IMPLEMENTATION AND ACCREDITATION OF THE TRAINING MANUAL FOR GROUNDWATER RESOURCE MANAGEMENT AND GROUNDWATER GOVERNANCE FOR MUNICIPALITIES IN SOUTH AFRICA

Mr J de Lange, Dr YL Kotzé, Dr L Esterhuizen, Ms RG Phuthi, Ms L Makofane, Ms NP Chovu

WATER RESEARCH COMMISSION

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Implementation and Accreditation of the Training Manual for Groundwater Resource Management and Groundwater Governance for Municipalities in South Africa

Quick Reference Booklet to Groundwater Resource Management and Groundwater Governance for Municipalities in South Africa

Report to the
Water Research Commission

by

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CONTENTS

LIST OF FIGURES

ACRONYMS & ABBREVIATIONS

CMA	Catchment Management Agencies
GIS	Geographical Information Systems
GRP	Groundwater Resource Potential
IWMB	International Water Management Bodies
WUA	Water User Associations

STRUCTURE OF THE QUICK REFERENCE BOOKLET

The report consists out of 9 chapters:

- *Chapter 1* Hydrological Cycle
- *Chapter 2* Water Law
- *Chapter 3* Groundwater Management
- *Chapter 4* Groundwater Regulation
- *Chapter 5* Groundwater Quality
- *Chapter 6* Groundwater Quantity
- *Chapter 7* Groundwater Monitoring
- *Chapter 8* Data and Information Recording and Management
- *Chapter 9* Operational and Maintenance Related to Bulk Groundwater Supply Schemes

CHAPTER 1: HYDROLOGICAL CYCLE

1.1 INTRODUCTION

It is important to recognise 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.

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).

Figure 1.1 illustrates the hydrological cycle.

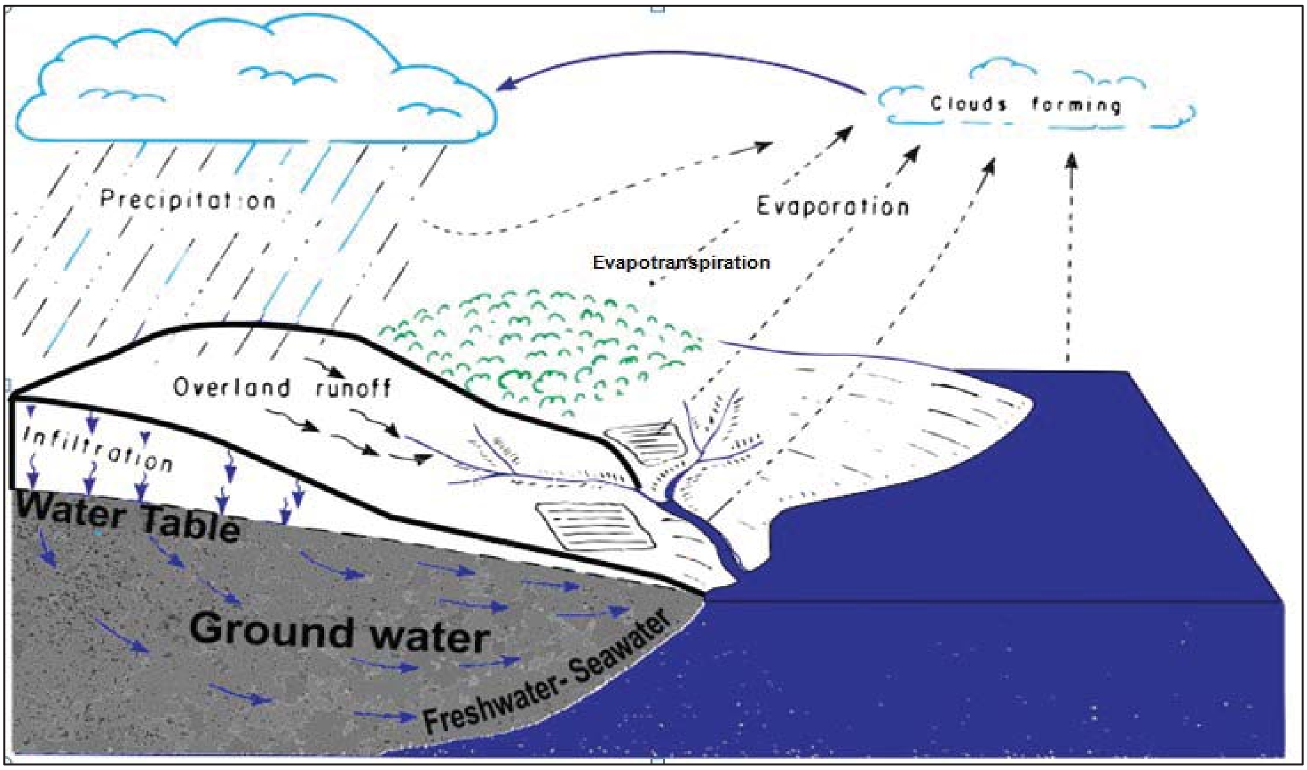

Figure 1.1. The hydrological cycle.

1.3 COMPONENTS OF THE HYDROLOGICAL CYCLE

Figure 1.2 indicates the components of the hydrological cycle.

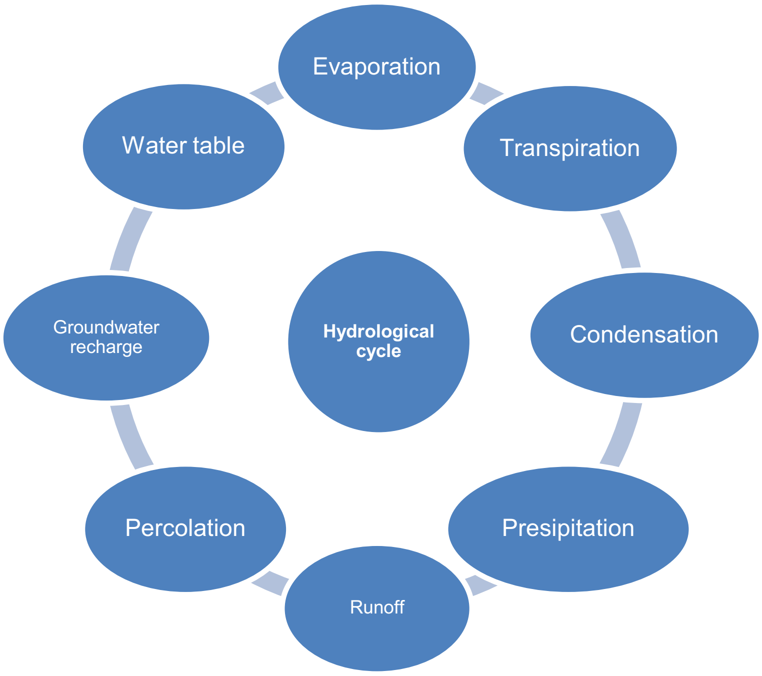

Figure 1.2. Indicates the components of the hydrological cycle.

