Groundwater Resource Directed Measures Manual

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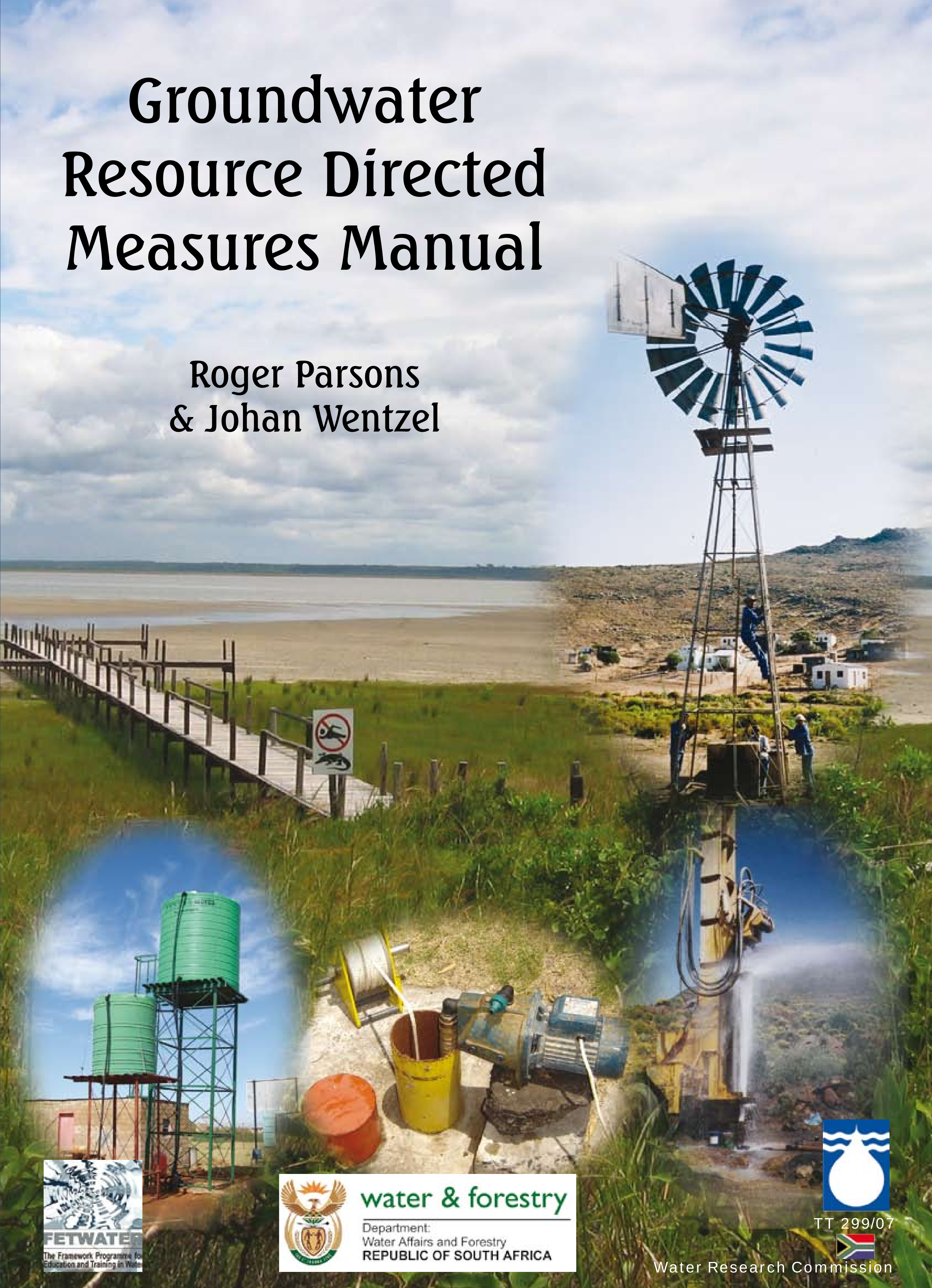

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The Framework Programme for Education and Training in Water

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SETTING RESOURCE DIRECTED MEASURES (RDM) FOR GROUNDWATER: A PILOT STUDY

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ACKNOWLEDGEMENTS

Parsons and Associates Specialist Groundwater Consultants, in collaboration with the Department of Water Affairs and Forestry (DWAF), were awarded a solicited research project by the Water Research Commission (WRC) to implement and test methodologies for determining the groundwater component of Resource Directed Measures (RDM) that were documented by Xu et al. (2003). The objectives of the research project were:

- To review and implement methods developed to set RDM for groundwater through an appropriate case study.
- To refine and adapt methods as a result of lessons learnt during the pilot study.
- To align methods with other components of RDM (e.g. estuaries, rivers and wetlands).

A guideline document and accompanying software were to be produced by the project. The guideline document was to be submitted to DWAF so the methods could be readily and properly implemented during future RDM assessments.

Subsequent to being awarded the project, FETWater identified an urgent need to implement a training program to improve skills within DWAF relating to RDM, with groundwater being identified as one of the areas requiring attention. Training was required before this research project was to be completed. As a result, a manual was produced for the FETWater Training and which relied heavily on work undertaken as part of the WRC research project. Likewise, the WRC research project benefited from additional resources injected by the FETWater initiative. As a result of the FETWater training program, DWAF injected additional funds for developing the software. This manual has hence been funded through the following organisations, all of which is fully acknowledged:

- Water Research Commission
- the FETWater Programme (through the Department of Water Affairs and Forestry and the Flemish Trust Fund)
- Department of Water Affairs and Forestry.

While Roger Parsons and Lloyd Flanagan of Parsons and Associates and Johan Wentzel of DWAF undertook much of the research, products resulting from this research project were very much a team effort. Zahn Munch, FC Basson and Julian Conrad of GEOSS assisted in the data management and GIS components of the study. Dr Ingrid Dennis and Rainier Dennis (both of IGS) assisted in the development of the GRDM Manual and the GRDM Software.

Software initially developed by Prof Gerrit van Tonder was modified to assist practitioners when applying the approach as set out in this manual. Permission from Prof van Tonder to do so is acknowledged, as is his role in helping to develop and guide the groundwater component of RDM determinations.

The GRDM Manual was reviewed by Phil Hobbs (formerly of Hobbs Consulting), Prof Gerrit van Tonder (IGS) and Andrew Mavurayi (DWAF), while Robyn Arnold (Write Connection) and Philip van Zyl (C3 Communications) respectively assisted in the editing of the manual and atlas.

In addition to the above, a number of people supported the research effort through discussions and attendance of meetings and workshops. Their contributions are also acknowledged.

DWAF first documented methods to undertake the groundwater component of RDM determinations in Volume 6 of the September 1999 version of Resource Directed Measures for Protection of Water Resources. This was then built on by Xu et al. (2003) and others. A number of research projects and Reserve determinations have since been undertaken. In preparing this GRDM manual, cognisance was taken of the outcomes of this work. While the manual essentially represents a revised version of the DWAF (1999) and Xu et al. (2003) documents, officials, managers and practitioners should be aware of the developing nature of this field. Until the Minister of Water Affairs and Forestry has published methods to classify resources, determine the Reserve and set Resource Quality Objectives in the Government Gazette, all Reserve determinations are deemed preliminary.

Until the methods are published, documenting current approaches and methods in this manual plays an important role in ensuring that the methods proposed are scientifically and legally defensible. It is hoped that this manual will contribute to an improved understanding of the role of groundwater in the environment, develop expertise to undertake GRDM determinations and promote the exchange of information that will result in improved and more efficient methods.

Finally, a special word of thanks must go to Dr Kevin Pietersen, Ms Annette Wentzel and Mr Johan Wentzel for their ongoing commitment to facilitating methods to determine the groundwater component of RDM and the development of skills to do so.

Roger Parsons
March 2006

LIST OF ABBREVIATIONS

BHN	Basic Human Needs
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
CRD	Cumulative Rainfall Departure
DSS	Decision Support System
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
FET-Water	Framework Programme for Education and Training in Water
GMU	Groundwater Management Unit
GRDM	Groundwater Resource Directed Measures
GRU	Groundwater Resource Unit
ICM	Integrated Catchment Management
IFR	Instream Flow Requirements
IGS	Institute for Groundwater Studies
IWRM	Integrated Water Resource Management
K	Hydraulic Conductivity
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff

MLF	Maintenance Low Flow
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
SAM	Strategic Adaptive Management
SDC	Source Directed Controls
T	Transmissivity
TMG	Table Mountain Group
WARMS	Water Use Authorisation and Registration Management System
WEM	Water Environment Management
WMA	Water Management Area
WMS	Water Management System
WRC	Water Research Commission

UNITS OF MEASUREMENT

a	annum
cm	centimetre
d	day
ha	hectare
km^2	square kilometre
L	litre
L/p/d	litres per person per day
m	metre
m^2	square metre
m^3	cubic metre
Ma	million years
mamsl	metres above mean sea level
mbgl	metres below ground level
mbs	metres below sea level
Mm^3/a	million cubic metre
mg	milligram
mm	millimetre
mS	milliSiemen
s	second

GLOSSARY

GEOHYDROLOGICAL AND RELATED TERMS

Terms presented in this glossary where sourced from a variety of respected groundwater textbooks and dictionaries. They provide the context in which they are used in the GRDM Manual.

ABIOTIC: not pertaining to living organisms; environmental features such as temperature, rainfall, etc.

ABSTRACTION: the removal of water from a resource, e.g. the pumping of groundwater from an aquifer.

AEOLIAN: relating to or arising from the action of wind.

AEROBIC: a process that takes place in the presence of oxygen.

ALLUVIAL: sediments deposited by flowing water.

ALLUVIAL AQUIFER: an aquifer formed of unconsolidated material deposited by water, typically occurring adjacent to river channels and in buried or palaeochannels.

ALLUVIUM: a general term for unconsolidated deposits of inorganic materials (clay, silt, sand, gravel, boulders) deposited by flowing water.

ANAEROBIC: a process that takes place in the absence of oxygen.

ANISOTROPIC: having some physical property that varies with direction.

ANTECEDENT: a condition that exists before a particular event, e.g. soil moisture conditions before a rainfall event.

AQUATIC: associated with and dependent on water, e.g. aquatic vegetation.

AQUATIC ECOSYSTEMS: not defined by the National Water Act (Act No. 36 of 1998), but defined elsewhere 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 bed, formation or group of formations essentially impervious to water.

AQUIFER: a geological formation, which has structures or textures that hold water or permit appreciable water movement through them [from National Water Act (Act No. 36 of 1998)].

AQUIFER: strata or a group of interconnected strata comprising saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to borehole(s) and / or springs (a supply rate of 0.1 ℓ/s is considered a usable quantity).

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: the process whereby an aquifer is subjected to pumping from a borehole under controlled test conditions in order to determine the hydraulic parameters of the groundwater system through its response to the stress of abstraction.

AQUIFUGE: a seldom-occurring body of rock that contains no interconnected openings and neither absorbs nor transmits water.

AQUITARD: a saturated geological unit with a relatively low permeability that retards and restricts the movement of water, but does not prevent the movement of water; while it may not readily yield water to boreholes and springs, it may act as a storage unit.

ARTESIAN AQUIFER: refers to groundwater under hydrostatic pressure; see *confined aquifer*.

ARTESIAN BOREHOLE: commonly used to describe a flowing borehole, where the piezometric level is at an elevation higher than ground level.

ATTENUATION: the breakdown or dilution of contaminated water as it passes through the earth's material.

