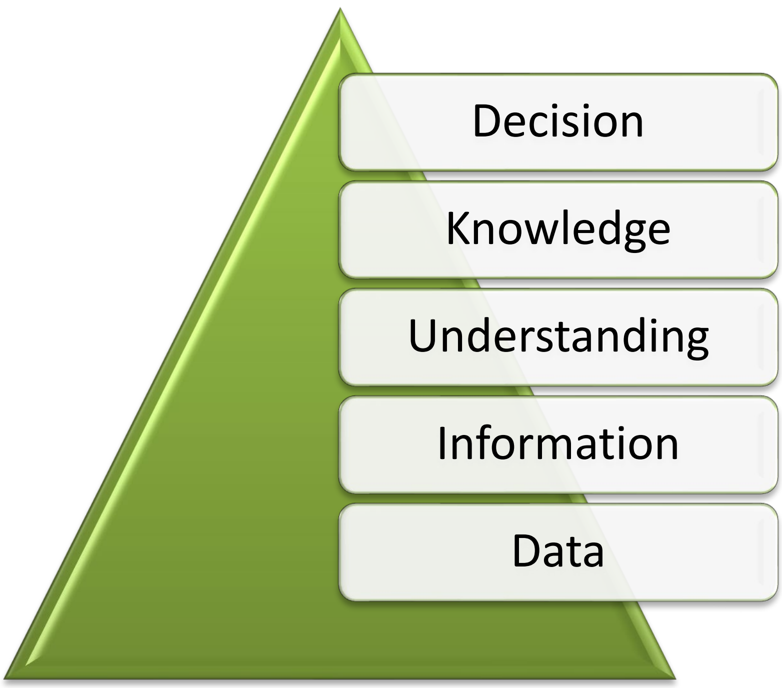

Figure 1: Hierarchy for monitoring information (Bosman, 2014).

7.2.3 Objectives of monitoring

It is said that you can't manage, what you can't measure. Groundwater management can't be implemented without appropriate monitoring. Objectives are described as a specific action on how goals and purposes of monitoring can be achieved (PNAMP, 2010).

It is important that objectives of groundwater monitoring are established, specified and recorded. By recording objectives misunderstandings can be avoided on a later stage, it can act as an effective communication method with sponsors and assure that a monitoring programme is a systematically planned exercise. They are also important to see if objectives are being met or not when evaluating the program.

To assist with the developing of groundwater objectives, the following questions might be considered: (Bartram and Ballance, 1996; PNAMP, 2010).

- Constraints that can play a role on monitoring programme
- Management requirements in regard to funding entities, managers, etc.
- Monitoring design characteristics
- What frequency should be used?
- What information is required on water quality?
- Which variables should be measured?
- Who is going to use the monitoring data and why?
- Why is monitoring going to be conducted? Is it for basic information, planning and policy information, management and operational information, regulation and compliance, resource assessment, or other purposes?

Below is a list of typical objectives in relation to monitoring for groundwater management. This list provides some examples and may be used to form a basis for establishing objectives (Bartram & Ballance, 1996; Department of Water Affairs and Forestry, 2006; Fretwell, Short & Sutton, 2003; Department of Environmental Protection, 2001; Water Research Commission, 2000; World Meteorological Organization, 2013; Bartram and Ballance, 1996; Bosman, 2014).

- Aquifer materials or their hydrologic properties characterize
- Detection of contaminated areas
- Develop and implement a national monitoring and information management plan to record and maintain easily accessible and accurate data to support decision making, reduce and manage risks and deal with emerging climate change impacts.
- Development of regulations covering the quantity and quality of waste discharges
- Development of water quality guidelines and/or standards.
- Ensure uninterrupted continuation of existing monitoring programmes
- Evaluation of the effectiveness of a water quality management.
- Groundwater resource characterized
- Identification of sources of pollution and extent of pollution
- Improve governance of monitoring and information management in the water sector.
- Measure the hydraulic head at a specific location in the groundwater flow system
- Provide access for conducting tests or collecting information necessary to
- Provide access to the groundwater system for collection of water samples
- Raise awareness of the importance of investing in the collection and management of high-quality water-related information for supporting water resource management.
- To obtain information on local groundwater quantity and detection of signs influencing water quality.
- Water pollution control programme development

7.2.4 Purpose of monitoring

"Why do we monitor?" This is the question we should start with in any attempt to assess groundwater monitoring. Being able to describe the purpose of monitoring create and assist a background for direct monitoring activities. The purpose is generally set by regulatory actions and laws (action plans, water standards, regulations, laws, directives) and aims to detect trends and evaluate the environmental and groundwater resource state (Kristensen & Bøgestrand, 1996).

A monitoring programme should start by discussing the real need for information and data. The purpose of monitoring is to supply information and data and verify that groundwater levels and groundwater quality is suitable for intended users and uses. Monitoring should reflect the data needs of the various water users involved. Many monitoring programmes serve several purposes such as defining, develop, and set objectives of management needs. A purpose of monitoring also determines if management objectives are being achieved, assessing trends, provide early warning systems programme evaluation and policy development (Bosman, 2014).

The need and purpose of monitoring depends on the type of facility that requires monitoring, the location of monitoring and the complexity of conditions (Department of Environmental Protection, 2001).

The purpose of monitoring groundwater provides data to assist management in groundwater resources (the availability, sustainability, protection, conservation, determining impacts on quality and quantity) and provides information for implementation and development of groundwater policies and their effectiveness (efficiency of policy, controls, treatments and use of restrictions.

7.3 Monitoring programme design

7.3.1 The Monitoring cycle

The monitoring cycle is a systematic planning process to develop acceptance or performance criteria for the collection, evaluation, or use of environmental data.
A well-developed monitoring design plays a critical role in ensuring that data are sufficient to draw relevant conclusions (U.S Environmental Protection Agency, 2002).

The monitoring cycle generally describe the steps and processes for effective water management. A monitoring cycle (figure 2) entails the process of defining the objectives and purposes of information needs, the design of a monitoring programme, the process of data collection types and processes and the process of data storage, analysis, interpretation and distribution (Bosman, 2014).