1.4 FACTORS INFLUENCING THE PROCESSES OF THE CYCLE

1.4.1 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).

1.4.2 Evapotranspiration

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

- The more energy available, the greater the rate of evapotranspiration.
- The humidity gradient.
- The wind speed.
- Water availability.
- Physical attributes of the vegetation.
- Soil characteristics.

1.4.3 Infiltration

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

- Precipitation and base flow.
- Soil characteristics and soil saturation.
- Land cover, slope of the land and evapotranspiration.

1.5 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.

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

1.6 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.

CHAPTER 2: WATER LAW

2.1 INTRODUCTION

Water legislation 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. The National Water Act, 1998 and the Water Services Act, 1997 should be used within each other side to side in regard to the water management regime in the Republic. The Water Services Act makes provision to ensure that all South Africans have access to basic water supply and sanitation.

2.2 WHY WATER LEGISLATION?

Water legislation is required to regulate development of water resources, limit activities that can compromise water availability, sustainability and quality, and address the threat to water pollution.

2.3 BASIC LEGAL CONCEPTS

The interpretation of the term 'legislation' differs 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, 1975 (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 IMPLEMENTATION OF WATER LEGISLATION

Successful implementation of water legislation depends on a numerous factors 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.

2.5 THE NATIONAL WATER ACT

2.5.1 Purpose of the Act

According to the National Water Act, 1998 (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:

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 makes provision for the National Government to be the custodian of the nation's water resources and requires 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.

2.6 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, 1998 (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.
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 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.

2.7 SUMMARY

The National Water Act, 1998 (Act 36 of 1998) provides 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.

CHAPTER 3: GROUNDWATER 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 in order to solve and mange 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 are reliant on groundwater resources.

3.2 IMPORTANCE OF GROUNDWATER MANAGEMENT

Groundwater is a vital resource and many nations 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 high-quality water supplies for both urban and rural populations and for irrigation of crops.

In South Africa, most water supplies in small towns, originate from groundwater sources. It is geographically widespread and almost two-thirds of South Africa's population depend on it for drinking water supply and domestic use. Therefore awareness and understanding will assist with the proactive management of groundwater in South Africa (Knüppe, 2010).

3.3 GROUNDWATER MANAGEMENT

3.3.1 Defining management

Daft and Marcic (2012) defined management as:

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

3.3.2 Groundwater management versus groundwater governance

Groundwater management's ultimate goal is to provide a sufficient amount and quality of water for human health, livelihood, and productivity. In addition to groundwater management, Moench et al. (2012) defined groundwater governance as:

"The process through which groundwater related decisions are taken and power over groundwater is exercised."

3.3.3 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 categorised as planning, organising, leading and controlling. These functions or so called "building blocks" provide valuable steps in the process to achieve organisational goals, and are related and interrelated to each other.

Figure 3.1. Indicates the four basic management functions.

3.3.3.1 Planning

Planning involves the process of selecting certain objectives and determines a sequence of steps and actions that need to be followed to achieve those objectives. Good management consist of good planning and it is always an ongoing process.

3.3.3.2 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.

3.3.3.3 Leading

Leading can be described as guiding or directing and is the process of motivate, influence, communicate and forming effective groups to achieve goals and objectives.

3.3.3.4 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.

3.3.4 Groundwater management

Groundwater management is 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.

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.

3.3.4.1 Data collection, capturing and monitoring

To develop an acceptable groundwater management strategy for a certain region in depth knowledge regarding the groundwater resource is required. A number of basic information is required to be able to manage groundwater effectively. As the groundwater abstraction rate increases, 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).

3.3.4.2 Legal framework

Effective ways of creating groundwater management are to establish and implement municipal by-laws. 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. 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. By-laws allows communities to be more involved in local government affairs, and encourage municipalities to engage more in communities. Through the development of by-laws, groundwater resources can be managed more effectively while placing emphasis on the protection of sustainability, conservation and the protection of the environment.

By focusing only 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.

3.3.5 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 required 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 programs. 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.

3.4 SUMMARY

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.

CHAPTER 4: GROUNDWATER REGULATION

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 ALLOCATION

4.2.1 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. 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.

4.2.2 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.

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 materialised and uncertainty is minimised. 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.

4.2.3 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. For improved 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).

4.2.4 Groundwater protection

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 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. A balance between water resource protection and the use of a water resource is described as integrated water resource management.

4.2.5 Groundwater Institutions

Institutional arrangements on municipal levels are needed such as institutions to have an effective regulatory environment where rules, goals and objectives can be achieved. 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, 1998 (Act 36 of 1998) 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.

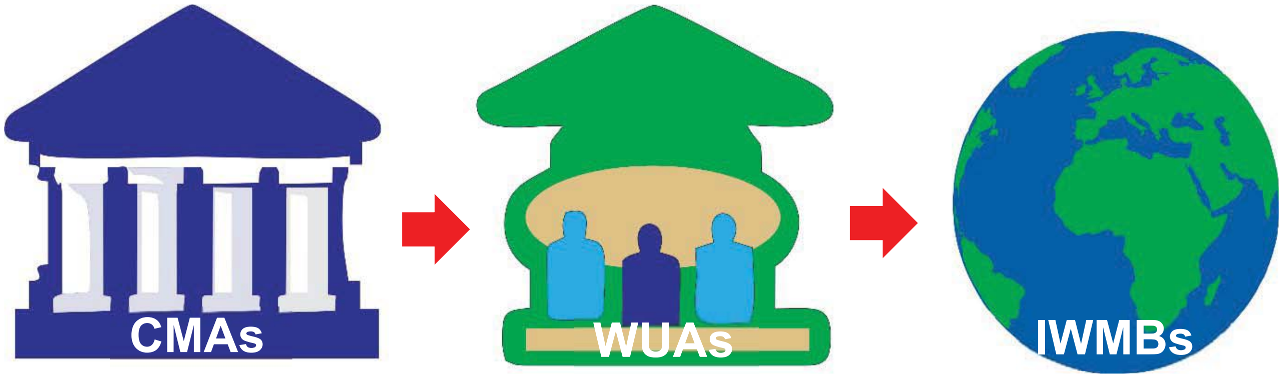

Figure 4.1. Institutional arrangements.

4.2.5.1 Catchment Management Agencies (CMAs)

A statutory body established in terms of the National Water Act, 1998 (Act 36 of 1998) is referred to as a catchment management agency. It is governed by a board, which is appointed by the Minister. 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 purpose of a Catchment Management Agency is to delegate water resource management to the regional or catchment level and primarily involve local communities in the process. Catchment Management Agencies form therefore the fundamental course of action for managing water resources at catchment management level and are required to seek co-operation between various stakeholders and interested parties on water related matters.

4.2.5.2 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 Catchment Management Agencies. 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).

4.2.5.3 Water User Associations (WUAs)

Water User Associations are 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. A water user association is an institution that serves its members and is governed by a management committee. It can also provide a method through which the catchment management strategy can be implemented at local level.