AVAILABLE DRAWDOWN: the height of water above the depth at which the pump is set in a borehole at the time of water level measurement (m).

BACTERIA: a large group of unicellular microscopic organisms lacking chlorophyll and multiplying rapidly by simple division.

BANK STORAGE: water that percolates laterally from a river in flood into the adjacent geological material, some of which may flow back into the river during low-flow conditions.

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

BASEFLOW INDEX: the ratio of the annual baseflow in a river to the total annual run-off.

BASIC HUMAN NEED: the least amount of water required to satisfy basic water requirements; this is currently set at 25 ℓ/cap·d.

BENEFICIAL USE: the use of the environment or any element of the environment that is conducive to the benefit of legitimate users.

BIOTIC: pertaining to living organisms.

BLOW YIELD: the volume of water per unit of time blown from the borehole during drilling (ℓ/s).

BOREHOLE: includes a well, excavation, or any other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer [from National Water Act (Act No. 36 of 1998)].

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.

BRACKISH: water that contains between 1 000 and 10 000 mg/ℓ of dissolved solids.

BRINE: water that contains more than 35 000 mg/ℓ of dissolved solids.

CAPILLARY RISE: the natural occurrence of water in contact with, but rising above, the water table; caused by the tensional forces in the pore spaces of soil, sediment and rock material. In fine-grained material, capillary rise amounts to 2–3 m, but measures only a few centimeters in coarser grained material.

CAPILLARY ZONE: the subsurface zone directly above the water table caused by capillary rise; also referred to as the *capillary fringe*.

CATCHMENT: the area from which any rainfall will drain into the watercourse, contributing to the runoff at a particular point in a river system; synonymous with the term *river basin*.

CHANNEL PRECIPITATION: precipitation that falls directly on to a surface water body during a precipitation event and makes an immediate (but usually small) contribution to stream flow; does not flow over or through land to reach the surface water body.

COEFFICIENT OF STORAGE: see *storage coefficient*

COMPREHENSIVE RESERVE ASSESSMENT: an assessment of the Reserve based on detailed data and observation; may include numerical modeling; also referred to as a full reserve assessment.

CONE OF DEPRESSION: the cone-shaped area around a borehole that results from the lowering of the water table or piezometric surface by abstraction.

CONFINED AQUIFER: an aquifer overlain by a confining layer of significantly lower hydraulic conductivity in which groundwater is under greater pressure than that of the atmosphere; also known as an artesian aquifer.

CONFINING LAYER: a layer of low permeability material overlying an aquifer, which restricts the vertical movement of water.

CONJUNCTIVE USE: combined use of surface and groundwater.

CONNATE WATER: water entrapped in the *interstices* of sedimentary rocks at the time of deposition.

CONSERVATION: to keep or protect from harm, decay or loss; implies wise use of a resource.

CONSERVATIVE POLLUTANTS: pollutants that move readily through the aquifer, with little reaction with the rock matrix, and are unaffected by biodegradation.

CONTAMINATION: the introduction of any substance into the environment by the action of man.

DEDICATED LAND: see *sacrificial land*.

DEGRADABLE POLLUTANTS: pollutants that readily break down.

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*.

DIFFERENTIATED PROTECTION POLICY: recognises that some resources require different levels of protection or even no protection at all.

DIFFUSE POLLUTION SOURCE: see *non-point source of pollution*.

DISCHARGE AREA: an area in which subsurface water, including water in the unsaturated and saturated zones, is discharged at the land surface.

DISCHARGE RATE: the volume of water per unit of time abstracted from a borehole (ℓ/s).

DISCONNECTED STREAM: a stream detached from and not in hydrological contact with the groundwater system below; a special case of an influent stream; also referred to as a detached stream.

DISSOLVED SOLIDS: minerals and organic matter dissolved in water.

DRAWDOWN: the difference between the observed groundwater level during pumping and the non-pumping or rest groundwater level in a borehole.

DRILL CUTTINGS: the rock chips resulting from the cutting action of the drill bit that return to the surface in the air and water stream blown from the borehole during drilling.

ECOLOGICAL SPECIFICATIONS: numeric descriptors of the groundwater component of the ecological Reserve.

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.

ECOTONE: a transition zone between different types of ecosystems; a region of overlapping plant associations, as that between two biomes or two adjacent ecosystems.

EFFLUENT: liquid waste or sewage discharge, usually discharged in rivers or the sea.

EFFLUENT STREAM: a stream fed directly by groundwater; the surrounding water table or piezometric surface is above the stream surface; opposite of *influent stream.*

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.

ENDORHEIC: term used to describe a blind or closed drainage system i.e. without any visible drainage outlet.

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 [from National Water Act (Act No. 36 of 1998)].

EVAPOTRANSPIRATION: the loss of moisture from the combined effects of direct evaporation from land and sea and transpiration from vegetation.

EXPLOITATION POTENTIAL: the rate at which groundwater can be withdrawn from a catchment without causing any detrimental impacts.

FAULT: a zone of displacement in rock formations resulting from forces of tension or compression in the earth's crust.

FINGERING: when a high-density liquid overlies a less dense liquid, or when a fluid spills onto an unsaturated granular medium, the resultant vertical flow is concentrated into discrete flowpaths (fingers) of very complex geometry. This fingering is, to some extent, chaotic, and cannot be exactly reproduced by either digital or analogue simulations.

FISSURES: a general term to include natural fractures, cracks and openings in consolidated rock caused by bedding planes, joints, faults, etc.

FITNESS-FOR-USE: water quality is such that it meets the requirements for a particular use. The five major groups of water users are recognised as domestic, agricultural, industrial, recreational or environmental users.

FLOW REGIME: recorded or historical sequence of flows used to create a hydrological profile of a water resource.

FLUVIAL: relating to or arising from the action of flowing water in a river.

FLUX: rate of groundwater flow per unit width of aquifer.

FORMATION: a general term used to describe a sequence of rock layers.

FRACTURE: cracks, joints or breaks in the rock that can enhance water movement.

FRACTURE FLOW: water movement that occurs predominantly in fractures and fissures.

FRACTURE ZONE: a zone of cracks or fissures within rocks.

FRACTURED AQUIFER: an aquifer that owes its water-bearing properties to fracturing caused by folding and faulting; see *secondary aquifer*.

FRESHWATER: water that contains less than 1 000 mg/ℓ salts.

FULL RESERVE ASSESSMENT: see *comprehensive Reserve assessment*.

GAINING STREAM: synonymous with *effluent stream*.

GEOHYDROLOGICAL REGION: a generic term used previously by DWAF (1999) to define or delineate an area within a significant water resource or homogeneous response unit with similar geohydrological characteristics, which result in the area fulfilling a unique and specific role in the hydrological system, no longer used in an RDM context and replaced by the simpler concept of *groundwater resource unit*.

GEOHYDROLOGICAL RESPONSE UNIT: a generic term used previously by DWAF (1999) to define or delineate the smallest groundwater unit considered; demarcated on the basis of homogeneous response unit and geohydrological region type; no longer used in an RDM context and replaced by the simpler concept of *groundwater resource unit*.

GEOHYDROLOGY: the study of the properties, circulation and distribution of groundwater; in practice used interchangeably with hydrogeology; but 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.

GEOMORPHOLOGY: the study of the form of the earth and the changes that take place in the process of developing landforms.

GRADIENT: see *hydraulic gradient*.

GROUNDWATER: water found in the subsurface in the saturated zone below the water table or piezometric surface i.e. the water table marks the upper surface of groundwater systems.

GROUNDWATER ALLOCATION: the volume of groundwater that can be abstracted from a resource unit without impacting the ability of groundwater to sustain the Reserve.

GROUNDWATER BODY: a rock or group of rocks comprising saturated earth material.

GROUNDWATER CONTRIBUTION TO BASEFLOW OR RIVER FLOW: that groundwater that discharges into effluent streams and sustains baseflow.

GROUNDWATER DEPENDENT ECOSYSTEM: an ecosystem – or component of an ecosystem – that would be significantly altered by a change in the chemistry, volume and / or temporal distribution of its groundwater supply.

GROUNDWATER FLOW: the movement of water through openings and pore spaces in rocks below the water table i.e. in the saturated zone.

GROUNDWATER MANAGEMENT UNIT: an area of a catchment that requires consistent management actions to maintain the desired level of use or protection of groundwater; delineation is based on management considerations rather than geohydrological criteria.

GROUNDWATER REGION: a broad geohydrological grouping by Vegter (2001) based on dominant aquifer type (primary, secondary), lithostratigraphy, physiography and climate; 64 groundwater regions have been identified.

GROUNDWATER RESOURCE: all groundwater available for beneficial use, including man, aquatic ecosystems and the greater environment.

GROUNDWATER RESOURCE UNIT: a groundwater body that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit; also referred to as a *groundwater unit*.

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: maximum amount of groundwater that can be abstracted per square kilometer per annum without depleting the aquifers.

HEAD: see *hydraulic head.*

HEAVY METALS: those elements with atomic numbers greater than 36 in Group III through V of the Periodic Table.

HETEROGENEOUS: refers to materials having different properties at different points; diverse in character or content; in reality, all aquifers are heterogeneous, although we assume homogeneity in order to simplify their analysis; opposite of *homogeneous*.

HOMOGENEOUS: a characteristic of the geological unit in which hydraulic conductivity is independent of position or direction; opposite of *heterogeneous*.

HOMOGENEOUS RESPONSE UNIT: a generic term used previously by DWAF (1999) to define or delineate an area with similar properties and characteristics or an area that behaves or responds in a similar fashion; no longer used in an RDM context and replaced by the simpler concept of *groundwater resource unit*.

HYDRAULIC CONDUCTIVITY: measure of the ease with which water will pass through earth 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 (in m/d).

HYDRAULIC GRADIENT: the slope of the water table or piezometric surface. It is a ratio of the change of hydraulic head divided by the distances between the two points of measurement.

HYDRAULIC HEAD: the height of a column of water above a reference plane.

HYDRIC SOILS: soils that are saturated or flooded long enough during the growing season to develop anaerobic conditions in their upper layers.

HYDROGRAPH: a graphical plot of hydrological measurements over a period of time, e.g. water level, flow, discharge.

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 selected to present data relative to hydrological or meteorologically phenomena; usually from 1 October to 30 September.

HYDROGEOLOGY: see *geohydrology*.

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; not to be confused with *percolation.*

INFLUENT RIVER: water is discharged from the river into the groundwater system.

INFLUENT STREAM: a *losing stream* above the water table that discharges into the underlying groundwater system; opposite of *effluent stream*.

INSTREAM FLOW REQUIREMENTS:

INTEGRATED MANAGEMENT: a management approach that serves to co-ordinate management of the environment as a whole, as opposed to individual parts.

INTERACTING STREAM: see *intermittent stream.*

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 FLOW: flow that occurs between individual grains of rock.

INTERMITTENT RIVER: conditions range seasonally between discharge from the river into the groundwater system and discharge from the groundwater system into the river; not to be confused with an *ephemeral river*.

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.

INTERSTICES: openings or void space in a rock capable of holding water.

ISOTROPIC: the condition of having properties that are uniform in all directions; opposite of *anisotropic.*

JUVENILE WATER: groundwater entering the hydrological cycle for the first time. It is doubtful whether any terrestrial water is truly juvenile and is totally insignificant volumetrically.

LACUSTRINE: wetlands such as dams and lakes situated in topographic depressions that have a total area greater than 8 ha.

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.