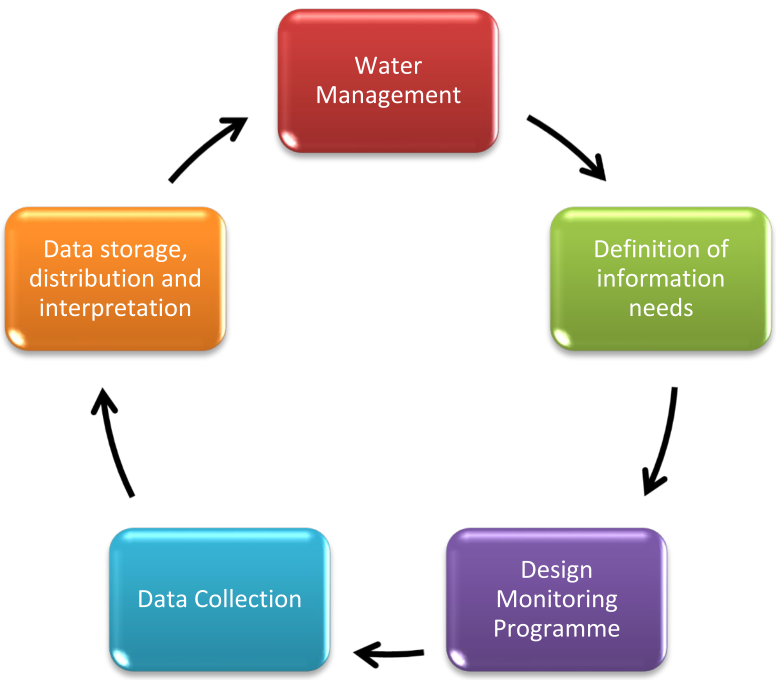

Figure 2: The monitoring cycle (Bosman, 2014).

7.3.2 Monitoring Programme

Monitoring programmes are usually developed to support and assist various management actions with different objectives. Monitoring programs assist in the following;

- Monitoring Locations
- Monitoring Frequency
- Data and information management and record keeping (discussed in Module 8)
- Reporting

7.3.2.1 Monitoring Locations

The main requirement and first task in groundwater design for a successful monitoring system is to determine the location of monitoring points (Department of Environmental Protection, 2001). Monitoring points can't be placed at random, but should be placed at the most suitable location to collect the required information and data accurately. A monitoring position that is not placed at the correct location might indicate incorrect groundwater information and data, which will lead to inaccurate evaluations, assessments and wrong decisions.

Before any monitoring location is selected, existing data should be assessed. This will assist in selecting the appropriate location and reduce cost of implementing a monitoring program. Existing data and information may be obtained from previous studies, site visits, aerial photographs, publications, geophysical and hydrological surveys as well as aquifer tests to name a few (Department of Environmental Protection, 2001).

A number of factors play a role in determining the location of monitoring points. (World Meteorological Organization, 2013; Department of Water Affairs and Forestry, 2006; Bosman, 2014; Fretwell, Short and Sutton, 2003):

- Accessibility to groundwater
- Activities nearby
- Physical constrains visible on site
- Pollution sources
- The purpose of monitoring programmes (objective and purpose).
- Variation in groundwater health and safety implications of the location low conditions and directions
- Depth of groundwater table
- Health and safety implications.

All the mentioned factors contribute towards defining the location of monitoring points and thus are a qualified person required to choose the appropriate location of groundwater monitoring points. These points should be clearly indicated, mapped and described in accessible format with coordinates (Department of Water Affairs and Forestry, 2006).

7.3.2.2 Monitoring Frequency

The monitoring frequency need to be defined once the location for monitoring points and the parameters to be measured is established. Monitoring frequency is dependent on the purpose of sampling, the type of sampling and the depth of the aquifer formations (Harter, 2003). Monitoring frequency in a monitoring program is among the most important components (Taylor and Alley, 2001).

Monitoring and sample frequency is depended and influenced by the characteristics of the water source and the amount of people allocated with water. Groundwater quality is generally described as more constant than other waters and less groundwater samples should be sufficient depended on the use for data (Water Research Commission, 2000). The minimum and recommended number of samples and sampling frequencies for different points in the water supply system is discussed in detail in the report: Quality of Domestic Water Supplies, Volume 2: Sampling Guide by The Department of Water Affairs and Forestry.

7.3.2.3 Reporting

Reporting vary greatly depending on the intended use and have to focus on the amalgamation of the data collected, rather than on the individual numbers that make up the data. In the reporting process it is important to remember that for effective understanding of reports that the resource and environmental situation must be clearly described and defined.

Keep in mind that not everyone is a specialist and that monitoring reports should be written in simple ways and should contain clear explanations (Bartram and Ballance, 1996). Monitoring results should be reported for a diverse audience in understandable terms that include the effects of processes, events and mechanisms on water.

7.4 Monitoring design

In the monitoring design process a few important parameters should be monitored;

- Groundwater level measurements
- Water Flow/Quantity monitoring systems
- Rainfall
- Field parameters
- Water quality
- Borehole development and yield testing.

7.4.1 Groundwater level measurements

The depth to the water level in the borehole is also called the static water level or the rest water level. This is the groundwater level in a borehole not influenced by artificial recharge or by abstraction. These values are used to determine hydraulic gradient and the direction of groundwater flow. The hydraulic gradient is described as the slope of the water table. This is therefore the change in hydraulic head (the elevation to which water will rise in a borehole connected to a specific point under pressure in an aquifer) over a certain distance (Department of Water Affairs, 2015).

By monitoring groundwater level measurements, information can be provided on the water levels within the boreholes and the hydraulic gradients within individual aquifers and between aquifers in layered aquifer systems. Groundwater level monitoring measurements over a long period is important and therefore provides information on the temporal trends in groundwater levels and flow direction due to the effects of groundwater abstraction, rainfall and drought (Sundaram *et al.*, 2009). Changes in water levels may perhaps directly be linked to groundwater quality changes.

Note that one can't monitor production boreholes with permanently installed pumping equipment without a piezometer tube to provide access to the borehole casing. The piezometer tube is a small diameter pipe alongside the main borehole casing. It is essential to have an established reference point when monitoring the depth to groundwater level. The reference point must be identified with a permanent marker or paint spot to provide a constant starting point for monitoring on the well casing (California Department of Water Resources, 2016).

7.4.1.1 Groundwater level measurements using a dip meter

The water level meter or dip meter uses a probe attached to a permanently marked polyethylene tape, fitted on a reel. The probe detects the presence of a conductive liquid between its two electrodes and is powered by a standard 9 volt battery. Once contact with water is made, the circuit is closed, sending a signal back to the reel. This will result in an activation of a buzzer and a light. The groundwater level is then determined by taking a reading directly from the tape, at the reference point marked on top of the borehole casing.