Water User Associations allow people to be more active within a community and to combine their resources and expertise to effectively manage and perform water-related activities. Some core functions of Water User Associations include the following:

- 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.

4.2.5.4 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.

4.3 SUMMARY

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.

CHAPTER 5: GROUNDWATER QUALITY

5.1 INTRODUCTION

According to the Groundwater Division 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 is dependable on temperature, pressure conditions, types of rock and soil formations through which the groundwater flows, and possibly on the residence time.

5.2 THE MEANING OF 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).

5.3 THE MEANING OF WATER QUALITY MANAGEMENT

Water quality management 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 water quality management entails the ongoing process of planning, development, implementation and administration of water quality management policies, 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, 2010).

The following 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.

5.4 NATURAL GROUNDWATER QUALITY

Groundwater is usually safe to drink without treatment, unlike surface water. It is dependable on point-sources and non-point sources of pollution. However, groundwater for bulk water supply is treated for drinking water purposes and domestic use. 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. 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).

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 or remediate.

5.5 GROUNDWATER POLLUTION

Groundwater can be contaminated in many ways. 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 may 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.

Figure 5.1 indicates various sources of groundwater pollution.

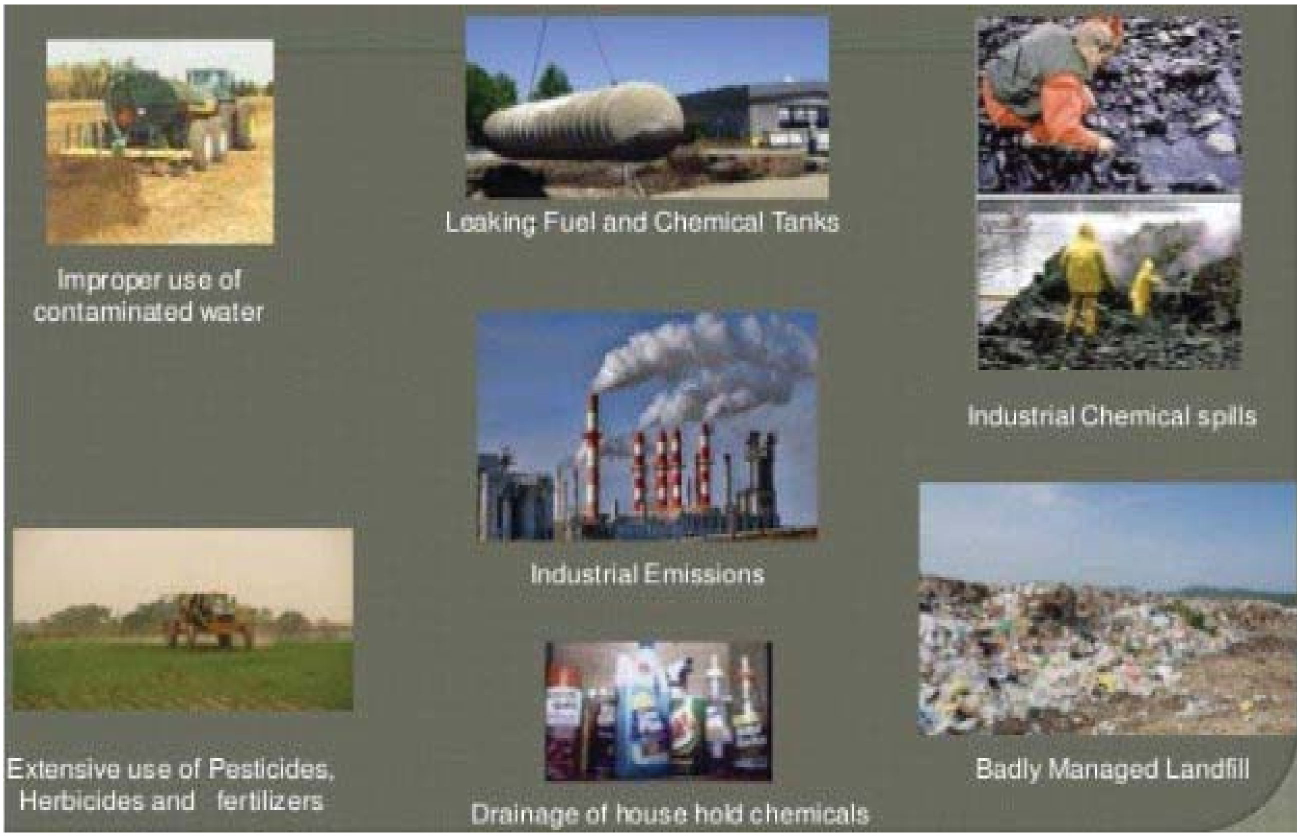

Figure 5.1. Indicates various sources of groundwater pollution.

5.6 PROTECTING GROUNDWATER FROM POLLUTION

Groundwater quality management should be pro-active in order to prevent and minimise groundwater contamination. Groundwater protection initially involves the assessment of aquifer pollution vulnerability and mapping of groundwater pollution hazards. Once the risk has been identified and assessed, then certain groundwater quality management practices may be introduced:

- Groundwater quality monitoring to assess actual groundwater quality status and changes to quality over time.
- Prohibition of certain activities in sensitive or vulnerable areas.
- Management of both the quality and quantity of effluent and waste disposal.
- Monitoring of compliance and enforcement.

