Groundwater Resource Directed Measures

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by

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List of Abbreviations

BFI	Baseflow Index
BHN	Basic Human Needs
CMA	Catchment Management Agency
CRD	Cumulative Rainfall Departure
DEAT	Department of Environmental Affairs and Tourism
DSS	Decision Support System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EARTH	Extended Model for Aquifer Recharge and Soil Moisture Transport through the Saturated Hardrock
EC	Electrical Conductivity
EIS	Ecological Importance and Sensitivity
EMC	Ecological Management Category
ER	Ecological Reserve
EWR	Ecological Water Requirements
GGP	Gross Geographic Product
GRDM	Groundwater Resource Directed Measures
GRIP	Groundwater Resource Information Project
ICM	Integrated Catchment Management
IFR	Instream Flow Requirements
IGS	Institute for Groundwater Studies
IUA	Integrated Unit of Analysis
IWRM	Integrated Water Resource Management
K	Hydraulic Conductivity
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MLF	Maintenance Low Flow
NAPLs	Nonaqueous Phase Liquids
NEMA	National Environmental Management Act
NGA	National Groundwater Archive
NGDB	National Groundwater Data Base
NWA	National Water Act (Act 36 of 1998)
NWRS	National Water Resource Strategy
PES	Present Ecological State
PESC	Present Ecological State Category
RDM	Resource Directed Measures
RQO	Resource Quality Objectives
RU	Resource Unit
S	Storativity

SA	South Africa
SAM	Strategic Adaptive Management
SANBI	South African National Biodiversity Institute
SDC	Source Directed Controls
T	Transmissivity
UA	Unit of Analysis
USGS	United States Geological Survey
WARMS	Water Use Authorisation and Registration Management System
WMA	Water Management Area
WMS	Water Management System
WRC	Water Research Commission
WR2005	Water Resources of South Africa 2005

Units of Measurement

a	annum
cm	centimetre
d	day
i	gradient
km^2	square kilometre
ℓ	litre
m	metre
m^2	square metre
m^3	cubic metre
mamsl	metres above mean sea level
mbgl	metres below ground level
mbs	metres below sea level
mm	millimetre
mS	millisiemens
q	flux
s	second

Definitions

Abstraction: The act of removing water from a groundwater resource.

Allocable Groundwater: The volume of groundwater available to allocate or distribute.

Alluvial Aquifer: An aquifer comprising unconsolidated material deposited by water, typically occurring adjacent to rivers and in buried paleochannels.

Anisotropy: Having some physical property that varies with direction.

Aquatic Ecosystems: Defined as the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones and reservoirs, lakes, wetlands and their fringing vegetation.

Aquiclude: A geologic formation, group of formations, or part of formation through which virtually no water moves.

Aquifer: Aquifer means a geological formation which has structures or textures that hold water or permit appreciable water movement through them.

Aquifer System: A heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.

Aquifer Testing: Aquifer testing involves the withdrawal of measured quantities of water from or the addition of water to, a borehole(s); and the measurement of resulting changes in head in the aquifer both during and after the period of abstraction or addition.

Aquitard: A saturated low permeability unit that can restrict the movement of groundwater. It may be able to store groundwater.

Artesian Aquifer: Artesian is a term originally applied to boreholes in Artois in France from which a constant supply of water was obtained because groundwater spontaneously discharged from them. It is suspected that the term was then applied to confined aquifers into which a number of artesian boreholes had been sunk. The term artesian aquifer is probably a misnomer and the term confined aquifer should rather be used.

Artesian Borehole: Boreholes that penetrate confined aquifers in which the piezometric surface is above ground level, so that the boreholes spontaneously discharge water without being pumped.

Assurance of Supply: The reliability at which a specific quantity of water can be provided.

Attenuation: The breakdown or dilution of contaminated water as it passes through the earth’s material.

Available Drawdown: Available drawdown in a borehole is the difference between the static water level or piezometric surface and the main water strike (in fractured aquifers) and the pump depth (in porous aquifers).

Available Yield: The amount of water that can be expected to be 'available' for use during any one year, at a specific assurance of supply, either from dams, rivers, or groundwater during any one year.

Bank Storage: Bank storage is water absorbed and stored by the soil pores of the bed and banks of a river, lake or reservoir during higher stage periods and returned, fully or partially to the water body as the water stage falls.

Baseflow: Sustained low flow in a river during dry or fair weather conditions, but not necessarily all contributed by groundwater; includes contributions from interflow and groundwater discharge.

Baseflow Index (BFI): The ratio of annual baseflow in a river to the total annual run-off.

Basic Human Need (BHN): The least amount of water required to satisfy basic water requirements; this is currently set at 25 ℓ/person/d.

Basic Water Supply: The prescribed minimum standard of water supply services necessary for the reliable supply of a sufficient quantity and quality of water to households, including informal households, to support life and personal hygiene.

Blow Yield: The volume of water per unit of time blown from the borehole during drilling.

Borehole: Includes a well, excavation, or any other artificially constructed or improved underground cavity which can be used for the purpose of intercepting, collecting or storing water in or removing water from an aquifer; observing and collecting data and information on water in an aquifer; or recharging an aquifer.

Borehole Log: A record of the geological and hydrogeological conditions encountered in the drilling of a borehole and the construction thereof.

Borehole Testing: The process whereby a borehole is subjected to pumping under controlled test conditions in order to determine the performance characteristics of a borehole.

Borehole Yield: The volume of water that can be abstracted from a borehole.

Catchment: Catchment in relation to watercourse or watercourses or part of a watercourse means the area from which any rainfall will drain into the watercourses, or part of a watercourse, through surface flow to a common point or points.

Classification: The classification system prescribed under the National Water Act (1998) provides guidelines on how to set appropriate levels of protection for water resources.

Conceptual Model: A conceptual model includes designing and constructing equivalent but simplified conditions for the real world problem.

Cone of Depression: The depression of hydraulic head around a pumping borehole caused by the withdrawal of water.

Confined Aquifer: A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

Confining Layer: A layer of low permeability material overlying an aquifer, which restricts the vertical movement of water.

Conjunctive Use: Combined use of surface water and groundwater.

Contamination: The introduction of any substance into groundwater systems by the action of man.

Desired Ecological Status: The future desired status of groundwater within the resource unit as used in setting the groundwater component of the ecological Reserve.

Detached Stream: See disconnected stream.

Discharge Area: That portion of catchment in which the net flow of subsurface water is directed toward the water table.

Discharge Rate: The volume of water per unit of time abstracted from an aquifer system.

Disconnected Stream: A stream detached from and not in hydrological contact with the groundwater system below.

Dissolved solids: Minerals and organic matter dissolved in water.

Drawdown: The distance between the static water level and the surface of the cone of depression.

Dug Well: A shallow large diameter man-made pit or hole from which groundwater can be abstracted

Dyke: A tabular or sheet-like body of igneous rock that cuts through and across the layering of adjacent rocks.

Ecological category: The assigned ecological condition by the Minister to a water resource that reflects the ecological condition of that water resource in terms of the deviation of its biophysical components from a predevelopment condition.

Ecological Water Requirements: The quantity and quantity of water of that resource that is required to maintain the said water resource in its assigned ecological category.

Ecologically Sustainable Base Configuration Scenario: The lowest acceptable level of protection required for the sustainable use of the entire integrated unit of analysis.

Ecology: The study of the interrelationships between organisms and their environment.

Ecoregions: Regions within which there is a relative similarity in the mosaic of ecosystems and ecosystem components (biotic and abiotic, aquatic and terrestrial).

Ecosystem: An organic community of plants, animals and bacteria and the physical and chemical environment they inhabit.

Ecosystem Goods, Services and Attributes: The goods, services and attributes that ecological systems provide that are critical to the functioning of the earth's life-support system, and which contribute both directly and indirectly to human welfare, and therefore have economic value.

Effluent Stream: A stream fed directly by groundwater; the surrounding water table or piezometric surface is above the stream surface; opposite of influent stream.

Electrical Conductivity (EC): Electrical conductivity is a measure of how well a material accommodates the transport of electric charge. The more salts dissolved in the water, the higher the EC value. It is used to estimate the amount of total dissolved salts, or the total amount of dissolved ions in the water.

Ephemeral Rivers: These rivers are generally storm-event driven and flow occurs less than 20% of the time; these rivers have a limited (if any) baseflow component with no groundwater discharge.

Estuary: A partially or fully enclosed body of water, which is open to the sea permanently or periodically, and within which the sea water can be diluted, to an extent that is measurable, with fresh water drained from the land.

Evapotranspiration: The loss of water from a land area through transpiration of plants and evaporation from the soil and surface water bodies.

Exploitation Potential: The volume of harvest potential that can practically be exploited due to borehole yield constraints.

Fault: A zone of displacement in rock formations resulting from forces of tension or compression in the earth’s crust.

Feasibility Study: The detailed analysis of a possible solution(s) described in the pre-feasibility study to a water resource related problem to determine if it is feasible.

Fissures: An extensive crack, break or fracture in rocks.

Fitness for use: Refers to water whose quality meets the requirements for a particular use.

Flow Regime: A hydrological profile of a water resource.

Fluvial: Of, or pertaining to, rivers; produced by river action.

Formation: A body of rock identified by lithic characteristics and stratigraphic position.

Fracture: Any break in a rock including cracks, joints and faults.

Fracture Flow: Water movement that occurs predominantly in fractures and fissures.

Fracture Zone: A zone of fissures, fractures, cracks, joints and faults within rocks.

Fractured Aquifer: An aquifer that owes its water-bearing properties to fracturing.

Freshwater: Water that contains less than 1 000 mg/l salts.

Gaining Stream: Synonymous with effluent stream.

Geohydrology: The study of the properties, circulation and distribution of groundwater.

Gross Geographic Product (GGP): Amounts to the total income or payment received by the production factors – land, labour, capital, and entrepreneurship – for their participation in the production within that area.

Groundwater: Water found in the subsurface in the saturated zone below the water table.

Groundwater Allocation: That volume of groundwater that can be allocated for use after consideration of the Reserve and Resource Quality Objectives.

Groundwater Divide: The boundary between two groundwater basins which is represented by a high point in the water table or piezometric surface.

Groundwater Monitoring: The regular or routine sampling, analysis and evaluation of one or more elements of the groundwater resource for a specific objective(s).

Groundwater Resource: All groundwater available for beneficial use, including man, aquatic ecosystems and greater environment.

Habitat: The environment or place where a plant or animal is most likely to occur naturally.

Hard-rock: Igneous, metamorphic and sedimentary rocks that lack adequate primary interstices to function as a primary aquifer.

Harvest Potential: The harvest potential is the maximum amount of groundwater that can be abstracted per square kilometre per annum in South Africa without depleting the aquifers.

Head: See hydraulic head.

Heterogeneous: Of dissimilar nature. Different in structure or composition throughout.

Homogeneous: Of the same or similar nature. Uniform in structure or composition throughout.

Hydraulic Conductivity: Measure of the ease with which water will pass through the earth's material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (m/d).

Hydraulic Gradient: The rate of change in the total hydraulic head per unit distance of flow in a given direction.

Hydraulic Head: Hydraulic head is the height above a datum plane such as sea level of the column of water that can be supported by the hydraulic pressure at a given point in a groundwater system.

Hydrogeology: In South Africa the terms *geohydrology* and *hydrogeology* are used interchangeably. In theory hydrogeology is the study of geology from the perspective of its role and influence in hydrology, while geohydrology is the study of hydrology from the perspective of the influence on geology.

Hydrograph: A graph which displays specific hydrological measurements over time, including water levels and discharges.

Hydrological Cycle: The continuous circulation of water between oceans, the atmosphere and land. The sun is the energy source that raises water by evapotranspiration from the oceans and land into the atmosphere, while the forces of gravity influence the movement of both surface and subsurface water.

Hydrological Year: A continuous 12-month period from 1 October to 30 September.

Hydrology: The study of the properties, circulation and distribution of water.

Hydrophytes: Plants that take their nutrients directly from water, typically found in water or wet habitats.

Hyporheic Zone: The saturated and biologically active zone in the permeable substrate beneath and adjacent to a riverbed.

Infiltration: The downward movement of water from the atmosphere into the ground.

Influent Stream: An influent stream is positioned above the water table and discharges into the underlying groundwater system.

Interacting Stream: See Intermittent Stream.

Integrated Unit of Analysis: A water resource catchment that incorporates a socio-economic zone, but is defined by a watershed.

Interflow: The rapid flow of water along essentially unsaturated flow paths, water that infiltrates the subsurface and moves both vertically and laterally before discharging into other water bodies.

Intergranular Aquifer: A term used in the South African map series referring to aquifers in which groundwater flows in openings and void space between grains or weathered rock.

Intermittent Stream: Rivers and streams whose interaction with groundwater depends on the fluctuating position of the water table, ranging from effluent streams in the wet season to influent streams in the dry season.

Isotropy: The condition of having properties that are uniform in all directions.

Karst Aquifer: Limestone and dolomite areas that possess a topography peculiar to and dependent upon underground solution and the diversion of surface waters to underground routes.

Latrine: A pit used for the disposal of human excreta, particularly prevalent in rural areas.

Leachate: Any liquid, including any suspended components in the liquid that has percolated through or drained from human-emplaced materials.

Lithology: Lithology refers to the physical characteristics of rock.

Losing Stream: See Influent Stream.

Major Aquifer System: Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m).

Mine: A mine can be defined as an excavation in the earth, from which substances such as ores and minerals are extracted.

Minor Aquifer System: These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable.

Monitoring Borehole: A borehole used to measure groundwater trends.

Multiphase Flow: Two or more distinct phases of a compound or its breakdown products flowing through the subsurface at the same time.

Nonaqueous Phase Liquids (NAPLs): Organic compounds that do not dissolve readily in water.

Observation Borehole: A borehole used to measure the response of the groundwater system to an aquifer test.

Paleochannel: A paleochannel is an old or ancient channel.

Perched Aquifer: Aquifers that contain perched groundwater, i.e. bodies of groundwater separated from an underlying body of groundwater by an unsaturated zone.

Perennial Stream: Streams where surface flow persists throughout the year.

Permeability: The ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (expressed as $m^3/m^2/d$ or m/d); it is an intrinsic property of the porous medium and is dependent of the properties of the saturating fluid.

Phreatophytes: Plants that habitually obtain water from below the water table or from the capillary fringe directly above the water table.

Piezometer: A non-pumping borehole, generally of small diameter, for measuring the elevation of a water table or collecting water samples.

Piezometric Surface: An imaginary or hypothetical surface of the piezometric pressure or hydraulic head throughout all or part of a confined or semi-confined aquifer; analogous to the water table of an unconfined aquifer.

Pollution: Pollution means the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it –

a) less fit for any beneficial purpose for which it may reasonably be expected to be use;
b) harmful or potentially harmful –
    to the welfare, health of safety of human beings;
    to any aquatic or non-aquatic organisms;
    to the resource quality; or
    to property.

Poor Aquifer System: These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Porosity: Porosity is the ratio of the volume of void space to the total volume of the rock or earth material.

Porous Media: A geological formation with voids or pore spaces within the porous texture that can hold water or permit water movement.

Potable Water: Water that is safe and palatable for human use.

Pre-Development Condition: The condition of that resource prior to significant alteration to its biophysical components by human impact.

Pre-feasibility Study: A Pre-feasibility study focuses on the additional work that has been identified in the Reconnaissance study to better define the options available for solving a water resource problem.

Preferential Flow: The preferential movement of water through more permeable zones in the subsurface.

Primary Aquifer: An aquifer in which groundwater moves through the original interstices of the geological formation.

Quaternary Catchment: A fourth order catchment in a hierarchal classification system in which a primary catchment is the major unit.

Recharge: The addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.

Recharge Area: An area over which recharge occurs.

Reconnaissance Study: A desktop study of options available on a catchment scale to solve a water resource related problem.

Remediation: Reduce the concentrations of contaminants in groundwater to some acceptable level.

Remote Stream: See Disconnected Stream.

Reserve: Reserve means the quantity and quality of water required –

a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No 108 of 1997), for people who are now or who will, in the reasonably near future, be –

    relying upon;

taking water from; or

being supplied from,

the relevant water resource; and

b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use the relevant water resource.

Resource: A resource is a substance or item available for use. A natural resource is a resource that man can use, but cannot manufacture or create.

Resource Directed Measures (RDM): A term used but not defined by the National Water Act. The objective of Resource Directed Measures is to facilitate the proactive protection (for use) of the country's water resources, in line with sustainability principles. The National Water Act (NWA) recognises the need to develop and use the country's water resources to grow. However, the Act also recognises that our water resources should not be used to the detriment of future users. RDM hence strives to ensure that the water resources are afforded a level of protection that will assure a sustainable level of development for the future. To this end, RDM comprises three main interrelated components, namely:

- Classification
- Reserve
- Resource Quality Objectives.

Resource Quality: The quality of all the aspects of a water resource including –

- the quantity, pattern, timing, water level and assurance of instream flow;
- the water quality, including the physical, chemical and biological characteristics of the water;
- the character and condition of the instream and riparian habitat; and
- the characteristics, condition and distribution of the aquatic biota.

Resource Quality Objectives (RQOs): A term used but not defined by the National Water Act. Resource Quality Objectives are used to put a Classification and Reserve into practice by specifying conditions that will ensure that the Class is not compromised and the Reserve can be met. Resource quality may relate to critical flows, groundwater levels and quality that must be maintained. The objectives are to articulate goals that result from the catchment visioning process, but must be based on DWAF policy statements and methodologies and aligned with the National Water Resource Strategy.

Rest Water Level: The groundwater level in a borehole not influenced by abstraction or artificial recharge.

Riparian Habitat: Area of land directly adjacent to a stream or river, influenced by stream-induced or related processes.

River: A physical channel in which runoff will flow from higher to lower ground, and to the sea.

River System: A network of rivers ranging from streams to major rivers and, in some cases, including rivers draining naturally into separate catchments that have been interconnected by man-made transfer schemes.

Rock: Any mass of mineral matter, whether consolidated or not, which forms part of the earth's crust.

Runoff: All surface and subsurface flow from a catchment, but in practice refers to the flow in a river, i.e. excludes groundwater not discharged into a river.

Safe Yield: 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.

Saline Intrusion: The replacement of fresh groundwater by saline water in an aquifer, usually as a result of groundwater abstraction.

Sanitation: The prescribed minimum standard of services necessary for the safe, hygienic and adequate collection, removal, disposal or purification of human excreta, domestic waste-water and sewage from households, including informal households, to support life and personal hygiene.

Saturated Zone: The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere.

Seasonal Stream: These streams are driven by seasonal rainfall patterns and flow occurs between 20% and 80% of the time. These streams have a limited baseflow component with little or no groundwater discharge.

Secondary Aquifer: An aquifer in which groundwater moves through secondary openings and interstices, which developed after the rocks were formed.

Semi-confined Aquifer: An aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur.

Significant Water Resource: A term used but not defined by the National Water Act. It relates to the size of the water resource rather than its importance. A resource is deemed to be significant if it is large enough to warrant its own Reserve determination.

Sill: Sheet-like body of igneous rock which conforms to bedding or other structural planes.

Sinkhole: Sinkholes are subsidence or collapse features that form at points of local instability and are usually associated with dolomite or karstic landscapes.

Situation Assessment: An assessment describing the status quo of groundwater-related issues within a study area.

Soil: The usually thin upper surface layer of the earth's crust comprising living organisms, organic matter, decomposed rock or unconsolidated sediments, water and gases with properties attributable to the interaction of its parent material, time, climate, fauna and flora.

Sole Source Aquifer: An aquifer that is needed to supply 50% or more of the domestic water for a given area, and for which there are no reasonably available alternative water sources should the aquifer be impacted upon or depleted.

Special Aquifer System: An aquifer designated as such by the Minister of Water Affairs, after due process.

Specific Yield (Sy): The ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium.

Spring: A point where subsurface water emerges at surface, usually as a result of topo-graphical, lithological or structural controls.

Storage Coefficient (S): The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Stream: A small narrow river; often used interchangeably with river.

Subsurface Water: All water occurring beneath the earth's surface, including soil moisture, that in the vadose zone and groundwater.

Surface Water: Bodies of water, snow or ice on or above the surface of the earth (such as lakes, streams, ponds, wetlands, etc.).

Sustainable Development: Use, development and protection of natural resources in a way and at a rate that allows for social, economic and cultural needs of people and communities to be met without compromising the ability to meet the needs of future generations.

Transmissivity (T): The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average hydraulic conductivity and thickness of the saturated portion of an aquifer.

Unconfined Aquifer: An aquifer where the water table is the upper boundary and with no confining layer between the water table and the ground surface. The water table is free to fluctuate up and down.

Unsaturated Zone: That part of the geological stratum above the water table where interstices and voids contain a combination of air and water, synonymous with zone of aeration or vadose zone.

Velocity: Two types of groundwater velocities are of interest to geohydrologists:

- *Darcy flux*: The Darcy flux (or velocity) is the hydraulic conductivity (K) times the gradient of the water/piezometric level (i.e. q=Ki).
- *Seepage velocity*: The seepage velocity is defined as the Darcy flux divided by the effective porosity. This is also referred to as the average linear velocity.

Vulnerability: The vulnerability of groundwater to contaminants generated by human activities taking into account the inherent geological, hydrological, hydrogeological characteristics of an aquifer.

Water Course: A river or spring; a natural channel in which water flows regularly or intermittently; a wetland, lake or dam into which, or from which, water flows; any collection of water that the Minister of Water and Environmental Affairs may, by notice in the Government Gazette, declare to be a water course (National Water Act, Act 36 of 1998).

Water Management Area (WMA): An area established as a management unit in the National Water Resource Strategy within which a Catchment Management Agency will conduct the protection, use, development, conservation, management and control of water resources in South Africa.

Water Resource: Includes a water course, surface water, estuary or aquifer.

Water Table: The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is equal to that of the atmosphere.

Watershed: Means a line of separation between water resources.

Wellfield: A group or cluster of boreholes in an area used collectively to supply sufficient groundwater to a user or users.

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

Xerophytes: Plants that have adapted to dry or arid conditions.

Yield: The quantity of water removed from a water resource, e.g. yield of a borehole.

1 Why is a Manual Necessary?

1.1 Background

Water is a natural resource and belongs to all the people of South Africa. Sustainability, equity and efficiency are identified by the South African government as central guiding principles in the protection, use, development, conservation, management and control of water resources. These principles recognise the following:

- basic human needs of present and future generations,
- the need to protect water resources (for use),
- the need to share some water resources with other countries,
- the need to promote social and economic development through the use of water and
- the need to establish suitable institutions in order to achieve the purpose of the National Water Act (Act No. 36 of 1998) (NWA).

To be able to implement the NWA, the Minister needs to ensure that the tools and expertise required to implement the Act are available. This manual addresses the methods and procedures needed to implement Resource Directed Measures (RDM). To distinguish between RDM in general and RDM related to groundwater, the term Groundwater Resource Directed Measures (GRDM) will be used when the focus is only on groundwater. However it is important to note that the NWA clearly includes groundwater in a unitary hydrological cycle and in the definition of a water resource, but the characteristics of groundwater sometimes require it to be considered or managed differently to other water resources.

In essence, this manual is about the techniques to ensure that groundwater resources will be used in a sustainable way as prescribed by the NWA. This forms the cornerstone of the long-term sustainable use of the resource – the other two components being equity and efficiency.

The NWA aims to ensure access to a limited resource on an equitable basis in an integrated, manageable and sustainable manner. The NWA moves away from riparian and property rights, but recognises basic human needs and water needs to sustain the environment. The promulgation of the NWA has resulted in significant changes in the way in which we use and manage water. Because of the shift from private to public water, this is particularly true of the groundwater component of the hydrological system that was previously regarded as private.

1.2 Layout of manual

Chapter 1 motivates why it is necessary to have a manual.

Chapter 2 provides a detailed discussion of the National Water Act. More specifically it focuses on Chapter 3 of the NWA which discusses protecting the health of South Africa's water resources. The aim of protecting water resources is to ensure that water is available for current and future use. Protection therefore involves the sustaining of a certain quantity and quality of water to maintain the overall ecological functioning of rivers, wetlands, groundwater and estuaries.

Chapter 3 focuses on data requirements. The purpose of collecting data is to obtain information on which to base management decisions. The aim and purpose of groundwater data collection for the Reserve must be defined before the process is actually started. The purpose of data collection for the Reserve must be to assist in the quantification of the resource. A wide range of data and information can be used to characterise the geohydrology of an area. Based on the amount and quality of data available, the geohydrologist will need to provide an indication of the level of confidence of the assessment.

Chapter 4 explains the initiation of a GRDM study. It is largely a DWA management task undertaken by the RDM Chief Directorate and the assigned RDM Study Manager, with specialist groundwater input being provided by DWA personnel.

Chapter 5 discusses the development of a classification system for water resources, the classification of water resources, the determination of resource quality objectives (desired level of protection of a water resource) as well as the protection of the Reserve for all or part of any significant water resource.

Chapter 6 includes requirements for the Reserve. The Reserve is part of the national water resource within each water management area that is under the direct control of the Minister. It is water that is 'set aside' to: provide for basic human needs, and protect water ecosystems (sustain healthy ecosystems).