7.4.1.2 Steps in measuring the groundwater level

(Sundaram *et al.*, 2009 and California Department of Water Resources, 2016)

1. Wash your hands or wear disposable gloves- remember your working with drinking water.
2. Ensure that the dip meter is clean.
3. Before starting record the sampler's name, the date and time of measurement as well as the elevation (relative to sea level) and coordinates of borehole in a logbook or monitoring form that has been determined by utilizing local benchmarks and survey instruments.
4. Water levels will be measured from reference point marked at each well. The measuring point is located on the top of the steel protective casing (surface casing).
5. Switch the dip meter on when having an on/off switch.
6. Remove or open the end cap on top of piezometer tube.
7. Lower the dip meters probe slowly into the piezometer until an audio signal, light indicator, or meter deflection is noted – this will be the position of groundwater level.
8. Double check the position on cable by lowering and lifting the probe a little while checking the audio signal, light indicator, or meter deflection.
9. Keep the correct position with fingers or by temporally marking or pinching the cable.
10. Read and record the measurements seen on cable on your logbook.
11. Subtract the height of the casing above the ground level from the measurement. To record the water level relative to the ground surface, the measured distance between the measuring reference point (e.g. top of casing) and the ground surface is subtracted.
12. Check and insure that the measurements are recorded correctly, i.e.15 metres and 8 centimetres is recorded as 15.08 m and not 15.8 m. 15.8 m is thus 15 metres and 80 centimetres.
13. Clean the probe and cable and dry it probably to prevent contamination on next borehole.
14. Close or put back the end cap on top of piezometer tube.

7.4.2 Water Flow/Quantity monitoring systems

The best way to successfully monitor groundwater flow/quantity is by installing flow meters.

Although the installation of water flow meters not a common practice is among the majority of water supply boreholes, it will provide an effective monitoring system to record the volume of water pumped on a daily basis (Meyer, 2002). The ability of any flow meter is to accurately measure a wide range of flow rates.

Groundwater flow monitoring is very site specific and is dependent on the local geohydrology. Thus is a suitable qualified person necessary to evaluate and assist in the technical procedure of a groundwater flow monitoring program (Department of Water Affairs and Forestry, 2006).

7.4.3 Rainfall

Meyer (2002) described that rainfall an important role play in the recharge of aquifers. Therefore is the monitoring of rainfall a vital component in groundwater management and the data of monitored rainfall can be used to estimate groundwater recharge. The installation of low cost rain gauges can be used to monitor rainfall on a daily basis but the manually recorded data is often unreliable. Thus should a cumulative rainfall sampler be used that will allow rainfall measurements to be recorded an extended period without the loss or manipulated data.

7.4.4 Field parameters

The assessment and analysis of various physical, chemical and microbiological features and variables in groundwater can be determined by testing field parameters on site (Bartram and Ballance, 1996). A number of reasons contribute to the fact why "location based" field analysis is a significant advantage and include the following; (Weaver, Cavé and Talma, 2007), (Bartram and Ballance, 1996)

- Samples are not yet contaminated or changed in terms of characteristics due to storage in a container
- The efficiency of purging can be monitored and check
- The procedure or sampling sequence may be determined in relation to the result of certain values

- Obtain reliable values of groundwater field parameters that might change during the transport of sampling bottles
- Some variables must be measured after the sample collection due to aeration, oxidation and degassing
- Field analysis may be the only feasible way to obtain water quality information, when there are no laboratories within a reasonable distance of the sampling stations.

Field testing procedures and steps can be accessed in (Weaver, Cavé and Talma, 2007) and field testing methods include;

- Temperature
- pH
- Electrical conductivity (EC)
- Redox potential (Eh)
- Dissolved oxygen (DO)
- Alkalinity

7.4.4.1 Temperature

Temperature has an important influence on the physicality and chemistry characteristics of the water and is often the easiest field parameter to measure (Sundaram *et al.*, 2009). The temperature of groundwater is a significant parameter in water quality because it regulates the concentration dissolved oxygen of the water and influences the tempo of biological and chemical reactions (Frankenberger and Esman, 2012). The rate of chemical and metabolic reactions generally increases at higher water temperatures, and higher temperatures also increase the solubility of salts in water but decrease the solubility of gasses in water.

It is important that the groundwater temperature is measured in situ, since the fact that a water sample will reach the same temperature gradually as the surrounding air (Bartram and Ballance, 1996).The fluctuation in groundwater temperatures that is relative constant throughout the year is determined by geological factors, such as the groundwater formation, heat transferability of rocks, anthropogenic factors and the distance between the surface and groundwater (Sundaram *et al.*, 2009). Groundwater is typically measured in situ with a thermometer or TLC device and indicted in degrees Celsius or Fahrenheit.

7.4.4.2 pH

The amount and chemical form of several substances (organic and inorganic) dissolved in groundwater along with the alkalinity and acidity of groundwater is generally described by the pH of groundwater (Sundaram *et al.*, 2009). pH is described as the measurement of the concentration of hydrogen ions in a solution. The results fluctuate on a scale 0 to 14 (<7 is acidic, 7=neutral, >7 is basic) (Frankenberger and Esman, 2012). Values above 14 and below 0 are achievable in concentrated solutions, but not found in groundwater.

The suitability of groundwater for rural, domestic and commercial uses, the effect of toxicity of other substances and the ability of groundwater to transport harmful chemicals are important properties controlled by the pH of Groundwater (Sundaram *et al.*, 2009).

Groundwater pH may be affected by affected by numerous factors like the bedrock within the aquifer, nearby pollution sites and acid mine drainage. Field measurements of the pH is essential, otherwise the analysis should be completed in a laboratory within a 24 hour period (Frankenberger and Esman, 2012).

7.4.4.3 Electrical conductivity (EC)

Conductivity is described according to Weaver, Cavé and Talma (2007) as the ability of an aqueous solution to conduct an electric current. In simple terms described as the ability of water to pass an electrical current. Conductivity in groundwater is affected and depended by the presence of inorganic dissolved solids chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge) (Frankenberger and Esman, 2012). This is used as an indicator of how salt-free, ion free, or impurity free a sample of water is. EC profiling is also used to determine the depths of fractures which intersect the borehole. The lower the EC of the water is, the purer the water. The higher the EC value of the water, the higher the conductivity of the water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity (Sundaram *et al.*, 2009).

Note that all measurements is reported in millisiemen per metre (mS/m) and that the EC is measured in the field due to the fact that conductivity changes with storage time and is temperature-dependent (Bartram and Ballance, 1996).

7.4.4.4 Redox potential (Eh)

A measure of the oxidising/reducing conditions of the groundwater system is determined by redox potential (Eh) (Sundaram *et al.*, 2009). Redox is measured in units of millivolts (mV) and is usually reported as relative to the standard hydrogen electrode (SHE). Redox potential data is useful in interpreting metal species in solutions.

7.4.4.5 Dissolved oxygen (DO)

The dissolved oxygen concentrations remain a good indication of water quality and typically depend on the physical, chemical and biochemical activities in the water body (Bartram and Ballance, 1996). Dissolved oxygen (DO) concentration represents the amount of oxygen that is dissolved in a waterbody and is proportional to the local atmospheric pressure and inversely related to water temperature and salinity (Frankenberger and Esman, 2012). Dissolved oxygen can be influenced by the rapid decomposition of organic materials, high ammonia concentrations, high temperatures and low flow.