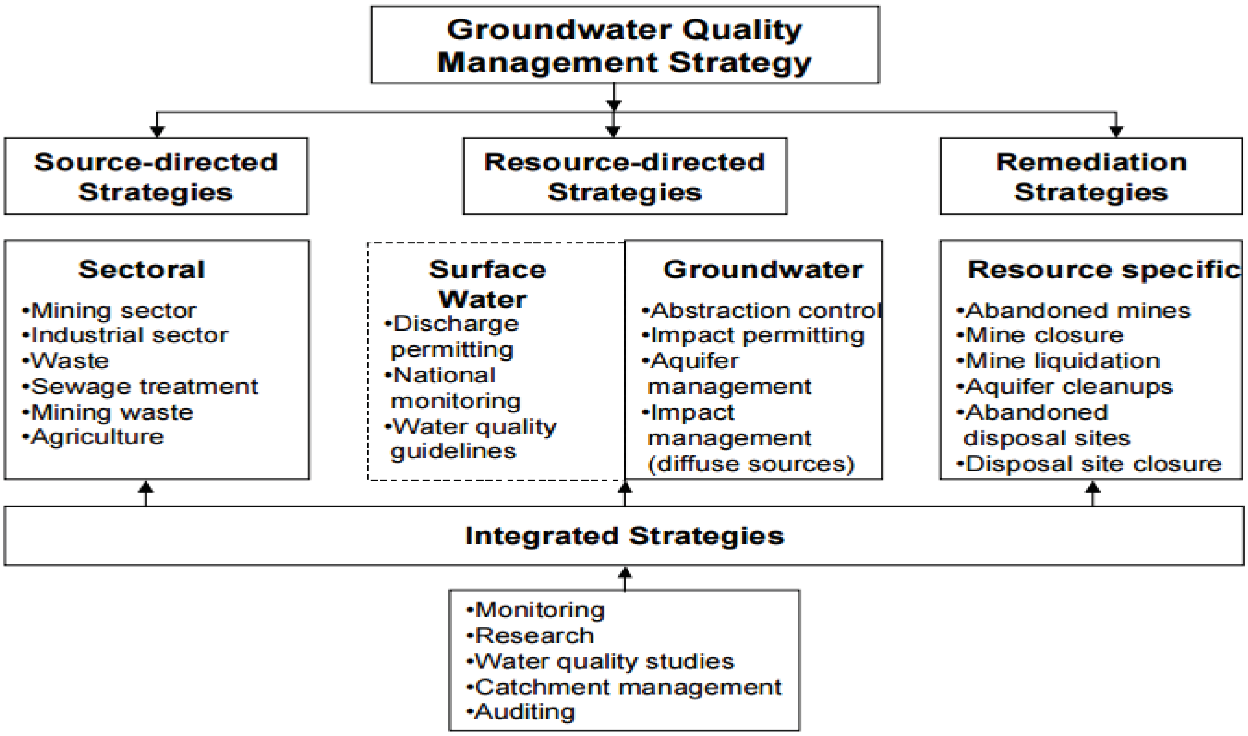

Figure 5.2. Illustrates integrated strategies to manage groundwater quality in South Africa.

5.7 SUMMARY

Groundwater is 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.

Groundwater is accessed by means of drilling boreholes or utilising springs. 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, and effluent discharge from industries.

CHAPTER 6: GROUNDWATER QUANTITY

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 500mm compared to the world average of 860mm. 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. 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 quarzitic 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.

6.2 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 6.1 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).

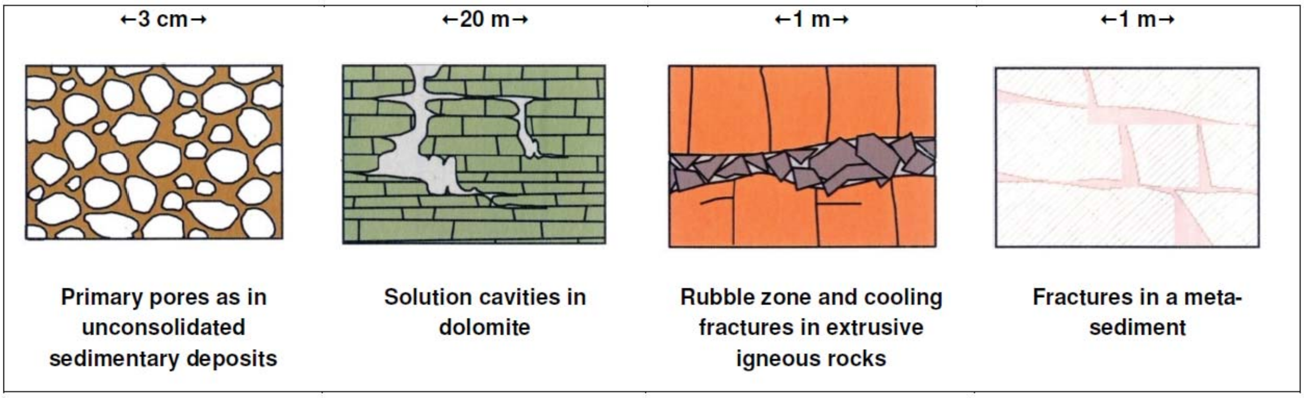

Figure 6.1. Different aquifer permeability types.

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.

Table 6.1 indicates aquifer systems in South Africa (Parsons, 1995).

Table 6.1. Indicates aquifer systems in South Africa (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.

6.3 QUANTIFICATION OF GROUNDWATER RESOURCES

In 2003, the Department of Water and Sanitation initiated the Phase 2 Groundwater Resources Assessment (GRA2) project, the main aim of which was to quantify South Africa's groundwater resources. The project also A raster or grid based GIS model was developed and all and outputs were produced at a cell size of 1x1km. Key focus was placed on aquifer storage, recharge and yield.

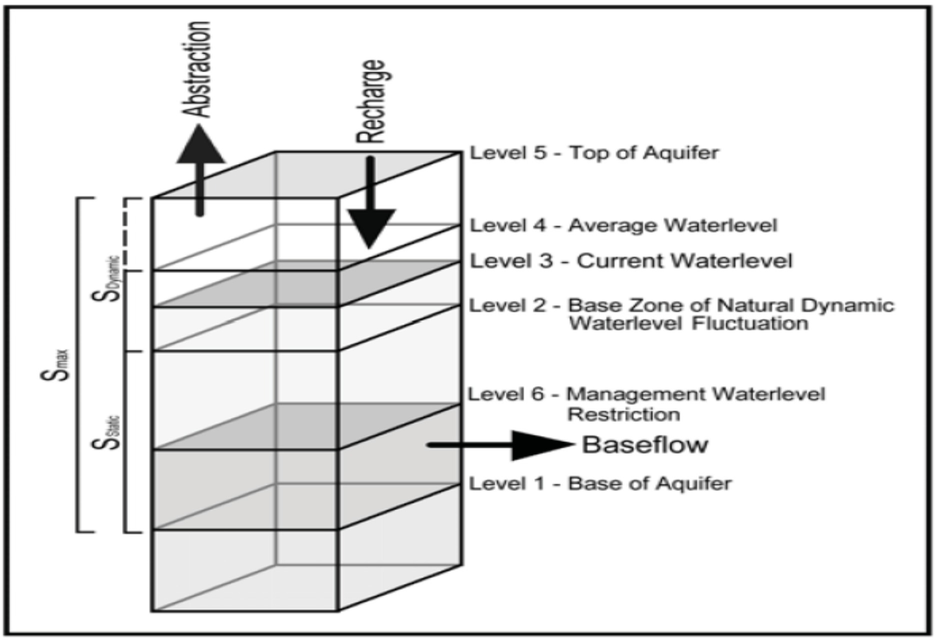

Figure 6.2. Six Levels in Aquifer System used to assess volumes of Groundwater held in storage.

6.3.1 Groundwater resource potential

The Groundwater Resource Potential (GRP) is defined as the maximum volume expressed in m^3 of groundwater that can be abstracted per unit area per annum without causing any long-term 'mining' of the aquifer system without continued long-term declining water levels). The GRP is based purely on physical inputs and outputs as well as 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.