LIMITED DEGRADATION POLICY: aims to maintain groundwater at as high a quality as possible, but allows contamination up to certain set protection levels and standards.

LITHOLOGY: the physical character of rocks.

LOCAL SCALE: this scale would typically consider water users or groups of users such as farms, irrigation boards, towns, local authorities, etc.

LOSING STREAM: synonymous with *influent stream*.

MAJOR AQUIFER SYSTEM: highly permeable formations, usually with a known or probable presence of significant fracturing; may be highly productive and able to support large abstractions for public supply and other purposes; water quality is generally very good.

MESOPHYTES: plants that grow under well-balanced moisture conditions.

METEORIC WATER: water originating from rainfall, usually recent, hence actively involved in meteoric circulation, as opposed to *connate water*.

MINOR AQUIFER SYSTEM: fractured or potentially fractured rocks that do not have a high primary permeability, or other formations of variable permeability; aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.

NATIONAL SCALE: this scale covers the total area of South Africa and would be measured in millions of square kilometres.

NON-AQUIFER: a groundwater body that is essentially impermeable does not readily transmit water and/or has a water quality that renders it unfit for use.

NON-AQUIFER SYSTEMS: 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 unusable; groundwater flow through such rocks does take place and needs to be considered when assessing the risk associated with persistent pollutants.

NON-DEGRADABLE POLLUTANTS: pollutants that do not readily break down.

NON-DEGRADATION POLICY: a protectionist approach, which strives to preserve all resources in their pristine state.

NON-POINT SOURCE OF POLLUTION: pollution from broad areas rather than from discrete points.

NUTRIENTS: substances that help living things to grow, e.g. nitrogen, phosphate, potassium.

OUTCROP: the occurrence of rock at the ground surface. When a rock is visible in, for instance, cliffs and quarries, the rock is said to be *exposed*.

OVERLAND FLOW: flow of water over the land surface usually originating from precipitation or snowmelt; general term used loosely to include all surface runoff.

OXIDATION: the addition of oxygen to a compound; entails the loss of an electron.

PALEOCHANNEL: a buried stream channel.

PALUSTRINE: freshwater wetland environments other than those along rivers and lakes, dominated by trees, shrubs, emergent vegetation, mosses and lichens.

PERCHED AQUIFERS: aquifers that contain perched groundwater i.e. bodies of groundwater separated from an underlying body of groundwater by an unsaturated zone.

PERCHED GROUNDWATER: an independent and unconfined volume of groundwater separated from an underlying main body of groundwater by an unsaturated zone; typically occurs above discontinuous impermeable layers.

PERCHED SPRINGS: springs fed by water in the unsaturated zone and interflow.

PERCHED WATER TABLE: localised, unconfined groundwater separated from the underlying main body of groundwater by an unsaturated zone, i.e. the local water table is not in hydraulic continuity with the regional groundwater system.

PERCOLATION: the process of the downward movement of water in the unsaturated zone under the influence of gravity and hydraulic forces; term used to differentiate from infiltration, which specially refers to the movement of water from the atmosphere into the ground.

PERENNIAL: lasting through a year or several years i.e. a river that flows all year round or a wetland that remains wet all year round.

PERMEABLE: materials that allow liquids (and gases) to flow through them.

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 $m^3/m^2 \cdot d$ or m/d). It is an intrinsic property of the porous medium and is independent of the properties of the saturating fluid; not to be confused with *hydraulic conductivity*, which relates specifically to the movement of water.

PHREATIC ZONE: see *saturated zone*.

PHREATOPHYTES: long-rooted plants that habitually obtain water from below the water table or from the capillary fringe directly above the water table.

PIEZOMETRIC LEVEL: the elevation to which groundwater levels rise in boreholes that penetrate confined or semi-confined aquifers.

PIEZOMETRIC SURFACE: an imaginary surface representing 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.*

POINT SOURCE OF POLLUTION: pollution from discrete and definable points as opposed to pollution from broad areas.

POLLUTION: the introduction into the environment of any substance by the action of man that is, or results in, significant harmful effects to man or the environment.

POLLUTION PLUME: area of degraded water in a stream or aquifer resulting from migration of a pollutant.

POOR AQUIFER SYSTEMS: see *non-aquifer systems*.

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

POTABLE WATER: water that is safe and palatable for human use.

POTENTIOMETRIC SURFACE: see *piezometric surface*.

PRECAUTIONARY PRINCIPLE: promotes the adoption of a conservative approach, particularly in those cases where knowledge is limited or risk unknown; requires that people err on the safe side when taking decisions.

PREFERENTIAL FLOW: the preferential movement of groundwater through more permeable zones in the subsurface.

PRELIMINARY RESERVE ASSESSMENT: because strategies, methods and tools are still in the process of being developed and refined, all Reserve determinations are considered preliminary (in a legal context) until methods to be used for determining the Reserve are published in the *Government Gazette*.

PRESENT ECOLOGICAL CLASS: current status of groundwater within the resource unit as used in setting the groundwater component of the ecological Reserve.

PREVENTION: to defend from harm, decay or loss; implies limited or no use of a resource.

PRIMARY AQUIFER (SA): an aquifer in which water moves through the original interstices of the geological formation.

PRIMARY AQUIFER (USA): an aquifer currently being used by a major municipal water supply system.

PRIMARY INTERSTICES: interstices that were made contemporaneously with the rock formations.

PRINCIPAL AQUIFER (USA): highly productive formations that are not intensively used as water supplies at present; are viewed as potential water supplies but their yields have not been fully established.

PRISTINE: remaining in a pure or natural state.

PRIVY: the enclosure for a toilet where this is not incorporated into a house.

QUATERNARY CATCHMENT: a fourth order catchment in a hierarchal classification system in which a primary catchment is the major unit.

QUICKFLOW: by convention, that portion of *stormflow* that is not part of baseflow and includes overland flow; occurs in direct response to rainfall.

RADIUS OF INFLUENCE: the maximum extent of the *cone of depression*.

RECHARGE: the addition of water to the zone of saturation, 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.

REGIONAL SCALE: this scale is equitable to surface water catchment areas and would typically be measured in thousands to hundreds of thousands of square kilometres.

REGOLITH: the mantle of fragmented or loose material of residual or transported origin, comprising rock debris, alluvium, aeolian deposits, and *in situ* weathered and decomposed rock and typically overlies bedrock; it includes soil.

REHABILITATION: to restore to a former condition or status.

REMEDIATION: to restore to health; requires that impact is reduced to some acceptable level.

REMOTE STREAM: see *disconnected stream*.

RENEWABLE WATER SUPPLY: rate of supply of water available in an area on an essentially permanent basis.

RESERVE: the quantity and quality of water required to supply the basic needs of the people to be supplied with water from that resource, and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of water resources.

RESOURCE: a substance or item available for use. A natural resource is a resource that man can use but not manufacture or create.

RESOURCE QUALITY: the quality of all aspects of a water resource including (a) the quality, pattern, timing, water level and assurance of instream flow, (b) the water quality, including the physical, chemical and biological characteristics of water, (c) the characteristic and condition of the instream and riparian habitat, and (d) the characteristics, condition and distribution of aquatic biota.

RESOURCE QUALITY OBJECTIVE: 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.

RESOURCE UNITS: areas of similar physical or ecological properties that are grouped or typed to simplify the Reserve determination process.

REST WATER LEVEL: the groundwater level in a borehole not influenced by abstraction; synonymous with *static water level*, but no groundwater levels are ever truly static as they continually respond to recharge, discharge and abstraction.

RIPARIAN: 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; generally larger than a *stream*, but often used interchangeably.

ROCK: any consolidated or unconsolidated earth material, specifically excluding soil.

ROCK UNIT: any geological formation, or part thereof, that can be mapped and evaluated as to its general water-bearing and water quality characteristics.

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.

SACRIFICIAL LAND: land used for spreading sewage sludge, above the normal requirements for agricultural land; regarded as land that could be impaired as a result of the spreading practice.

SAFE YIELD: amount of water that can be withdrawn from an aquifer without producing an undesired effect.
SALINE INTRUSION: replacement of freshwater by saline water in an aquifer, usually as a result of groundwater abstraction.

SALINE WATER: water that is generally considered unsuitable for human consumption or for irrigation because of its high content of dissolved solids.

SANITATION: the treatment and disposal of waste from the human body and grey water generated through household activity.

SANITARY SEAL: the seal comprising the cement grout with which the annulus between the borehole sidewall and the casing is filled to prevent the ingress of foreign material into the borehole via this space.

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

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

SECONDARY AQUIFER: an aquifer in which water moves through secondary openings and interstices, which developed after the rocks were formed i.e. weathering, fracturing, and faulting.

SECONDARY INTERSTICES: openings in the rock that were developed by processes that affected the rocks after they were formed.

SEDIMENT: particles derived from rocks or biological material that has been transported by air or water.

SEEP: a diffuse wetland area where interflow and groundwater emerges, usually at a slow rate or small volume, to become surface flow.

SEMI-CONFINED AQUIFER: an aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur; also referred to as a *leaky aquifer*.

SIGNIFICANT WATER RESOURCES: used but not defined by the National Water Act (Act 36 of 1998); 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.

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 AQUIFERS: 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 CAPACITY: the rate of discharge of a water well per unit of drawdown, usually expressed as $m^3/d \cdot m$.

SPECIFIC YIELD: ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity from that mass.

SPRING: a point where groundwater emerges, usually as a result of topographical, lithological or structural controls,

STATIC WATER LEVEL: see *rest water level*

STORAGE COEFFICIENT: the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head

STORMFLOW: increased runoff in a river or stream associated with a particular rainfall event or storm; includes contributions from *channel precipitation*, *quickflow* and rapid *interflow*.

STREAM: a small narrow river; often used interchangeably with *river*.

STRESSED AQUIFER: term used, but not defined by the National Water Act (Act No. 36 of 1998); but using the stress index presented in this manual, an aquifer is said to be stressed when at least 65% of estimated recharge is abstracted from that aquifer.

SUBSURFACE WATER: all water occurring beneath the earth's surface, including soil moisture, moisture in the vadose zone and groundwater.

SUBTERRANEAN WATER: not a widely used geohydrological term; a general term used synonymously with *subsurface water*.

SURFACE WATER: bodies of water, snow or ice on or above the surface of the earth (such as lakes, streams, ponds, wetlands, etc.).

SURFACE RUNOFF: that part of the total runoff that travels over the ground surface to reach a stream or river channel.

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.

TEST PUMPING: see *aquifer testing and borehole testing*.

TOTAL RUNOFF: the total volume of water that flows in a stream, including contributions from channel precipitation, quickflow, interflow and the groundwater contribution to river flow.

TRANSMISSIVITY: the rate at which a volume of water is transmitted through a unit width of aquifer under a unit hydraulic head (m^2/d); product of the thickness and average hydraulic conductivity of an aquifer.

TYPING: a process of grouping areas with similar characteristics, e.g. ecological, geological, and hydrological.

UNCONFINED AQUIFER: an aquifer with no confining layer between the water table and the ground surface where the water table is free to fluctuate.

UNCONSOLIDATED SEDIMENTS: consists of fragments of weathered rock material (including clays, silts, sand, gravels and cobbles) that have not been cemented to form solid rock.

UNDERGROUND WATER: not a recognised geohydrological term; term used, but not defined in the National Water Act (Act No. 36 of 1998); meaning is unclear; thought to be a general term referring to *subsurface water*.

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*.

VADOSE ZONE: see *unsaturated zone*.