7.4.4.6 Alkalinity

Alkalinity values change rapidly when groundwater samples have been withdrawn from boreholes. To ensure accurate measurements, these variables should be monitored and measured in the field (DWAF, 1998). The alkalinity of water is its capacity to neutralise acid. The alkalinity of some waters is due only to the bicarbonates of calcium and magnesium (Bartram and Ballance, 1996). Alkalinity is described as the acid neutralising capacity of water.

7.4.5 Water Quality

The quality of water or water quality in the monitoring process can be described as the suitability of water for various uses in terms of its concentration and state in relation to the physical characteristics, organic and inorganic material present in the water (Bartram and Ballance, 1996). The analysis of groundwater quality monitoring, consist of a number of parameters and include chemical, physical and bacteriological tests (Meyer, 2002).

The physical, chemical or biological characteristics present in groundwater are usually determined by in situ measurements and by the analysis of groundwater samples. The four key components in groundwater quality monitoring are on site/field measurements, the analysis and collection of groundwater samples, the assessment of the analytical results and the reporting of the findings (Bartram and Ballance, 1996). Groundwater quality depends on a number of factors and includes human activities, composition of recharge water and rainfall, relationship between groundwater and soil, and physical, geochemical, and biochemical processes within aquifers (Bartram and Ballance, 1996).

Groundwater quality testing must be a compulsory action for municipalities providing bulk groundwater supply to communities.

7.4.5.1 Sampling

Appropriate sampling procedures are necessary for the effective monitoring of groundwater quality. The monitoring of groundwater quality samples is dependent on different sampling techniques. Chemical and microbiological monitoring samples require distinct sampling techniques to ensure that contamination of samples does not occur. The process of sampling groundwater in boreholes may require purging or stratified techniques depending on the purpose for the water quality sampling (Weaver, Cavé and Talma, 2007).

The principle behind purging a well prior to sampling is to remove stagnant water from the well bore to assure that the sample is representative of the groundwater in the geologic formation being sampled. Stagnant water in the well bore results from the water's contact with the casing and atmosphere between sampling events and removal of stagnant water is important because it modifies the chemistry of groundwater (Department of Environmental Protection, 2001).

Purging of the borehole involves the removal of sufficient water until the field chemistry parameters (pH, EC, DO, Eh, temperature, and turbidity) remain stable. For most cases, this involves the removal three times the volume of water contained in the borehole and should be removed in high yielding boreholes to remove the dead volume (Weaver, Cavé and Talma, 2007).

Stratified sampling is done by the process of sampling a relative small amount of water from specific depths within a borehole, but the water column should not be disturbed excessively while sampling. This process will identify horizons where pollution enters the borehole. It is desirable to conduct an electrical conductivity profile to indicate inorganic pollution that can determine the need for stratified sampling.

Sampling processes, collection and steps is described in Quality of Domestic Water Supplies Volume 2: Sampling Guide (Water Research Commission, 2000).

7.4.6 Borehole development and yield testing

Note that the process of monitoring already starts at the drilling process. When developing a new borehole it is important to record all relevant information from the specific borehole or get the information from the driller. Information includes:

- BH diameter
- Drilling record, i.e. depth, geology, water strikes, blow yield, rate of penetration, date of completion, casing collar height, coordinates
- Water samples
- Selection, type and diameter of casings and screens
- Type of Sanitary seal
- Type of drilling method
- Borehole drilling Chips

Yield testing methods to be monitored include slug, step/drawdown and constant rate tests. All of these yield testing methods should be monitored to determine the best safe yield for a specific borehole. The safe yield is defined as the maximum rate of withdrawal that can be sustained by an aquifer without causing an unacceptable decline in the hydraulic head or deterioration in water quality in the aquifer (Department of Water Affairs, 2015).

7.5 Summary

The term monitoring provide and include data on groundwater quantity and quality of the resource itself and is an integral aspect of groundwater management.

The design of a systematic significant monitoring program for groundwater management requires the proper definition of objectives from which quantitative criteria can be derived. The objective of a primary monitoring network can be defined as monitoring the actual condition of groundwater systems.

Monitoring of groundwater is an important component in groundwater management and is also described in general terms as the ongoing process of collecting data and the organising and assessment of data into information to improve decision making and determine performance progress and trends.

It is important to remember that you can’t manage what you can’t measure.

7.6 Exercises and tasks

1. Define monitoring
2. What are the main objectives for monitoring?
3. Describe and illustrate the monitoring cycle.
4. Name, describe and develop a monitoring program for your municipality with guidance to this module.

7.7 Further reading

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Module 8: Data and information Recording and Management

Contents

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8. Learning objectives:

- Data and information recording and management
- Basic tools/devices for data recording and management
- Relevant Legislation

8.1 Introduction

"Information management deals with the value, quality, ownership, use and security of information in the context of organizational performance (Wilson, no date)."

Information management is described as the management of information assets and the principles of turning data into information, knowledge, action and value. The comprehensive process on the allocation of groundwater is dependent on quality, accurate and timely information. Thus is there a need to identify main issues, effective implementation and the need for information management functions in regard to groundwater management within a defined practical management unit (Owen *et al*., 2010).

8.2 Information and Data Management

8.2.1 Information and Data Management Process

The general information management process steps that can be used to manage and derive any desired information for decision-making and informing stakeholders is given in Figure 1. These management steps are required before data and information can be effectively used.