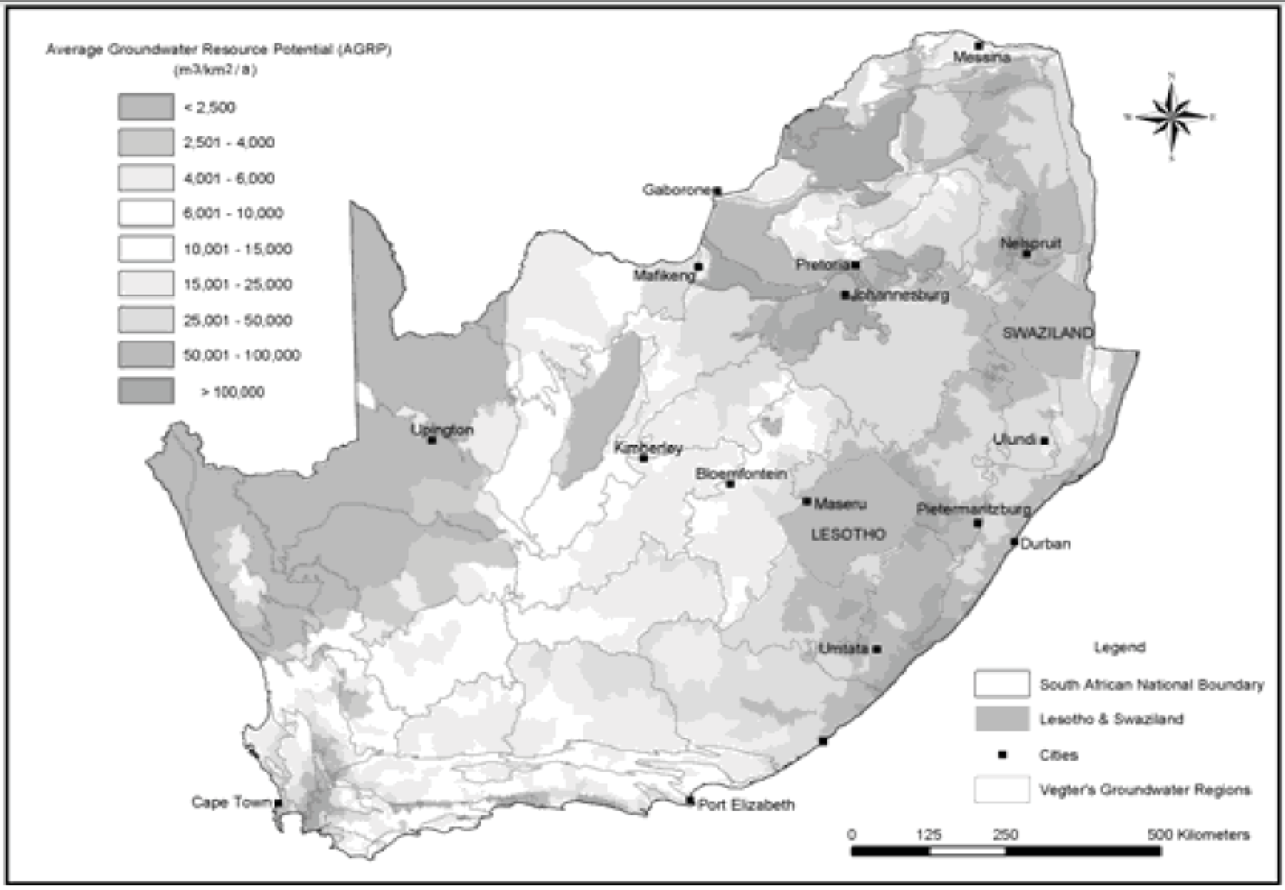

Figure 6.3. Average Groundwater Resource Potential for South Africa.

6.3.2 Potable groundwater exploitation potential

The Potable Groundwater Exploitation Potential of aquifers in South Africa 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 6.4 indicates Potable Groundwater Exploitation Potential of South Africa (Groundwater strategy, 2016).

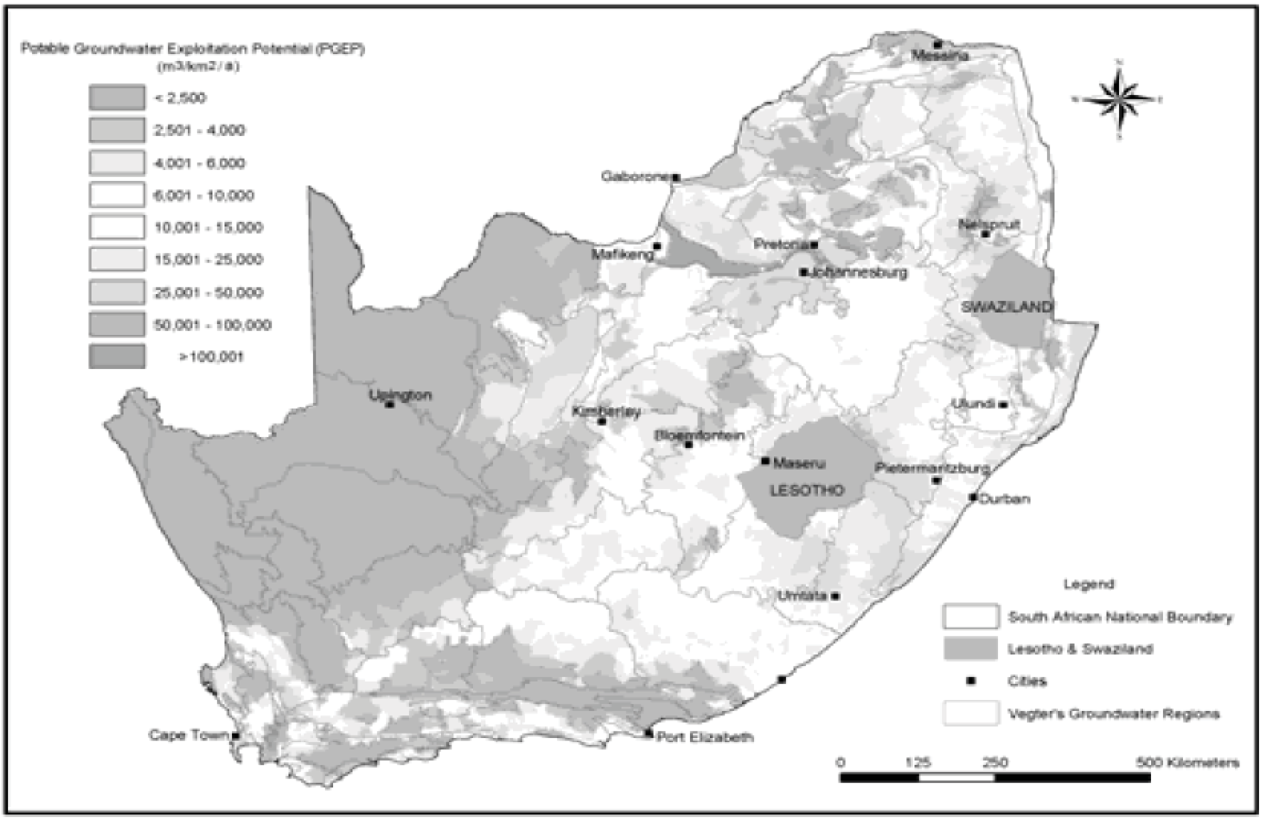

Figure 6.4. Potable Groundwater Exploitation Potential of South Africa (Groundwater strategy, 2016).