VIRUS: any group of submicroscopic (invisible under an ordinary microscope) entities consisting of a single nucleic acid surrounded by a protein coat and capable of replication only within the cells of animals and plants.

VLEI: a colloquial South African term for wetland.

VULNERABILITY: the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer.

WATER-BEARING: water-yielding in terms of carrying or conveying.

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 Affairs and Forestry may, by notice in the *Government Gazette*, declare to be a *water course* National Water Act (Act No. 36 of 1998).

WATER RESOURCE: includes a water course, surface water, estuary or aquifer.

WATER STRESS: term used, but not defined by the National Water Act (Act No. 36 of 1998); relates to instances where demands for water are approaching or exceed available supply, where water quality problems are imminent or already exist, or where water resource quality is under threat.

WATER TABLE: the upper surface of the saturated zone of an unconfined aquifer at which pore pressure is at atmospheric pressure, the depth to which may fluctuate seasonally.
WATER YEAR: see *hydrological year.*

WELL: see *borehole;* used in South Africa to refer to a shallow large diameter hole used for abstracting groundwater; in USA synonymous with *borehole*.

WELL FIELD: a group of boreholes in a particular area usually used for groundwater abstraction purposes.

WELLPOINT: shallow, small diameter hole used to abstract groundwater from a primary aquifer.

WETLAND: land that 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* [from National Water Act (Act No. 36 of 1998)].

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.

ZONE OF AERATION: see *unsaturated zone.*

ZONE OF SATURATION: see *saturated zone*.

1. INTRODUCTION

1.1 Preamble

Sustainability, equity and efficiency are identified 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,
- 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).

National government is responsible for the achievement of these fundamental principles in accordance with a mandate for water reform. The Minister of Water Affairs and Forestry has ultimate responsibility to fulfil obligations relating to the use, allocation, protection and access to water resources.

To be able to implement the National Water Act (Act No. 36 of 1998), the Minister needs to ensure that the tools and expertise required to implement the Act are available. The Department of Water Affairs and Forestry (DWAF) set about developing the required methods and procedures needed to address the Reserve, a provision in the Act that requires water be set aside for basic human needs and aquatic ecosystems before allocation to other users. With the support of FET-Water and the Water Research Commission, this manual documents methods and approaches to be used when addressing the groundwater component of RDM.

1.2 Purpose of this manual

As the implementation of the National Water Act (Act No. 36 of 1998) proceeds, a plethora of new terms (jargon), documents and guidelines have emerged. Little of the work has been finalised to date, because of the dynamic nature of the process. As a result, guidelines for practitioners, including regional staff, on how to determine the Classification of a significant water resource, set the Reserve and define Resource Quality Objectives are lacking.

This manual documents approaches and methods currently acceptable to DWAF, but will need to be updated as methods and procedures are finalised and implemented.

1.3 Structure of manual

This manual is divided into three main parts. The first provides some background on the National Water Act and resource directed measures (Chapters 1–4). Methods and tools used for undertaking GRDM assessments are presented in Chapters 6–12. The third part of the manual includes a case study of the E10 catchment.

1.4 Some useful references

The following references formed the basis on which this training manual and the methods herein were developed. Note that much of the conceptual thinking around Resource Directed Measures and RDM presented in these references are not included in this manual.

Constitution of the Republic of South Africa (Act No. 108 of 1996).

National Water Act (Act No. 36 of 1998).

DWAF (1999) Water resources protection policy implementation – resource directed measures for the protection of water resources, Volumes 2–6, Version 1.0. Department of Water Affairs and Forestry, Pretoria.

DWAF (2004) National Water Resource Strategy. First edition. Department of Water Affairs and Forestry, Pretoria.

DWAF (2003b) Resource Directed Measures – Module 1 – Introductory module. October 2003 edition. Department of Water Affairs and Forestry, Pretoria.

DWAF (2003c) The Framework Programme for Education and Training in Water (FET-Water) – A Guideline. Draft first edition, November 2003. Department of Water Affairs and Forestry, Pretoria.

DWAF (2004) Guide to the National Water Act. Department of Water Affairs and Forestry, Pretoria.

2. NATIONAL WATER ACT

2.1 Preamble

During Water Year held in 1970, it was clear that South Africa would run into water supply problems by the year 2000, especially in Gauteng and major metropolitan areas. Complex inter-basin transfer schemes, such as the Lesotho Highlands Water Project and the Tugela-Vaal, Usutu-Vaal and Orange-Fish-Sundays Rivers schemes, helped postpone the onset of water shortages. Had no action had been taken, South Africa would currently be facing a supply crisis. Addressing the problem required innovative thinking, strategies, legislation and timeous implementation. The National Water Act (NWA) (Act No. 36 of 1998) is one of the outcomes of the process aimed at addressing issues relating to water in the country.

The now-repealed Water Act of 1956 (Act 54 of 1956) dealt with water in public streams. Groundwater was considered a private use and received virtually no protection from abstraction, except in the so-called Government Subterranean Water Control Areas. The old Act also largely ignored environmental issues, equity issues and downstream water requirements. The Forestry Act of the time allowed the planting of commercial forests in sensitive runoff and recharge areas, under a permit system affording virtually no cognisance to ecological and environmental issues.

A change in government in 1994 was opportune to address the shortcomings of existing legislation and the water needs of the country. Nearly all components of the hydrological system (including groundwater) now fall under the NWA. The integrated management of all water resources and, where appropriate, delegation of management functions to regional or catchment levels enables everyone to participate in the management of the country’s water resources.

The NWA provides a legal framework for the effective and sustainable management of South Africa’s water resources. The purpose of the Act is to ensure the nation's water resources are protected, used, developed, conserved, managed and controlled in ways that take into account, among other factors, wide consultation with all interested and affected parties and environmental and socio-economic factors. As the public trustee of the nation’s water resources, the National Government, acting through the Minister of Water Affairs and Forestry, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate.

2.2 Foundations of water management in South Africa

The Constitution is the highest law of the land, and all other laws must be aligned with it. As a result, the Constitution and Agenda 21 (which is an international plan for sustainable development to which South Africa is a signatory) formed the basis for water management in South Africa. To implement water policy, two new acts were drafted and signed into law:

- **National Water Act (Act No. 36 of 1998):** This Act deals with the management of water resources, and its purpose is to ensure that there will be water for basic human needs and for the economic development of the country. The NWA recognises the interdependency of all the components of the water cycle and that these should be managed as a single resource.

- **Water Services Act (Act No. 108 of 1997):** This Act provides the right to access to basic water supply and sanitation and provides the framework for delivery of these water services to the people of the country.

Water is a natural resource and belongs to all the people of South Africa. The Department of Water Affairs and Forestry (DWAF) has the responsibility of managing water resources on behalf of the people of South Africa. In order to achieve this, a National Water Resource Strategy (NWRS) was developed. The strategy describes the ways in which all water resources will be protected, used, developed, conserved, managed and controlled. This long-term plan is to be reviewed every five years.

This manual focuses on Chapter 3 (sections 12–18) of the National Water Act, which deals with the protection of water resources. This includes Classification, Resource Quality Objectives and the Reserve – collectively referred to as Resource Directed Measures or RDM.

Everybody has the right to an environment not harmful to their health and well-being, to have an environment protected for the benefit of present and future generations, and to have access to sufficient food and water.

Constitution of the Republic of South Africa (Act No. 108 of 1996)

2.3 Fundamental principles of water management in South Africa

The main responsibility of DWAF is to ensure that sufficient water of an acceptable quality is available to meet basic human needs and to support economic and social development. 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 sustaining 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).

For something to be sustainable, it must help create economic growth, it must be fair about who benefits (social equity) and it must not damage the environment (ecological integrity). The slogan ‘Some, for all, forever’ neatly encapsulates these principles.

The NWA requires water management strategies be addressed at both national and catchment level. A National Water Resource Strategy was developed as a framework for managing water resources in the country. As new policy and legislation cannot be implemented overnight, priority areas are being identified where action is urgently needed.

The NWA requires a balance between use and protection. While it is desirable that we do not impact our water resources, it is also desirable that we have economic growth and address poverty in the country. Some impact is hence inevitable. The NWRS aims to provide a framework in which this balance can be attained.

South Africa has been divided into 19 Water Management Areas (WMA) (Figure 2.1). These WMAs will be managed by catchment management agencies (CMAs), which will be responsible for implementing the NWRS as well as catchment-specific strategies. Catchment management strategies (CMS) must be in harmony with the NWRS and must include a water allocation plan.

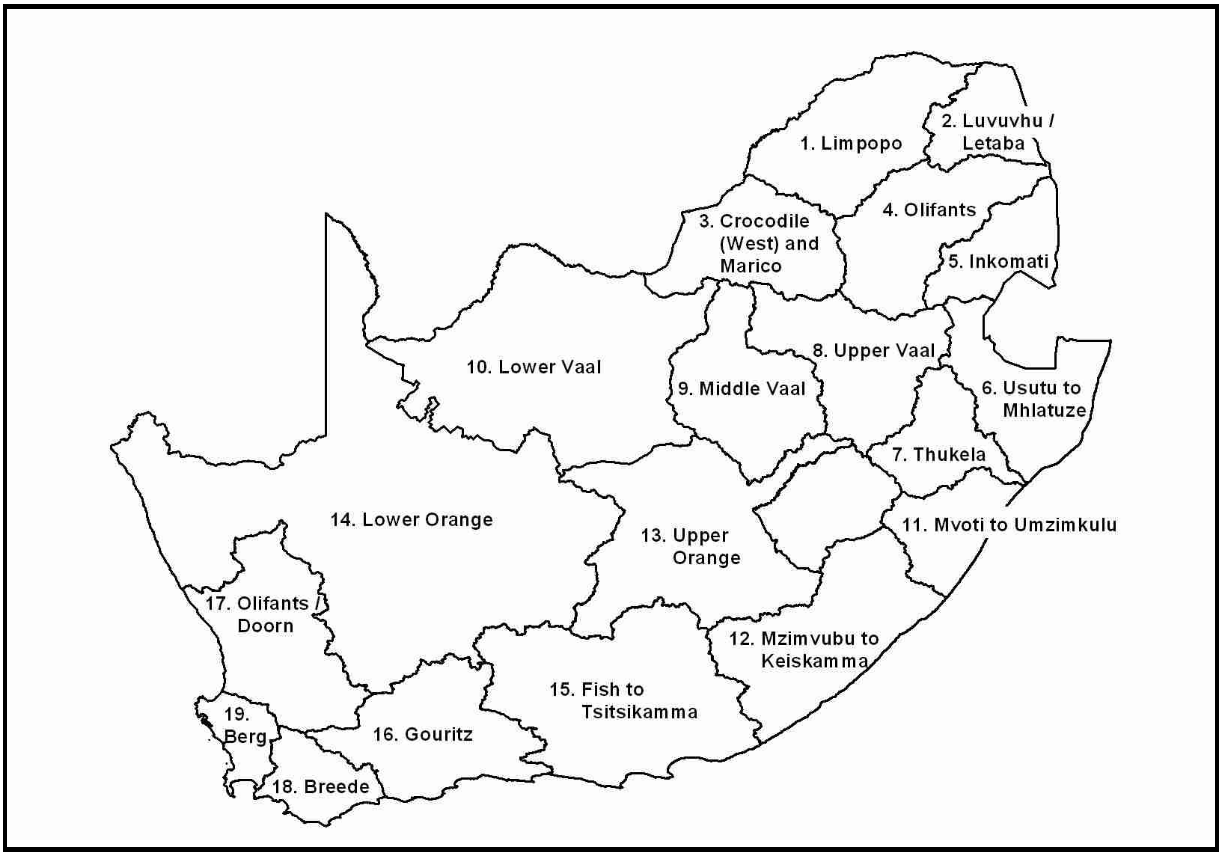

Figure 2.1: National scale map of water management areas in South Africa

2.4 Protection of water resources

Chapter 3 of the NWA provides legal decision-making tools for attaining a balance between protecting and using water resources. These include:

- Classification systems for water resources
- The Reserve
- Resource Quality Objectives
- Source-directed controls (pollution prevention and remediation)
- Emergency incidents.