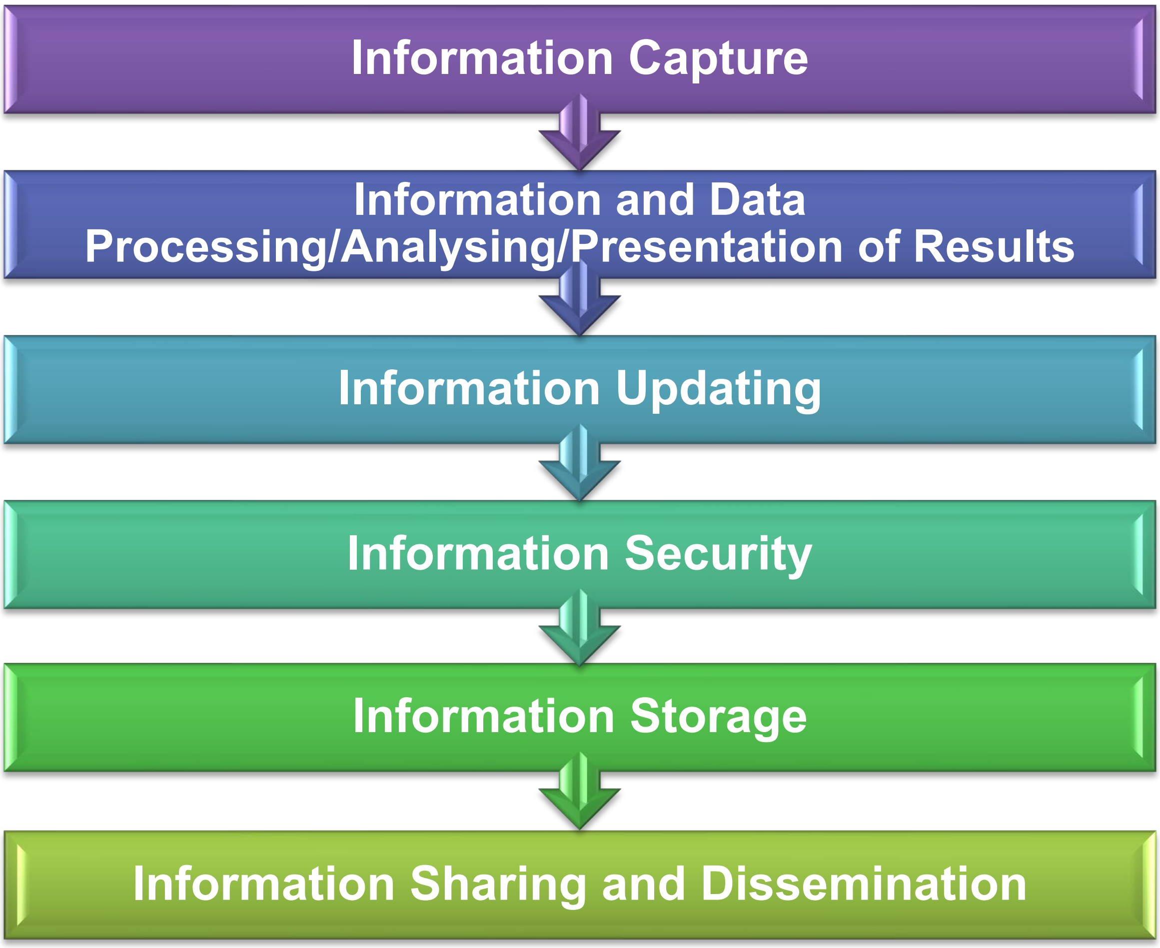

Figure 1: Information Management Process steps adapted from (Owen *et al.*, 2010)

8.2.1.1 Information Capture

This process entails the collection of raw data such as quality and quantity parameters, groundwater users, groundwater uses, groundwater levels and flow directions to name a few. The monitoring chapter (Chapter 7) in this guideline provide more examples and information for capturing raw data. The initial step in information capturing typically starts with information capture objectives, purposes, methods and steps for accessing desired information (Owen *et al.*, 2010).

8.2.1.2 Information and Data Processing/Analysing/Presentation of Results

Data processing is the method by which raw data is transformed into spatial information, time series, quality diagrams and statistics (Jousma, 2006). There is hence, a need to determine and decide the level of quality control programme necessary to produce the desired information and to define the processing mechanisms to be used.

Note that this task of data processing is usually reserved for or managed by the hydrologist or hydrogeologist. The processing of data should allow for interpretation of the groundwater resource.

Different types of data processing are often used and the presentation of results is discussed individually for the following three parameters:

- Groundwater Levels
- Statistical Analysis of data
- Groundwater Chemistry

8.2.1.2.1 Groundwater levels

Groundwater level data and information can be presented spatially as groundwater level contour maps or as a time series in the form of hydrographs.

Groundwater level contour maps

These maps represent the elevation of water level in respect to a reference level (sea level). Water level data need to be converted from the form of depth below surface to the form of water table elevation to construct contour maps.

Contour maps might indicate average values over a period or just indicate a single date. Note that for effective interpretation of a water table contour map one need to consider topography, drainage patterns, recharge, discharge and subsurface geology. The data and time period should also be presented on the map. Groundwater level contour maps acts as visual inspection on which groundwater level data can be checked and monitored (Jousma, 2006).

Groundwater level hydrographs

Groundwater level hydrographs show the variation of groundwater levels for a particular location in time (Jousma, 2006). It is indicated that water levels fluctuate when the water table increase or decrease as a result of storage and therefore it can be plotted on a hydrograph (figure 2).

Hydrographs are a fundamental component of the assessment of hydrological factors and they indicate a way to relate and evaluate impacts on the groundwater resource by natural and human influences.

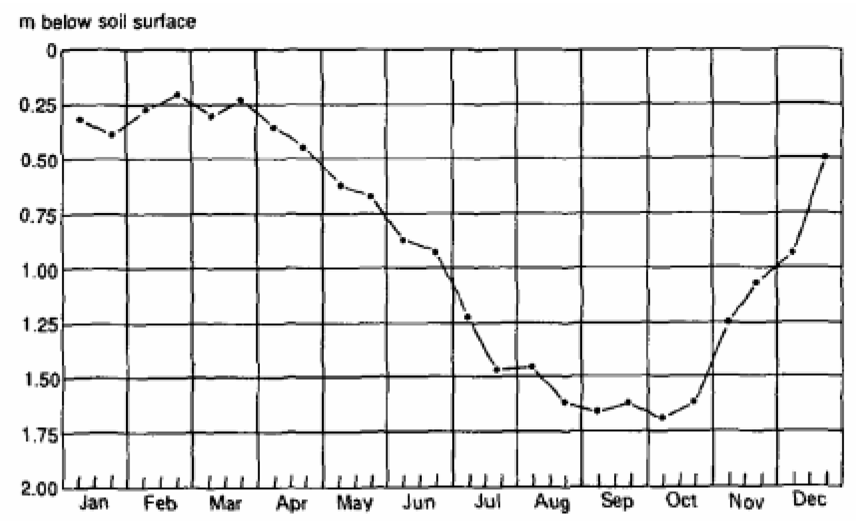

Figure 2: Hydrograph of a Water Table Observation Well (Kumar, 2014)

8.2.1.2.2 Statistical Analysis of data

Statistical analysis of data or statistical approaches includes graphical and mathematical methods to analyse monitoring groundwater data (Commonwealth of Pennsylvania, 2001). The graphical procedures summarize, interpret and visualize data which is used for the assessment of statistical features and includes box and whisker plots (figure 3) and time series plots. Mathematical methods include the calculation of the mean, median, average, data distribution and indicate trend analysis.