Chapter 7 discusses how each major water resource will be protected and used. This is called determining the resource quality objectives. RQOs must set objectives for the management of water resources in a catchment or other UAs, (if applicable) and by its very nature be applicable on that scale.

Chapter 8 presents a set of tools to assist in all the calculations necessary to conduct a GRDM study. These tools are included in the GRDM software which accompanies the manual.

Chapters 8 and 10 provide background to the two case studies included in the GRDM software.

2 What does the National Water Act say?

2.1 Preamble

Water is a natural resource and belongs to all the people of South Africa. South Africa is not a water-rich country and, as a result, water has to be managed and used wisely. Water management in South Africa is based on three key principles:

- **Sustainability**: Water use must promote social and economic development, but not at the expense of degrading the environment (technical component).
- **Equity**: Every citizen of the country must have access to water and the benefit of using water (social component).
- **Efficiency**: Water must not be wasted and must be used to the best possible social and economic advantage (economic component).

The Department of Water Affairs (DWA) has the responsibility of managing water resources (taking into account the interdependency of all the components of the hydrological cycle) on behalf of the people of South Africa. The National Water Act (1998) provides a legal framework for the effective and sustainable management of South Africa's water resources. The NWA therefore provides decision-making tools to achieve a balance between protecting and using South African water resources.

Chapter 3[1] of the NWA focuses on protecting the health of South Africa's water resources. The aim of protecting water resources is to ensure that water is available for current and future use. Protection therefore involves the sustaining of a certain quantity and quality of water to maintain the overall ecological functioning of rivers, wetlands, groundwater and estuaries. This Chapter (parts 1, 2 and 3) of the NWA therefore introduces series of measures which together are intended to protect all water resources. These measures are referred to as Resource Directed Measures, and in the case of where it is related to groundwater, as Groundwater Resource Directed Measures (GRDM). These measures include Classification, Quantification of the Reserve and Resource Quality Objectives.

2.2 Gazetted approach to Resource Directed Measures

The Water Resource Classification System and other measures laid down by the Act are together intended to ensure the ecological sustainability of all the significant water resources by taking into consideration the social and economic needs of competing interests by all who rely on the water resources.

[1] Chapter 3 of the NWA is documented in Appendix A.

2.2.1 Procedure for determining different classes of water resources

The class of a water resource must describe –

a) the extent of use of the water resource;

b) the Reserve;

c) the resource quality objectives; and

d) the determination of the allocable portion of a water resource for use.

Water resources must be classified into one of the following classes –

a) **Class I water resource**: This is one –

(i) which is minimally used; and

(ii) in which the configuration of the ecological categories of the water resources within a catchment results in an overall condition of that water resource that is minimally altered from its pre-development condition.

b) **Class II water resource**: This is one –

(i) which is moderately used; and

(ii) in which the configuration of ecological categories of the water resources within a catchment results in an overall condition of that water resource that is moderately altered from its pre-development condition.

c) **Class III water resource**: This is one –

(i) which is heavily used; and

(ii) in which the configuration of ecological categories of the water resources within a catchment results in an overall condition of that water resource that is significantly altered from its pre-development condition.

The procedure to determine the different classes of water resources must comprise of the following seven steps:

a) **Step 1**: Delineate the units of analysis and describe the *status quo* of the water resource or water resources.

b) **Step 2**: Link the socio-economic and ecological value and condition of the water resource or water resources.

c) **Step 3**: Quantify the ecological water requirements and changes in non-water quality ecosystem goods, services and attributes.

d) **Step 4**: Determine an ecologically sustainable base configuration scenario.

e) **Step 5**: Evaluate scenarios within the integrated water resource management process.

f) **Step 6**: Evaluate the scenarios with stakeholders.

g) **Step 7**: Gazette and implement the class configuration.

2.2.2 Procedure for determining the Reserve

For each water resource class, the procedure for the determination of the Reserve must comprise of the following eight steps:

a) **Step 1**: Initiate the basic human needs and ecological water requirements assessment.

b) **Step 2**: Determine eco-regions, delineate resource units, select study sites and, where appropriate, align with Step 1 of the water resource classification procedure set out in Regulation 2(4).

c) **Step 3**: Determine the reference conditions, present ecological status and the ecological importance and sensitivity of each of the selected study sites.

d) **Step 4**: Determine the basic human needs and ecological water requirements for each of the selected study sites and, where appropriate, align with Step 3 of the water resource classification procedure set out in Regulation 2(4).

e) **Step 5**: Determine operational scenarios and its socio-economic and ecological consequences.

f) **Step 6**: Evaluate the scenarios with stakeholders and align with Step 6 of the water resource classification procedure set out in Regulation 2(4).

g) **Step 7**: Design an appropriate monitoring programme.

h) **Step 8**: Gazette and implement the Reserve.

2.2.3 Procedure for determining Resource Quality Objectives

For each water resource class, the procedure for establishing resource quality objectives must comprise of the following six steps:

a) **Step 1**: Identify water users within each water resource management unit, and where appropriate, align with Step 1 of the water resource classification procedure set out in Regulation 2(4).

b) **Step 2**: Determine the present state per water user and, where appropriate, align with Step 5 of the water resource classification procedure set out in Regulation 2(4).

c) **Step 3**: Determine the desired water quality per user and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).

d) **Step 4**: Determine water user specifications and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).

e) **Step 5**: Determine water quality requirements of water uses and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).

f) **Step 6**: Gazette and implement the resource quality objectives.

These regulations shall be called the Regulations for the Establishment of the Classification System, 2010.

2.3 What is our responsibility according to Chapter 3 of the NWA?

Thompson (2006) discusses the clear management objectives as set out in the NWA (1998) (by making use of the resource directed measures) should be set and be given effect to for the desired level of protection of the water resource to Thompson (2006) –

- satisfy the water quality requirements of the water users as far as possible; and

- protect the aquatic ecosystems in the water resources in order to secure ecologically sustainable development and use of the water resources.

The resource directed measures consist of the following:

- Developing a system to classify the nation’s water resources which provides guidelines and procedures for determining the different classes of water resources.

- Determining the class and resource quality objectives of all or part of the water resource considered to be significant by making use of the classification system, so as to establish clear goals to be achieved for the different components of the water resource.

- Determining the Reserve for all or part of the water resource considered to be significant so as to determine the quantity and quality of water necessary to satisfy basic human needs and to protect the aquatic ecosystems.

Classifying water resources include:

- Establish procedures for determining the Reserve.

- Establish procedures to satisfy the water quality requirements of water users as far as reasonably possible, without significantly altering the natural water quality characteristics of the resource.

- Set out water uses for instream and land-based activities, which activities must be regulated or prohibited in order to protect the water resource.

The system may also provide for other matters relating to the protection, use, development, conservation, management and control of water resources.

The resource quality should include descriptive and quantitative specifications for aquatic ecosystems and users of a water resource and may relate to the following:

- The Reserve of the water resource.

- The instream flow of the water resource.

- The water level of the water resource.

- The presence and concentration of particular substances in the water of the water resource.

- The characteristics and quality of the water resource and the instream and riparian habitat of the water resource.

- The characteristics and distribution of aquatic biota of the water resource.

- The regulation or prohibition of instream or land-based activities which may affect the quantity of water in or quality of the water resource.

- Other characteristics of the water resource.

The requirements of the aquatic ecosystem will generally dictate the value of a specific resource quality objective, except if there is a sensitive user.

The aim in determining the class and resource quality objectives of a water resource is to establish clear goals relating to the different components of the water resource concerned. In determining these objectives, a balance should be sought between the need to protect and sustain the water resources on the one hand, and the need to develop and use them, on the other. It should take into consideration the services to be delivered by water resources.

The classification system for groundwater will be generically similar to that for surface water, but due to the nature of groundwater, it will have its own unique features. Groundwater resources differ from surface water resources in that they are not confined to distinct, visible channels, move very slowly and are less prone to rapid temporal variations than surface water. As the rehabilitation of polluted and or impacted aquifers is technically very difficult, a lengthy, costly and careful approach to groundwater protection is required.

Because of the contribution of groundwater to surface water flow in certain circumstances, the volume of groundwater that could be abstracted without impacting the ability of the groundwater to sustain or contribute to the surface water Reserve has to be taken into account. This should be done by determining the recharge to a particular groundwater resource, assessing the contribution to baseflow or a surface water resource and calculating the basic needs to be met from groundwater. It is also necessary to control the amount of water abstracted to protect the structural integrity of the aquifer and to protect the terrestrial ecosystems dependent on the groundwater supplies.

As soon as reasonably practicable after the class of a water resource or part thereof has been determined, the Reserve for that resource or part thereof must be determined. The determination must be in accordance with the class of the water resource and ensure that adequate allowance is made for each component of the Reserve.

The Reserve for a specific water resource is the quantity as well as the quality of water from that resource necessary to –

- satisfy basic human needs by securing a basic water supply as prescribed under the Water Services Act (Act 108 of 1997), for people who are currently or who will in the reasonably near future be relying upon that resource, who will be taking water from that resource or will be supplied from that resource (known as the basic human needs Reserve); and
- protect the aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource (known as the ecological Reserve).

The ecological Reserve should be determined by using approved methods. The methods require quantification of the flow, habitat and water quality requirements of all the ecosystems in the water resource in order for them to remain at or attain the selected level of health, and therefore classification of the ecosystem.

2.4 References

- Department of Water Affairs. 2010. *Regulations for the establishment of a water resource classification system*. Pretoria.
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- Water Services Act (Act 108 of 1997).
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- Thompson, H 2006. *Water Law: A practical approach to resource management and the provision of services.* Juta and Co Ltd, ISBN 10: 0-7021-6732-0, Cape Town.

3 Data Requirements and Interpretation

3.1 Data

The purpose of collecting data is to obtain information on which to base management decisions. Water science is based on quantitative methods to delineate, evaluate and understand water resources. The main purpose is to determine water quantities and qualities to be able to plan ahead for management purposes. The aim and purpose of groundwater data collection for the Reserve must be defined before the process is actually started. The purpose of data collection for the Reserve must be to assist in the quantification of the resource.

A wide range of data and information can be used to characterise the geohydrology of an area. Based on the amount and quality of data available, the geohydrologist will need to provide an indication of the level of confidence of the assessment. Possible sources of data are listed in Table 1.

Table 1: Possible sources of data used during GRDM assessments

DATA NEEDED	DATA AND INFORMATION	SOURCE
Study area	Quaternary catchment boundaries	WR2005
Population data	Population statistics	Central Statistical Services Regional and local municipalities
Conservation areas		DWA
Water sources	Flow-gauging stations	DWA
Physiography	Topographical maps – 1:250 000 – 1:50 000 (if needed)	Dir. Surveys and Land Information
Climatic data	Rainfall data Evaporation data	Weather Bureau WR2005 SA Atlas of Agrohydrology and Climatology Local communities, mines and industry DWA Department of Agriculture, Forestry and Fisheries
Geology	Geological maps – 1:250 000 – 1:50 000 (if available)	Council for Geoscience DWA Consultants Mines
Physiography	Remote sensing maps and data – satellite images – aerial photographs	Satellite Applications Centre Directorate Surveys and Land Information
Soils	Soil maps	Department of Agriculture, Forestry and Fisheries Agricultural Research Council WR2005
Drainage	Flow data Wetland inventory	DWA WR2005 Working for Wetlands

DATA NEEDED	DATA AND INFORMATION	SOURCE
	Springs	DWA
Surface water information	Cross sections of river beds Dam releases and seepages	DWA Consultants River Health Program
Vegetation and land-use		SANBI WR2005 DEAT
Geohydrology	Geohydrological maps – national groundwater maps – harvest potential map – groundwater vulnerability map – 1:500 000 geohydrological maps	WRC DWA
Geohydrological data	Geohydrological data – national groundwater database – hydrochemical database – geohydrological reports – field assessments	DWA: NGDB/NGA DWA Regional Offices Water Research Commission Local authorities Consultants GRIP (where applicable)
Groundwater use (for vegetation, mining, agriculture, forestry, domestic supply, etc.)	WARMS database Regional databases Geohydrological reports Satellite images	DWA Regional Offices Water Research Commission Local authorities Consultants GRIP (where applicable)
Catchment study reports	General and historical information relating to water resources	DWA
Internal Strategic Prospective (ISP) Reports	General and historical information relating to water resources	DWA

3.2 Uncertainty associated with groundwater parameters and methods of analysis

Geohydrological parameters that are used to measure data, and are used to interpret and analyse information, are evaluated in terms of levels of uncertainty in this section. The data parameters are listed and classified in terms of the character of the variable, field measurement methods, statistical distribution, methods of interpretation and level of uncertainty. The evaluation shows the following (Table 2):

- **Direct field measurements**: Only three direct groundwater parameters, namely water levels, abstraction rates and water quality, can be quantitatively and directly measured in the field. The level of uncertainty at the data points are low, but spatial analyses techniques are required to interpolate the data across the area of interest. The spatial interpolation introduces a level of uncertainty.
- **Rainfall** is also an important direct field measurement that can be made. It is the driving force behind recharge and requires statistical analysis. It can be considered as an indirect parameter as it influences recharge that is a more complex variable. Uncertainty in rainfall is also introduced where interpolations between measurement stations are made.
- **Geohydrological zones** are well-mapped from geological data sources. This data is generally available for the two-dimensional case. Geohydrology becomes much more complex when three-dimensional considerations are made that introduces a higher level of uncertainty.

- **Derivations based on analytical models**: Hydraulic groundwater (or aquifer) parameters such as transmissivity (or hydraulic conductivity) are indirectly derived from analytical and numerical models, based on field tests. The indirect nature of these parameters introduces a higher level of uncertainty.
- **Other sources and sinks (dams, springs, wetlands, alien vegetation, etc.) that are estimated using qualitative field measurements or remote sensing**: Remote sensing would, for example, be used to determine the area of a wetland or alien vegetation patch which will be used to derive water use values. A higher level of uncertainty is introduced as derivations are made based on remote sensing information. The quantification of these sources and sinks are usually conservative estimates as very few field measurements are available.
- **Estimations based on a qualified guess**: The groundwater parameters of recharge and storativity cannot be measured or determined directly from field measurements such as aquifer tests. In most cases only an initial estimation or guess can be made that can be qualified using analytical techniques (chloride and isotope methods) or from long-term monitoring data. The conundrum is that these two parameters are the most important in determining sustainable resource quantities.

Based on the above geohydrology can be classified as a non-unique science associated with a high degree of uncertainty. The aim has to be on maximising the data that exists and the analysis methods that can be used to characterise and understand the level of uncertainty. The level of uncertainty needs to be reduced for the purposes of decision-making for management purposes as it is becomes very difficult, expensive and even impossible to reduce uncertainty beyond certain ranges. Data and uncertainty can therefore not be evaluated in the absence of a decision-making framework or methodology, which should underpin the point of sufficiency of data.

Refer to Appendix B for more information concerning uncertainty.

Table 2: Geohydrological data parameters, assessment methods, interpretation and uncertainty

NO	VARIABLE	VARIABLE CHARACTER	VARIABLE FIELD MEASUREMENT OR ASSESSMENT METHOD	DISTRIBUTION	METHODS OF ASSESSMENT	METHODS OF INTERPRETATION	UNCERTAINTY IN PARAMETER, METHODS OF ASSESSMENT AND INTERPRETATION
1	Water levels (piezometric heads)	Spatial and temporal	Measured (quantitative)	Probabilistic (spatially variable)	Measured at borehole (data points)	Statistical in terms of variability	Low
2	Abstraction rates	Spatial and temporal	Measured (quantitative)	Probabilistic (spatially variable)	Measured at borehole (data points)	Statistical in terms of variability	Low
3	Water quality	Spatial and temporal	Measured (quantitative)	Probabilistic (spatially variable)	Measured at borehole (data points)	Statistical in terms of variability	Low
4	Rainfall	Spatial and temporal Highly variable	Measured (quantitative)	Probabilistic	Measured at rainfall stations	Statistical in terms of variability Monte Carlo in terms of future probabilities	Low to medium
5	Transmissivity	Spatial	Calculated from field tests	Probabilistic (spatially variable)	Measured at borehole (data points)	Statistical	Medium to high
6	Other sources and sinks (dams, springs, wetlands, alien vegetation, etc.)	Spatial	Calculated from field tests or estimated using qualified guess	Probabilistic (spatially variable)	Quantified using field measurements or estimated using remote sensing	Statistical	High
7	Groundwater recharge	Spatial and temporal High variability	Calculated Can be qualified using long-term monitoring data	Probabilistic Probabilistic	Quantified using the chloride method, isotopes, analytical and numerical models	Statistical in terms of variability Monte Carlo in terms of future probabilities	Very high
8	Storativity (specific storage, specific yield)	Spatial	Calculated Can be qualified using long-term monitoring data	Probabilistic	Quantified using field measurements at boreholes	Statistical	Very high

In most cases, variables such as transmissivity, recharge and storativity are estimated (qualified guess) and assumed to be spatially consistent with the same geohydrological unit or formation.

3.3 Sparse data and uncertainty

Geohydrological data is often sparse and multivariate, associated with a high degree of uncertainty. This problem can be addressed by utilising geospatial methodologies that are designed for this purpose (Wellman & Poeter, 2006). The various methods that are recommended to be used for the purposes of the assessment of the groundwater component of the reserve are:

1. Temporally variable data (groundwater use, rainfall, recharge, water levels, etc.):
   - Mean
   - Standard deviation
   - Percentile values for levels of assurance
   - Regression (correlation)
   - Hypothesis testing
   - Bayesian estimation using preconditioning and posterior conditioning.
2. Spatially variable data (groundwater use, transmissivity, rainfall, recharge, water levels, etc.):
   - Linear interpolation
   - Kriging
   - Inverse distance to a power
   - Nearest neighbour

Two methodologies are suggested to accommodate uncertainty, namely:

- Probabilistic analyses which are well established. These methods do require large datasets which can be skewed.
- Fuzzy Set Theory is an emerging method which includes the knowledge of experts and is well-suited for small datasets.

Important outcomes are to determine the variability of the various geohydrological parameters as it is the variability (temporal and spatial) that increases the uncertainty, which in turn makes the management of the resource more challenging.

3.4 The effect of scale

Scales are an important element in GRDM assessments for different reasons. Firstly, place-based analysis seeks for detecting vulnerability at a certain locality, implying the selection of a unit of analysis. Secondly, systems and processes operate at a wide variety of spatial and temporal scales requiring a holistic overview of processes at multiple scales. Thirdly, cross-scale interaction exerts a crucial influence on outcomes at a given scale.

The analyst must pre-determine the scale of the assessment as it will influence the data collection programme and the uncertainty. All data and uncertainty will be relative to the scale of the assessment.

Dealing with scale within GRDM process

Quaternary scale: Transmissivity and recharge are the two key parameters that are scale-dependent. It is suggested that transmissivity be estimated with the assured yield model on a quaternary scale with the transmissivity falling between the harmonic and geometric mean. Recharge must be generated stochastically. Existing datasets and maps are required.

Wellfield Scale: The GRDM toolset (see Chapter 8 for more detail) to determine required information. Field data such as pumping tests is important. Boundaries must be delineated.

It is suggested that the analyst start on a quaternary scale. At this scale ground-water flow occurs at a local, sub-regional and regional level as shown in Figure 1.

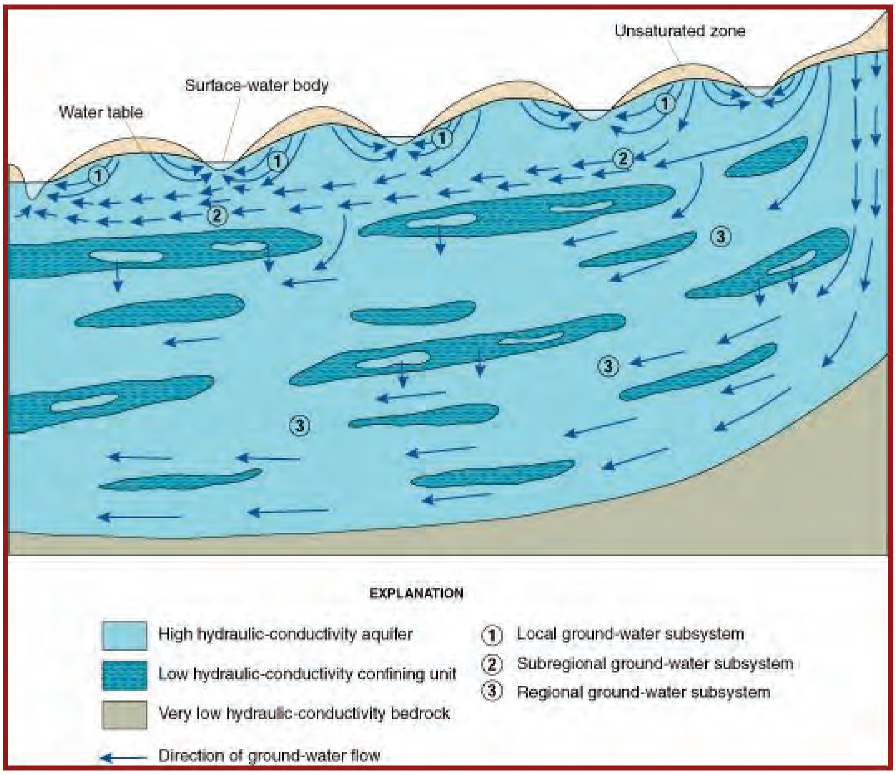

Figure 1: Groundwater flow at a quaternary scale (Source: USGS, 1998)

3.5 The role of assumptions

In all groundwater investigations, assumptions must be made. In reality, assumptions are part of the data collection and interpretation process. The derivation of aquifer parameters are based on analytical and numerical analysis techniques or models that make assumptions in order to arrive at solutions. The well-known Theis or Cooper-Jacob assumptions are based on two-dimensional, horizontal flow, uniform homogeneous and infinite aquifers, etc. (Kruseman & De Ridder, 1991). Except for the three directly measurable data parameters (water levels, abstraction rates and water quality), assumptions form an integral part of the data interpretation and decision-making process.

It is proposed that conservative assumptions be used, in line with the precautionary principle required by the National Environmental Management Act (NEMA, 1998). Assumptions used in this way would always have the effect that more water is available than the actual case. The assumption would serve as a safety factor against uncertainty; the higher the uncertainty, the larger the safety factor. Care should be taken not to become over-conservative in the use of assumptions.

Typical examples of assumptions include the following (Parsons & Wentzel, 2007):

- Groundwater systems are generally resilient and can normally recover from most perturbations. However, it is accepted that groundwater contamination can persist over decades and centuries.
- Groundwater resources can be developed and used to some point, without significantly impacting the ability of groundwater resources to sustain the Reserve or meet the RQOs.
- The ability of a geohydrological system to satisfy basic human needs, RQOs and the ecological Reserve is not impacted if regional groundwater levels do not decline significantly over the long term and ambient groundwater quality remains within natural limits.
- The sustainable rate at which groundwater can be abstracted is a function of the average long-term annual recharge, while the volume of groundwater held in storage acts as a buffer during dry periods.
- It is assumed that recharge and groundwater abstraction are distributed relatively evenly throughout significant water resources.
- The validity of each GRDM assessment will be reviewed at least every five years using monitored data from the study area.
- The GRDM assessment will be carried out by persons qualified and experienced in the field of groundwater hydrology who, in turn, will collaborate with other specialist hydrologists and ecologists. The GRDM assessment will also be subject to formal review.

3.6 Information required for GRDM process

It is difficult to provide a template of the information required, as the detail of information will vary according to the level of GRDM assessment undertaken, the nature and extent of data available for the area and the particular area being assessed. However, the type of information required for a sound conceptual understanding of an area is presented in

Table 3. This list could also be used as a basic template for the conceptual report to be prepared on completion of the study (Parsons & Wentzel, 2007).

TABLE 3: BASIC INFORMATION REQUIRED FOR A CONCEPTUAL UNDERSTANDING OF THE STUDY AREA

1. Introduction
- Terms of Reference
- Project team
- Sources of data
- Work undertaken

2. Background Information
- Locality and extent of study area (map), including quaternary catchments and catchment areas
- Population and sources of water
- Land use (map), including urban, agricultural, forestry, mining, industry
- Conservation and protected areas (map)
- Water sources, including dams, interbasin transfer schemes, groundwater, etc.