Those approaches that target protecting the health of a water resource are described as Resource Directed Measures. These address the quantity and quality of water in a water resource, the animals that live in that resource, and vegetation around the resource. Those approaches that target the control of impacts that result (or could result) from the use of a water resource or adjacent areas are described as source-directed measures or controls. Source-directed controls typically aim to control and manage pollution (disposal of effluents) and over-use of water resources (abstraction of water). Though these two controlling mechanisms are interlinked and have a degree of overlap, this manual focuses on Resource Directed Measures, commonly abbreviated as RDM. The overall water resource management business process envisaged by DWAF (1999) is illustrated in Figure 2.2.

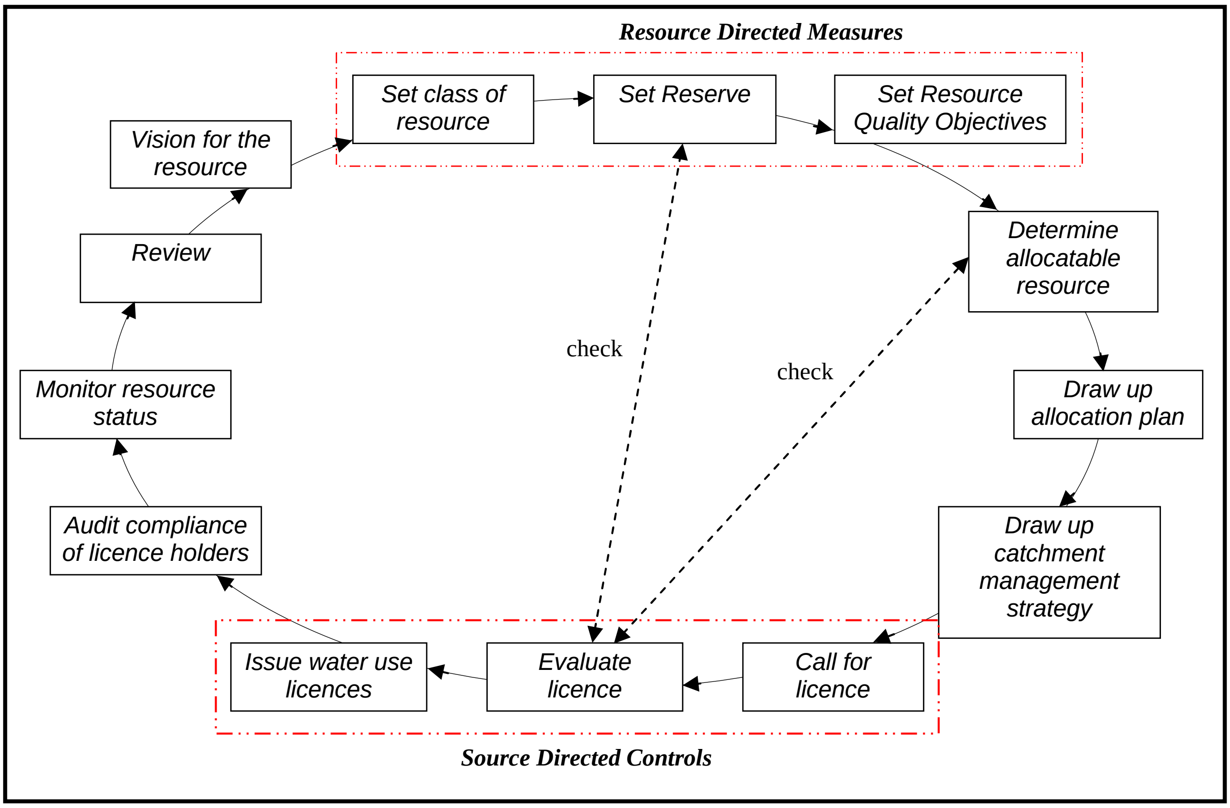

Figure 2.2: The water resource management business process presented by DWAF (1999).

Source-directed controls

Some examples of source-directed measures already in place are:

- General authorisation of water use
- Licensing of water use
- License-specific conditions
- Minimum requirements for waste disposal
- General and special standards for effluent disposal
- Special standards for phosphate for the discharge of water containing waste.

It is important to recognise that RDM is a strategy and approach developed to implement the National Water Act, although this is not mentioned *per se* in the Act. Classification, the Reserve and Resource Quality Objectives are mentioned as tools in the Act, but not RDM.

Because of the physical differences between surface and groundwater, this manual specifically focuses on Resource Directed Measures relating to groundwater. These are abbreviated as GRDM. While it is true that all water resources need to be managed in a holistic manner, management also needs to take into account the unique characteristics of the different components of the hydrological cycle. The wide geographic extent and slow rate of movement are just two of the characteristics of groundwater that make it significantly different from surface water bodies. Groundwater is not afforded sufficient protection under the Reserve, particularly in those areas where the resource has no apparent link to surface water. In these areas, Classification and Resource Quality Objectives are the mechanisms used to ensure the sustainable use of the resource, as dictated by the NWA.

2.5 Water use

The NWA requires all water use to be authorised. This tool aims to promote the wise use of water. Before any water use can be authorised, water has to be set aside for the Reserve, international obligations, inter-basin transfers, strategic use and future use. These allocations are to be done at a national level by DWAF. CMAs are responsible for authorising and allocating the balance of the water resource at a catchment level.

Four main mechanisms for authorising water use have been established in the NWA and National Water Resource Strategy (DWAF, 2004). It is recognised that the biggest water users pose the biggest risk to impacting negatively on water resources. Moreover, DWAF does not have sufficient resources to authorise all water use through licensing. To overcome this problem, various mechanisms of authorisation were developed (Figure 2.3):

- Schedule 1 Use – the National Water Act automatically authorises people who use small amounts of water for household use, watering gardens and animals (not for commercial purposes) and storing or using rainwater from a roof to do so. No numeric limits are specified for Schedule 1 Use.
- General Authorisation – in terms of section 39 of the National Water Act, users may use water without a licence provided the water use is within the conditions of the General Authorisation. The General Authorisation was first published in the *Government Gazette* of 8 October 1999 (GG No. 20526 Notice 1191). However, a revised General Authorisation was published on 27 February 2004. In terms of the General Authorisation, water users must still register their use, but need not apply for a licence.
- Continuation of Existing Lawful Use – any lawful water use under any law passed between 1 October 1996 and 31 September 1998 can continue, until such users are licensed.
- Licensing – All water users who fall outside these definitions require a licence. A licence entitles a water user to use water within the conditions of the licence. These conditions must be reviewed every five years and a licence may only be issued for a maximum of 40 years. At present, a process for individual licence application and evaluation is in use, but this will shortly be streamlined.

In instances where there is not enough water for all users and the water resource is considered stressed, e.g. water use (or demand) is greater than the volume of water available, then a process of compulsory licensing will be invoked. This could result in the withdrawal of generally authorised use and continuation of existing lawful use. All water users – excluding Schedule 1 users – will have to apply for a licence.

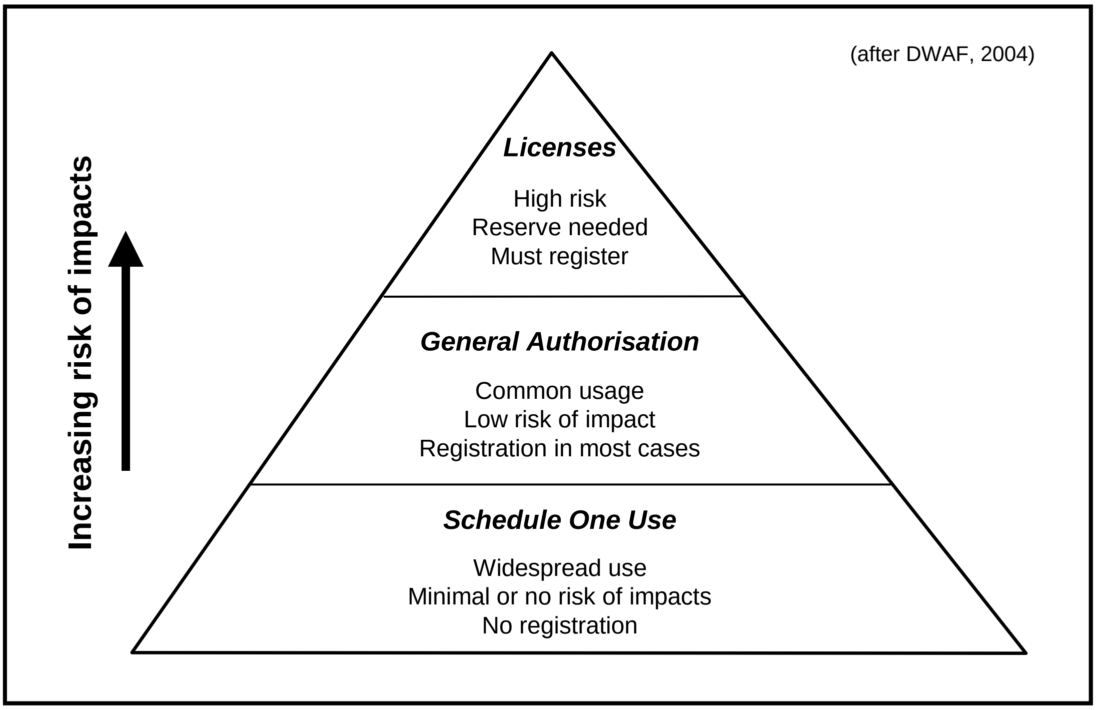

Figure 2.3: Schematic representation of mechanisms used to regulate the use of water

From the National Water Act: Definition of Water Use

Under Section 21 of the National Water Act (Act No. 36 of 1998), water use includes:

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

Note: Water uses in **bold** relate directly to groundwater.

2.6 Management and monitoring

The Minister of Water Affairs and Forestry is the public trustee of water resources and has the overall responsibility for all aspects of water management. However, responsibility and authority for water management will eventually be devolved to a local level. It is planned that DWAF will ultimately provide national policy and a regulatory framework for water resource management, and will make sure that other water institutions are effective. It is expected that the Department will be responsible for quantifying the Reserve, for example, while CMAs will be responsible for allocating available water resources, managing the allocation process and monitoring both water use and resource response to that use.

Monitoring and monitoring information systems form a crucial part of the management of the country's water resources. Extensive monitoring already takes place, but both surface and groundwater monitoring programmes need to be extended. Similarly, the information systems on to which monitored data are captured also need to be revised and updated on a regular basis.

2.7 In summary

The NWA aims to ensure access to a limited resource on an equitable basis in an integrated, managed and sustainable manner. The Act moves away from riparian and property rights, but recognises basic human needs and water needs to sustain the environment. The promulgation of the Act 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. Because strategies, methods and tools are in the process of being developed and refined, methods and tools discussed in this manual remain preliminary (in a legal context) until published in the *Government Gazette*.