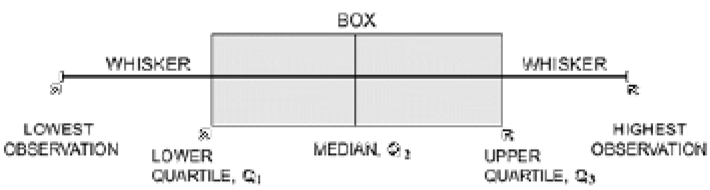

Figure 3: Box and whisker plot (PDF statistics)

8.2.1.2.3 Groundwater Chemistry

Water quality diagrams help to assess and evaluate the water type. This classification and evaluation of water types form a fundamental component in understanding the hydrogeology and hydrological factors (Jousma, 2006). These factors are determined by chemical analyses, where the data from which may be grouped and statistically evaluated (Zaporozec, 1972).

There are a significant number of methods and techniques that may be used depending on the physical and chemical properties of groundwater. These methods help to classify, compare and summarize large volumes of data (Zaporozec, 1972).

Plots such as Piper, Durov or Stiff diagrams help to evaluate and characterize groundwater resources and illustrate any changes in the hydrochemical facies (Jousma, 2006).

Piper diagrams

Piper diagrams are used for the comparison of many waters. These diagrams indicate inorganic compounds/concentrations with the cations and anions shown by separate plots (Bosman, 2014).

Piper diagram is used as an effective graphical representation of chemistry in water samples in hydrogeological studies and groundwater management.

Piper diagrams thus indicate the interpretation of major ionic species in [% meq/L] as seen in figure 4.

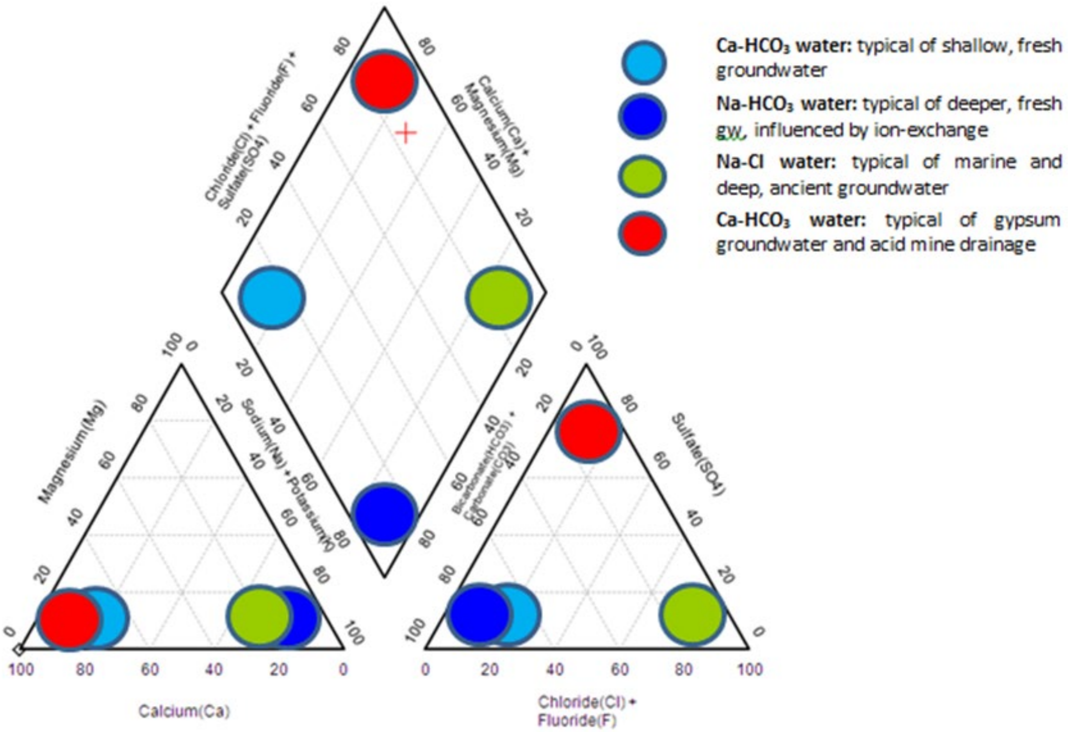

Figure 4: Interpretation of a Piper Diagram (Bosman, 2014)

Durov diagrams

The Durov diagram assists with the analysis of chemical compositions and total dissolved solids. The Durov diagram is provides more information on the hydrochemical facies by assisting in the process to identify water types and displays geochemical processes that could assist in understanding and evaluating the quality of groundwater.

The diagram (figure 5) is a combined plot consisting of 2 ternary diagrams (cations plotted against anions).

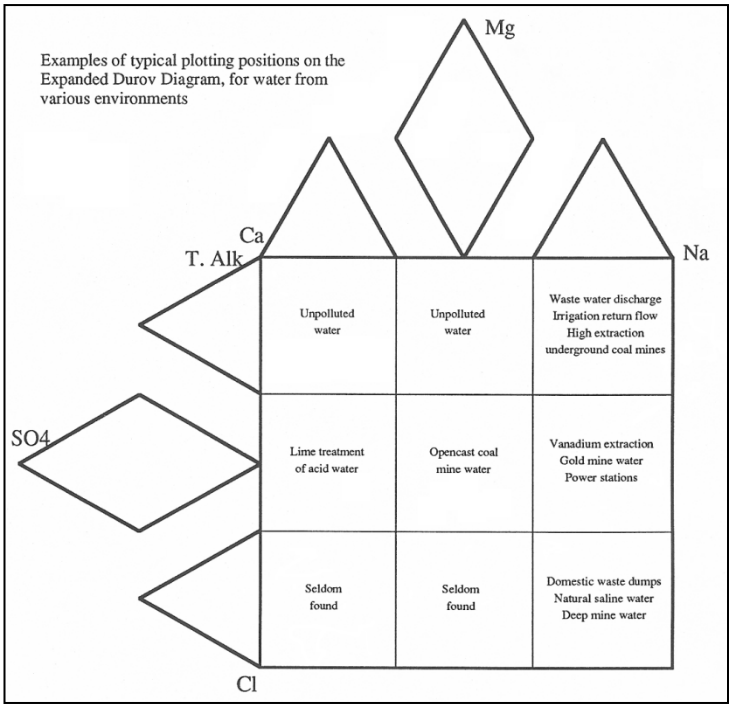

Figure 5: Durov Diagram (Bosman, 2014)

Stiff diagrams

The Stiff diagram (Figure 6) is a distinctive method that graphically represents different water ions. This diagram indicates the differences or similarities in water and changes associated with depth in water composition. The major ionic species is indicated as milli-equivalents per litre [meq/L].