6.3.3 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 is a management decision that will reduce the total volume of groundwater available for development – referred to as the Utilisable Groundwater Exploitation Potential. 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 etcetera can all be factored in using this approach.

The Utilisable Groundwater Exploitation Potential under normal rainfall conditions and under drought conditions is estimated at 10,353 and 7,536 Mm^3/a, respectively. The Utilisable Groundwater Exploitation Potential represents a management restriction on the volumes that may be abstracted based on the defined maximum allowable water level drawdown. 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.

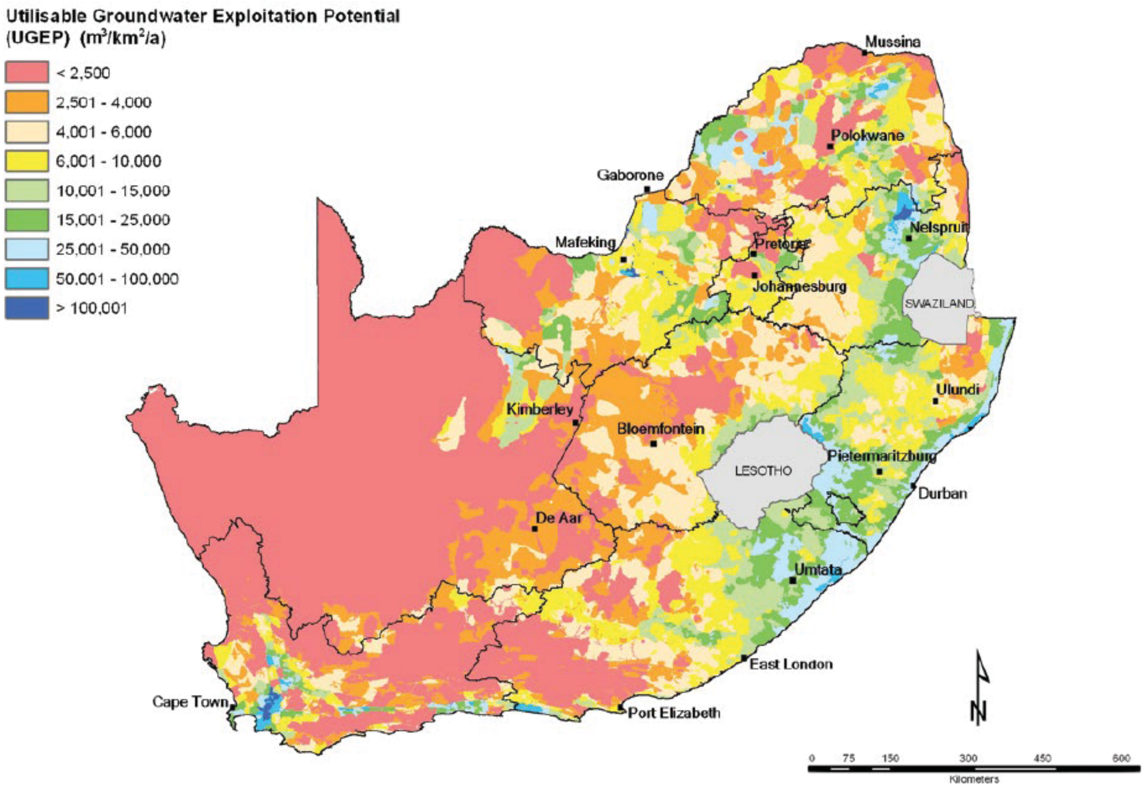

Figure 6.5. Utilisable Groundwater Exploitation Potential for South Africa (Groundwater strategy, 2016).

6.4 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 such as the proportion of rainfall percolates into the ground to become groundwater, the quality of the groundwater, and the properties of the aquifer such as an aquifer that supports only very low yielding boreholes 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 stored surface water resources: The total volume of available, renewable groundwater in South Africa, the Utilisable Groundwater Exploitation Potential is 10 343 million m³/a or 7 500 million m³/a under drought conditions.

6.5 GROUNDWATER, DROUGHT AND 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.

The advantages of groundwater are much lower evaporation, evapotranspiration and slower declines in drought years because the volumes stored underground are so much higher compared with surface water that it should form a key part of the 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 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 performed on various aspects of groundwater including quality and quantity to quantify the impact on groundwater and on the communities that are dependent on groundwater. Artificial recharge, groundwater data collection and groundwater research all form part of our strategy for meeting climate change.

6.6 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 “Average Groundwater Exploitation Potential” 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.

CHAPTER 7: GROUNDWATER MONITORING

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).

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, program 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 MONITORING DEFINED

(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.

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.

7.3 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 plays an important role and form the foundation for management.

A reliable dataset can only be achieved through approved, standardised, capturing procedures of quality approved data" (Department of Water Affairs, 2010). A lack of data and skills results in inadequate information for decision support and poor management of the resource.

Figure 7.1 illustrates the hierarchy of monitoring information.

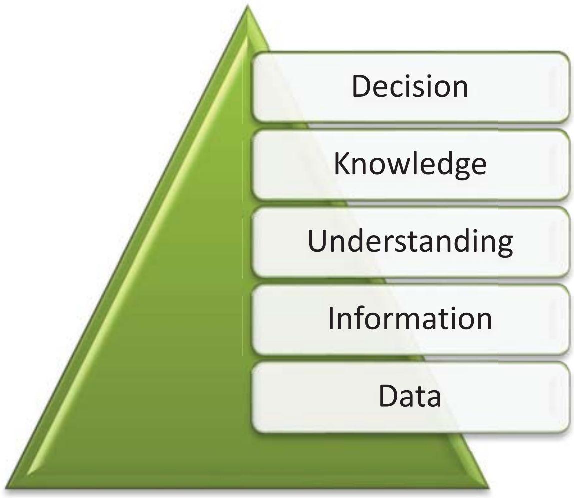

Figure 7.1. Hierarchy of monitoring information.

7.4 OBJECTIVES OF MONITORING

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 and assure that a monitoring program is a systematically planned exercise. It is 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 may be considered: (Bartram and Ballance, 1996):

- Constraints that can play a role on monitoring program.
- 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:

- Aquifer materials or their hydrologic properties characterise.
- 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 programs.
- Evaluation of the effectiveness of a water quality management.

- Groundwater resource characterised.
- 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.
- 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 program development.

7.5 MONITORING PROGRAM DESIGN

7.5.1 The Monitoring cycle

The monitoring cycle generally describe the steps and processes for effective water management. A monitoring cycle 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).