2.8 Some useful references

National Water Act (Act No. 36 of 1998).

Water Services Act (Act No. 108 of 1997).

DWAF (2004) National Water Resource Strategy, First edition. Department of Water Affairs and Forestry, Pretoria.

DWAF (2004) Guide to the National Water Act. Department of Water Affairs and Forestry, Pretoria.

3. RESOURCE DIRECTED MEASURES

3.1 Overall process

The objective of Resource Directed Measures (RDM) 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 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.

The relative importance of the three components of the protection of groundwater resources was discussed in Chapter 2. Sequential steps to be followed when assessing these three components are illustrated in Figure 3.1, and are briefly described in this chapter. More detailed discussions are presented in Chapters 6–11. It is important to remember that RDM is part of an overall iterative process used to manage the water resources of South Africa, as illustrated in Figure 2.2. RDM focuses on the principle of sustainability, while equity and efficiency are addressed elsewhere in the water management process.

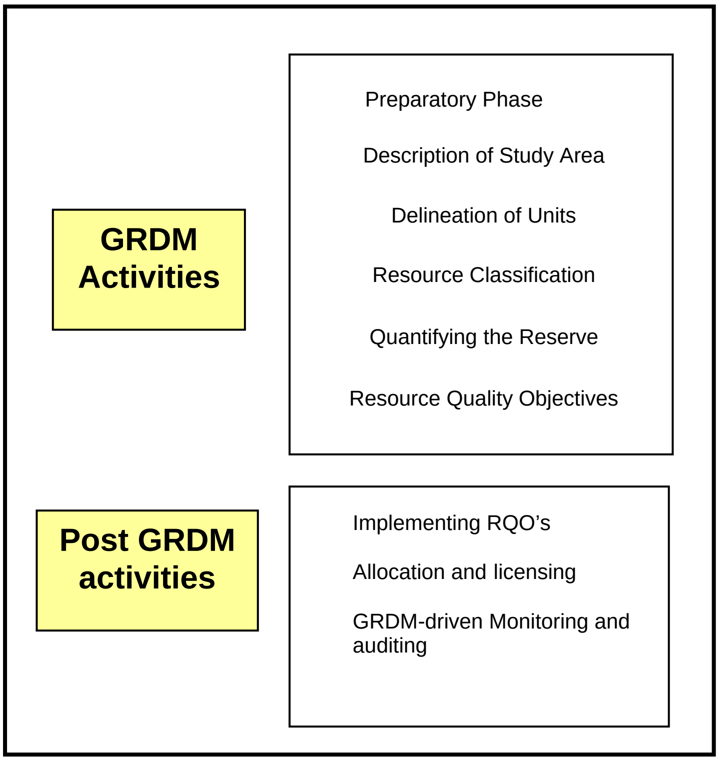

Figure 3.1: Sequential process of GRDM studies

Because the NWA is still in its infancy, and much of the policy, strategy and tools for its implementation are still being developed, a large amount of confusion and misinterpretation occur. It is crucial that DWAF foster a common understanding of these tools – both internally and externally. In addition, a large amount of jargon and literature are being generated. To counteract this, an extensive glossary is included in this manual as well as in the Software to give guidance regarding groundwater and GRDM terminology. Figure 3.1 provides a précis of the overall process used to assess the groundwater component of RDM, and each component is addressed in more detail in subsequent chapters.

Key Note: RDM and the Reserve

The terms *RDM* and *the Reserve* are often used interchangeably, which is incorrect. RDM refers to one of the strategies adopted by DWAF to implement the National Water Act and includes Classification, the Reserve and Resource Quality Objectives. The Reserve is just one part of RDM, and specifically refers to the quantity and quality of water required to meet basic human needs and those of aquatic ecosystems.

3.2 Assumptions related to GRDM

Understanding the role of groundwater in sustaining the environment is still in its infancy. To be able to undertake GRDM assessments and quantify the volume of groundwater required to meet Classification requirements and to sustain the Reserve, a number of assumptions are made:

- 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 RQO's.
- The ability of a geohydrological system to satisfy basic human needs, RQO's 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.

Key Note: GRDM versus the Reserve

From a groundwater perspective, GRDM is more important than the Reserve on its own. While the Reserve only addresses the role groundwater plays in meeting basic human needs and sustaining aquatic ecosystems such as rivers and wetlands, GRDM allows the use and protection of the entire groundwater resource to be addressed holistically.

3.3 Steps in undertaking a GRDM assessment

Initially, a seven-step process was proposed for undertaking the groundwater component of RDM (DWAF, 1999). This was selected to ensure uniformity with other components of RDM (quantity, quality, wetlands and estuaries). However, revisions that are more recent have moved away from the seven-step process and proposed different approaches. While most of the revisions follow the same basic approach, the number of steps is not uniform.

The GRDM methodology has grouped together activities that have a key outcome. This approach is simple, logical and easy to implement. This manual addresses only those technical components that have to be addressed by the groundwater specialist of the RDM project team. An overview of the GRDM process is presented below, but discussed in more detail in Chapters 6–11.

3.3.1 Preparatory phase

Who	DWAF RDM Scoping Team, which is to include a hydrologist, geohydrologist and ecologist
Purpose	To initiate a GRDM study Set the level of GRDM assessment required Appoint a GRDM assessment team
How	Using expert knowledge of the water resources of an area and an understanding of local management issues Desktop GRDM assessment
Key Outcomes	Map defining the area to be studied Selection of the level of GRDM assessment required Project Terms of Reference Appointment of a project team to undertake the assessment

A GRDM study can be initiated by DWAF Head Office as part of the compulsory licensing process, or by a DWAF Regional Office in response to a licence application or anticipated application. This is largely a management task, with specialist groundwater input being provided by DWAF personnel.

As a means of initiating the study and setting the level of GRDM assessment required (and hence the Terms of Reference), it is recommended that a desktop GRDM assessment be undertaken. In some cases, a Scoping Study can be undertaken if information that is more detailed is required before the level can be set.

Key Note: Quaternary catchment as the basic resource unit

The NWA states that the Minister must determine the Reserve for all or part of every significant water resource, with the term ‘significant’ relating to the aerial extent of the resource, and not to its importance.

The basic unit of any GRDM assessment is the quaternary catchment, but the area undergoing compulsory licensing or the scale or extent of the proposed application usually defines the extent of the study.

3.3.2 Description of study area

Who	Project geohydrologist, with input from other specialists when required
Purpose	To describe the study area in terms of its physical and geohydrological characteristics in detail appropriate to the level of GRDM assessment required
How	This is essentially a data gathering and analysis phase, typical of any geohydrological resource assessment. Approaches, methods and tools typically used in geohydrological assessments are used
Key Outcomes	Geohydrological report of the area, including maps and tables, documenting characteristics such as climate, topography, drainage, geology, geohydrology, groundwater use, surface–groundwater interaction, groundwater-dependent ecosystems etc.

This phase is probably the longest in the GRDM determination process, as it entails the collection of data and information on which the GRDM assessment is based. The collected information is then analysed and a conceptual understanding of the geohydrology of the study area developed. In the case of desktop or rapid assessments, readily available data can be used. The most easily accessible data sets are those generated by the GRAII project and are included in the Software that accompanies this manual. Data as presented on the 1:500 000 scale geohydrological maps of South Africa could form the basis of the assessment. The output would be a one or two page report. In the case of a comprehensive assessment, an iterative process of data collection, fieldwork and data analysis could result in a substantial geohydrological report.

3.3.3. Delineation of units

Who	Project geohydrologist, with input from other specialists when required
Purpose	Delineate groundwater resource units based on quaternary catchment boundaries, aquifer type (primary aquifer, secondary aquifer, dolomitic aquifer) and other physical, management and/or functional criteria
How	Quaternary catchments form the basic unit for a GRDM assessment. These units can then be further subdivided (or grouped). Areas of similar character are mapped into distinct units using expert judgement and interpretation

Key Outcomes	Map showing the extent of the groundwater resource GRDM assessment data sheet, in which the name of each unit and its aerial extent are recorded

Based on the description of the study area, areas of similar character are demarcated. Other components of the water cycle such as wetlands and rivers must also be considered at this stage to assess possible interdependency and promote the integrated water resource management vision of the NWA.

Resource units are areas of similar physical or ecological properties that are grouped or typed to simplify the Reserve determination process. Typically, this would be based on quaternary catchment boundaries and whether the aquifers are primary aquifers, secondary aquifers or dolomitic aquifers. For intermediate and comprehensive GRDM assessments, a similar approach is followed but a more detailed delineation may be required. The more detailed delineation could be based on factors such as geology, topography, groundwater dependence and use.

3.3.4 Resource Classification

Key Note: Classification and categorisation

In the context of RDM and the ongoing development thereof, the term ‘classification’ is being used to refer to the class assigned to a water resource after catchment visioning. The class is based on both the state of a water resource and the state to which stakeholders want the resource to be managed. Until the public participation process has been run, the term *category* is being used to distinguish between groupings based on technical considerations and the classification based on the catchment visioning process.

Who	Project geohydrologist, with input from other specialists when required
Purpose	To define the present status category and water resource category of each groundwater resource unit using the prescribed categorisation system, the output of which will feed into processes for setting desired management classes for significant water resources
How	Using the conceptual understanding of geohydrological conditions in an area, the level of change from natural must be assessed. Using a set of guiding tables, the present status category and water resource category of each groundwater unit is determined. Categorisation is based on both quantifiable and non-quantified parameters, as well as expert judgement
Key outcomes	Categorisation of each groundwater resource unit (natural, good, fair, poor) GRDM assessment data sheet, in which the category of each unit is recorded

The key outcome of this phase is to define the water resource category for each groundwater resource unit (natural, good, fair, poor). In essence, the classification process aims to define a resource with respect to the current impact on the resource. A range of factors can be considered, including recharge, groundwater use and contamination or expected contamination status. The difference between reference conditions and present status is used to assess the sustainability of current groundwater use and the stress status of the groundwater resource. A single present status category is assigned to each groundwater response unit, which in turn is used to determine the water resource category of each unit. This technical geohydrological information is then fed into the broader RDM Classification process that aims to set management classes for each water resource unit.

3.3.5 Quantification of the Reserve

Who	Project geohydrologists, with support from the hydrologist
Purpose	To quantify the volume of groundwater that can be abstracted from a groundwater unit without impacting the ability of the groundwater system to contribute to the Reserve (basic human needs, ecological requirements)
How	Quantify recharge to the unit, using appropriate methods Quantify the groundwater contribution to baseflow and groundwater-dependent ecosystems, using appropriate methods Quantify the basic human needs of the unit to be met from groundwater
Key outcomes	GRDM assessment data sheet, in which recharge, groundwater contribution to baseflow and basic human needs are recorded Calculation of the Reserve as a percentage of recharge and the groundwater allocation

The only right to water in the NWA is water for basic human needs and for the environment. This is in contrast to earlier legislation (Water Act of 1956) in which riparian water rights were recognised, and groundwater was considered private. Rights relating to basic human needs and the environment form the Reserve, and DWAF may only allocate water after the Reserve has been considered. Basic human needs include water for cooking, drinking and personal hygiene, currently set at 25 ℓ/cap·d.

From the NWA: Definition of the Reserve

Under the National Water Act (Act No. 36 of 1998), 'the 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 (Act 108 of 1997) for people to be supplied with water from that resource, and

(b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of water resources.