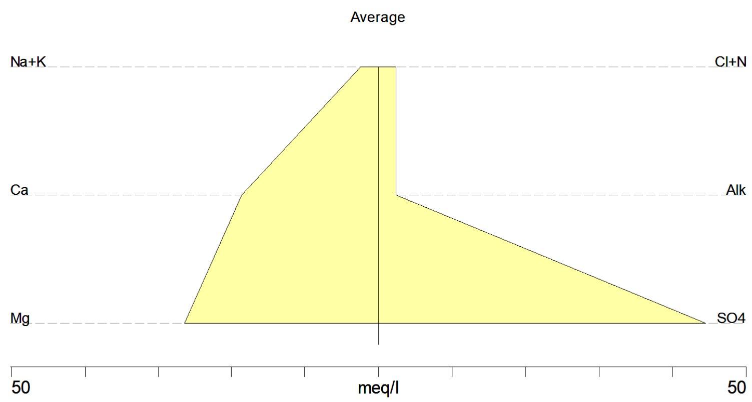

Figure 6: Stiff Diagram (Bosman, 2014)

8.2.2 Information Management Tools

Information management is described as discussed earlier in this module as the management of information assets and the principles of turning data into information, knowledge, action and value. Information management also include the distribution of that information.

To facilitate the organisation and classification of information a variety of tools are available and consist of:

- Geographical Information Systems (GIS)
- “Google Earth” Program
- Manual Systems

8.2.2.1 Geographical Information Systems (GIS)

Geographical information systems also known as GIS is a computer based software used to display and analyse spatial data that are linked to databases. Spatial data is described as data with a geographical component connected to some place on the earth. GIS is thus a tool used to capture, store, process, analyse and visualize spatial information.

As soon as a specific database is updated, the associated map will be updated as well. Basically by continually updating data captured from monitoring, updated maps are available for stakeholders to view (Owen *et al.*, 2010). The disadvantages of GIS are that the required software is often expensive like Esri ArcGis but freeware like QGIS is available and user friendly. Another disadvantage is that special training is required to use the software programme. Geographic Information Systems (GIS) can perform complex data manipulations, analyse and display a combination of information graphically (Department of Water Affairs and Forestry, 2006).

8.2.2.2 “Google Earth” Program

The “Google Earth” programme or freeware is a combines the power of the Google Search engine with other factors such as satellite imagery, maps, terrain and 3D buildings. A bird’s eye view of the world's geographic information for any area is thus available. Google earth can be used to assist in identifying geological boundaries using surface features to infer tectonic structures. Google Earth is also valuable for mapping out boundaries and identifying borehole locations (Owen *et al.*, 2010).

8.2.2.3 Manual Systems

Manual systems refers to a system where all relevant data, information, documents, maps, field notes and drawings are stored in hard copy format. This method involves minimal capital cost and no computer software or training is required. Disadvantages of a manual system is that physical storage is often not enough, data can be manipulated and the update of information is time consuming (Department of Water Affairs and Forestry, 2006).

8.3 Data and Information Recording Tools

8.3.1 Field Notebook/Logbook

A field logbook or field notebook should be completed and maintained for all sampling and monitored events. The purpose of a logbook is to keep accurate written records of the field personal daily activities in a bound logbook that will be sufficient to recreate the project field activities without reliance on memory. This book would be used to describe monitoring procedures (U.S. Environmental Protection Agency, 2010).

In logbooks/notebooks field personal should record sufficient information so that someone can reconstruct the field activity without depending on field sampler memory. It is important to note that all entries must be written in black waterproof ink or in pencil. The book must contain accurate documentation of field activities, field data observations, deviations from project plans, problems encountered, and actions taken to solve the problem. In addition to the investigation data and documenting field activities, field logbooks should include, but are not limited to the following: (U.S. Environmental Protection Agency, 2010):

- Arrival on site and departure from site date and times
- Project personnel and subcontractor personnel on site
- Date and time of activities
- Site location and coordinates

- Purpose of site visit
- Site and weather conditions
- Regulatory agencies and their representatives (including phone numbers, site arrival and departure times),
- Level of health and safety protection
- Identification of well
- Well depth
- Static water level depth
- Well yield – high or low.
- Purging device, purge volume and pumping rate
- Time well purged.
- Measured field parameters
- Sampling methodology and information
- Sample Locations (sketches are very helpful)
- Equipment calibration records
- Equipment present and equipment used
- Sample Source, identifications, container used and labelling names
- Specific considerations associated with sample acquisition
- A chronological description of the field observations and events
- Sample conditions that could potentially affect the sample results
- If deviating from plan, clearly state the reason(s) for deviation
- Persons contacted and topics discussed
- Daily Summary

8.3.2 Field Investigation Data Forms

Groundwater sampling information to be recorded on the Groundwater Sampling Field Data Sheet includes:

- Instrument calibration data
- Water levels
- Purge volumes and analysis data
- Field measurements
- Sampling information
- Shipping information.

8.3.3 Chain of Custody

A chain-of-custody record should be established to provide the documentation necessary to trace sample possession from time of collection to final laboratory analysis. Components of sample custody procedures include the use of field logbooks, sample labels, custody seals, and Chain of Custody (COC) forms. Each person involved with sample form will accompany the samples during shipment from the field to the laboratory (U.S. Environmental Protection Agency, 2010).

The record should account for each sample and provide the following information (Kasich, Taylor and Nally, 2012):

- Sample identification number.
- Printed name and signature of collector.
- Date and time of collection
- Specific location of sample collection
- Description of samples
- Sample type (i.e. groundwater).
- Identification of well
- Number and types of containers.
- Parameters requested for analyses.
- Preservatives used.
- Carrier used.
- Printed name and signature of person(s) involved in the chain of possession18.
- Date/time samples were relinquished by sampler and received by the laboratory
- Internal temperature of shipping container upon opening at laboratory, if applicable.
- Presence/absence of ice.
- Special handling instructions (if any).

More complex diagrams that can be used for the interpretation of chemistry are the Piper and Durov diagrams. These diagrams are discussed in detail in the *Minimum Requirements for Monitoring at Waste Management Facilities* (DWAF, 2005).

8.4 Summary

The term information management is a new way to reflect the role of information in organizational performance and it has a substantial impact on the thinking of professionals and management personal working in a variety of fields. Without an effective data recording and management program, management in groundwater would not succeed.

8.5 Exercises and tasks

1. Define information management
2. What are the six steps in the information and data management process?
3. Name different ways to represent groundwater chemistry data?
4. Information management tools are describe as the process of turning data into information. Name two useful tools that can be implemented at your municipality.

8.6 Report from student for evaluation and assessment.

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Module 9: Operational and maintenance related to bulk groundwater supply schemes

Contents

9. Learning objectives

To understand and describe the following:

- Operation and maintenance
- Effective operation strategy

9.1 Introduction

The objective of a successful operation and maintenance programme related to bulk groundwater supply schemes is to provide safe drinking water.

It has been observed that lack of attention to the important aspect of Operation & Maintenance of water supply schemes in several towns often leads to deterioration of the useful life of the systems necessitating premature replacement of many system components.