3. Physiography and Climate
- Topography (map), including slope, geomorphological classification and mountain ranges
- Climate, including rainfall (volumes, seasonality) and evaporation (volumes, seasonality) (map)
- Geology (map), including lithology, stratigraphy and structure
- Soils
- Drainage, including rivers, dams and lakes, wetlands, springs and vleis, mean annual runoff (MAR), baseflow and baseflow indices, groundwater contribution to baseflow and ecological water requirements (EWR) (if available)
- Vegetation (map), including types and classification (e.g. Acocks, Low and Rebelo)

4. Geohydrology
- Aquifer types (primary, secondary) (map)
- Hydraulic characteristics and range of parameters (T, K, S)
- Typical drilling targets
- Boreholes and borehole characteristics (depth, yield, construction) (map)
- Groundwater abstraction and use (domestic, RDP, industrial, agricultural, mining)
- Groundwater levels and depth to groundwater, groundwater level contour map and hydraulic gradient (map), typical seasonal and annual fluctuations of groundwater levels – particularly in the vicinity of surface water bodies
- Groundwater quality (e.g. Piper or Durov diagrams, contour maps, statistical analyses and description)
- Source and potential sources of groundwater contamination
- Known incidences of groundwater contamination in a catchment
- Recharge
- Groundwater potential, including harvest potential
- Surface– groundwater interaction, including groundwater contribution to baseflow, groundwater-dependent ecosystems and wetlands
- Aquifer classification (sole source, major, minor, poor) (map)
- Aquifer vulnerability (map)
- Aquifer stress status
- Conceptual geohydrological model of study area, including a water balance

A key component in this report must be a discussion on the confidence of data collected and the impacts thereof on the assessment.

3.7 References

- Kruseman GP and de Ridder NA. 1990. *Analysis and evaluation of pumping test data* (Second ed.). Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement. ISBN 9070754207.
- National Environmental Management Act (Act 107 of 1998).
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- USGS 1998. Groundwater and Surface water: A single resource. U.S. Geological Survey Circular 1139. Denver, Colorado.

4 Initiate GRDM Study

4.1 Initiation

The initiation of a GRDM study is largely a DWA management task undertaken by the RDM Chief Directorate and the assigned RDM Study Manager, with specialist groundwater input being provided by DWA personnel.

When initiating a study:

- the area to be studied needs to be defined
- the level of confidence of the GRDM set
- the project Terms of Reference set
- the study team needs to undertake the assessment identified and appointed.

4.2 Approach

4.2.1 Set up study

A core study team must be selected that represents key disciplines and will mostly likely consist of a project leader, a geohydrologist, a hydrologist, a geomorphologist/geo-grapher/GIS specialist, a socio-economist and an ecologist. All should have local knowledge of the groundwater systems, because these are usually data-poor systems and heavy reliance will be made on the specialists' intuitive understanding of them.

It is recommended that the GRDM Study Manager appoint a reviewer at the outset of the project so that he or she can advise the Study Manager regarding the adopted approach and the credibility of the results obtained.

At this point, a budget and work plan should be prepared and approved and, in consultation with DWA, the range of scenarios to be considered should be agreed. This is essential, as the chosen range will guide the kinds of data to be collected, appropriate specialists needed and the analyses to be done.

4.2.2 Define the groundwater resource

At the earliest stage of a GRDM assessment, whether it is a pre-emptive activity or in response to a licence application, a decision has to be made on whether on the level of the assessment.

The groundwater resource can be defined according to:

- the possible geographical extent of the study area and a brief description thereof
- the role of groundwater in terms of sustaining other components of the hydrological system (baseflow to rivers, wetlands and estuaries)
- the degree of groundwater dependence (both social and environmental), including volumes of groundwater abstracted
- any identified aquifer stresses (quantity and quality)
- geohydrological data and information available.

4.2.3 Levels of assessment

Four levels of GRDM determination are recognised, with each expected to yield a greater level of confidence in the results. However, it must be noted that data availability will dictate the confidence level. The following general features characterise the differences between the four levels:

- **Desktop**: These determinations are done using readily available data and information; extrapolate the results from previous more detailed and localised assessments; have low intensity information requirements and yield results of very low confidence.
- **Rapid**: Similar to desktop determinations, but include a short field trip to assess present state; typically used to assess individual licence applications with low impact, in unstressed catchments and/or catchments of low ecological importance and sensitivity.
- **Intermediate**: These determinations yield results of medium confidence; require field investigations by experienced specialists. They are used to assess implications of individual licences of moderate impacts in relatively stressed catchments.
- **Comprehensive**: Comprehensive GRDM determinations aim to produce high confidence results and are based on site-specific data collected by a team of specialists; used for all compulsory licensing exercises, as well as for individual licence applications that could have a large impact in any catchment, or a relatively small impact in ecologically important and sensitive catchments. It is important to note that a comprehensive study does not GUARANTEE high confidence results – there might be more confidence in your DATA, but all that might achieve is increased appreciation of the COMPLEXITY of the system, and NO increase in confidence on what USE is SUSTAINABLE.

Accepting that DWA does not have the time or resources to undertake comprehensive GRDM assessments of each significant water resource, a hierarchical approach is required. Lower levels of confidence can be accepted in unstressed catchments, in catchments where the impact of groundwater use is low or in catchments where groundwater plays a limited role in sustaining the EWRs. Conversely, high levels of confidence are required in stressed, ecologically sensitive or important catchments (or parts thereof) and where groundwater abstraction is known to have significant negative regional impacts.

TABLE 4 and TABLE 5 provides a guide for the selecting the level of assessment.

TABLE 4: GUIDE FOR SETTING THE LEVEL OF GRDM ASSESSMENT

INDICATOR (ECOSYSTEMS AND BASIC HUMAN NEEDS)	AQUIFER TYPE		
	LOW YIELDING	MODERATE YIELDING	HIGH YIELDING
Sole source dependency	Intermediate	Comprehensive	Comprehensive
Highly impacted	Intermediate	Comprehensive	Comprehensive
High risk of contamination / over-abstraction	Rapid	Intermediate	Comprehensive
Moderately impacted	Rapid	Intermediate	Intermediate
Moderate risk of contamination / over-abstraction	Rapid	Intermediate	Intermediate
No sole source dependency	Rapid	Rapid	Intermediate
Low level of impact	Rapid	Rapid	Intermediate
Low risk of contamination / over-abstraction	Rapid	Rapid	Intermediate

TABLE 5: GROUNDWATER SIGNIFICANCE

AQUIFER TYPE	DESCRIPTION
Sole-source aquifer	An aquifer used to supply[2] 50% or more of water for a given area and for which there are no reasonably available alternative sources of water.
Major aquifer	A high-yield[i] aquifer system of good quality water.
Minor aquifer	A moderate-yield[ii] aquifer system of variable water quality.
Poor aquifer	A low- to negligible-yield[iii] aquifer system of moderate to poor water quality.
Special aquifer	An aquifer system designated as such by the Minister of Water Affairs and Forestry, after due process.

Notes (Parsons & Wentzel 2007):

[i] Harvest potential greater than 50 000 $m^3/km^2 \cdot a$ or average borehole yield greater than 2 ℓ/s.

[ii] Harvest potential between 10 000 and 50 000 $m^3/km^2 \cdot a$ or average borehole yield between 1 and 2 ℓ/s

[iii] Harvest potential less than 10 000 $m^3/km^2 \cdot a$ or average borehole yield less than 1 ℓ/s

The same level of assessment need not be applied across a study area. Rapid level assessments could suffice in low usage areas, in low stress areas or in instances where usage is expected to have limited impact. Assessments that are more detailed could be undertaken in areas where specific problems occur or in areas where the underlying groundwater system is clearly stressed. During the preparatory phase and prior to commissioning GRDM assessments, significant water resources in a study area requiring higher levels of assessment must be identified. These are referred to as multilevel GRDM assessments (Parsons & Wentzel, 2007).

Once this has been completed the future stresses/impacts (such as type of proposed development) need to be taken into account.

The results of the entire investigation lead to the assigning of the level at which the GRDM assessment is to happen and DWA can set up the terms of reference. A key factor

[2] Use can be due to anthropogenic activities or ecological requirements

controlling the success of any project is the completeness and clarity of the terms of reference. The terms of reference should –

- set out the nature and extent of work required;
- form the basis of the tender process; and
- used to ascertain whether the GRDM assessment has been completed to specification.

4.3 References

- National Environmental Management Act (Act 107 of 1998).
- National Water Act (Act 36 of 1998).
- Parsons, R. & Wentzel, J. 2007. *Groundwater resource directed measures manual*. Water Research Commission Project No: TT299/07, Pretoria.

5 Groundwater Resource Directed Measures: Classification

Classification is used to:

- define the present status of the water resource;
- Define the state towards which the water resource needs to be managed sustainably.

5.1 Preamble

The NWA makes provision for the protection of water resources, which is fundamentally related to their use, development, conservation, management and control. The NWA lists several measures to ensure a comprehensive protection of all water resources, including classification, the Reserve and Resource Quality Objectives, which focus on the water resource as an ecosystem rather than simply on water itself as a commodity. Resource directed measures comprise of the development of a classification system for water resources, the classification of water resources, the determination of resource quality objectives (desired level of protection of a water resource) as well as the protection of the Reserve for all or part of any significant water resource. The latter specifies the quantity and quality of water required to satisfy basic human needs by securing a basic water supply, and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource. These measures are to be developed progressively within the contexts of the National Water Resource Strategy and Catchment Management Strategies, though a preliminary determination of the Reserve may be made and later superseded by a new one if a resource has not yet been classified.

Under Chapter 3 of the NWA, the Minister is required to develop and use a classification system to determine the Class and Resource Quality Objectives of all or part of water resources considered significant. Each class in the classification system needs to state what kinds of impacts on the water resources are acceptable and what kinds of impacts are not acceptable in order to protect the resource. With regard to water quality management, the NWA states that the classification system for water resources may establish procedures which are designed to satisfy the water quality requirements of water users as far as is reasonably possible, without significantly altering the natural water quality characteristics of the resource. The water quality, in this regard, includes all aspects of a water resource, i.e. beyond quantitative and ecological aspects; and also the water quality, including the physical, chemical and biological characteristics of the water.

The main objective of the classification process is to ensure that the resource can be utilised sustainably in the long term if the proposed class is adhered to. This has led to the concept of groundwater stress as an indicator. Stress should be defined in such a way that it reflects the long-term sustainable utilisation of the Resource, incorporating all the legal requirements that must be considered.

Classification is a legal mechanism that can be used to protect groundwater resources in the absence of an ecological link. The intention of the NWA is that the Reserve process should cover the detail of resource protection, and that protection measures be quantified in setting the RQOs.

5.2 Classification process

The procedure for determining the different classes of a water resource is divided into six steps (as shown in Figure 2):

Step 1: Delineate the units of analysis (UA) and describe the *status quo* of the water resource(s)

The key outcome of this step is a map demarcating UAs, each of which is to be classified, a Reserve assessment undertaken and Resource Quality Objectives (RQOs) set. In most instances, it is assumed that the UA is the quaternary catchment[3]; however, this might not always be the case. The UAs are decided based on geohydrological, hydrological and ecological criteria, taking into account the significance of groundwater (TABLE 4 and TABLE 5). Other aspects such as physical and management criteria must also be considered.

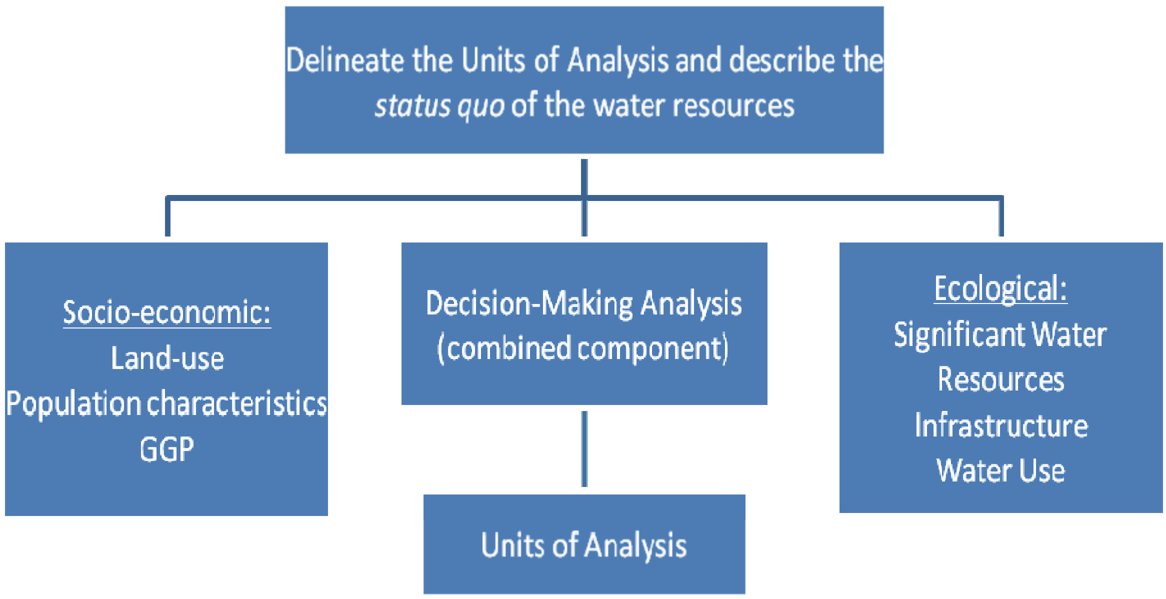

Figure 2: Delineation of UAs

The catchment should be described in as much detail as possible with appropriate maps included to assist the specialists in collecting data (relevant to the particular catchment

[3] Surface water and groundwater divides do not correspond. However groundwater must be considered in terms of an integrated water resource.

area) on their specialist fields and to identify the main areas of impact in the catchment. This would then also assist the GIS specialist in determining the UAs.

Basic data for various sources are documented in TABLE 1.

Step 2: Link socio-economic and ecological value and condition of the water resource(s)

The project team can then select areas for more detailed studies. Groundwater nodes need to be established with the objective of predicting probable surface water – groundwater areas of interaction, specifically, of groundwater supplying water to rivers, springs, wetlands and other terrestrial ecosystems. To this end, a multi-tiered approach to establishing the location and number of nodes in a target catchment is recommended. The nodes may capture the following:

- Lithological boundaries at aquifers and aquitards.
- Groundwater contribution to base flow.
- Groundwater contribution to wetlands.
- Geological faults.
- Groundwater levels.
- Springs.

Stakeholders should be the primary drivers of the GRDM process and they should be included in the assessments to ensure all their concerns and issues are addressed. Socio-economic[4] issues must be taken into account. These include factors such as land-use, population statistics and gross geographical product (GGP).

[4] A summary of a socio-economic assessment is documented in Appendix C.

Step 3: Quantify the ecological water requirements and changes in non-water quality ecosystems goods, services and attributes

This step is where the ecological requirements, basic human needs, etc. are calculated. The data required and documented in Chapter 4 are used in the quantification of the resource. Tools are provided (Chapter 8) to do the actual calculations. Typical calculations include:

- Recharge estimation
- Groundwater surface water interaction
- Groundwater use
- Groundwater quality estimations
- Aquifer vulnerability

Step 4: Assess system and set baseline class (or configuration)

The concept of a baseline configuration in groundwater is not easy to quantify. However, the objective of Step 3 of the classification procedure is to set the water quantity (use) and quality base configuration in terms of long-term sustainability.

Indexes or indicators are selected to describe the baseline class and are used in scenarios to describe change. They should cover the main physical and chemical aspects of the system, including issues raised by stakeholders. Potential indicators are suggested in this section.

Defining the point at which a resource is no longer being used in a sustainable manner is generally very difficult. The level of sustainability probably fluctuates through time, and impacts from over-use could manifest themselves some time after the impact was caused. The change from sustainable use to over-use is gradational, and not necessarily marked by some distinct change. Indicators of quantitative unsustainable groundwater use include:

- Land subsidence or sinkhole formation.
- Long-term declining water levels on a regional level.
- Long-term declining water quality levels.

A guide for assessing the status of groundwater units based on observed impacts resulting from groundwater abstraction is presented in TABLE 6.

TABLE 6: GUIDE FOR SETTING THE PRESENT CLASS OF A GROUNDWATER UNIT BASED ON OBSERVED ENVIRONMENTAL IMPACT INDICATORS

PRESENT CLASS	GENERIC DESCRIPTION	AFFECTED ENVIRONMENT
Minimally used (I)	The water resource is minimally altered from its pre-development condition	No sign of significant impacts observed
Moderately used (II)	Localised low level impacts, but no negative effects apparent	Temporal, but not long-term significant impact to: – spring flow – river flow – vegetation – land subsidence – sinkhole formation – groundwater quality
Heavily used (III)	The water resource is significantly altered from its pre-development condition	Moderate to significant impacts to: – spring flow – river flow – vegetation – land subsidence – sinkhole formation – groundwater quality

Defining stress

The concept of stressed water resources is addressed by the NWA, but is not defined. Part 8 of the Act gives some guidance by providing the following qualitative examples of 'water stress':

- Where demands for water are approaching or exceed the available supply.
- Where water quality problems are imminent or already exist.
- Where water resource quality is under threat.

The groundwater stress index reflects water availability versus water used. Groundwater use should include water utilised by current water users, water required to sustain the Reserve as well as for basic human needs.

The Stress Index for an assessment area is defined as follows:

$$SI(\%) = \frac{gwUse}{Recharge} \times 100$$

where

gwUse = Current groundwater use

Recharge = Recharge (as a volume)

In calculating the Stress Index, the variability of annual recharge is taken into account in the sense that not more than 65% of average annual recharge can be allocated on a catchment scale (TABLE 7).

TABLE 7: GUIDE FOR DETERMINING THE LEVEL OF STRESS OF A GROUNDWATER UNIT

PRESENT CLASS	DESCRIPTION	COMPLIANCE (SPATIAL/TEMPORAL)
I	Minimally used	≤20%
II	Moderately used	20-65%
III	Heavily used	> 65%

A guide for quantifying groundwater use is documented in TABLE 8.

TABLE 8: GUIDE FOR QUANTIFYING GROUNDWATER USE

ACTIVITY	PERCENTAGE OF RECHARGE
Stock watering, farm domestic water supply, rural water supply	Use ranges between 5% and 20% of recharge
Small-scale irrigation, rural water supply, water supply for villages and small towns	Use ranges between 20% and 40% of recharge
Water supply for large rural communities, medium to large towns, large-scale irrigation	Use ranges between 40% and 65% of recharge

The NWA states that the system for classifying water resources may consider water quality requirements of water users without significantly altering the natural water quality characteristics of the resource. It gives a clear mandate to consider the fitness for the proposed beneficial use under consideration of the natural or geogenic background, which may actually render it unsuitable for the proposed use (e.g. natural fluoride concentrations exceeding drinking water limits).

Domestic use (human consumption) is considered by the authors as the highest beneficial use, with the supposedly most stringent quality requirements. It is assumed that any water resource, which is deemed fit for human consumption, also meets the requirements of aquatic ecosystems. While the water quality requirements of aquatic ecosystems might differ and are in fact for several elements even more stringent than for domestic use (e.g. Cd), the chosen approach avoids the pitfall of equating groundwater quality in the sub-surface to water quality discharging into a surface water body. In other words, the methodology recognises the processes occurring in discharge areas in general (e.g. evapotranspiration) and the enhanced microbiological and chemical reactions (e.g. Redox or cation exchange reactions) in the hyporheic zone specifically (Figure 3), without trying to quantify them by setting only domestic use requirements for the groundwater resource itself.

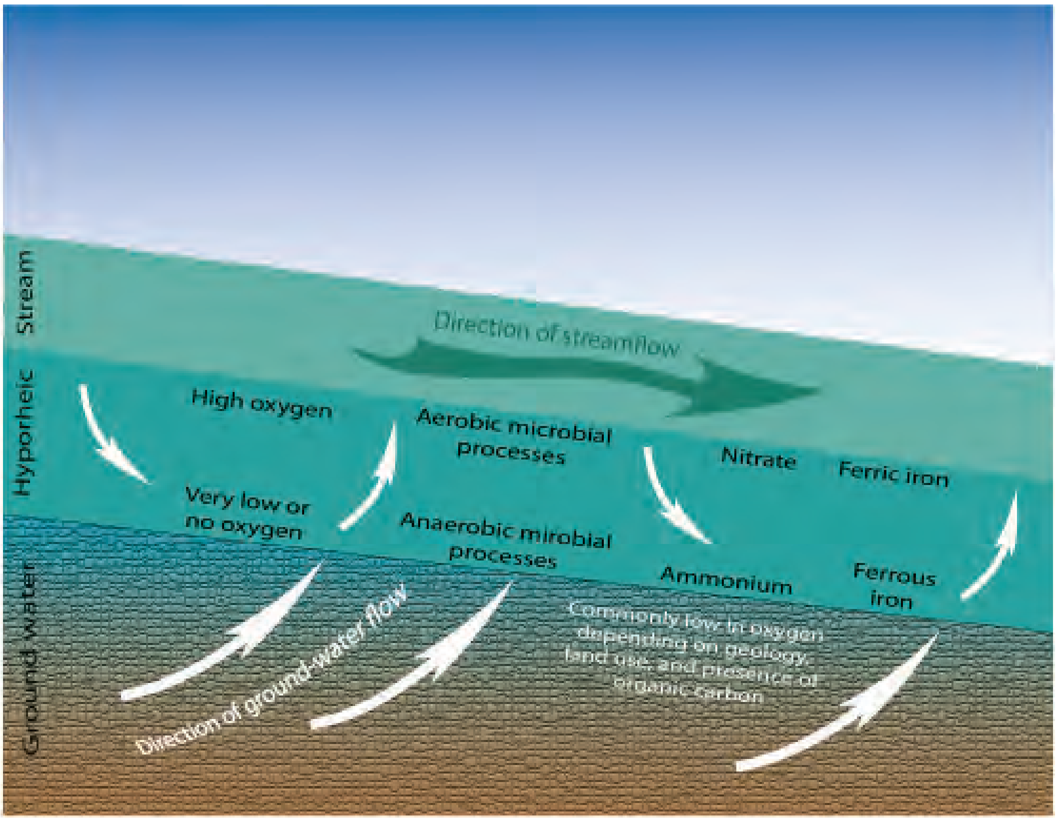

Figure 3: Chemical reactions in the hyporheic zone (Winter *et al*. 1998)

It is therefore recommended to use the South African Water Quality Guidelines Vol. 1 – Domestic use (DWAF, 1996), or the national drinking water standard (SANS 241: 2006) for the present status category assessment of a water resource (TABLE 9).

TABLE 9: PRESENT STATUS CATEGORY BASED ON DWA WATER QUALITY GUIDELINES FOR DOMESTIC USE

PRESENT CLASS	DESCRIPTION	COMPLIANCE (SPATIAL/TEMPORAL)
I	DWA class 0 or 1 or natural background	95 %
II	DWA class 2 (95 % compliance) or natural background (75 % compliance)	75 %
III	DWA class 3 or 4 or natural background (<75 % compliance)	<75 %

Step 5: Scenario development within the IWRM process

The objective of Step 5 of the classification procedure is to evaluate scenarios within the IWRM process so that a subset of catchment configuration scenarios can be put forward for stakeholder evaluation in Step 5. The current Classification (*status quo* and management) of the Resource should be presented to stakeholders and they must be informed of the implications thereof. Different management scenarios can include changes in land use and climate change impacts. It is for them to decide, taking the social and economic considerations into account, whether they would like to change the Management Class.

Step 6: Evaluate scenarios with stakeholders

This phase will normally be part of the bigger assessment where groundwater has been integrated into the other components of the Reserve. The procedure as spelt out by Dollar *et al*. (2006) should be followed.

Step 7: Gazette class configuration

This phase will normally be part of the bigger assessment where groundwater has been integrated into the other components. The procedure as spelt out by Dollar *et al.* (2006) should be followed.

Step 6 and 7 are not included in the scope of this report.

5.3 References

- DWAF (1996). *South African Water Quality Guidelines Vol. 1 – Domestic use*. 2nd ed., Department of Water Affairs and Forestry, Pretoria.
- Dollar, EJ, Brown, C, Turpie, J, Turton, A, Colvin, C, Hallowes, J and Manyaka, S, (2006). *Rationale and proposed framework for an integrated National Water Resource Classification System.* "Straw-dog One". Department of Water Affairs and Forestry, Pretoria.
- SANS 241-2 (2006). Drinking water Part 2: Application of SANS 241-1. South Africa Bureau of Standards.
- Winter, TC, Harvey, J., Franke, OL and Alley W. (1998). *Ground water and surface water : a single resource*. U.S. Geological Survey circular 1139. Denver, Colorado.

6 Groundwater Resource Directed Measures: The Reserve

Setting the Reserve:

- Should be set as soon as the class is determined for each Unit of Analysis
- It is the water set aside to provide for basic human needs and protect aquatic ecosystems

6.1 Preamble

The Reserve is an integral part of the resource quality objectives and should be set as soon as the class is determined for each water resource. The requirements of the Reserve and all other demands on the water resource are covered by the determination of the resource quality objectives. The Reserve is part of the national water resource within each water management area that is under the direct control of the Minister. It is water that is 'set aside' to:

- provide for basic human needs, and
- protect water ecosystems (sustain healthy ecosystems).

The Reserve is the only right to water in the National Water Act. It therefore has priority over all other water use. In other words the amount of water required for the Reserve must be met before water resources can be allocated to other water users.

6.2 Reserve determination process

The procedure for determining the Reserve is divided into eight steps and is inter-linked with the classification:

Step 1: Initiate the basic human needs and ecological water requirements assessment

The groundwater component of the Reserve is the part of the groundwater resource that sustains basic human needs and in some instances contributes to EWR. To be able to quantify the groundwater component of the Reserve, the volume of groundwater needed for BHN and contributing to EWR needs to be quantified.