By definition, only part of the groundwater system is included in the Reserve. Where groundwater contributes to or supports basic human needs or aquatic ecosystems, groundwater forms a component of the Reserve and hence has to be considered. However, groundwater also occurs in areas away from aquatic ecosystems and supports other components of the environment that may not form part of the Reserve. In such instances, groundwater protection is mainly affected through Classification and Resource Quality Objectives.

The outcome of this phase of the work is to determine a quantity of groundwater that can be abstracted from each resource unit without significantly impacting that unit's ability to sustain the Reserve and meet the RQOs. No method is provided to address the groundwater quality component of the Reserve. Groundwater quality issues are generally addressed under source directed controls, Classification and Resource Quality Objectives.

Calculation of the groundwater allocation is undertaken by a suitably experienced groundwater specialist, and the outcome is presented in a GRDM data sheet documenting recharge to a groundwater resource unit, the baseflow requirement met from groundwater and the basic human needs to be satisfied from groundwater supplies. This information is used to calculate the groundwater allocation.

Key Note: The bucket analogy

Conceptually, it is very easy to understand and illustrate the concept of the Reserve when considering surface water resources. Using the well-documented bucket analogy, the Reserve is the water that must always be left in the bucket for basic human and ecological needs. However, the same analogy cannot be used for groundwater because if we lower the water table too much, groundwater discharge to surface water bodies will diminish or cease altogether.

3.3.6 Setting Resource Quality Objectives

Who	Project Geohydrologist, aquatic ecologist, catchment manager
Purpose	Set RQOs for each resource unit using rules for selected classes
How	Based on the conceptual understanding of the area, select key measurable indicators as RQOs (e.g. water levels, total dissolved solids (TDS), faecal coliforms, etc) and the level at which they should be maintained (natural, slightly modified, etc.)
Key outcomes	List of RQOs to guide management and monitoring activities.

Resource Quality Objectives are clear goals that balance the need to protect and sustain a water resource with the need to develop and use them. At the same time as setting the Reserve for all water resources in the country, DWAF will determine Resource Quality Objectives for each significant water resource that is based on the level of Classification and Reserve. These objectives will tell managers how much water is needed to keep a water resource healthy, what the quality of the water should be and what the condition of the animals and plants should be. The outcome from this phase is a list of goals – either numeric or descriptive – which can be used to set aquifer management criteria.

3.3.7 Review

DWAF (1999) proposed each assessment of the groundwater allocation of a significant water resource be reviewed by a panel of experts prior to setting the Reserve. This review process was a mechanism aimed at:

- Overcoming data shortage problems expected in many of the catchments (i.e. expert judgment)
- Including experienced practitioners in the GRDM process in an efficient manner
- Checking and standardising GRDM assessments.

The proposed review by a panel of experts should be adopted by DWAF to improve the level of confidence of each assessment. While much of the preparatory work can be undertaken by junior or less experienced geohydrologists, the appointed review panel can consider each assessment in terms of the conceptual understanding of the study area, the linkage of groundwater to other components of the hydrological system and the validity of the set Resource Quality Objectives.

3.4 Post-GRDM assessment activities

Setting RQOs marks the completion of the technically driven components of the GRDM process. However, the process is not only technically based. It must also consider social, economic, efficiency and other factors. Because of this, the process has to be iterative to allow for consideration of the outcome of the catchment visioning process and linkages to other components of the hydrological cycle that may have emerged during the GRDM assessment. In addition, once the RDM assessment is in place, monitoring requirements and allocation of the water resource has to be considered.

3.4.1 Implementing Resource Quality Objectives

It is crucial that specialists are aware of management activities relating to the implementation and enforcement of RDM in general and GRDM in particular. Giving effect to the RQOs includes the catchment visioning process and publishing the Reserve for public review and comment. The two other principles of the NWRS - namely equity and efficiency - also need to be addressed. Information supplied by the groundwater specialist during the GRDM process is also used during the water allocation and licensing processes.

It is a requirement that any Reserve set by the Minister be published for comment and review and, once finalised, be published in the *Government Gazette*. To date, no Reserve determinations have been gazetted as the methods have yet to be finalised, and all Reserve determinations are still considered preliminary.

To give effect to the Reserve of a significant water resource, a strategy needs to be developed to achieve the Class, Reserve and RQOs set for that resource. Ultimately, this will be the responsibility of a catchment management agency. However, until CMAs are established, this function will continue to be the responsibility of DWAF regional offices.

Development of a catchment management strategy is a long-term participative process involving stakeholders in the catchment. The strategy needs to consider the National Water Resource Strategy and address compliance with a specified Reserve. In catchments where current levels of water use prevent compliance with the Reserve in the short term, the catchment management strategy needs to include a phased approach that will result in compliance being achieved over a period.

3.4.2 GRDM-driven monitoring

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. Information obtained from post-GRDM assessment monitoring will be used in the review of the assessment (usually within a period of five years). Monitoring forms an essential part of what must be a seamless process of managing the country's water resources. Guidelines regarding GRDM-driven monitoring and how it fits in the broader process of groundwater monitoring in South Africa are currently lacking.

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. Todd et al. (1976) defined monitoring as "*… a scientifically designed surveillance system of continuing measurements and observations, including evaluation procedures*". 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.

All three levels of groundwater monitoring are required by the GRDM assessment process (Table 3.1). In broad terms, **national level** monitoring is the responsibility of central government (DWAF) and aims to provide a national perspective on the status of groundwater resources for planning and management purposes. It provides information pertaining to reference conditions required for assessing the state of groundwater resource units (Chapter 8). A national groundwater monitoring programme is currently in place and comprises some 400 monitoring stations. Monitoring at a **regional level** could be described as catchment scale monitoring, and will typically be the responsibility of CMAs. This level represents the most suitable platform for monitoring within the context of RDM, since it provides a synthesis of groundwater resource status and trends at a scale more appropriate for implementing meaningful resource management measures, standards and regulations. **Local level** monitoring encompasses the collection of specified site-focused and use-related groundwater data by, among others, the water user. This is the level at which the CMA should assess compliance with licensing conditions. An example of local level monitoring currently undertaken is that at waste disposal sites and that which is undertaken by groundwater users.

Once the GRDM assessment has been completed, monitoring requirements need to be considered. The GRDM assessment team must, as part of RQOs, give guidance on the type of monitoring required, while ensuring that monitoring remains both realistic and affordable. The design of any monitoring programme needs to consider the following:

- Objectives of monitoring
- Methods, location and frequency of monitoring
- Capture and reporting of data
- Implementation and management of monitoring
- Cost of monitoring.

Until such time as guidelines are available regarding GRDM-driven monitoring requirements and how these fit into the broader perspective of groundwater monitoring in South Africa, geohydrologists in DWAF Regional Offices and the Sub Directorate: Groundwater Resource Assessment and Monitoring should be consulted in order to prepare a groundwater monitoring plan for a groundwater resource unit.

Table 3.1: Three-tier level of groundwater monitoring

Level	Management Responsibility		Scientific Focus		Time Frame
1	National	DWAF	Referential	Countrywide status of groundwater resources	Long-term
2	Regional	DWAF Regional Office Catchment management agency Water Services Authority	Proactive/ Reactive/ Control	Response of resource unit(s) and their supporting groundwater system(s)	Medium-term
3	Local	Water user Water User Association Water Services Institution	Auditing	Compliance with water use license conditions	Short-term

3.4.3 Allocation

An area currently requiring urgent attention is that of allocating water to users. A GRDM assessment is only the start of the water resource management process and aims to determine the total amount of groundwater in a significant water resource and the amount that can theoretically be abstracted sustainably without impacting the ability of groundwater to support the Reserve. No attempt is made to apportion or allocate water to individual users or applicants. This occurs in a subsequent process that is not addressed in this training manual.

Chapter 4 of the National Water Act considers use and licensing of water. Issues relating to equity and efficacy are addressed in the allocation process, and section 27 of the Act is onerous in terms of the aspects to be considered in allocating water. When allocating water through general authorisation or licensing, the responsible authority must take into account all relevant factors, including:

- Existing lawful water uses
- The need to redress the results of past racial and gender discrimination
- Efficient and beneficial use of water in the public interest
- The socio-economic impact of the water use or uses if authorised, or the failure to authorise the water use or uses
- Any catchment management strategy applicable to the relevant water resource
- The likely effect of the water use to be authorised on the water resource and on other water users
- The Class and the Resource Quality Objectives of the water resource
- Investments already made and to be made by the water user in respect of the water use in question
- The strategic importance of the water use to be authorised
- The quality of water in the water resource which may be required for the Reserve and for meeting international obligations; and
- The probable duration of any undertaking for which a water use is to be authorised.

While the principles of allocation are addressed by the National Water Act and the National Water Resource Strategy, mechanisms and tools to allocate water are not discussed in this manual. Clear guidelines are required to help managers allocate water, particularly those in the Regional Offices or CMAs whose responsibility it is to manage the allocation process.

Key Note: Water rights and property ownership

As the National Water Act (Act No. 36 of 1998) no longer recognises riparian water rights and groundwater is no longer private, property ownership no longer guarantees access to water.

The allocation and management of our water resources are key to the success of the National Water Act (Act No. 36 of 1998), and it will be important for GRDM managers and practitioners to understand the principles on which allocation will be based. This is particularly true when delineating groundwater resource units. While it is important that delineation be based on sound scientific principles, it is equally important that the outcome of the GRDM assessment process can feed into the allocation process.

3.5 Responsibilities of stakeholders within DWAF

Most RDM studies currently undertaken by the Directorate: Resource Directed Measures (D: RDM) are licence driven. Typically, Regional Offices receive an application for a licence and forward the application to the D: RDM requesting that an RDM study be undertaken, as a Reserve has to be signed off before a licence can be issued. Regional Offices must supply as much background information as possible to the D: RDM, including the potential impact of the application on the status of the resource.

A Study Manager is assigned in the D: RDM to do the study and submit the necessary documentation to the Director-General of DWAF, who signs off the Reserve. The potential impact of the proposed abstraction on the current availability of water would determine the level of GRDM assessment required.

If other components of the Reserve, such as wetlands, are involved, the team needs to be multidisciplinary in composition. Applications for a licence where groundwater does not play an obvious role are also normally screened to verify this assumption. Before the legal document is submitted to the Director-General for signature, another Study Manager will review the study from both a technical and legal angle.

DWAF has also drawn up a list of priority areas earmarked for comprehensive level studies, and four of these studies are currently being undertaken. The work is being done by consultants, and DWAF officials that are knowledgeable about the area of interest in the RDM assessment process are usually included.

3.6 In summary

GRDM comprises six sequential phases of investigation, including Classification, Reserve determination and setting Resource Quality Objectives. It forms part of the water management process in South Africa required by the National Water Act (Act No. 36 of 1998). GRDM focuses on the principles of sustainability, while equity and efficiency are addressed elsewhere in the water management process. Because of groundwater's unique characteristics, methods of assessment are somewhat different from other components of the hydrological system (rivers, wetlands, estuaries), but it is crucial that RDM assessments be undertaken in an integrated manner.

3.7 Some useful references

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4. LEVELS OF GRDM DETERMINATION

4.1 Introduction

Ideally, all water resources in South Africa should be assessed to the same degree and the results of the assessment should be of a high confidence. In addition to the fact that the tools and methods required to undertake RDM assessments being of a preliminary nature, the country does not have the manpower or financial resources to carry out RDM assessments countrywide in the short term. To overcome this problem and in line with a differentiated approach adopted by DWAF (2000), two strategies are being used:

- Priority areas are being identified
- Different levels of RDM assessments are being used.