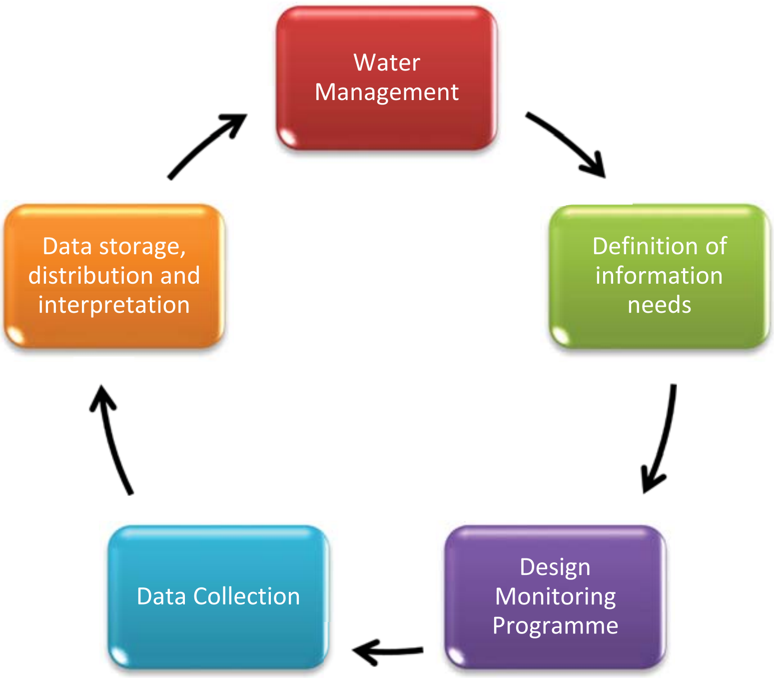

Figure 7.2. The monitoring cycle.

7.5.2 Monitoring Program

Monitoring programs 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.
- Reporting.

7.6 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.

7.6.1 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.

7.6.2 Steps in measuring the groundwater level

Wash your hands or wear disposable gloves- remember your working with drinking water.

Ensure that the dip meter is clean.

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.

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).

Switch the dip meter on when having an on/off switch.

Remove or open the end cap on top of piezometer tube.

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.

Double check the position on cable by lowering and lifting the probe a little while checking the audio signal, light indicator, or meter deflection.

Keep the correct position with fingers or by temporally marking or pinching the cable.

Read and record the measurements seen on cable on your logbook.

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.

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.

Clean the probe and cable and dry it probably to prevent contamination on next borehole.

Close or put back the end cap on top of piezometer tube.

Figure 7.3. Groundwater level measuring steps.

7.6.3 Water Flow/Quantity monitoring systems

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

7.6.4 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.

7.6.5 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:

- 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
- Redox potential
- Dissolved oxygen
- Alkalinity

7.6.6 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 testing is a compulsory action for municipalities providing bulk groundwater supply to communities.

7.6.7 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 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).

7.6.8 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;

- Borehole 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).

7.7 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.

CHAPTER 8: DATA AND INFORMATION RECORDING AND MANAGEMENT

8.1 INTRODUCTION

Information management deals with the value, quality, ownership, use and security of information in the context of organisational performance. 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.

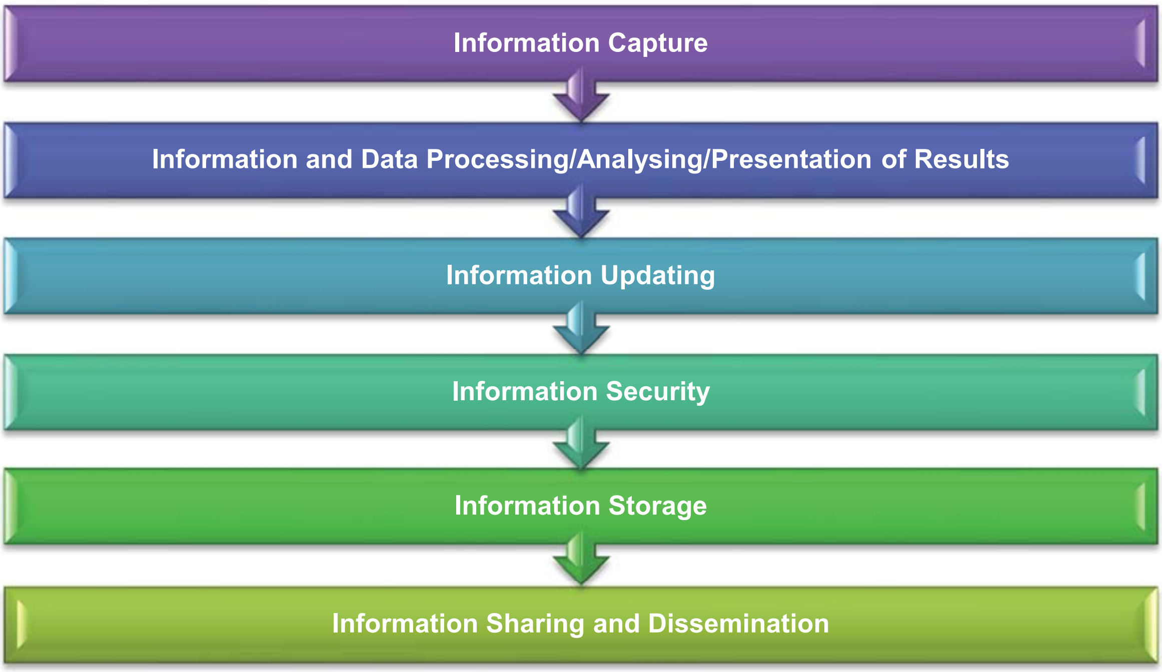

Figure 8.1. Information management process steps.

8.2.2 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. These factors are determined by chemical analyses, where the data from which may be grouped and statistically evaluated. 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. Plots such as Piper, Durov or Stiff diagrams help to evaluate and characterize groundwater resources and illustrate any changes in the hydrochemical facies.

8.2.2.1 *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. A piper diagram is used as an effective graphical representation of chemistry in water samples in hydrogeological studies and groundwater management.

Piper diagrams indicate the interpretation of major ionic species in [% meq/L] as seen in figure 8.2.