The EWRs of the Resource in question must consider the following:

- Groundwater contribution to baseflow in rivers.
- Groundwater contribution to wetlands.

- Groundwater contribution to springs and other GDEs[5].

The groundwater component of the Reserve is defined by the following relationship:

$$Reserve(\%) = \frac{EWRgw + BHNgw}{Re} \times 100$$

where

Re = recharge
BHN_{gw} = basic human needs derived from groundwater
EWR_{gw} = groundwater contribution to EWR

Groundwater should only be allocated to users and potential users once the volume of groundwater that contributes to sustaining the Reserve has been quantified and RQOs have been met. Note that RQOs can be based on both the Reserve and Classification.

The challenge for the geohydrologist is to establish the relationship (spatially and temporally) between the volume of water that can be abstracted without significantly impacting the Reserve.

Recharge

Recharge is defined as the addition of water to the zone of saturation. Generally, this only includes contributions from precipitation. However, indirect recharge (seepage) from rivers, dams and wetlands can be substantial under specific conditions and should be considered, if known. Aquifers can also be recharged by inflows from adjacent groundwater bodies.

Recharge is one of the most important parameters in assessing the volume of groundwater that can be sustainably abstracted from an aquifer system, but due to rainfall variability and aquifer heterogeneities is very difficult to quantify.

Guidance regarding data sources and available estimation tools is given in Chapter 8.

The quantification of the Reserve might require that groundwater inflows and outflows be calculated in addition to recharge from precipitation. Methods for calculating inflows and outflows are described in Chapter 8.

Basic Human Needs

Currently, basic human needs (BHN) are set at 25 ℓ/p/d. The source of population statistics used for this calculation must be clearly referenced. Although normally quite small in comparison to other uses, it must be borne in mind that this is a right to water and must be legally protected.

[5] GDEs are not documented as part of the Reserve in the NWA, but included in the NWRS (only those of national significance).

Groundwater contribution to ecological requirements

Where applicable, the following groundwater contributions must be stipulated:

- Baseflow to rivers.
- Springs.
- GDEs (including springs and wetlands).

Chapter 8 gives an overview of methodologies that can be applied to assess these contributions.

Step 2: Determine eco-regions, delineate resource units and select study sites

This aligns with Step 1 of the water resource classification procedure (see Section 5.2) set out in Regulation 2(4).

Step 3: Determine the reference conditions, present ecological status and the ecological importance and sensitivity of each of the selected study sites

This aligns with Step 2 of the water resource classification procedure (see Section 5.2) set out in Regulation 2(4).

Step 4: Determine the basic human needs and ecological water requirements for each of the selected study sites

This aligns with Steps 3 and 4 of the water resource classification procedure (see Section 5.2) set out in Regulation 2(4).

Step 5: Determine operational scenarios and its socio-economic and ecological consequences

This aligns with Step 5 of the water resource classification procedure (see Section 5.2) set out in Regulation 2(4).

Step 6: Evaluate the scenarios with stakeholders

This aligns with Step 6 of the water resource classification procedure (see Section 5.2) set out in Regulation 2(4).

Step 7: Design an appropriate monitoring programme

The Minister of water Affairs is the public trustee of water resources and has the overall responsibility for all aspects of water management. However, responsibility as well as authority for water management will eventually be devolved to a local level. It is planned that DWA will ultimately provide national policy and a regulatory framework for water resource management, and will make sure that other water institutions are effective. Monitoring essentially falls outside the GRDM process, but is required to ensure that the Reserve and Resource Quality Objectives are both realistic and are adhered to. Monitoring forms an essential part of what must be a seamless process of managing the country's water resources.

Groundwater monitoring has the simple goal of quantifying the behaviour and response of groundwater systems to various controls and stressors (recharge, discharge, abstraction, etc.). The response of groundwater systems is typically manifested by variation in groundwater levels, a change in groundwater quality, or both. Analysis and interpretation of monitoring data and information enables the groundwater environment to be better understood and is therefore vital for sound and responsible groundwater resource management (Parsons and Wentzel, 2007).

Extensive monitoring already takes place, but both surface and groundwater monitoring programmes need to be extended. Similarly, the information systems used to capture monitored data also need to be revised and updated on a regular basis.

However it is costly and labour intensive to monitor extensively. Considering that also moderate yielding aquifers can have a significant contribution to water supply schemes, it is proposed to combine the actual or potential importance of an aquifer and the groundwater quality to arrive at a recommended monitoring class for all aquifers as shown in Figure 4.

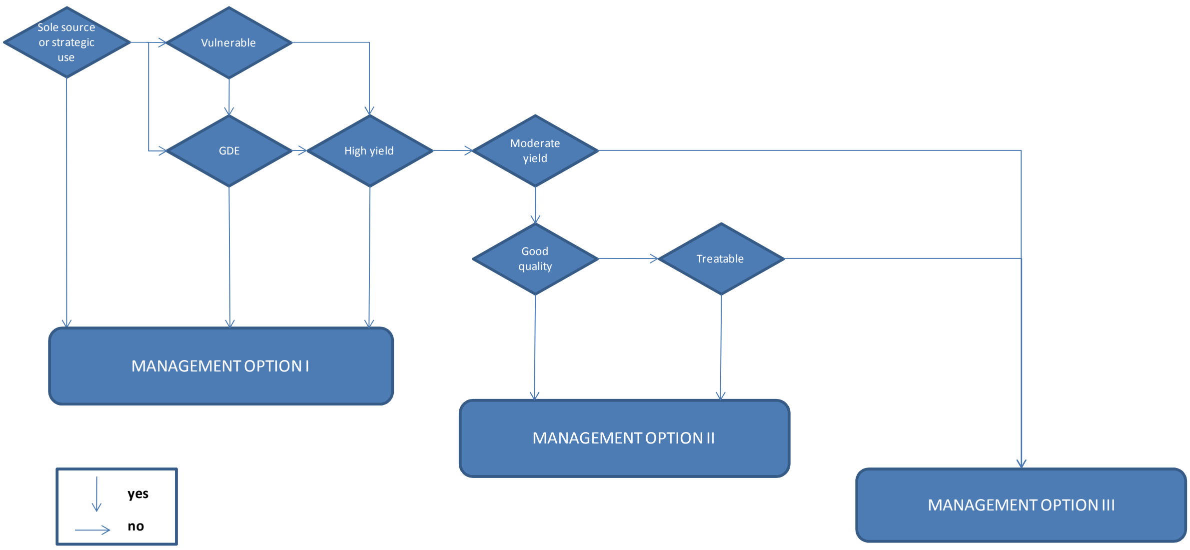

Figure 4: Flow chart to determine the recommended aquifer management class

It must be stressed that only GDE's of national significance (aquatic ecosystem in groundwater discharge zones supporting a unique habitat – after EPA 1987) should be considered in such assessment. Similarly, only highly vulnerable groundwater resources should be considered.

The management options are defined according to TABLE 9.

Table 9: Definition of Management Options

Management Option	Recommended Monitoring*
I	Monthly monitoring of groundwater levels and chemistry
II	Monitoring of groundwater levels and chemistry every 3 months.
III	Monitoring of groundwater levels and chemistry every 6 months

Water quality analysis should include the following parameters: pH, EC, Ca, Mg, Na, K, Palk, MAlk, F, Cl, NO_2(N), Br, NO_3(N), PO_4, SO_4.

Step 8: Gazette and implement the Reserve

Step 8 is not included in the scope of this report.

7 Groundwater Resource Directed Measures: Resource Quality Objectives

These are statements about:

- What the quantity of the water should be.
- What the quality of the water should be.
- What the condition of the instream and riparian (river bank) habitat should be.
- What the condition of the aquatic animal and plant life should be.

7.1 Preamble

Once each major water resource is classified, national government through the Minister needs to determine how the water resource will be protected and used. This is called determining the resource quality objectives. RQOs must set objectives for the management of water resources in a catchment or other units of analysis, (if applicable) and by its very nature be applicable on that scale. RQOs should spell out the principles upon which licensing conditions are based. In general terms, RQOs establish clear goals relating to the quantity and quality of a water resource. They provide goals and objectives that frame the vision for sustainable use of a water resource, and hence form the basis for catchment decision-making and management.

Typical characteristics of RQOs include the following:

- They set limits that are simple and measurable.
- They set the limits of acceptable impact.
- They may be numeric or descriptive.

7.2 Resource Quality Objective process

Setting RQOs requires an understanding of groundwater resources and their boundary conditions, uses of groundwater, the importance of various uses and the agreed degree of modification of the resource (Colvin *et al*., 2003) as measured through the Classification. When setting RQOs, consideration must also be given to ecological dependencies on groundwater and the consequences of modifying the geohydrological regime. It is crucial that RQOs are directly linked to both the Classification and the Reserve to ensure their legal position in the event of disputes. Therefore for each water resource class, the procedure for establishing resource quality objectives must comprise of the following six steps:

Step 1: Identify water users within each water resource management unit, and where appropriate, align with Step 1 of the water resource classification procedure set out in Regulation 2(4) of gazetted Classification.

Step 2: Determine the present state per water user and, where appropriate, align with Step 5 of the water resource classification procedure set out in Regulation 2(4).

Step 3: Determine the desired water quality per user and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).

Step 4: Determine water user specifications and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).

Step 5: Determine water quality requirements of water uses and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).

Step 6: Gazette and implement the resource quality objectives.

With Step 6 not being included in this document.

Water use should be managed in a sustainable way. The only way to ensure that a borehole is managed sustainably is to monitor water levels over time. It is, however, not always possible to monitor all boreholes in an area due to time, budget and capacity constraints, and it might be required to identify representative monitoring boreholes for a specific aquifer. This is usually done by comparing trends in time series data. Once a network of monitoring boreholes is identified, the following criteria should be applied:

- Allow water levels to drop during dry periods, but never allow water levels to reach the main water strike as this might cripple the borehole.
- If the water levels don't recover to previous levels after a wet period, abstraction rates should be lowered. As long as water levels recover after wet periods, the use is considered sustainable. Figure 5 shows examples of water levels that reflect sustainable usage.

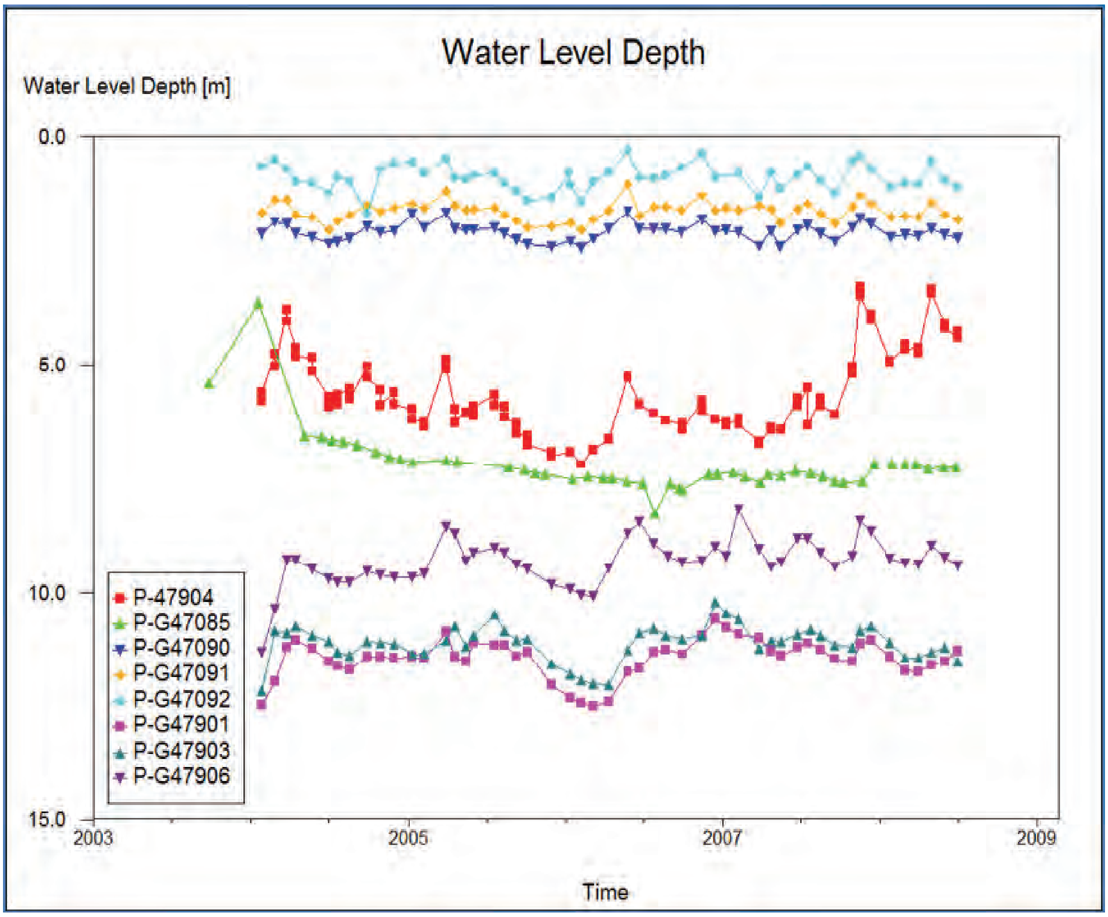

Figure 5: Time series water levels of boreholes

7.2.1 Defining RQOs for Rivers

Rivers can be groundwater fed and/or have groundwater dependant riparian vegetation (if not dependent on bank storage from the river). Therefore both these issues should be considered when setting the RQOs, while groundwater dependent riparian vegetation is addressed under Section 7.2.3, the amount of groundwater flowing into a river needs to be calculated (i.e. groundwater contribution to baseflow). Once this has been quantified, the RQO can be set as a minimum groundwater level or gradient to be maintained for a certain distance from the river.

7.2.2 Defining RQOs for Wetlands and Estuaries

RQOs for groundwater driven wetlands/estuaries/riparian vegetation must also be determined, as shown in Figure 6. The amount of groundwater flowing into these regions needs to be calculated. Once this has been calculated, the RQO can be set as a groundwater level or gradient to be maintained for a certain distance from the wetland/estuary.

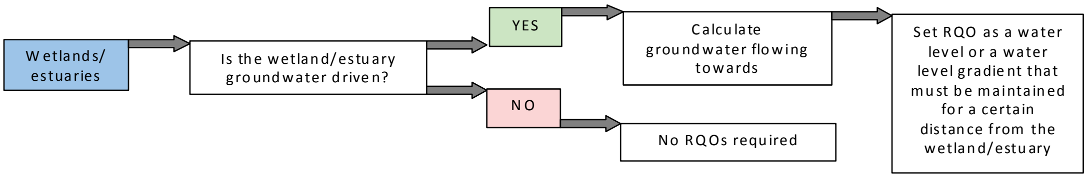

Figure 6: Setting RQOs for wetlands and estuaries

7.2.3 Defining RQOs for Springs

Springs are groundwater driven and therefore need to be protected. However, the way in which they are protected differs between hot and cold springs. Hot or thermal springs, according to Kent (1949), are those for which the water temperature is above 30°C. Their groundwater source is usually very deep beneath the earth's surface and generally an RQO is not necessary. The capture area for a cold water spring can be determined by using standard borehole capture area methods. A minimum distance for any potentially harmful activities (boreholes, possible pollution sources) must be allocated from the spring.

A note on rivers, wetlands and springs . . .

The protection distances to rivers, wetlands and springs are based on the concept of preserving the groundwater flux to the surface water body in question. The flux in each case is determined on local scale, e.g. the groundwater contribution to baseflow for a river stretch. By dividing the flux to a river stretch W through the recharge associated with the contributing catchment, the area A to be protected is obtained. Once the area A is known, the associated protection distance L can be calculated (refer to Figure 7).

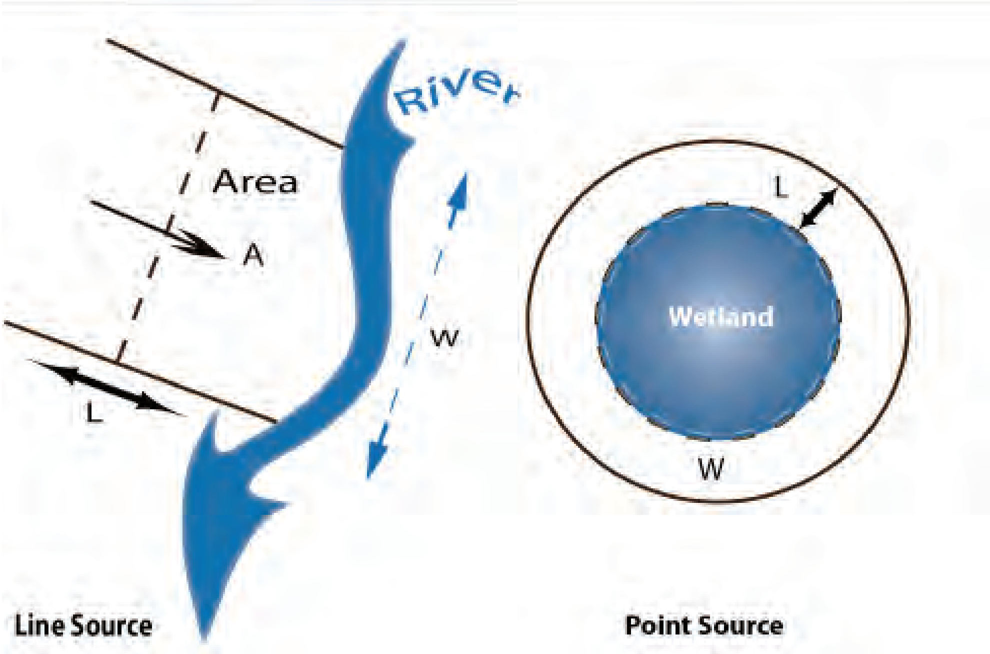

Figure 7: Protection zones for rivers

In local level river stretches, wetlands and springs affected by current and future borehole development need to be identified and the associated protection distances calculated and enforced.

7.2.4 Defining RQOs for BHNs, Strategic use and International obligations

Groundwater use for basic human needs, strategic use[6], and international obligations must be protected (Figure 8). The required flow rates must be calculated and protection zones delineated. RQO's can be set as a groundwater level or gradient to be maintained for a certain distance, or as an assurance of supply (sustainability) of the groundwater resource.

[6] Relating to the identification of long-term or overall aims and interests and the means of achieving them

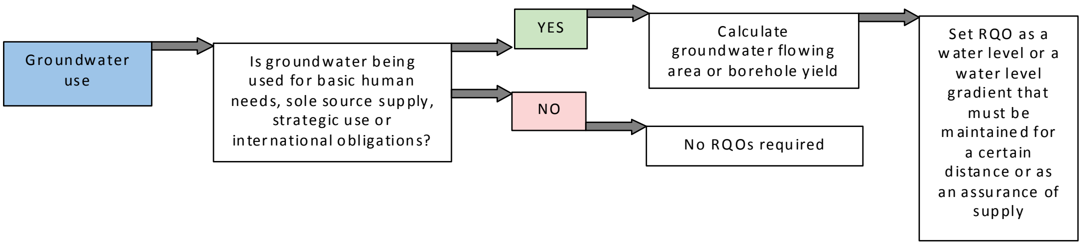

Figure 8: RQOs for BHNs, strategic use and international obligations

A note on **boreholes . . .(NOT REQUIRED BY NWA)**

The radius of influence for boreholes can be used as a conservative guide for development of new boreholes. The radius of influence can be determined by setting the drawdown to zero in the Cooper-Jacob equation. Due to the nature of the drawdown curve represented by the Cooper-Jacob equation it is not always a practical radius due to the fact that the drawdown curve tends to zero over a long distance. A more practical approach would be to set the drawdown to something like 10 cm and calculate the radius of influence accordingly. The following table shows the practical implication of this if the following constant parameters are assumed:

- Abstraction = 1 m^3/d
- Transmissivity = 5 m^2/d
- Storativity = 0.001
- Time = 360 days

Allowed Drawdown (cm)	Radius of Influence (m)
0	2012
1	1469
5	418
10	87

Note that not setting the drawdown to zero makes the radius of influence dependent on both the abstraction and the time that abstraction takes place.

If a new borehole cannot be placed according to the specified radius of influence due to physical constraints, e.g. geophysical results or property boundaries, the borehole may be placed on the optimal position taking into account all factors as long as proper water level management takes place.

7.3 References

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8 Tools to Assist in an Assessment

8.1 Linkages to surface water (USGS, 1998)

8.1.1 Is there a link?

Rivers

The interaction of groundwater with surface water depends on the physiographic and climatic setting of the landscape. For example, a stream in a wet climate might receive groundwater inflow, but a stream in an identical physiographic setting in an arid climate might lose water to groundwater.

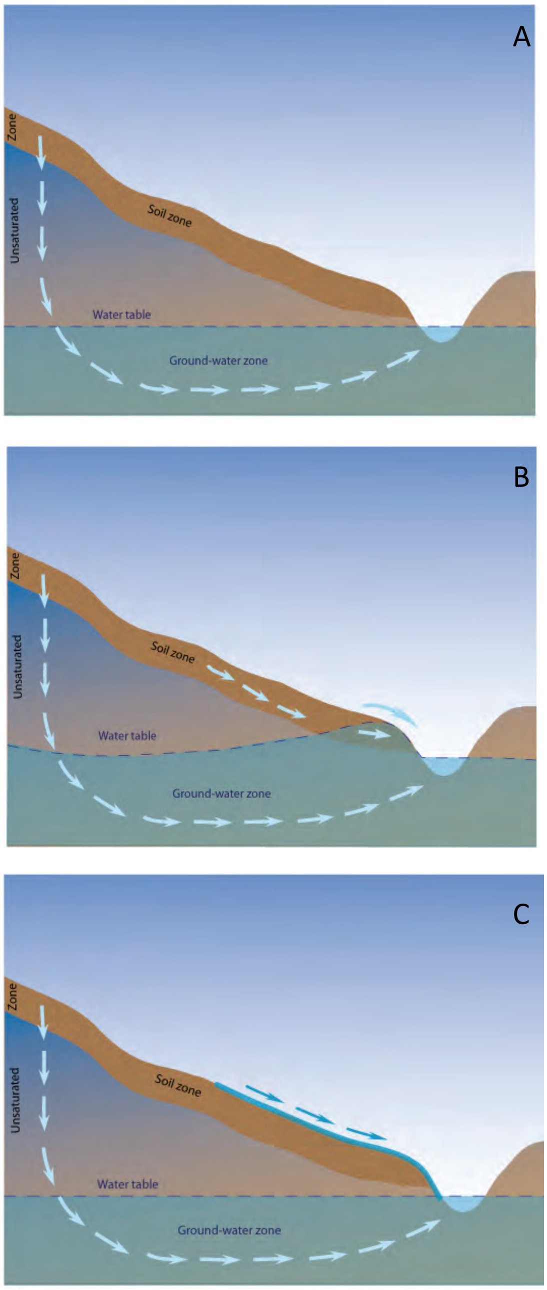

Figure 9: Water from precipitation moves to the mountain

The hydrology of mountainous terrain is characterised by highly variable pre-cipitation and water movement over and through steep land slopes. On mountain slopes, macropores created by burrowing organisms and by decay of plant roots have the capacity to transmit subsurface flow downslope quickly. In addition, some rock types underlying soils may be highly weathered or fractured and may transmit significant additional amounts of flow through the subsurface. In some settings this rapid flow of water results in springs.

Between rainfall periods, streamflow is sustained by discharge from the ground-water system (Figure 9A). During intense rainfall events, most water reaches rivers very rapidly by partially saturating and flowing through the highly conductive soils. On the lower parts of hill slopes, the water table sometimes rises to the land surface during rainfall events, resulting in overland flow (Figure 9B). When this occurs, precipitation on the saturated area adds to the quantity of overland flow.

When rainfall persists in mountainous areas, near-stream saturated areas can expand outward from streams to include areas higher on the hillslope. In some settings, especially in arid regions, overland flow can be generated when the rate of rainfall exceeds the infiltration capacity of the soil (Figure 9C).

Near the base of some mountainsides, the water table intersects the steep valley wall some distance up from the base of the slope. This results in perennial discharge of groundwater and, in many cases, the presence of wetlands. A more common hydrologic process that results in the presence of wetlands in some mountain valleys is the upward discharge of groundwater caused by the change in slope of the water table from being steep on the valley side to being relatively flat in the alluvial valley. Where both of these water-table conditions exist, wetlands fed by groundwater can be present.

Another dynamic aspect of the interaction of groundwater and surface water in mountain settings is caused by the marked longitudinal component of flow in mountain valleys. The high gradient of mountain streams, coupled with the coarse texture of streambed sediments, results in a strong down-valley component of flow accompanied by frequent exchange of stream water with water in the hyporheic zone. Streams flowing from mountainous terrain commonly flow across alluvial fans at the edges of the valleys. Most streams in this type of setting lose water to groundwater as they traverse the highly permeable alluvial fans.