Some of the key issues contributing to the poor Operation & Maintenance have been Identified as follows according to Azad (2005):

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

Therefore, there is a need for an effective operation strategy and legal framework for groundwater supply schemes.

9.2 What is operation and maintenance

9.2.1 Operation

Operation related to bulk groundwater supply schemes refers to timely and daily operations otherwise known as routine work. These operations include a series of actions completed by operators on different components of a system such as equipment, plant and machinery (Ministry of water and energy, 2013).

Other activities include the proper major operations to deliver safe drinking water, the correct handling of equipment, machineries and facilities and enforcing policies and procedures (Davis and Brikké, 1995).

9.2.2 Maintenance

The term maintenance is defined as a series of activities aimed at keeping the plant, equipment, structures and other related facilities in optimum serviceable condition and working order (Jain, 2013).

Maintenance can be divided into preventive, corrective and reactive maintenance adapted from (Davis and Brikké, 1995; Ministry of water and energy, 2013; Brikké, 2000 and Castro, Msuya and Makoye, 2009):

9.2.2.1 Preventive maintenance

This is the actions performed on a regular and timely basis to ensure that equipment and infrastructure are operating effectively and are in good condition to preserve assets and minimize unforeseen failures. These actions consist of regular inspections, servicing, minor repairs and replacement.

9.2.2.2 Corrective maintenance

Actions performed to repair or either restores malfunctioning equipment and infrastructure to sustain reliable facilities and ensure effective operating conditions. Actions may result from problems that were discovered during the preventive maintenance process or as a result of failures during operation.

9.2.2.3 Reactive maintenance

Reactive maintenance also referred to as crisis maintenance, is the response reaction to public complaints, emergency breakdowns and a crisis to restore a failed supply.

By only implementing and relying on crisis maintenance it may lead to a complete system failure because of frequent breakdowns, poor service level, high operation and maintenance costs and user dissatisfaction.

9.3 Objectives of operation and maintenance

The main objectives of an efficient operation and maintenance program related to bulk groundwater supply schemes is to operate water facilities efficiently to provide a reliable supply of safe drinking water, in adequate quantities at a suitable pressure and to maintain and operate the functions of the bulk groundwater supply scheme in working condition (Jain, 2013).

Objectives of operation and maintenance are not possible unless it includes the actions that will reduce the impact on quantity and quality of water sources of the environment. The objectives are achieved through appropriate planning, design and construction in the operation and maintenance plan of bulk water supply schemes (Ministry of water and energy, 2013).

9.4 An Effective Operation and Maintenance Strategy

An effective operation and maintenance strategy is required because the lack of interest and enthusiasm to the important aspects of operation & maintenance of bulk groundwater supply schemes, typically leads to the deterioration and dysfunction of systems and contribute to poor operation and maintenance.

The minimum requirements for an effective operation and maintenance strategy according to Azad, 2005 are:

- Preparation of a plan for operation and maintenance.
- Providing required personnel to operate and maintain.
- Availability of spares and tools for ensuring maintenance.
- Preparation of GIS based maps of the system
- Preparation of a water audit and leakage control plan
- Maintaining records on the system including history of equipment, cost, life, etc.

9.4.1 Preparation of a plan

It is essential to prepare a plan/program for operation and maintenance of each and every major unit and for the entire operation and maintenance scheme.

The general operation and maintenance plan should be constructed scheme wise for their various individual units. This plan/program needs to contain procedures and actions, checks and inspection at routine intervals.

Development of individual plans for operation and maintenance must be prepared for all relative units, systems and pieces of equipment. It is essential according to Jain (2013), that each individual unit or system have a plan to fix responsibility, timing of action, ways and means of achieving the completion of action and contain what objectives are meant to be achieved by this action.

The plan/program should be followed by trained staff and will form the basis for supervision, evaluation and inspection of the status of an effective operation and maintenance plan/program.

9.4.2 Providing required personnel to operate and maintain

Personal, management and staff responsible for the operation and maintenance plan must be experienced, efficient, motivated and well qualified. Operating staff is required to run the system plan while supervisory staff, like management is needed to monitor the operations and provide professional support.

The management at municipalities have to become more service orientated and be enthusiastic and equipped to run an effective operation and maintenance plan.

Personal, management and staff should be carefully chosen for the job description and trained to carry out important and necessary actions.

Training of these above mentioned individuals entail that a clear and define job description shall be prepared for each operator. This will contain detailed instructions on how to carry out actions required in the operation and maintenance plan. Training will normally include personnel management, job training, performance tasks and problematic case studies. This training is vital to prevent experimentation by operating personnel to interfere with equipment and systems.

9.4.3 Availability of spares, supplies and tools for ensuring maintenance

It is vital that municipalities have all the essential spare parts and tools available at all times for operational and maintenance work. This will reduce the down time of a supply scheme and increase maintenance (Ancheta, 2012).

To assure that spares, supplies and tools do not get replenished, it is best to manage and maintain an inventory register and keep tools locked in a safe location with minimal access (Castro, Msuya and Makoye, 2009). The inventory list of spare parts that have to be readily available can be drafted on the basis of manufacturer's recommendations or the consumption of material in previous years. It will also be important to arrange quality checks for all tools before storage and that routine maintenance of tools and plants is necessary for ensuring that they are in a fit state to be used when repairs and replacements are taken up (Azad, 2005).

9.4.4 Maintenance of records

The requirement for good maintenance records is often overlooked. The maintenance plan programme contains as to what should be done and when. A record and report system shall be compulsory to list all basic data of equipment and the history of the equipment. A reporting system will assist the operator to notify the supervisor/ manager of the problems of each system and piece of equipment that require repair and replacement attention (Azad, 2005).

A typical record list includes the following:

1. Name of equipment and location of equipment
2. Number available or installed
3. Serial number
4. Type and class
5. Date of procurement/installation
6. Cost of procurement and installation
7. Name of manufacturer with address and telephone No.

8. Name of distributor/dealer if purchased through them with address and telephone number.
9. Name of servicing firm with address and telephone number.
10. Service manuals
11. Descriptive technical pamphlets
12. Major overhauls: Details of date, nature of cost
13. When next overhaul is due.
14. Date, type and cost of repairs and replacement
15. Cost of spares and cost of labour for repairs.

9.5 Summary

The main difference between operation and maintenance is that operation involves activities necessary to deliver the service, while maintenance involves activities that keep the system in good operating condition.

The performance and management process can only be effective implemented and achieved if recording of the events is done and evaluated using properly set standards and if the process is done by trained staff regularly.

9.6 Exercises and tasks

1. Name and describe a few key issues that can contribute to poor operation and maintenance.
2. Define the operation and maintenance process.
3. Develop an operation and maintenance program for bulk water supply schemes for your municipality with guidance to this manual.

9.7 Further reading

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9.8 Report from student for evaluation and assessment

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