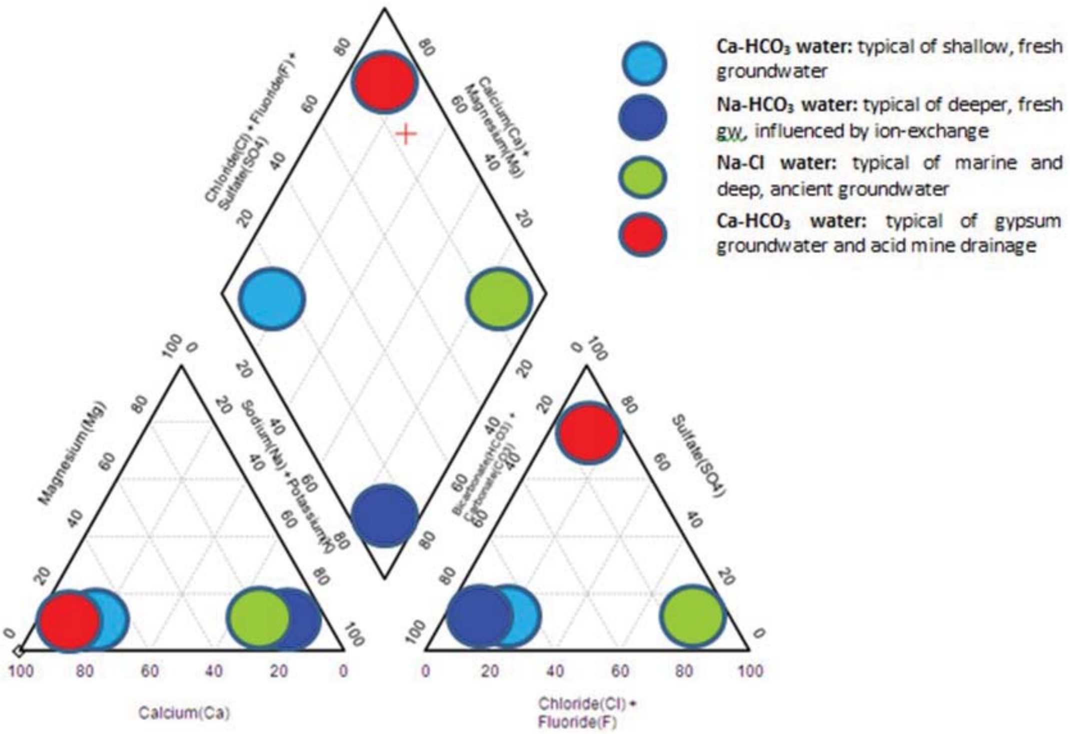

Figure 0.1. Interpretation of a Piper diagram.

8.2.2.2 *Durov diagrams*

The Durov diagram assists with the analysis of chemical compositions and total dissolved solids. The Durov diagram is provides 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 in figure 8.3 is a combined plot consisting of 2 ternary diagrams. Cations were plotted against anions.

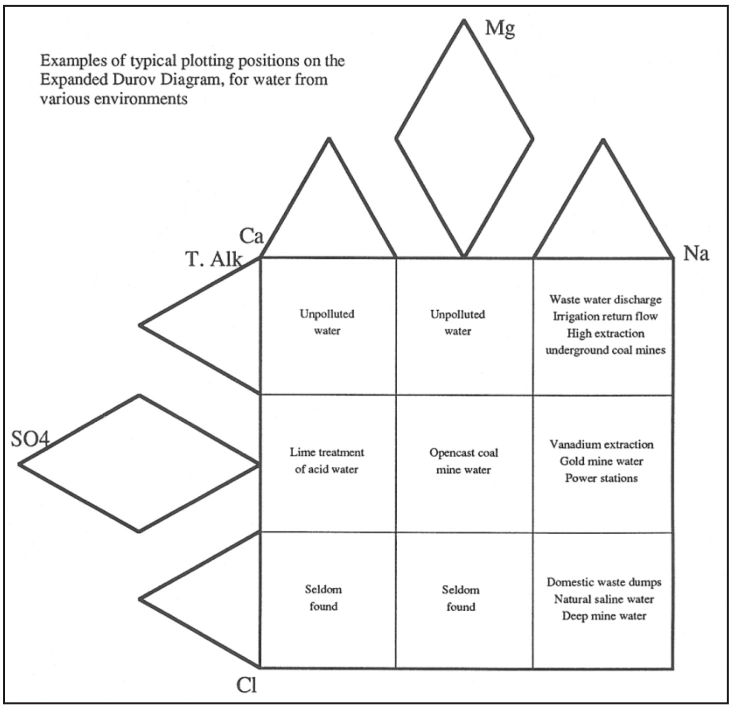

Figure 0.1. Interpretation of a Durov diagram.

8.2.2.3 Stiff diagrams

The Stiff diagram as in figure 8.4 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].

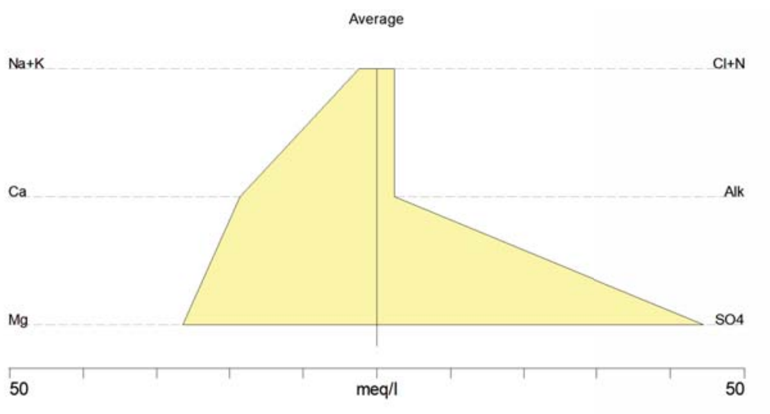

Figure 0.1. Interpretation of a Stiff diagram.

8.3 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.
- “Google Earth” Program.
- Manual Systems.

8.4 DATA AND INFORMATION RECORDING TOOLS

8.4.1 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 reasons for deviation.
- Persons contacted and topics discussed.
- Daily Summary.

8.4.2 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.

8.4.3 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 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:

- 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.,ground water).
- 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 custody.
- Date and time samples were relinquished by sampler and received by the laboratory.
- Internal temperature of shipping container upon opening at laboratory, if applicable.
- Presence or absence of ice.
- Special handling instructions as and if applicable.

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).

8.5 SUMMARY

The term information management is a new way to reflect the role of information in organisational 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.

CHAPTER 9: OPERATIONAL AND MAINTENANCE RELATED TO BULK GROUNDWATER SUPPLY SCHEMES

9.1 INTRODUCTION

The objective of a successful operation and maintenance program 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 and 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 and maintenance have been identified as follows according to (Azad, 2005):

- Lack of finance, equipment, material, and inadequate data on operation and 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 operation and maintenance manual.
- Lack of real time field information.

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. 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.

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. Maintenance can be divided into preventive, corrective and reactive maintenance.

9.2.3 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.

9.2.4 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.

9.2.5 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.

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.

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 and life.

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 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, and ways and means of achieving the completion of action and contain what objectives are meant to be achieved by this action. The plan 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 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.

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. 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 program 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. A typical record list includes the following:

- Name of equipment and location of equipment.
- Number available or installed.
- Serial number.
- Type and class.
- Date of procurement/installation.
- Cost of procurement and installation.
- Name of manufacturer with address and contact details.
- Name of distributor/dealer if purchased through them with address and telephone number.
- Name of servicing firm with address and telephone number.
- Service manuals.
- Descriptive technical pamphlets.
- Major overhauls: Details of date, nature of cost.

- When next overhaul is due.
- Date, type and cost of repairs and replacement.
- 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.

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