The geochemical environment of mountains is quite diverse because of the effects of highly variable climate and many different rock and soil types on the evolution of water chemistry. During heavy precipitation, much water flows through shallow flow paths, where it interacts with microbes and soil gases. In the deeper flow through fractured bedrock, longer term geochemical interactions of groundwater with minerals determine the chemistry of water that eventually discharges to streams. Mixing of these chemically different water types result in geochemical reactions that affect the chemistry of water in streams.

In some landscapes, stream valleys are small and they commonly do not have well-developed flood plains. However, major rivers have valleys that usually become increasingly wider downstream. Terraces, natural levees, and abandoned river meanders are common landscape features in major river valleys, and wetlands and pools commonly are associated with these features.

The interaction of groundwater and surface water in river valleys is affected by the interchange of local and regional groundwater flow systems with the rivers and by flooding and evapotranspiration.

Small streams receive groundwater inflow primarily from local flow systems, which usually have limited extent and are highly variable seasonally. Therefore, it is not unusual for small streams to have gaining or losing reaches that change seasonally. For larger rivers that flow in alluvial valleys, the interaction of groundwater and surface water usually is more spatially diverse. Groundwater from regional flow systems discharges to the river as well as at various places across the flood plain. If terraces are present in the alluvial valley, local groundwater flow systems may be associated with each terrace, and pools and wetlands may be formed because of this source of groundwater. At some locations, such as at the valley wall and at the river, local and regional groundwater flow systems may discharge in close proximity. Furthermore, in large alluvial valleys, significant down-valley components of flow in the streambed and in the shallow alluvium may also be present. Added to this distribution of groundwater discharge from different flow systems to different parts of the valley is the effect of flooding. At times of high river flows, water moves into the groundwater system as bank storage. The flow paths can be as lateral flow through the riverbank or, during flooding, as vertical seepage over the flood plain. As flood waters rise, they cause bank storage to move into higher and higher terraces.

The water table generally is not far below the land surface in alluvial valleys. Therefore, vegetation on flood plains, as well as at the base of some terraces, commonly has root systems deep enough so that the plants can transpire water directly from groundwater. Because of the relatively stable source of groundwater, particularly in areas of groundwater discharge, the vegetation can transpire water near the maximum potential transpiration rate, resulting in the same effect as if the water were being pumped by a borehole. This large loss of water can result in drawdown of the water table such that the plants intercept some of the water that would otherwise flow to the river.

A river hydrograph consists of three components: direct runoff, interflow through the unsaturated zone and groundwater discharge from the saturated zone. Although a baseflow is often defined as the groundwater discharge from the saturated zone in classic hydrogeological textbooks the word *baseflow* is generally known to many hydrologists as delayed flow components (mainly groundwater), as opposed to a quick, direct runoff. Thus, baseflow itself is not indicative of origins of water sources. The baseflow is normally separated by removing the direct runoff from a hydrograph. As a result, such a baseflow component may still contain some interflow component.

Wetlands

The link between groundwater and wetlands is still poorly understood (and researched) in South Africa. However, it is suspected that many wetlands depend – at least to some degree (both spatially and temporally) – on a contribution from groundwater. This is especially true during the dry season where the groundwater contribution is critical in sustaining the ecology of the wetland.

The link is mostly geologically controlled, and to understand the interaction, a three-dimensional model must be considered. The most basic types of interaction are illustrated in the following diagrams (Adapted from RAMSAR Conference, 2005) and shown in Table 10.

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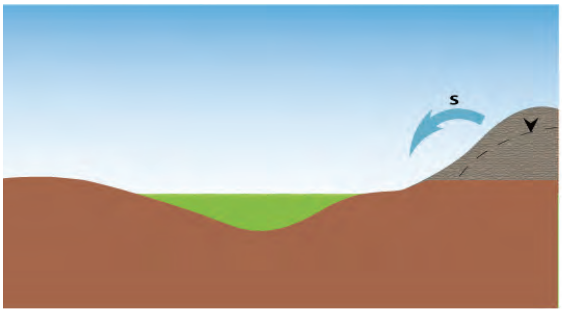
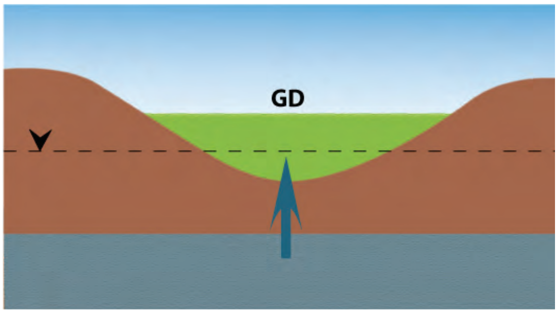
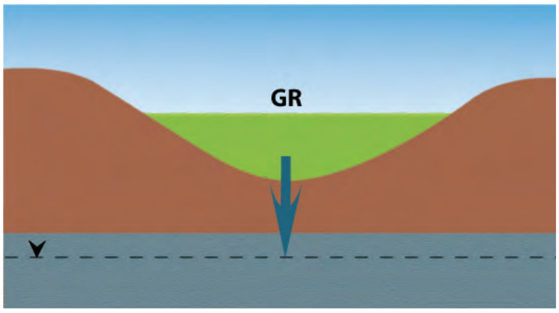
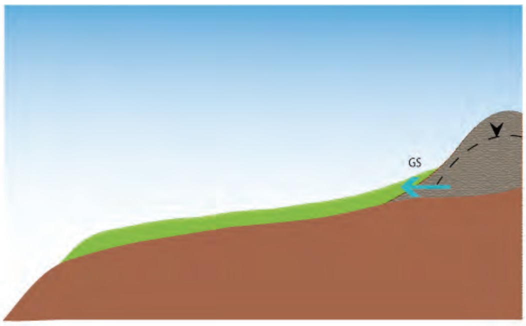
TABLE 10: DIFFERENT TYPES OF WETLANDS

<table>
<tr><td>
</td><td>S: spring
Water seeping from an aquifer onto the surface of a wetland. This is often associated with the location of an aquiclude beneath the aquifer.</td></tr>
<tr><td>
</td><td>GD: groundwater discharge
Water moving vertically upwards into a wetland from an underlying aquifer. The piezometric head/water level of the aquifer is higher than the water level in the wetland. In some instances a lower permeability layer between the wetland and the aquifer that could limit water flow.</td></tr>
<tr><td>
</td><td>GR: groundwater recharge
Water moving vertically downwards from a wetland to an underlying aquifer. The piezometric head/water level of the aquifer is lower than the water level in the wetland. In some instances a lower permeability layer between the wetland and the aquifer limit water flow.</td></tr>
<tr><td>
</td><td>GS: groundwater seepage
Water moving laterally into a wetland from an adjacent aquifer. In some instances a lower permeability layer between the wetland and the aquifer limit water flow.</td></tr>
</table>

According to the RAMSAR Convention, seven types of wetland (irrespective of their groundwater dependency) are recognised, based on landscape location and water transfer mechanisms. Their possible interaction with groundwater (where applicable) is indicated in TABLE 11 and graphically displayed in Figure 10.

TABLE 11: LINK BETWEEN LANDSCAPE AND WATER TRANSFER MECHANISMS FOR WETLANDS

LANDSCAPE LOCATION	SUBTYPE BASED ON WATER TRANSFER MECHANISM
Flat upland wetlands	Upland surface water-fed
Slope wetlands	Surface water-fed Surface and groundwater-fed Groundwater-fed
Valley bottom wetlands	Surface water-fed Surface and groundwater-fed Groundwater-fed
Underground wetlands	Groundwater-fed
Depression wetlands	Surface water-fed Surface and groundwater-fed Groundwater-fed
Flat lowland wetlands	Lowland surface water-fed
Coastal wetlands	Surface water-fed Surface and groundwater-fed Groundwater-fed

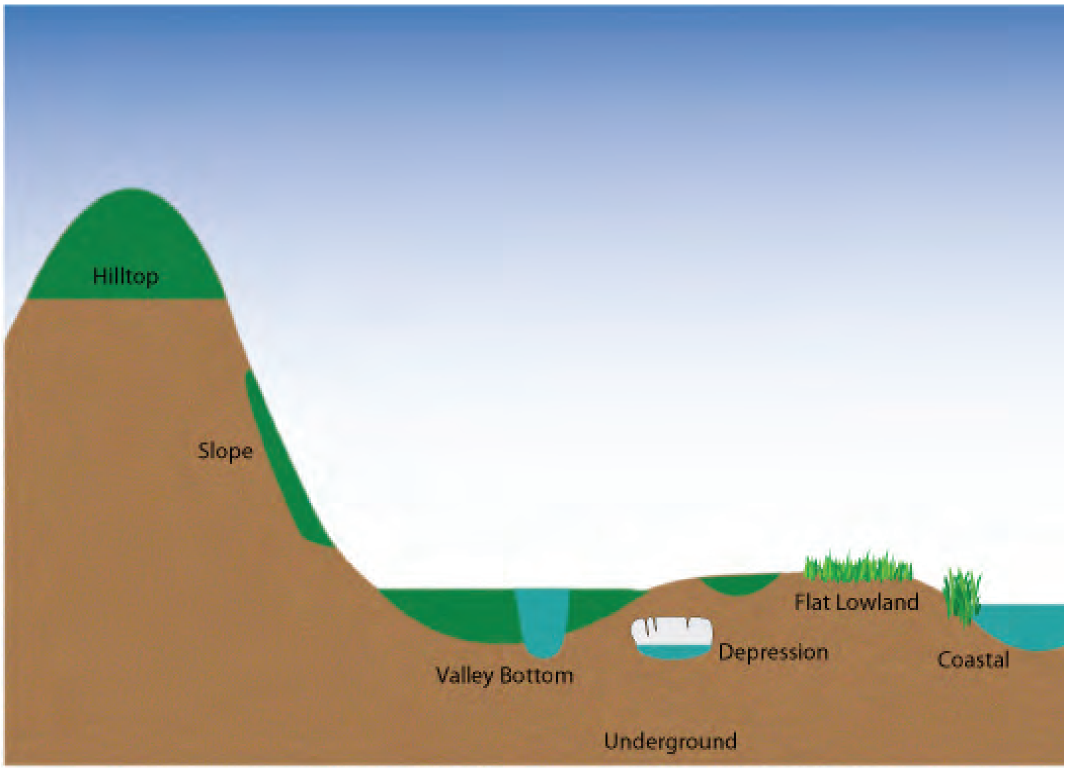


Figure 10: RAMSAR defined wetlands

8.1.2 How to calculate the groundwater – surface water interaction

Rivers

The first step in quantifying surface-groundwater interaction is to classify the river. Any classification scheme must balance between what is scientifically desirable and what is practically workable. While, for example, a morphological subdivision of the rivers into, for example, headwater, mountain or lowland sand bed streams is generally desirable and will assist indirectly in the quantification of surface-groundwater interactions. Based on the literature review of surface-groundwater interaction methodologies, the following characteristics of rivers emerged as most important for the application of mathematical models:

- Gradient between piezometric surface and river stage (either side).
- Occurrence and characterisation of clogging layers in the riverbed.
- Hydrogeological characteristics of the strata along the river stretches.
- Regional groundwater gradients.

A simple two tier classification scheme, with a geological classification of the river-aquifer setting followed by a brief hydraulic classification of the interaction is proposed. The approach combines and extends the hydraulic classification by Vegter & Pitman (2003) with geological features similar to the method of the Environment Agency (2002). Similar to the geomorphologic classification the primary geological classification (Figure 11) differentiates between rivers flowing in porous media or over bedrock. A third class accounts for valley trains underlain by aquitards, a typical situation of an alluvial aquifer along a river stretch underlain by impervious hard rocks. This scenario can also accommodate other aquifer of limited, strip type aerial extent. The porous media is further subdivided into alluvial sediments and weathered hard rock (residual soils) and the occurrence of any semi- or impervious layers noted. If an impervious layer impedes any surface-groundwater exchange, the river is insulated.

The bedrock media are further subdivided into hard rocks, dolomites and hardpans (the latter indicative of paleo-pedogenic processes) and the surface-groundwater interaction characterised as absent, localised (e.g. swallow holes, single major spring within a river) or continuous (diffuse gains/losses along river stretch).

Combinations of these classes (e.g. a river within an alluvial river train flowing through weathered hard rock or bedrock) are possible and should be noted. This will assist in the conceptualisation of the surface-aquifer system. A river within an alluvial river train flowing through weathered hard rock would for example require the calculation of an effective transmissivity for the two systems if the abstraction occurs within the weathered hard rock.

The primary classification identifies already whether surface-groundwater interactions must be considered and narrows down the applicable mathematical models for specific settings. While numerical models are in principal applicable to any of the geological settings, narrow strip aquifers should for example be described with the model of Butler et al. 2001. Localised surface-groundwater interactions should only be described with a numerical model or, in the case of a stream disappearing in a swallow hole, as one resource.

Following the conceptualisation of the geological setting the type of surface-groundwater interaction is classified in principal accordance to Vegter & Pitman (2003), i.e. based on the prevailing hydraulic gradient (Figure 12). Note that the occurrence of impervious or semi-pervious material in the riverbed is not part of the hydraulic, but geological classification. This means a clogging layer can occur in any hydraulic settings and limit or impede the exchange between surface and groundwater.

As before the secondary hydraulic classification gives guidance on the applicable mathematical model. While losing rivers can be described with analytical or numerical models, through-flow rivers, which gain and loose water simultaneously, should be described with numerical models. Once rivers become perched (groundwater table/capillary fringe below base of river) the unsaturated flow or free drainage of surface water through the semi-pervious bottom layer (typically found in perched rivers) to the groundwater table becomes constant, i.e. independent of the depth to groundwater. Such situations can either be described with a constant loss term per river length or with numerical models.

If a river experiences seasonal alternating effluent and influent conditions, the quantification of interaction should be performed with numerical models or separately for each season with analytical models. Seasonal or continuous effluent conditions can be described with numerical models or the analytical solution by Chen & Yin (2004), which accounts for a prevailing gradient between the aquifer and the gaining river.

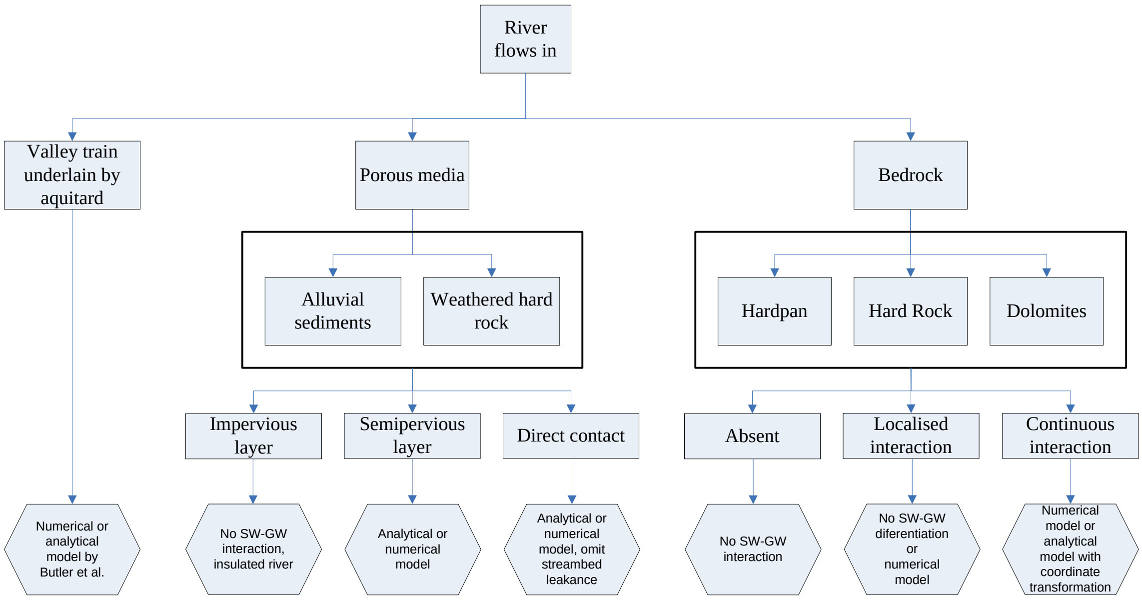


Figure 11: Primary geological classification scheme for surface-groundwater interaction assessment

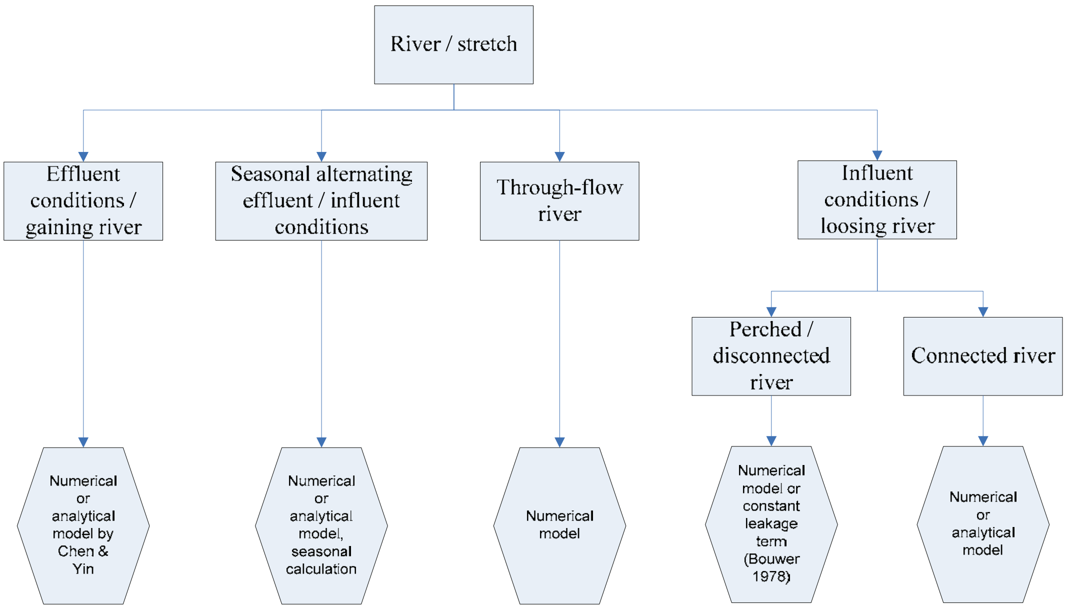


Figure 12: Secondary hydraulic classification scheme for surface-groundwater interaction assessment

There are various methods with which the groundwater contribution to baseflow can be calculated. Some of these methods will be discussed in this Section.

Herold method of baseflow separation

The Herold method is one of the common methods used in South Africa to determine the groundwater contribution to flow in a river. The method is based on the total flow in the river being equal to the groundwater contribution and surface runoff. The assumption is then made that all flow below a certain value (called *GGMAX*) is groundwater flow. The value of GGMAX is adjusted each month according to the surface runoff during the preceding month and is assumed to decay with time.

Recession curve by Moore

The recession curve is the specific part of the hydrograph after the crest (and the rainfall event) where streamflow diminishes. The slope of the recession curve flattens over time from its initial steepness as the quickflow component passes and baseflow becomes dominant. A recession period lasts until streamflow begins to increase again due to subsequent rainfall. Hence, recession curves are the parts of the hydrograph that are dominated by the release of water from natural storages, typically assumed to be groundwater discharge. Recession segments are selected from the hydrograph and can be individually or collectively analysed to gain an understanding of these discharge processes that make up baseflow.

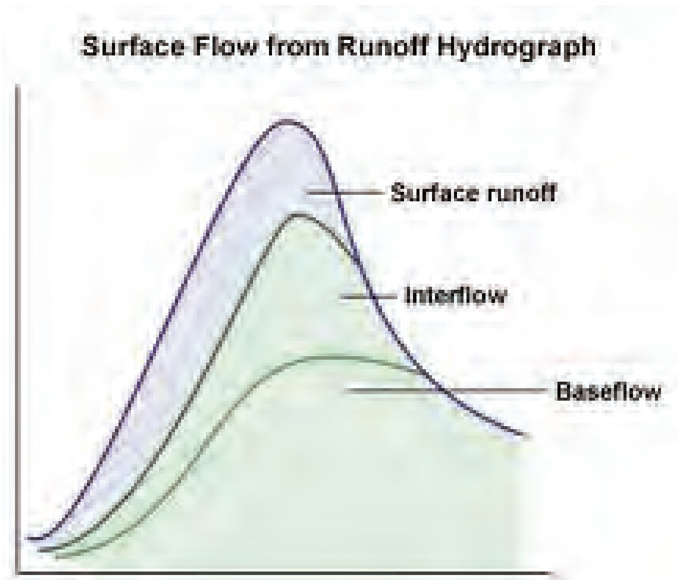


Figure 13: Recession curve

Stang and Hunt

Stang (1980) and Hunt (1999) presented an analytical solution for a homogeneous, isotropic aquifer of infinite lateral extent, with dominant lateral flow and constant T (Dupuit flow), overlain by an infinitely thin stream with a semi-pervious layer. This means that the solution for a fully penetrating streambed can be applied to a slightly penetrating streambed. A solution for the depletion rate for a finite stream reach, using the Stang/Hunt solution, is given by the Environment Agency (2002a).

Butler

The (Laplace-space) solution of Butler *et al.* (2001) also considers, in addition to a partially penetrating stream underlain by a semi-pervious layer, an aquifer of finite lateral extent. Bounded or strip aquifers are frequently observed in valleys and for alluvial aquifers consisting of river sediments (river trains).

For the sake of simplicity the solution is not given here. The authors list the assumptions/limitations of their model as follows:

- Vertical flow is negligible.
- The aquifer is isotropic.
- The stream level is not affected by pumping.
- A fully penetrating and screened well.
- The aquifer heads remain above the stream bottom.

Chen & Yin

The (semi-analytical) solution of Chen & Yin (2004) is a solution for a partially penetrating stream, adding a gradient between the aquifer and the gaining river.

Chemical method

This method is widely applied by geohydrologists. It would apply to any conservative constituents like Chloride. The formula is presented as follows (Freeze & Cherry, 1979):

$$Q_g = Q_T \cdot \left((C_r - C_d) / (C_g - C_d) \right)$$

where

Q_g	=	groundwater contribution
Q_T	=	the total streamflow
C_d, C_g & C_d	=	chemical concentrations for direct runoff, river and groundwater, respectively.

The equation makes use of groundwater concentration C_g, direct runoff concentration C_d and stream concentration C_r. It must be applied with care near the sea and in areas where the annual recharge is erratic and low.

SHE and SHETran (numerical model)

The Système Hydrologique Européen (SHE) is a physically-based distributed hydrological numerical modelling system that integrates surface and subsurface flow (including unsaturated vertical flow) on a catchment scale. The model assumes an unconfined aquifer underlain by an aquiclude (impermeable layer). The surface-groundwater interaction is a function of the head difference between the river and the aquifer and can account for clogging layers on the streambed as well as disconnected streams (Bathurst & Cooley, 1995).

MODFLOW – SFR1 (numerical model)

The STREAMFLOW ROUTING, package SFR1, allows for water in-/outflows from run-off, precipitation and evapotranspiration within each reach. In comparison to the RIVER or BRANCH packages, the hydraulic conductance of the riverbed is calculated from input data (hydraulic conductivity, thickness, stream length and stream width) or computed based on streamflow (conductance as a function of river width). Leakage from perched rivers is modelled with a unit gradient between the bottom of the streambed and the water table and assuming that the hydraulic conductivity of the underlying aquifer exceeds the leakage rate.

MODFLOW – SFR2 (numerical model)

A recent extension of the SFR2 package by Niswonger and Prudic (2005) allows modelling the unsaturated vertical flow between streams and aquifers, hence enabling the description of, for example, limited leakage due to the relative permeability of the unsaturated zone.

It is recommended that more than one method be applied to validate results.

Wetlands

In order to assess wetlands the following must be considered:

- Gradient between piezometric surface and the water level in the wetland.
- Occurrence and characterisation of clogging layers in the wetland.

The groundwater contribution to the wetland can be estimated using Darcy's Law, which states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path:

$$Q = T\,i\,w$$

where:

Q = discharge (m^3/d)

T = transmissivity (m^2/d)

i = groundwater gradient
w = length of the river (m)

The hydraulic gradient can be approximated from surface topography. Approximation of the transmissivity of the aquifer in the vicinity of the wetland is far more difficult. The reader is referred to Section 7.6 for more detail.

8.2 Terrestrial vegetation

This class of groundwater dependent ecosystem includes vegetation communities that do not rely on expressions of surface water for survival, but which have seasonal or episodic dependence on groundwater. Groundwater systems may be locally recharged during a pronounced wet season.

Terrestrial vegetation communities are influenced by several of the key groundwater attributes, as follows:

- **Level**: Most terrestrial groundwater dependent ecosystems require groundwater levels in unconfined aquifers to be at least episodically or periodically within their root zone. Groundwater would typically be required to satisfy evaporative demand during times when soil water availability is low.
- **Flux**: In addition to being at a level accessible to plant roots, groundwater flux would need to be sufficient to sustain a level of uptake by vegetation that at least partly satisfies evaporative demand.
- **Quality:** Salinity would typically be the key indicator of groundwater quality for such ecosystems. Terrestrial ecosystems may also be sensitive to groundwater contamination by nutrients, pesticides or heavy metals; however, little is known of their response.

The amount of groundwater needed for these systems must be defined by an ecologist. It is important to note that only those that are of national importance need to be considered in the Reserve.

Crop and forest water use can be determined using the BEWAP water model. BEWAP is a water balance model. Simulations can be run for various vegetation types and an average use can be included in the groundwater use calculations.

8.3 Recharge

Recharge remains one of the critical parameters to determine in all geohydrological studies, and is one of the most difficult to quantify. Kirchner *et al*. (1991), Giekse (1992), Bredenkamp *et al.* (1995) and Xu and Beekman (2003) provide good descriptions of methods that can be used to quantify recharge. Usually the method used to quantify recharge is dependent on the data available on which to base the assessment. It is recommended that more than one method be used.

8.3.1 Maps

Two national scale maps of recharge are currently available. Both maps are useful for obtaining a quick indication of recharge in a particular area. However, they must be used with caution. They provide only an indication of average recharge over an area and cannot be used to determine recharge on a local scale. Whenever possible, more detailed and site-specific information should be used.

8.3.2 Chloride mass balance method

Aquifer systems are mainly recharged via preferential pathways such as fractures, dykes, bedding planes and highly weathered zones. The recharge from rainfall was estimated using the Chloride Mass Balance (CMB) method and is expressed as a percentage of the Mean Annual Precipitation (MAP). The method is based on the following equation:

$$\%\ Recharge = \frac{Chloride\ concentration\ in\ rainfall}{Chloride\ concentration\ in\ groundwater} * 100$$

The assumptions necessary for the successful application of the chloride method are as follows (Van Tonder & Xu, 2001):

- There is no source of chloride in the soil water or groundwater other than precipitation.
- Chloride is conservative in the system.
- Steady state conditions are maintained with respect to long-term precipitation and chloride concentration in that precipitation, and in the case of the unsaturated zone.
- A piston flow regime, which is defined as downward vertical diffuse flow of soil moisture, is assumed. However this assumption may be invalidated if the flow through the unsaturated zone is along preferred pathways.

The CMB method is the only analytical method that could be applied to the recharge calculation due to the lack of time series monitoring data across the study area. Ecca formations are known for their high chloride values, which will result in a lower recharge estimation than the actual value. Previous studies have shown that a dilution factor of 2.0 is sufficient to correct the CMB method in Ecca rich areas.

8.3.3 EARTH model

EARTH is an abbreviation for **E**xtended model for **A**quifer **R**echarge and soil moisture **T**ransport through the unsaturated **H**ardrock and is a curve-fitting procedure used to determine recharge at a single borehole. The general equation used in the model is:

$$S\frac{dh}{dt} = \mathrm{Re}\,ch\arg e - \left(\frac{h}{DR}\right)$$

where:

S = specific yield
dh/dt = change in water level head during one month
DR = drainage resistance (a site specific parameter)
h = groundwater level

Monthly groundwater level and rainfall data are required by the model, as is an estimate of the specific yield of the aquifer. While the method appears promising, it is doubtful that a simple averaging of groundwater recharge values from point locations irregularly scattered in heterogeneous fractured-rock aquifers will result in a reliable assessment of recharge across the aquifer.

8.3.4 Cumulative rainfall departure method

The Cumulative Rainfall Departure (CRD) method is a water balance approach and is based on the premise that groundwater level fluctuations are caused by rainfall events. Bredenkamp *et al.* (1995) applied the method successfully in South Africa.

The method provides an integrated average recharge value. It also provides a useful tool with which to generate groundwater level or spring flow data missing from monitored records. The method requires monthly rainfall and groundwater level data, as well as information pertaining to aquifer properties (storativity), abstraction and the size of the recharge area. The CRD method cannot be applied in areas with no or very small groundwater level fluctuations.

8.3.5 Saturated volume fluctuation method

The saturated volume fluctuation (SVF) method incorporates a lumped parameter approach taking in account aquifer water levels, abstraction from the aquifer and natural flow. Bredenkamp *et al.* (1995) applied this method successfully in South Africa. The general equation used to determine recharge is:

$$h_i = h_{i-1} + R_i/S + (I_i - O_i)/SA - Q_o/SA$$

where:

h_i = head at month i (m)
h_{i-1} = head at previous month
R_i = recharge in month i (m)
I_i, O_i & Q_o = inflow, outflow and abstraction in month i (m^3/month)
A = area of aquifer (m^2)

S = specific yield

A good spatial distribution of boreholes is a prerequisite for the successful application of this method.

8.3.6 Isotopes

Oxygen-18 and deuterium are naturally occurring stable isotopes of oxygen and hydrogen. Moisture fluxes or recharge estimates may be derived from a relationship between $^{2}\delta$ displacements of isotopic compositions of soil moisture from the local meteoric line and the inverse of the square root of recharge. It has been determined that in a $^{18}\delta - {}^{2}\delta$ plot, the displacement of soil moisture is represented by a line parallel to the local meteoric water line (MWL) and is proportional to the inverse of the square root of the recharge rate. The amount of displacement from the local MWL is controlled by a balance between the isotopic enrichment attained in the upper layers of the soil (due to evaporation) and dilution of this isotopic enrichment by rainfall. The following equation can be derived assuming that the number of rainfall events is proportional to the total recharge:

$$\Delta\delta = \frac{C}{\sqrt{\mathrm{Re}\,ch\,\mathrm{arg}\,e}}$$

The constant C represents the slope of a line through the inverse of the square root of recharge rates obtained from other recharge estimation methods. In South Africa the equation used to determine the recharge is:

$$\Delta\delta = \frac{20}{\sqrt{\mathrm{Re}\,ch\,\mathrm{arg}\,e}}$$

It is important to note that this method is only applicable if recharge is less than 20 mm/a.

8.4 Inflows and outflows

The inflows and outflows from the IUA can be estimated using Darcy's Law, which states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path:

$$Q = T\,i\,w$$

where:

Q = discharge (m^3/d)
T = transmissivity (m^2/d)
i = groundwater gradient
w = length of the river (m)

The hydraulic gradient can be approximated from surface topography. Approximation of the transmissivity of the aquifer is far more difficult. The reader is referred to Section 7.6 for more detail.

8.5 Aquifer vulnerability

The aquifer vulnerability assessment technique relies on readily available information for a study area. Utilising the geohydrological setting, inferences are made as to the soil's geochemical nature and the potential for contaminants to migrate from the soil surface to the groundwater table. The term geohydrological setting refers to a composite description of all the major geologic and hydrologic factors. These types of analyses apply to areas on the order of 0.5 km^2 and more (Delleur, 1999).

The DRASTIC method is classified as an overlay technique and provides a simple and straightforward means of assessing the susceptibility of certain areas to contaminants. The acronym DRASTIC refers to the seven factors utilised in the rating system — depth to groundwater, recharge rate (net), aquifer media, soil media, topography, impact on vadose zone, and hydraulic conductivity.

Each of these is assigned a value based on a rating. These factors are adjusted by a weighting factor and summed to calculate the pollution potential or DRASTIC index (Delleur, 1999). The aquifer vulnerability is calculated using the following parameters:

- **Groundwater Level [mbgl]**: The water levels across the area are presented as a histogram and the bin with the highest frequency is chosen as a representative water level. An example is shown in Figure 14. When more than one dominant water level exists, the shallower level is used to obtain a conservative vulnerability estimate.

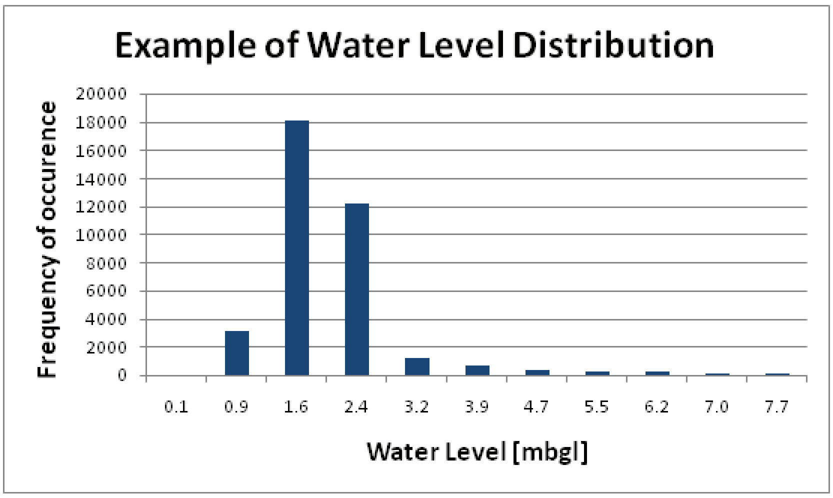


Figure 14: Water level distribution

- **Slope of the area [%]**: Random elevation samples taken over the area are used to produce a distribution of representative slopes over the area. An example is shown in Figure 15. When more than one dominant slope exists, the smaller one is used to obtain a conservative vulnerability estimate.
- **Recharge [%]**: The recharge percentage is the calculated value from all existing recharge data.
- **Soil Media**: Soil media information is obtained from soil covers available for the area.
- **Aquifer Media**: Aquifer media is associated with geology in the area, and can also be confirmed by borehole logs that are available for some of the boreholes.
- **Vadose Zone**: The Vadose zone types for most of the country are available and associated with the soils and geology present in the area.

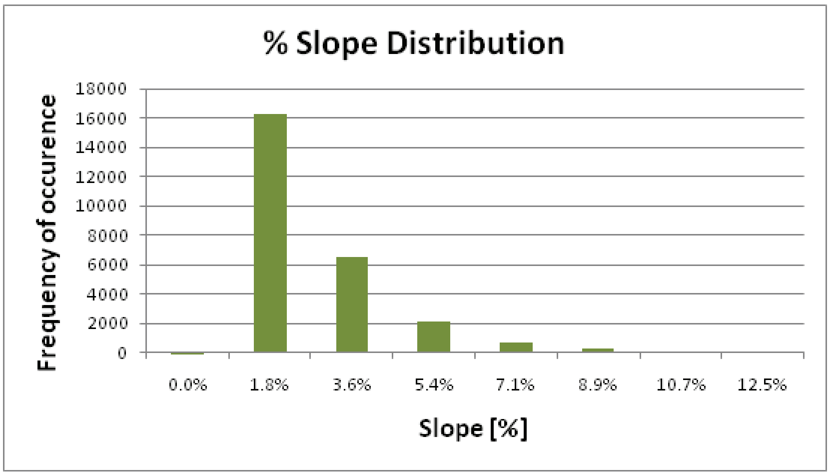


Figure 15: Slope distribution

The DRASTIC formula for groundwater in South Africa according to Lynch *et al.* (1984) is as follows:

$$\text{DRASTIC INDEX} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w$$

The weights of each of the above-mentioned terms are:

Depth to groundwater (D_w) = 5
Recharge (R_w) = 4
Aquifer media (A_w) = 3
Soil media (S_w) = 2
Topography (% slope) (T_w) = 1

A guideline for the ratings is provided in TABLE 12.

TABLE 12: RATING VALUES USED FOR THE DRASTIC CONCEPT

Depth to groundwater (D_R) Range (m)	Rating
0-5	10
5-15	7
15-30	3
>30	1

Net recharge (R_R) Range (mm)	Rating
0-5	1
5-10	3
10-50	6
50-100	8
>100	8

Aquifer media (A_R) Range (m)	Rating
Dolomite	10
Intergranular	8
Fractured	6
Fractured and weathered	3

Topography (T_R) Range (% slope)	Rating
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

Soil media (S_R) Range (mm)	Rating
Sand	8-10
Shrinking and/or aggregated clay	7-8
Loamy sand	6-7
Sandy loam	5-6
Sandy clay loam and loam	4-5
Silty clay loam, sandy clay and silty loam	3-4
Clay loam and silty clay	2-3

Impact of the vadose zone (I_R) Range	Rating
Gneiss, Namaqua metamorphic rocks	3
Ventersdorp, Pretoria, Griqualand West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutpansberg, Karoo (northern), Bushveld, Olifantshoek	4
Karoo (southern)	5
Table Mountain, Witteberg, Granite, Natal, Witwatersrand, Rooiberg, Greens one, Dominion, Jozini	6
Dolomite	9
Beach sands and Kalahari	10

8.6 Methods to assist with setting RQOs

8.6.1 Predicting drawdown as a result of abstraction

Many available methods can be used to predict the drawdown resulting from abstracting groundwater from a borehole. While use of numeric models allow for more sophisticated assessment (consideration of boundary conditions, assessment of the effects of pumping more than one borehole at a time, etc.), use of the Cooper-Jacob equation allows for a rapid calculation of drawdown-distance relationships when a borehole is pumped at a constant rate (Kruseman & De Ridder, 1991).

$$s = \frac{2.3Q}{4\pi T}\log\left(\frac{2.25Tt}{r^2 S}\right)$$

where:

s = drawdown (m)

T = transmissivity (m^2/d)

t = time (d)

r = radius of borehole (m)
S = storativity

To be able to predict the drawdown in a borehole, information about the aquifer (transmissivity and storativity) is required, as is the radius of the borehole and the rate and duration of abstraction. By rearranging the equation, it is possible to estimate the drawdown at some distance from the borehole. This is useful when setting RQOs relating to allowable drawdowns and set back distances.

8.6.2 Estimating allowable rates of abstraction

An exclusion or protection zone may be negatively impacted if abstraction from a borehole induces a cone of depression that extends into that zone, as indicated in Figure 16. It is possible to calculate the radius of influence that a particular abstraction rate will induce, as well as calculate the maximum rate of abstraction allowed in order not to impact a protection zone some distance away from the pumped borehole.

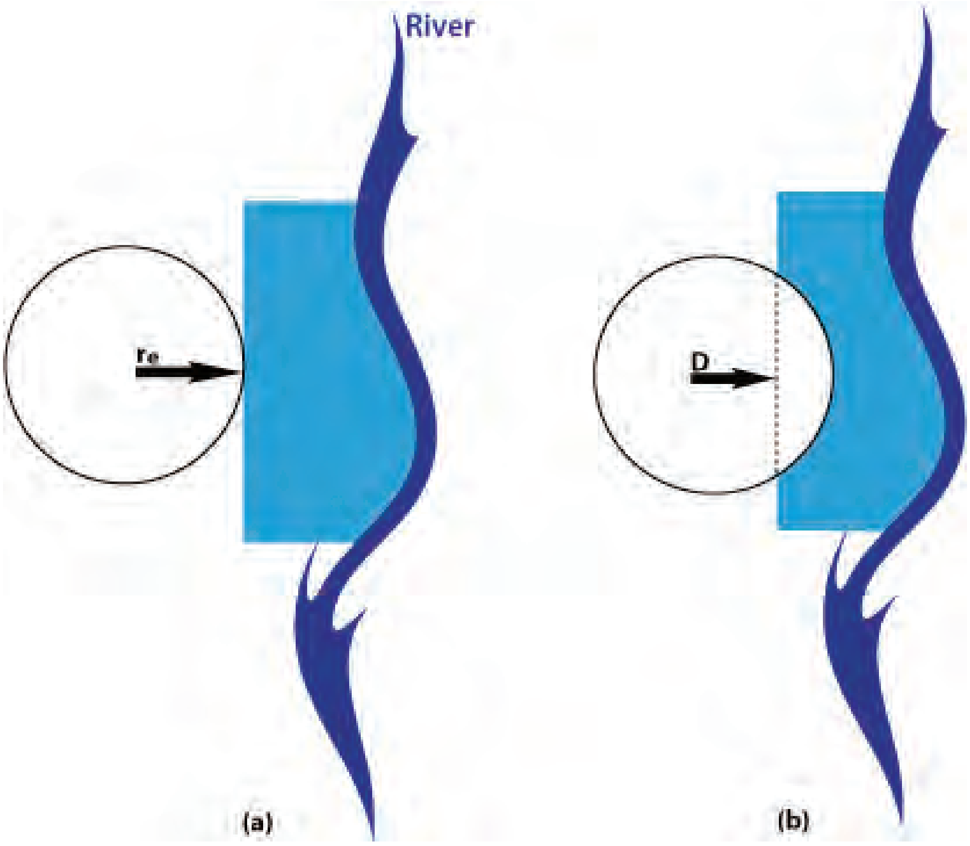


Figure 16: Graphical representation of the radius of influence (r_e) used to estimate the sustainable yield of a borehole (a) when the borehole does not influence the ecological protection zone and (b) when the borehole influences the ecological protection area

As indicated in Figure 16, in order for a borehole not to influence a water body, it should be located at least a distance r_e + L from the body, where L is the distance between the river and the border of the ecosystem protection zone . If *D* is the distance between the borehole and the closest boundary of a protection zone and $D > r_e$, then abstraction from the borehole will not influence the protection zone. Conversely, if $D < r_e$, then abstraction from the borehole will have an influence on flow to the area. The rate at which a borehole can be pumped in order not to influence the protection – termed here as the *allocatable safe yield* of the borehole (Q_s) – can be estimated calculated using the following equation derived by GJ van Tonder:

$$Q_s = BR$$

where:

Q_s = allocatable safe yield of *a* borehole (m^3/a), inside an area B *(m^3)*
B = πD^2 if $D < r_e$
B = $\pi (r_e)^2$ if $D > r_e$
r_e = radius of influence after 365 days (m)
R = effective annual recharge (m/a)

When the distance between a borehole and the boundary of a protection zone is known (D), it is possible to predict the duration of pumping before the radius of influence will reach the boundary, i.e. where r_e = D:

$$td = SD^2 / (2.25T)$$

where:

td = duration of abstraction before the r_e = D (days)
S = storativity
D = distance between borehole and boundary of protection zone (m)
T = transmissivity (m^2/d)

If, for some reason, a borehole is pumped at a rate greater than the determined allocatable safe yield, it is possible to estimate the maximum number of days per year that the borehole can be pumped at the actual rate of abstraction. It should be noted that during the period of abstraction, the radius of influence may extend into the protection zone.

$$td = (Qs / Q) \times 365$$

where:

td = period of pumping allowed per annum (days) at a rate Q
Qs = allocatable safe yield (m^3/d)
Q = actual rate of pumping (m^3/d)

8.6.3 Borehole protection zones from on-site sanitation

Basic human need boreholes are important for many rural communities. However, the influence of pit latrines have to be taken into account as these are in most cases the only form of sanitation. There are two elements of concern in groundwater, namely nitrates and microbial contaminants. Nitrates cause cyanosis due to methaeglobinemia, which is toxic to infants. Nitrate can also reduce to nitrite, which combines with haemoglobin (oxygen-carrying red blood cell) to form methaemoglobin. Methaemoglobin is incapable of carrying oxygen. Bacteria and viruses can cause a number of illnesses such as typhoid fever, cholera, gastro-enteritis, hepatitis and meningitis.

Protection zones around planned boreholes are included to ensure there will be no effect on the groundwater quality as a result of on-site sanitation.

The radius of a fracture as defined and calculated in the FC-spreadsheet (Van Tonder *et al*., 2001) can be used to determine the protection zone. Various protection zones can then be delineated with associated risks as shown in TABLE 13.

TABLE 13: RISK ASSOCIATED WITH VARIOUS PROTECTION ZONES

RISK	PROTECTION ZONE
High or very high risk of microbial pollution	2 times fracture radius
Low risk for microbial pollution	1 times fracture radius
No risk for microbial pollution	0.5 times fracture radius
High risk for N for infants	2 times fracture radius
Low risk for N for infants	1 times fracture radius
No risk for N for infants	0.5 times radius

In many cases fracture information is not available, therefore a correlation between fracture radii and transmissivity was determined by GJ van Tonder:

$$Fracture_{radius} = 0.28T + 53$$

Transmissivity values can then be used to determine the fracture radii and protection zones.

8.7 How to deal with scale

The quaternary scale is the current basis for large scale groundwater reserve determinations. The current methodology assumes that a percentage recharge is placed on the total area which translates into a volume. The methodology implies a uniform abstraction over the whole area which will not show large areas as stressed, but the converse is true for smaller areas. Proportional volumes are then calculated for sub-areas.

8.7.1 Assured yield

Instead of just using a box model based on a volume approach a quaternary should be modelled as a single-cell model which uses historic precipitation data and translates this into aquifer water level data through the use of the Saturated Flow Volume calculation. For smaller areas a proportional yield will be calculated again.

An assurance of supply is then calculated in terms of a reference water level set for the quaternary as a whole (Figure 17). The water balance term is considered as a lumped parameter for assured yield purposes. The water level fluctuations can then be translated to an equivalent transmissivity based on the balanced flux through the system.

8.7.2 Aquifer Parameters

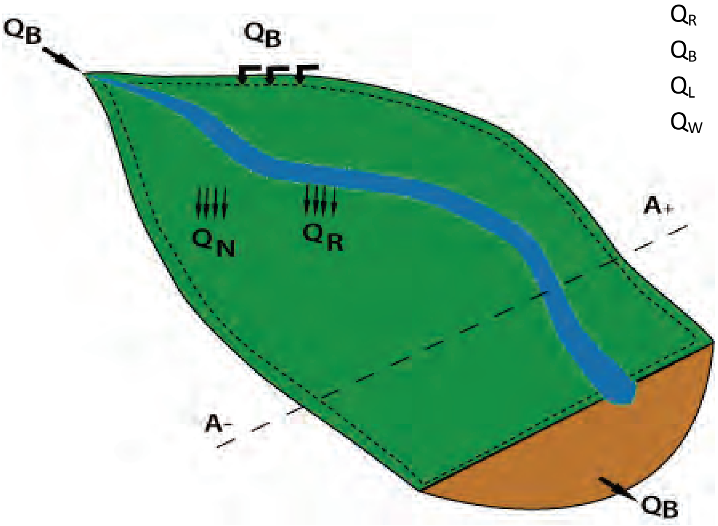
The most crucial aquifer parameter to be obtained is the transmissivity. A representative transmissivity of the quaternary can be obtained from the method described above and this should lie between the harmonic and geometric mean of available transmissivities for the entire quaternary. Current research being conducted by the Water Research Commission indicates that the harmonic mean of transmissivities holds true for pumping conditions and the geometric mean is the upper bound for natural conditions on a large scale.

On wellfield scale, pump test data should be used to calculate transmissivities, since boundary conditions will have an effect on the transmissivities which were not considered in the large scale analysis. If no pump test data is available for a specific borehole it is suggested that the harmonic mean of the area be used as a conservative approach.

8.7.3 Recharge

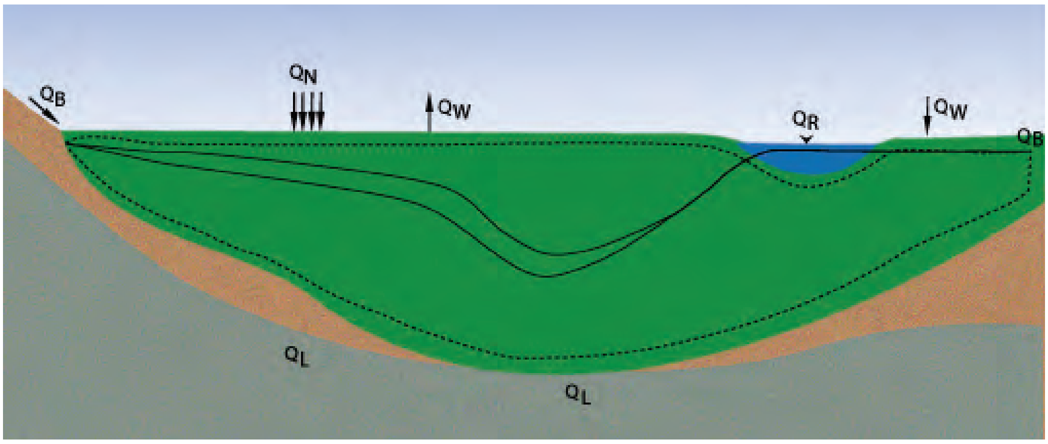
On large-scale, existing data sets and maps should be consulted for a recharge estimate for the area. On wellfield scale, any of the existing methods presented in the toolbox can be used. The selected method will be governed by the availability of the required data of each method.

Natural



Q_N	Natural groundwater recharge/discharge
Q_R	Exchange with surface water
Q_B	Subsurface flow over boundary
Q_L	Leakage component coming from adjacent aquifers
Q_W	Local exfiltration/infiltration

Cross-section (A)



Approximation

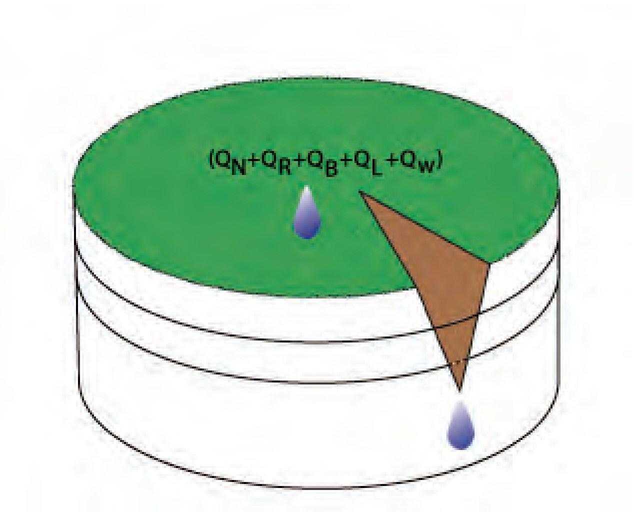


Figure 17: Assurance of yield

8.8 References

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9. Case Studies

PLEASE NOTE: The purpose of the text in this manual regarding the two case studies is to introduce the study areas, with the actual GRDM results contained in software.

9.1 Case Study 1: Mokolo River

The study area falls within the Limpopo WMA forming part of the Limpopo Province in the northern part of the Republic of South Africa (Figure 18). The area consists of quaternary catchments A42A-A42J covering an area of approximately 8100 km^2. The two main towns located in the study area include Lephalale (Ellisras) and Vaalwater. The Mokolo River is the major river system flowing through the study area eventually joining the Limpopo River to form the international boundary between South Africa and Botswana.

The topography (Figure 19) varies depending on the type of geological formations present. The northern part of the study area, is typically characterized as relatively flat lying with elevations ranging between 600 to 700 mamsl. Hills are associated with the Bushveld Igneous Complex. The central and southern part of the area is underlain by rocks of the Karoo Supergroup and Waterberg Formation. The mean annual precipitation on average varies between 300 mm and 500 mm. The mean annual potential evaporation is more than twice the amount of rainfall over most of the area. It varies across the Mokolo Catchment from about 1600 mm/a in the south to about 2000 mm/a in the north.

The vegetation of the Mokolo Catchment is characterized by mostly Bushveld Biomes in the north, central regions, southeast and southwest. North Eastern Mountain Sourveld biome occur in localized areas in the south (Low et al., 1996).

The geology of the study area is discussed in the following sub-sections:

- The north of the study area is underlain by rocks of the Beitbridge Complex and Hout River Gneiss formation forming part of the Basement Complex. The Basement Complex is mainly characterized by granites, granodiorite, migmitites and gneiss but also comprises of metamorphosed sediments, slate, talc schists and sandstone.

- Intrusive igneous rocks (Bushveld Igneous Complex) are found to the north, south and east of the study area consisting mainly of the Rustenburg layered suite (Rooiberg Group). This rock formation ranges in composition from ultramafic to acidic rocks and includes an economically (Platinum) important layer comprising mainly of granodoirite, gabbro, norite, anorthosite and granite.

- The southern part of the study area is underlain by the Waterberg Formation that consists of three main subgroups; the Setlaole, Makgabeng and Mogalakwena formations. The basal Setlaole Formation is composed of coarse granulestone and is locally conglomeratic. This formation is interpreted to have been deposited in a fluvial, braided river environment. The Makgabeng Formation consists of large-scale trough and planar cross-bedded fine- to medium-grained sandstone. The Mogalakwena Formation consists of interbedded sheets of granulestone and conglomerate.

- The Karoo Supergroup, consists mainly of sedimentary rocks. The Waterkloof Formation (Ecca Group), forming part of the Ellisras basin, comprises of diamictite, mudstone and conglomerates. The mudstones are believed to represent glacio-lacustrine deposits where-as the conglomerates and diamictite are believed to have formed as subaqueous outwash deposits formed due to the retreating glacier.

- Quaternary deposits cover large portions of the Basement Complex and the northern reaches of the Waterberg Formation. Sediments such as calcrete, ferricrete, gravel red sand and alluvium are found throughout the Mokolo Catchment. Alluvium of up to 5 meters in thickness with a coarse sand base is present along the Mokolo River.

The following aquifers have been identified in the study area (DWA, 2010):

- The northern region of the study area is underlain by basement aquifers that comprise of deeper fractured (i.e. secondary) aquifers overlain by a weathered horizon of variable thickness. Thick, weathered aquifer zones are expected in areas where the bedrock has been subjected to intense fracturing. The existence of diabase and dolerite dykes forms poor groundwater targets due to the lack of weathering on the margins of these dykes with the basement rocks (gneiss), especially below the static water level. The most noticeable aquifer within the basement rocks are the ENE trending zones of shearing, faulting and brecciation and are usually covered with Quaternary deposits contributing to the aquifer's storage potential.

- The Waterberg aquifer is predominantly of a fractured and weathered type potentially connected to alluvial deposits occurring along the Mokolo River. The main groundwater targets are associated with fractured dyke contacts and fault zones. The Waterberg formation is associated with steep topography and shows generally poor capability to produce huge amounts of groundwater. Recharge to the aquifer, often discharged on the steep slopes, provides baseflow to the rivers. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.

- The Karoo aquifer shows similar aquifer properties as the Waterberg aquifer comprising of fractured rocks with a porous matrix. However, groundwater resources and especially the development thereof, are limited due to the low recharge to these aquifers.

- Alluvial aquifers are recharged during periods of high stream-flows and discharge events (from the Mokolo dam) as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers.

Based on detailed field work to classify the groundwater-surface water interaction of the Mokolo River as part of the groundwater Reserve determination study for the Mokolo catchment the following conceptual aquifer model is proposed:

- The alluvial aquifer associated with the Mokolo River is in direct contact with the river.

- The alluvial aquifer is generally unconfined.

- The regional aquifers show marginal gradients towards the Mokolo River course and exchange water with the river only indirectly via the alluvial deposits.

- The surface-groundwater exchange between the alluvium and the Mokolo River occurs on a far shorter time scale in comparison to the interaction between the regional and alluvial aquifers.

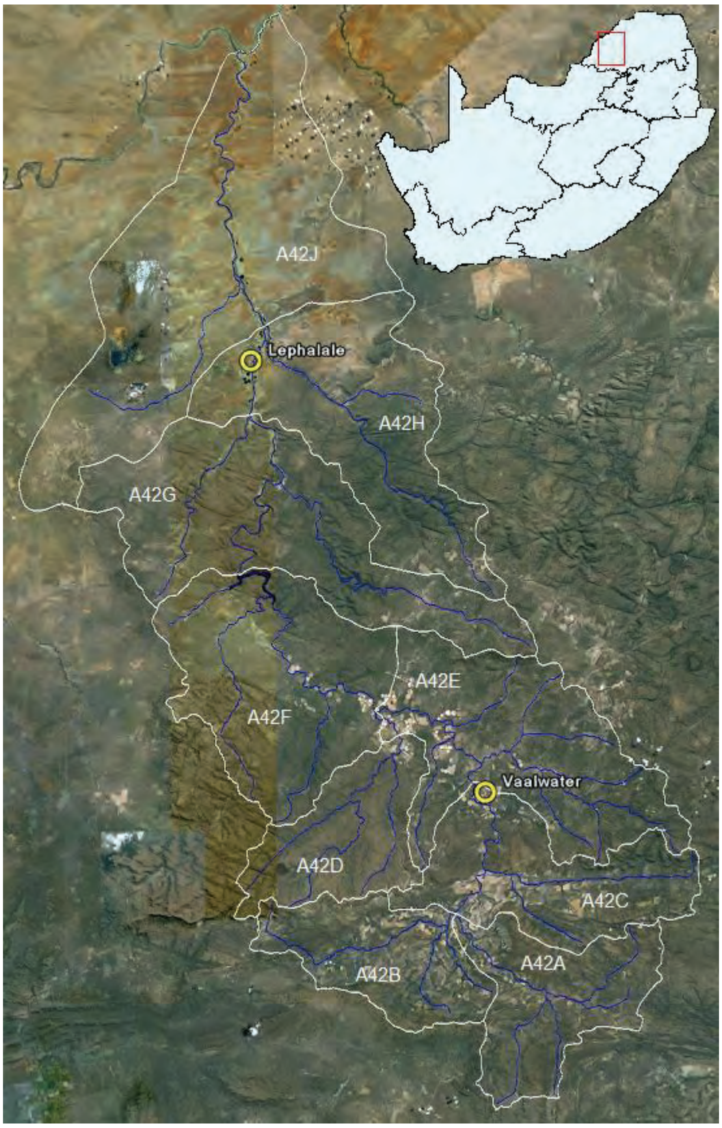

Figure 18: Location of study area

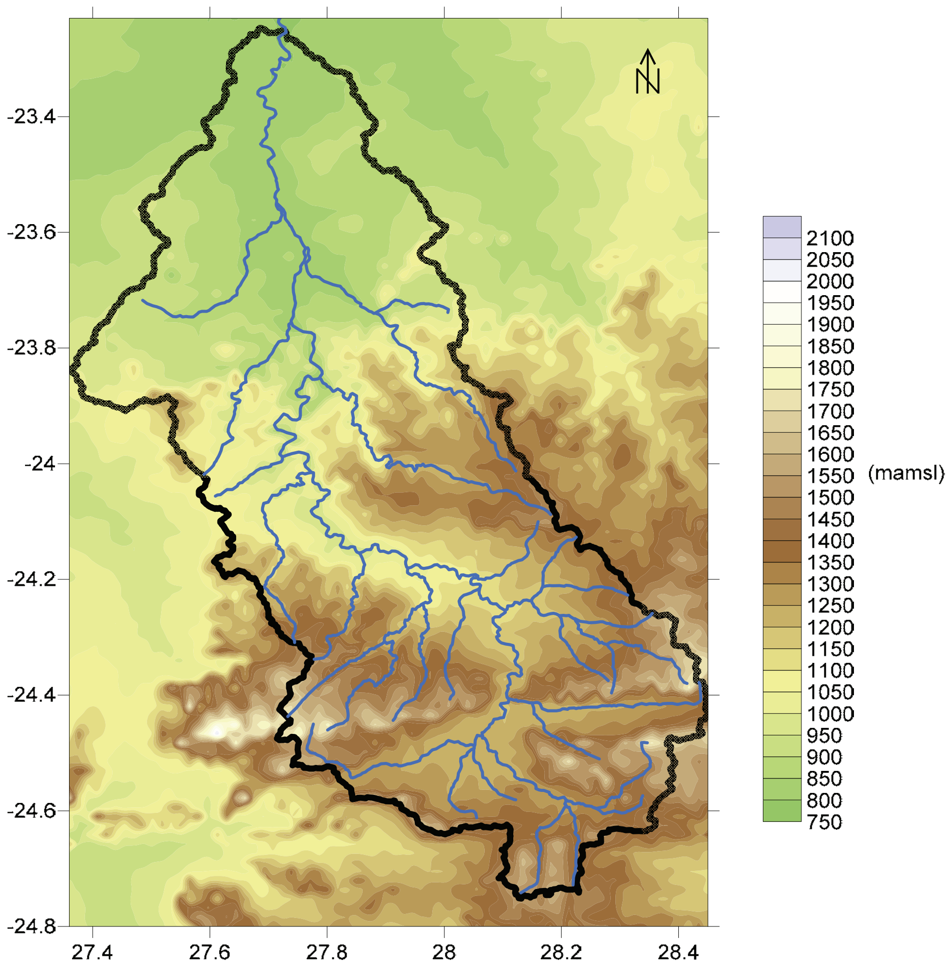

Figure 19: Topography

Please note the step by step GRDM analysis for this case study is included in the GRDM software.

9.2 Case Study 2: Thukela River

The Thukela River is a principal river of the KwaZulu-Natal province in South Africa, and is ranked as the second largest river in the country by volume. The Thukela catchment of 29000 km^2 produces around 8.5% of South Africa's stream flow from 2.5% of its area. It rises as a stream on the 3050 m high Mont-aux-Sources plateau near the merger point of the Lesotho – Free State Province borders. Its upper course lies within the Royal Natal National Park in the Northern Drakensberg. The river hurtles down a series of waterfalls as it drops a total of 948 m. The river cuts through the Thukela Gorge at the foot of the escarpment (approximately 1500 mamsl), passes through the Ladysmith Basin and becomes narrow and deep below Colenso. At Jameson's Drift, it enters the wide open Thukela Trough and then the coastal plain. The 405 km Thukela River mouth lies midway between Durban and Richards Bay, 10 km to the east of the national road bridge, 14 km to the south-east of the town Mandini and 104 km from Durban.

Major tributaries flowing into the Thukela River from the north are as follows:

- The Klip River, which passes through Ladysmith
- The Sundays River
- The Buffalo River, which rises above Newcastle

Major tributaries into the Thukela River from the south are as follows:

- The Little Thukela River
- The Bloukrans River
- The Bushmans River, passing though Estcourt
- The Mooi River

The Thukela Water Management Area (WMA) consists of the entire catchment of the Thukela River, also referred to as the 'V' Hydrological Drainage Region (Midgeley et al., 1994). The WMA contains 88 quaternary catchments (Figure 20).

The majority of land is used for agriculture, with relatively large areas of grassland. There is a small amount of forestry in this catchment, as found in the southern and eastern areas. The agriculture includes large areas of beef and dairy pastures, some sugar cane near the coast and around Weenen (both dry land and irrigated), vegetables and nuts, and some citrus farming on the coast near Mandini. The majority of irrigation uses sprinkler irrigation systems, but centre-pivot irrigation is also used in the western areas (especially around the Thukela River). Agriculture includes forestry, sugar cane plantations, stock farming and game farming. Mining activities in the Thukela WMA do not consume significant amounts of water, but do impact on the water quality, especially in the Buffalo River and Sundays River

Catchments. The main product of the mining industry in the Thukela WMA is coal. A number of other commodities such as sand and dolerite are also mined. The Vryheid Formation of the Ecca Group contains coal seams, which have been extensively mined in the past. The coal mines, scattered over the northern parts of the Thukela River Catchment, have either been closed for a number of years, or are in the process of closing down. Many of the older mines were never rehabilitated adequately. Consequently, these mines produce acid mine decant that enters the Thukela River system. The worst affected areas occur around Newcastle (Buffalo and Ngagane Rivers).

Commercial afforestation has been one of the major sources of alien vegetation in South Africa, largely as a result of poor forestry management practices in the past. About 44% of the area invaded by plantation trees (pine, eucalyptus and black wattle), overlaps with areas affected by commercial afforestation practices. Estimates of the reduction in run-off caused by alien vegetation show that this may be in the order of 55 million m^3/a.

The catchment experiences a wide range of climatic conditions, ranging from generally wet and cold in the Drakensberg Mountains to dry and hot in the Thukela Valley from Colenso towards the coast, and hot and humid at the coast. Summers are generally hot with temperatures often exceeding 35^{o}C. Winters are cold, particularly in the west and north, where temperatures fall below freezing and frost occurs regularly. Along the coast, conditions are generally more temperate.

Rainfall varies significantly throughout the catchment and exhibits a strong correlation with relief. Rainfall is strongly seasonal, with in excess of 80% occurring as thunderstorms during the period from October to March. The peak rainfall months are December to February in the inland areas and November to March at the coast. Mean annual precipitation ranges from in excess of 1500 mm in the west to 750 mm, to over 1000 mm at the coast. Corresponding mean annual run-off figures are in excess of 600 mm in the west (40% of MAP), 80 mm (11% of MAP) in the central (Ladysmith) area and 180 mm (18% of MAP) at the coast. In general, the MAP is about 840 mm, and the corresponding MAR 131 mm (16% of MAP). The MAR of the Thukela is estimated at 3799 million cubic metres per annum. Snowfall on the Drakensberg mountains between April and September has a significant influence on the climate of the WMA. Frost occurs inland from May to August. The average number of heavy frost days per annum range from one to thirty days for the inland areas, to zero for the eastern coastal area. Evaporation increases from the coast westwards. At the coast, evaporation amounts to about 1300 mm/a, and increases to 1600 mm/a in the central part of the study area. Evaporation along the escarpment ranges between 1300 and 1400 mm/a.

The Thukela WMA is predominantly underlain by strata from the Karoo Supergroup (Figure 21). Capping these sedimentary layers are igneous rocks, which, because of their greater resistance to weathering, form the high mountains of Lesotho. In geological terms, the deposits are fairly young. The rock types in the area are mostly sandstone, siltstone and mudstone, while basalt makes up the highest reaches of the Thukela drainage area. The outcrop of Dwyka Group Tillite is limited to the area around Kranskop. Sediments of the Ecca Group are found in the eastern part of the catchment and underlie much of the Sundays River and Buffalo River catchments, with rocks of the Vryheid Formation underlying much of the area. These rocks mainly comprise sandstones and are relatively resistant to erosion, resulting in relatively narrow and deeply incised river channels. The lower Beaufort Group (Adelaide subgroup) predominates in the western part of the catchment. These rocks are finer-grained and mostly comprise shales and mudstones, with subordinate sandstone horizons. A number of coal deposits are present within the Ecca Group of the Karoo Supergroup in the vicinity of Newcastle and Dundee. All the above sedimentary strata have been extensively intruded by dykes and sills of dolerite. These features play an important role in the geohydrology of the area, and significantly enhance the water-bearing properties of aquifers in the WMA. Small outcrops of granites from the Barberton Sequence occur west of Tugela Ferry. These are some of the oldest rocks known, and date in excess of 3000 Ma. Similarly, the Natal Metamorphic Province includes rocks of some 1000 Ma, but their extent is limited to the south-eastern part of the catchment between Kranskop and Mandini. The extent of the Natal Group is also limited to the area south-east of Kranskop. Younger unconsolidated sands are limited to the coastal area and are only of significance in the immediate vicinity of the estuary. King (1997) indicates the presence of localised, but significant alluvial sand deposits throughout the Thukela River Catchment. Some deposits reach a thickness of almost 40 m. The study area is mostly underlain by the Karoo Suspergroup and is either sub-horizontal or has a very gentle inland dip to the west, and a minor eastern coastal and coastal hinterland portion, wherein the structure comprises numerous south-easterly or seaward tilted fault blocks. These fault blocks play an important role in groundwater flow. In the low-standing east central portion of the basin, extending east to within about 20 km of the coast – 'Basement' rocks are exposed, comprising granite-gneiss, schists and amphibolites. Younger unconsolidated sands are limited to the coastal area and river beds.

Aquifers within the study area include:

- Weathered and fractured hard rock aquifer systems.
- Primary aquifers that are confined to a narrow strip along the coast and the middle reaches of the Thukela, Sundays and Buffalo Rivers. The primary aquifer in the immediate vicinity of the estuary provides a source of moderate quality water to the estuary during periods of low flow.

Except in the coastal area around the estuary, aquifers in the Thukela River Catchment are classified as minor aquifers. Median depth to the water table in the WMA is 0-35 m.

Groundwater yields from 'hard-rock' boreholes in the WMA are generally low and in the range 0.1 to 0.6 l/s, although significantly higher yields (3 l/s) can be obtained in geohydrologically favourable situations, such as fracturing and intrusive Karoo dolerite contact zones. Contacts between different lithologies were also seen to be important drilling targets. There is little difference in yield among the various geological formations.

Higher borehole yields can be obtained in some localities. Juxtaposition of sandstone horizons to dolerite, major structural features such as faults and fractures and more competent Natal Group quartzites and sandstones have produced borehole yields in excess of 2 l/s. The likelihood of obtaining yields in excess of 2 l/s, however, is less than 30%, while few boreholes yield more than 3 l/s.

Groundwater recharge over the WMA varies from 1 to 5 % of the mean annual precipitation (MAP), with an average of about 3 percent of the MAP. Overall, the average annual recharge over the WMA is some 25000 m^3/km^2, varying from about 40 000 m^3/km^2 in the higher rainfall portions of the area to about 15 000 m^3/km^2 in the portions with lower rainfall.

Baron et al. (1998) report that effective storage rather than recharge dictates the potential of aquifer systems in the study area. They estimate the Harvest Potential for the Thukela River Catchment at 520 Mm3/a. Using the same data set, Haupt (2001) defines the Exploitation Potential of the catchment as 230 Mm3/a. The Harvest Potential is adjusted on the basis of low borehole yields that prevent the full Harvest Potential. Haupt bases his reduction on an average borehole yield of 0.85 l/s.

Good quality groundwater is found in the mountain headwaters, with quality deteriorating in the direction of flow. Poorer quality groundwater is found in the lower reaches of the Upper Thukela, Bushmans and Mooi Catchments, probably reflecting the influence of the argillaceous sediments in this part of the study area. Instances of elevated fluoride were reported for the western part of the catchment. Groundwater pollution in the WMA is generally not significant in proportion and, when present, it is significantly localised.

Please note the step by step GRDM analysis for this case study is included in the GRDM software.

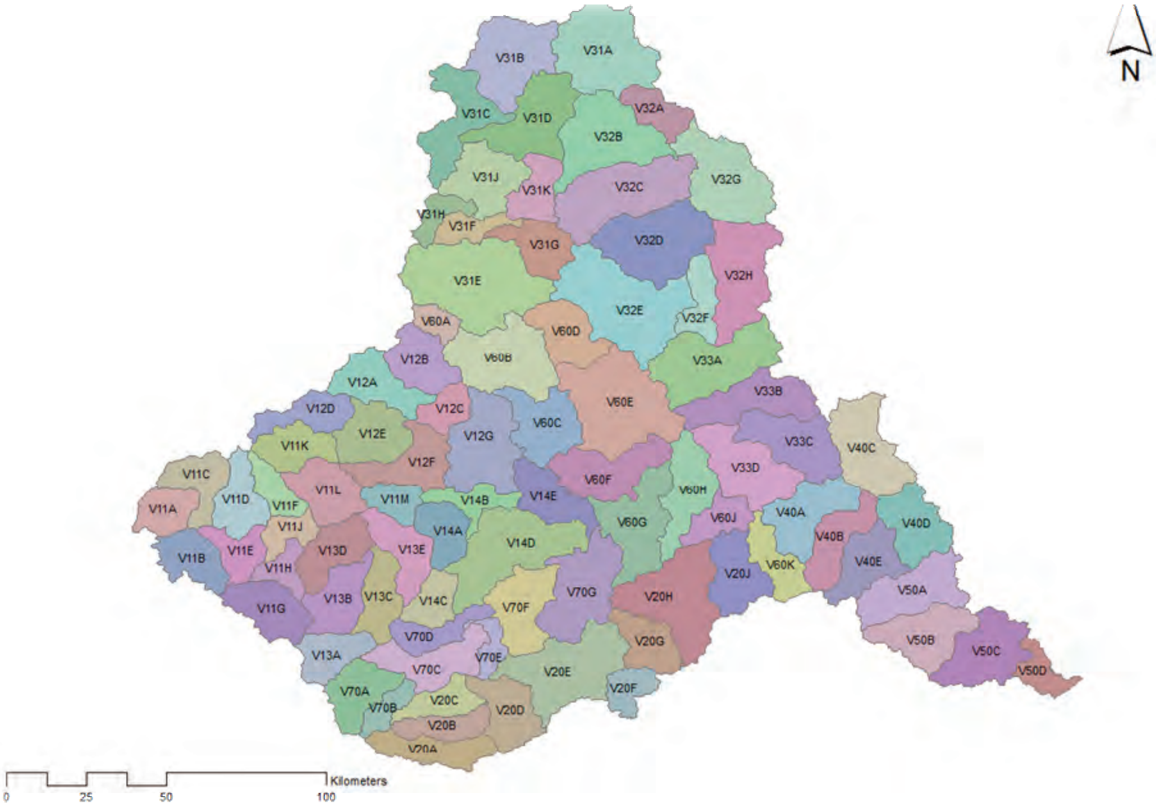

Figure 20: Quaternary catchments making up the Thukela Water Management Area

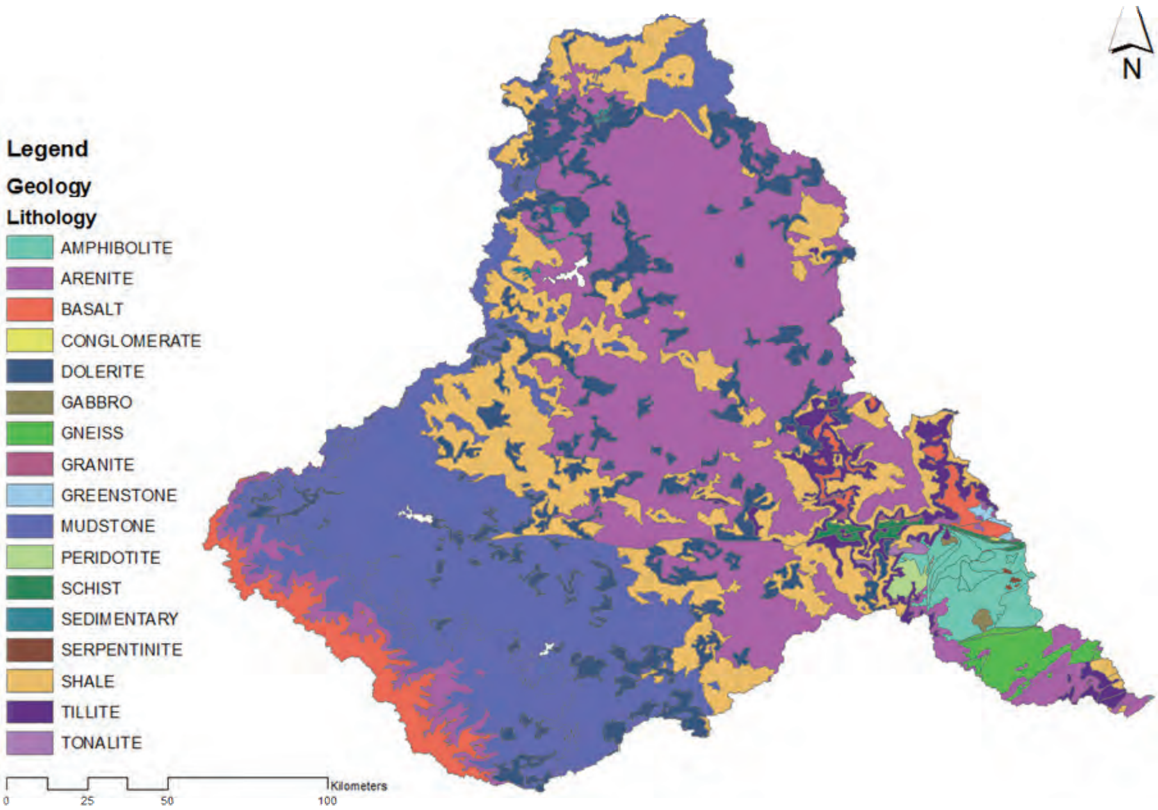

Figure 21: Geology of study area

Appendix A: Chapter 3 of the National Water Act

CHAPTER 3

PROTECTION OF WATER RESOURCES

The protection of water resources is fundamentally related to their use, development, conservation, management and control. Parts I, 2 and 3 of this Chapter lay down a series of measures which are together intended to ensure the comprehensive protection of all water resources. These measures ate to be developed progressively within the contexts of the national water resource strategy and the catchment management strategies provided for in Chapter 2. Part 4 and 5 deal with measures to prevent the pollution of water resources and measures to remedy the effects of pollution of water resources.

Part 1: Classification system for water resources

Part I provides for the first stage in the protection process, which is the development by the Minister of a system to classify the nation's water resources. The system provides guidelines and procedures for determining different classes of water resources.

Prescription of classification system

12. (1) As soon as is reasonably practicable, the Minister must prescribe a system for classifying water resources.

(2) The system for classifying water resources may —

(a) establish guidelines and procedures for determining different classes of water resources;

(b) in respect of each class of mater resource —

(i) establish procedures for determining the Reserve:

(ii) establish procedures which are designed to satisfy the water quality requirements of water users as far as is reasonably possible, without significantly altering the natural water quality characteristics of the resource:

(iii) set out water uses for instream or land based activities which activities must be regulated or prohibited in order to protect the water resource; and

(c) provide for such other matters relating to the protection, use, development, conservation, management and control of water resources, as the Minister considers necessary, *Part 2: Classification of water resources and resource quality objectives*

Under Part 2 the Minister is required to use the classification system established **in** ***Part I to determine the class and resource quality objectives of all or part of water resources considered to be significant. The purpose o f the resource quality objectives is to establish clear goals relating to the quality of the relevant water resources. In determining resource quality objectives a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other. Provision is made for preliminary determinations of the class and resource quality objectives of water resources before the formal classification system is established. Once the class of a water resource and the resource quality objectives have been determined they are binding on all authorities and institutions when exercising any power or performing any duty under this Act.***

Determination of class of water resources and resource quality objectives

13. (1) As soon as reasonably practicable after the Minister has prescribed a system for classifying water resources the Minister must, subject to subsection (4), by notice in the *Gazette*, determine for all or part of every significant water resource —

(a) a class in accordance with the prescribed Classification system; and

(b) resource quality objectives based on the class determined in terms of paragraph (a)

(2) A notice in terms of subsection (1) must state the geographical area in respect of which the resource quality objectives will apply, the requirements for achieving the objectives, and the dates from which the objectives will apply.

(3) The objectives determined in terms of subsection (1) may relate to —

(a) the Reserve;
(b) the instream flow;
(c) the water level;
(d) the presence and concentration of particular substances in the water;
(e) the characteristics and quality of the water resource and the instream and riparian habitat;
(f) the characteristics and distribution of aquatic biota;
(g) the regulation or prohibition of instream or and-based activities which may affect the quantity of water in or quality of t le water resource; and
(h) any other characteristic,

of the water resource in question.

(4) Before determining a class or the resource quality objectives in terms of subsection (1), the Minister must in respect of each water resource —

(a) publish a notice in the Gazette —

(i) setting out—

(aa) the proposed class;

(bb) the proposed resource quality objectives;

(cc) the geographical area in respect of which the objectives will apply;

(dd) the dates from which specific objectives will apply; and

(ee) the requirements for complying with the objectives; and

(ii) inviting written comments to be submitted on the proposed class or proposed resource quality objectives (a; the case may be), specifying an address to which and a date before which the comments are to be are to be submitted, which date may not be earlier than 60 days after publication of the notice:

(b) consider what further steps. if any, are appropriate to bring the contents of the notice to the attention of interested persons, find take those steps which the Minister considers to be appropriate; and

(c) consider all comments received on or before the date specified in paragraph (a)(ii).

Preliminary determination of class or resource quality objectives

14. (1) Until —

(a) a system for classifying water resources ha: been prescribed; or

(b) a class of a water resource or resource quality objectives has been determined, the Minister may, for all or part of a water resource make a preliminary determination of the class or resource quality objectives.

(2) A determination in terms of section 13 supervise a preliminary determination.

Giving effect to determination of class of water resource and resource quality objectives

15. The Minister, the Director-General, an organ of state and a water management institution, when exercising any power or performing any duty in terms of this Act, must give effect to any determination of a class of a water resource and the resource quality objectives as determined in terms of this Part and any requirements for complying with the resource quality objectives.

Part 3: The Reserve

Part 3 deals with the Reserve, which consists of two parts — the basic human needs reserve and the ecological reserve. The basic human needs reserve provides, for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene. The ecological reserve relates to the water required to protect the aquatic ecosystems of the water resource. The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the class the resource. The Minister is required to determine the Reserve for all or part of* any *significant water resource. If a resource has not yet been classified, a preliminary a determination of the Reserve may be made and later superseded by a new one. Once the Reserve is determined for a water resource it is binding in the same way as the class and the resource quality objectives.

Determination of Reserve

16. (1) As soon as reasonably practicable after the class of all or part of a water resource has been determined, the Minister must by notice in the *Gazette* determine the Reserve for all or part of that water resource.

(2) A determination of the Reserve must —

(a) be in accordance with the class of the water resource as determined in terms of section 13; and

(b) ensure that adequate allowance is made for each component of the Reserve.

(3) Before determining the Reserve in terms of subsection (i), the Minister must —

(a) publish a notice in the Gazette —

(i) setting out the proposed Reserve; and

(ii) inviting written comments to be submitted on the proposed Reserve, specifying an address to which and a date before which comments are to be submitted, which date may not be earlier than 60 days after the publication of the notice;

(b) consider what further steps, if any, are appropriate to bring the contents of the notice to the attention of interested persons, and take those steps which the Minister considers to be appropriate; and

(c) consider all comments received on or before the date specified in paragraph (a)(ii).

Preliminary determinations of Reserve

17. (1) Until a system for classifying water resources has been prescribed or a class of a water resource has been determined, the Minister—

(a) may, for all or part of a water resource; and

(b) must, before authorizing the use of water under section 22(5), make a preliminary determination of the Reserve.

(2) A determination in terms of section 16(1)supersedes a preliminary determination.

Giving effect to Reserve

18. The Minister, the Director-General, an organ of state and a water management institution, must give effect to the Reserve as determined in terms of this Part when exercising any power or performing any duty in terms of this Act.

Appendix B: Data uncertainty

Data, information and decision-making

Geohydrology is not an exact science and there are no unique solutions. It is therefore not useful to consider data as exact and to look for unique solutions. Data forms the basis of the decision-making process. When data is analysed, it becomes information which upon interpretation, is used to base management decisions. When quantification of groundwater resources is considered, issues with regards to the sufficiency of data are always an important and controversial aspect.

The concept of using a decision making framework approach to make management decisions, as opposed to purely a technical assessment, was proposed by Janse van Rensburg (1992). A decision-making methodology is proposed where the technical process is followed within regulatory and financial constraints and the level of information increases with each iteration until sufficient information is available to base the management decision/s on (Figure 22).

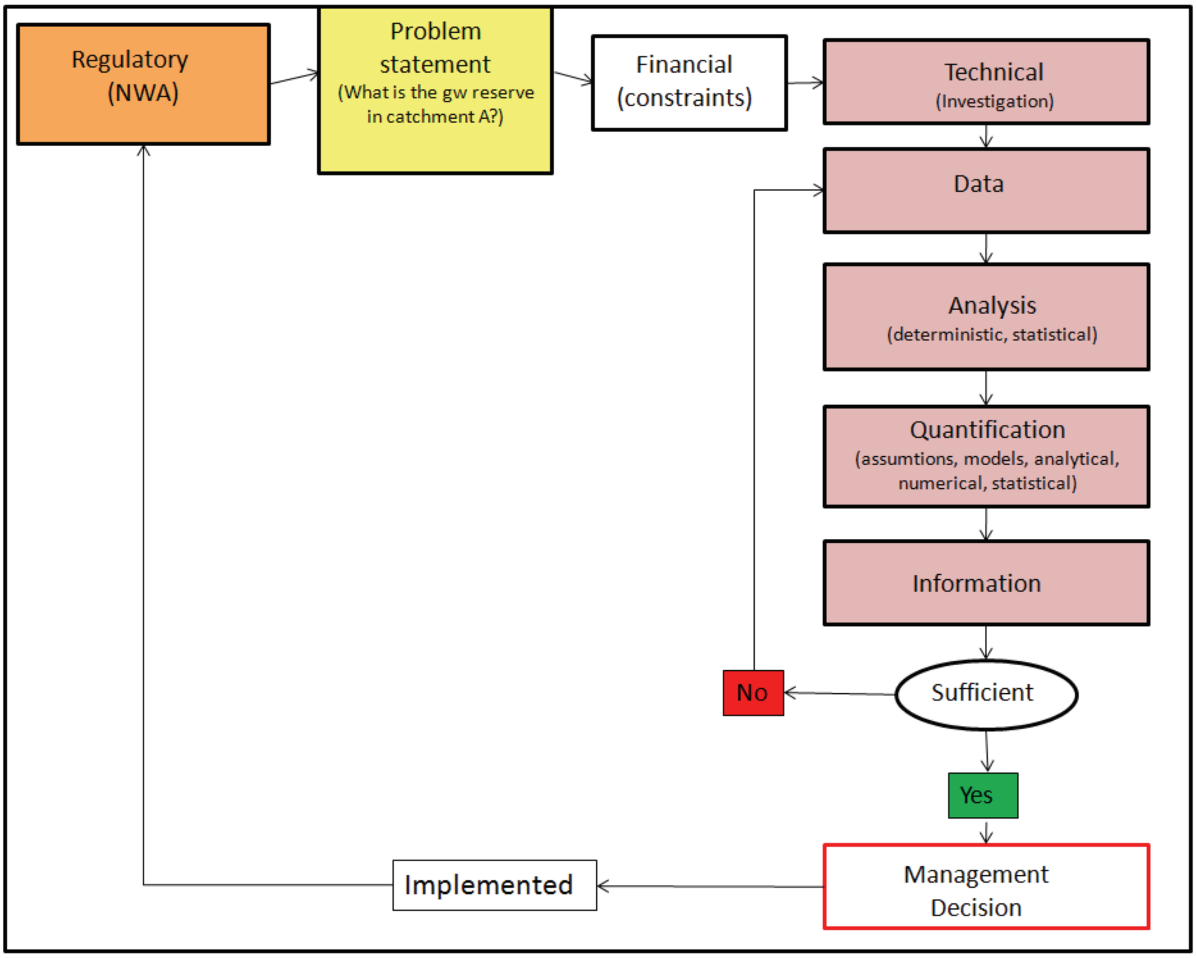

Figure 22: Proposed decision-making framework for the GRDM to provide perspective on where data fits in.

Data analysis

Since it is known that data is spatially and temporally variable, suitable analysis methods can be used that deals with uncertainty. Statistical methods are suited to deal with and characterise variability in data so that the analyst is aware of the potential effects of variability and uncertainty.

In terms of the decision-making process, the Bayesian approach is recommended with the use of a prior analysis that is updated with a posterior analysis as more data becomes available.

Method statement for data collection and interpretation

Data collection and interpretation without a framework within which it can or should take place would lead to ineffective and expensive exercises. A formal step-wise methodology is proposed that would ensure uniformity in the GRDM data collection and analysis approach (Figure 23):

1. Define the reserve level, objectives and outcomes.
2. Plan the data collection programme, interpretation with the scale and accuracy of the assessment. The scale and resolution of the assessment is important. It is recommended to start at a large- (Primary Catchment) scale with quaternary catchment scale resolution for rapid and intermediate that can be stepped down where more detail is required. It is not advisable to start at wellfield scale as the data accuracy would not be met at this scale for rapid and intermediate level assessments. The GRDM checklist (to be defined) should be consulted to ensure that all data requirements are met.
3. Obtain existing data from the GRDM library (to be created). Basic data (catchment sizes, hydrogeological units, rainfall, recharge estimates, abstraction rates etc) for all catchments and hydrogeological units exist for the whole country.
4. Interpret existing data using deterministic and statistical methods. Determine the variability of the data and characterise the uncertainty in parameters.
5. Resource quantification (modelling) to determine the nature of the areas considered.
6. Identify data gaps and sensitive parameters. This is required to focus the fieldwork which is often expensive. If from the resource assessment it is indicated that, for example, wetlands could have a more important influence on groundwater, the focus of data collection should not only be on boreholes.
7. Fieldwork programme that is focused at collection of the most important data parameters: From the statistical analysis (variability and uncertainty assessment), data

points can be visited where sparse data in sensitive areas exist. This action is foreseen for intermediate and especially comprehensive reserve levels.

8. Data re-interpretation and characterisation of uncertainty, using added value of fieldwork component: Based on the outcome, additional re-focused fieldwork and data collection could be done to decrease the level of uncertainty.
9. Update resource quantification assessment. Based on the outcome, additional re-focused fieldwork and data collection could be done to decrease the level of uncertainty.
10. Classification of the groundwater component of the reserve.

The data collection, interpretation and resource quantification are linked towards the decision-making or output of the GRDM. The data collection cannot stand alone as it would be without context. Data collection, especially fieldwork, is associated with high expenses and is limited by financial constraints (Figure 23). Statistical methods and analysis techniques such as modelling should be used to optimise data collection programmes.

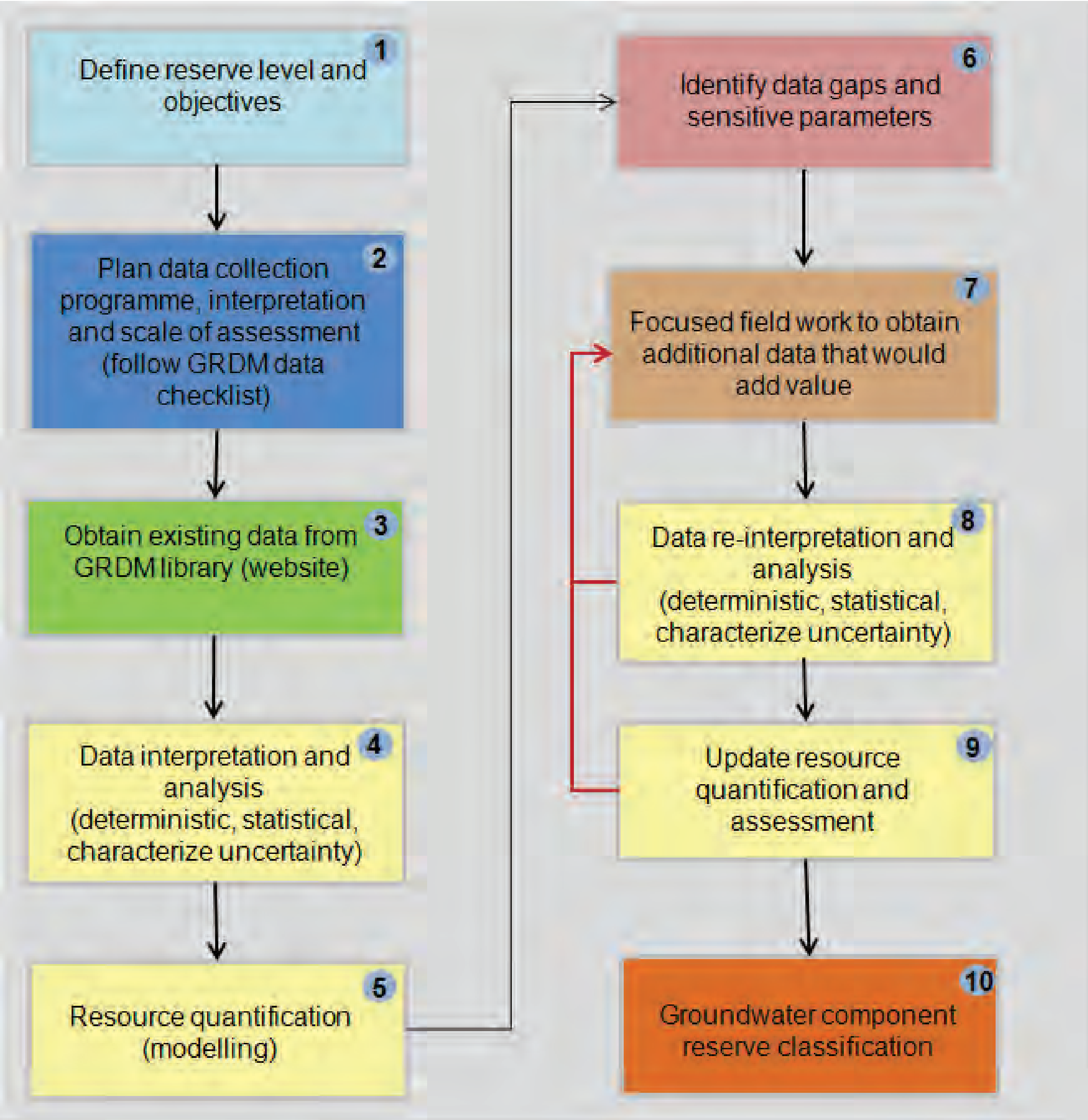

Figure 23: Proposed data evaluation and collection methodology

Appendix C: Summary of socio-economic assessment

Taken from: http://www.lic.wisc.edu/shapingdane/facilitation/all_resources/impacts/analysis_socio.htm

Introduction

Community members are constantly challenged by the need to balance fiscal, social, economic, and environmental goals. One aspect of this challenge is deciding how much and what types of new development the community can accommodate without compromising the day-to-day quality of life for residents. Socio-economic impact assessment is designed to assist communities in making decisions that promote long-term sustainability, including economic prosperity, a healthy community, and social well-being.

Assessing socio-economic impacts requires both quantitative and qualitative measurements of the impact of a proposed development.

What are socio-economic impact assessments?

A socio-economic impact assessment examines how a proposed development will change the lives of current and future residents of a community. The indicators used to measure the potential socio-economic impacts of a development include the following:

- Changes in community demographics;
- Results of retail/service and housing market analyses;
- Demand for public services;
- Changes in employment and income levels; and
- Changes in the aesthetic quality of the community.

Quantitative measurement of such factors is an important component of the socio-economic impact assessment. At the same time, the perceptions of community members about how a proposed development will affect their lives is a critical part of the assessment and should contribute to any decision to move ahead with a project. In fact, gaining an understanding of community values and concerns is an important first step in conducting a socio-economic impact assessment.

Changes in social structure and interactions among community members may occur once the new development is proposed to the community. In addition, real, measurable and often significant effects on the human environment can begin to take place as soon as there are changes in social or economic conditions.

Who should be involved?

Because socio-economic impact assessment is designed to estimate the effects of a proposed development on a community's social and economic welfare, the process should rely heavily on involving community members who may be affected by the development. Others who should be involved in the process include community leaders and others who represent diverse interests in the community such as community service organizations, development and real estate interests, minority and low income groups, and local environmental groups. In addition, local agencies or officials should provide input into the process of assessing changes in the social environment that may occur as a result of the proposed development (e.g. providing estimates and information demographics, employment and service needs).

How to conduct a socio-economic assessment?

The following section provides a two-step process for conducting a socio-economic impact analysis. The process is designed to establish a framework for evaluating cur-rent and future proposed developments in a community.

- Defining the scope of the Socio-Economic Impact Assessment

  The most reliable sources of information about community concerns and needs are residents and community leaders. Surveys and interviews are two excellent methods for identifying priority social and economic goals of the community. Interviews with community leaders can also provide valuable information about what social, economic and other issues are important to community members.

  The development impacts associated with a new development will vary depending on the proposed project's type, size, location, socio-economic characteristics of the community. As such it is important to be familiar with both the project characteristics and the social and economic resources of the community. The better one understands the proposed project, the more accurate will be the assessment in estimating potential impacts.

- Identifying and Evaluating Development Impacts
  - Quantitative Changes

    Demographic impacts include the number of new permanent residents or seasonal residents associated with the development, the density and distribution of people and any changes in the composition of the population, (e.g. age, gender, ethnicity, wealth, income, occupational characteristics, educational level, health status). Development invites growth in new jobs in a community and draws new workers and their families into the community, either as permanent or temporary residents. When this occurs, the incoming population affects the social environment in various ways including increased demand for housing and social services (e.g. health care, day care, education, recreational facilities). Because residents' needs depend on a wide range of variables (e.g. age, gender, employment status, income level and health status), the diversity of service needs are determined not only by the absolute size of the incoming population but also by the old and new populations' demographic and employment profiles. As a result, a proposed development may have a significant impact on the community's ability to accommodate new residents and adapt to changes in the social environment for existing residents. Assessing the magnitude and rate of population change has important implications for community infrastructure and service requirements and can play a major role in determining social impacts associated with the proposed development. There are numerous modelling techniques available to aid in assessing population impacts.

A housing market analysis helps determine whether the proposed development will be beneficial to your community in terms of its effect on your housing market needs. In the case of a residential development, the market study assists in ascertaining whether there is sufficient demand for the type of housing proposed and whether a sufficient number of households in the area can afford to purchase or rent the pro-posed type of housing. The analysis also assists in the examination of the connections between the housing market and employment. To understand the impact of a new residential development or a new employment centre on your housing market (or on the regional market), the initial step of the analysis is to complete an inventory and analysis of existing and projected housing needs—a supply and demand analysis. To better understand whether your community is meeting the needs of residents and workers in terms of affordability, an analysis of housing affordability which includes an examination of typical rents and mortgage payments compared to what households at various income levels can afford is necessary.

Retail market impacts caused by growing communities often attract a variety of new commercial developments including both free-standing stores and neighbourhood or community shopping centres. These developments provide a community with products, services and conveniences important to the quality of life of local residents. The challenge to accommodating these types of new developments becomes one of minimizing losses to existing retailers in the area, such as those downtown, while allowing the market to respond to the wishes of the increasingly demanding consumer. Before an analysis of a particular development can be conducted, the economic health of the local retail community must be assessed. This requires a close look at retail activity, particularly in the central business district. Key indicators of economic health in the retail sector include vacancy levels, property values, store turnover, retail mix, employment, tax revenues, new business incubation, critical mass/concentration of retail, and the availability of goods and services demanded by the community. Second, changes in trade area demographics should be estimated. The trade area is generally defined as the geographic area in which three-fourths of current customers reside. A significant increase in population could signal new opportunities for retail expansion or development. Third, regional retail competition must be assessed. New retail concepts are threatening traditional retail stores. Development directly influences changes in employment and income opportunities in communities. Such changes may be more or less temporary (e.g. construction projects, or seasonal employment) or may constitute a permanent change in the employment and income profile of the community should the development project bring long-term job opportunities for community residents (e.g. establishment of a light industrial, manufacturing, or commercial establishment). Assessing these types of changes is an important component of social impact analysis because growth in employment places additional demands on community services and resources.

- Community Perceptions

The attitudes community residents have toward development and the specific actions being proposed as well as their perceptions of community and personal well-being are important determinants of the social effects of a proposed action. Such attitudes are a reflection of the quality of life residents seek to enjoy and preserve, whether it be limiting growth in order to maintain the rural image of a small community; expanding the boundaries of the village; or providing a variety of housing choices to new, diverse residents and businesses. Changes in a community's social well-being can be determined by asking the individuals and representatives of groups or neighbourhoods in the area to make explicit their perceptions and attitudes about the anticipated changes in the social environment.

Information about attitudes and perceptions should be gathered from community leaders because their attitudes are important and may lend insight into the overall attitudes of residents if community leaders are perceptive and sensitive to community concerns and interests. However, it is perhaps more important, though generally more time-consuming and costly, to profile the attitudes of the residents living and working in the community and each of the distinguishable social groups because they represent the population in the community most affected by changes in social well-being. The responses may provide an indication of what additional information is necessary and in what detail it should be gathered for a particular proposed development.