Four levels of GRDM determination are recognised, with each expected to yield a greater level of confidence in the results. 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; take a matter of hours to complete; and yield results of very low confidence; usually the first step in any GRDM process and is a useful planning tool.
- 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; should take less than two weeks to complete.
- Intermediate: these determinations yield results of medium confidence; require field investigations by experienced specialists and should take about two months (but <6 months) to complete; used to assess individual licences for 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 should take less than two years to complete. Due to lack of long-term geohydrological data sets, GRDM assessments will only rarely be done at this level.

In essence, the same method and approach is used to undertake desktop and rapid GRDM assessments. Similarly, a single method and approach has been developed to undertake intermediate and comprehensive GRDM assessments. The chief difference between intermediate and comprehensive assessments is the nature and extent of data to be used in the assessment.

In accordance with the precautionary principle, lower-confidence assessments need to be more conservative in nature than higher-confidence assessments. The level of confidence required depends on:

- The degree to which groundwater in the catchment is already used
- The ecological sensitivity and importance of the catchment
- The nature, extent and probable impacts of the water uses for which a GRDM assessment is being undertaken.

In practice, it has been found that the method of determination used does not necessarily coincide with the level of confidence of the results obtained. For example, in instances where good baseline data sets exist with which to define biophysical relationships, then a short-duration rapid assessment can produce results of high confidence. Similarly, in instances with poor historical data, low confidence results will be obtained – irrespective of the time and cost of study. It is hence incorrect to assume that the degree of confidence in the results would increase in direct proportion to the time and cost of the study.

In general, increasing levels of confidence require increasing commitments of time by specialists, thereby impacting on the costs of the GRDM assessment. The level of confidence required therefore largely dictates the composition of the GRDM study team. Lower-confidence assessments will probably only require a groundwater specialist to undertake the assessment. However, intermediate and comprehensive determinations will require a study team including geomorphologists, hydrologists, geohydrologists, ecologists, sociologists, water resource managers, etc.

Key Note: Interdisciplinary approach

The National Water Act recognises a unitary hydrological cycle, resulting in a vision of integrated water resource management. This requires an interdisciplinary group of scientists and managers to undertake RDM assessments. As RDM assessments are often based on expert judgement, this collective approach ensures that assessments are never based on the judgement and expertise of one individual or specialist. When undertaking desktop or rapid assessments, a formal review process is crucial to compensate for the smaller teams undertaking the assessments.

4.2 Guides for setting the level of GRDM determination

Accepting that DWAF 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 Reserve. Conversely, high levels of confidence are required in stressed catchments, ecologically sensitive or important catchments or catchments where groundwater abstraction is known to be having significant negative impacts.

At present, no formal methods exist to guide the level of GRDM determination that is required. Xu et al. (2003) and Colvin et al. (2003) presented a generic guide for setting the level of GRDM required, based on aquifer type, dependency and impact (Table 4.1). DWAF (2003) presented a similar guide, but based on only stress and impact (Figure 4.1). This approach requires that the level of stress of a significant water resource be assessed as well as the potential impact of water use or proposed water use.

Table 4.1: Guide proposed by Colvin et al. (2003) for setting the required level of GRDM assessment

Indicator	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

Notes:

- *Low yielding – harvest potential less than 10 000 $m^3/km^2 \cdot a$ or average borehole yield less than 1 ℓ/s*
- *Moderately yielding – harvest potential between 10 000 and 50 000 $m^3/km^2/a$ or average borehole yield between 1 and 2 ℓ/s*
- *High yielding – harvest potential greater than 50 000 $m^3/km^2 \cdot a$ or average borehole yield greater than 2 ℓ/s*

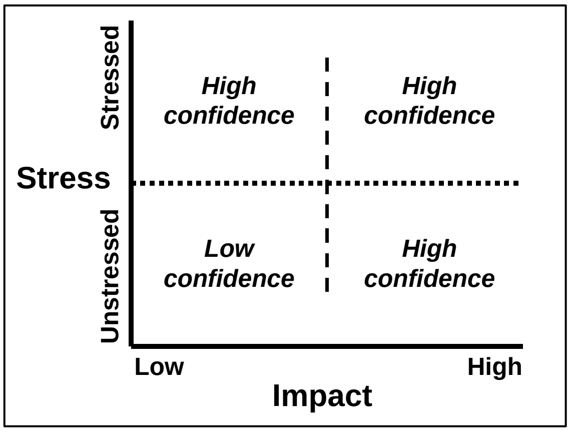

Figure 4.1: Level of confidence required for a GRDM assessment based on stress and impact (DWAF, 2003).

The term 'water stress' is used in the National Water Act and by the RDM fraternity, but has not been properly defined. The European Environmental Agency (as quoted by DWAF, 2003) defines water stress as that which occurs when the demand for water exceeds the available amount during certain periods or when poor quality restricts its use. Compulsory licensing has to be undertaken in areas of water stress, while it is generally accepted that higher-confidence RDM assessments are required in areas of greater water stress. A number of indicators can be used to assess the level of stress of a groundwater system:

- Groundwater level – a decreasing or downward trend in groundwater levels can reflect groundwater stress
- Groundwater quality – a deterioration of groundwater quality – as indicated by an increasing or upward trend in chemical concentrations of typical contamination indicators such as EC, K, P, N and others – can reflect groundwater stress
- Groundwater use – an increase in groundwater use within a catchment may imply increased stress on the groundwater resource
- Disputes – an increase in the number of legal cases or disputes around groundwater use can reflect groundwater stress
- Boreholes – an increase in the number of boreholes within a catchment or an increase in the number of boreholes drying up can reflect groundwater stress
- Ecosystems – collapse of groundwater-dependent ecosystems or a reduction in baseflow can reflect groundwater stress
- Pollution sources – an increase in the number of potential groundwater pollution sources, for example mining and industry, can reflect groundwater stress.

The groundwater level in a stressed aquifer may behave in a manner similar to that displayed in Figure 4.2. Unfortunately, this sort of information is seldom available. Furthermore, the degree of stress is gauged by comparing reference conditions and present status during the Classification process, or comparing the present state to the Resource Quality Objectives (see Chapter 9). These comparisons are only possible later in the GRDM process, while the level of confidence needs to be addressed at the outset.

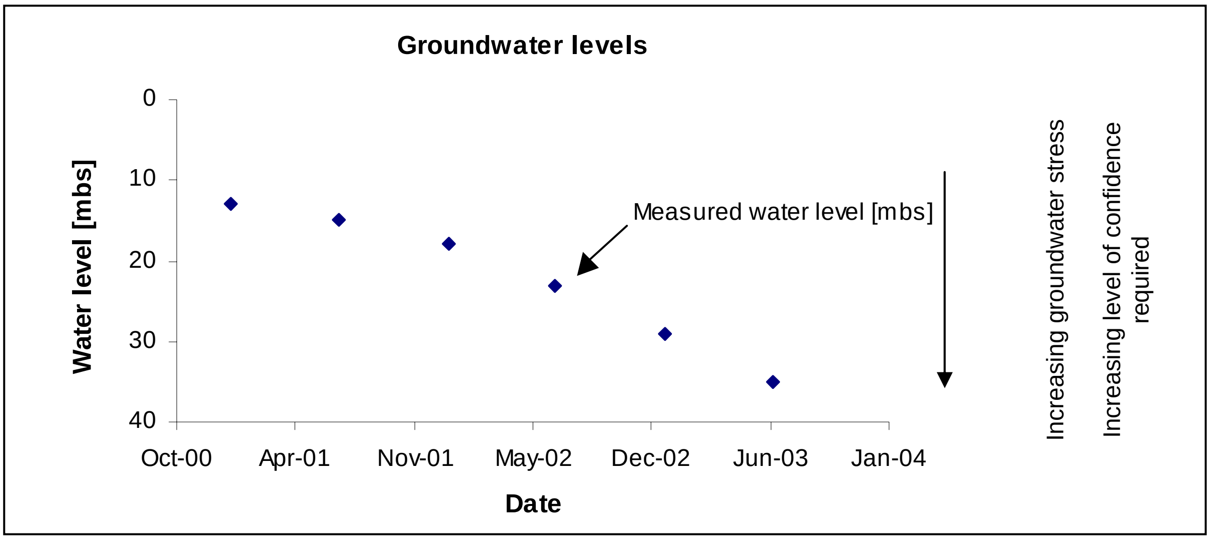

Figure 4.2: Using monitored groundwater level data to assess stress

One of the key learning points to emerge from GRDM investigations undertaken to date is that 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 were 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.

4.3 Recommended procedure

A desktop assessment should be the forerunner to all RDM assessments, including those where rivers, wetlands or estuaries are driving issues. DWAF officials familiar with geohydrological conditions in the area should undertake this assessment, or a groundwater specialist should be appointed by DWAF to assist in the matter. Part of the desktop GRDM assessment should include consideration of the state of stress of the groundwater system based on indicators highlighted in section 4.2 and the stress index presented in Chapter 9.

In the absence of a recognised procedure for setting the level of confidence required for a GRDM assessment, the following approach should be adopted:

- In instances where compulsory licensing is required (i.e. water use exceeds available resource), comprehensive GRDM assessments are to be undertaken.
- In instances where no indications of stressed groundwater systems are observed (in terms of the qualitative criteria set out in section 4.2) and the desktop GRDM assessment indicates that groundwater use is limited and potential use will have an insignificant or low impact, then a rapid GRDM assessment could be adequate.
- In instances where a large area has to be assessed or the desktop GRDM assessment does not provide adequate information on which to base a decision, then a Scoping Study should be considered (see Section 6.2). From this, it must be decided whether a rapid, intermediate, comprehensive or multilevel assessment is required.
- In instances where a low degree of stress is interpreted, moderate groundwater use is observed or low to moderate impacts or potential impacts are evident, then an intermediate GRDM assessment may be required. Impacts may include lowering of water tables or deteriorating groundwater quality on a local scale.
- In instances where

    - the groundwater system is considered to be stressed,
    - large volumes of groundwater are abstracted,
    - the impact of an activity on the groundwater system is or could be considered to be high,
    - incidences of groundwater-related disputes or conflicts are common,
    - or highly sensitive and important groundwater-dependent ecosystems are prevalent within a significant water resource,

  then a comprehensive GRDM assessment should be commissioned.

It is noted that the final decision regarding the most appropriate level of confidence required is to be motivated by the DWAF geohydrologist most familiar with the area and agreed to by the Regional Director and the RDM Director. The motivation must take account of the issues addressed in section 4.2 and be based on the official's knowledge of an area, as well as other available supporting data and information.

While it is strongly argued that all RDM assessments should include all components of the hydrological system (rivers, wetlands, groundwater and estuaries), not all components have to be assessed at the same level of confidence. However, for the IWRM vision of the National Water Act to be addressed, all components have to be considered.

4.4 In summary

Four levels are GRDM assessment is recognised – desktop, rapid, intermediate, comprehensive – with each providing an increased level of confidence. Increased levels of commitment and resources are required to attain higher levels of confidence. Desktop GRDM assessments can be completed in a matter of hours, but comprehensive GRDM assessments may take over a year to complete. The same level of assessment need not be applied across a study area, and a multilevel GRDM assessments approach can be adopted. 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 may be undertaken in areas where specific problems occur or in areas where the underlying groundwater system is clearly stressed. Scoping studies can be undertaken prior to commissioning GRDM assessments to identify ‘significant’ water resources in a study area requiring higher levels of assessment.

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5. UNDERSTANDING LINKAGES TO OTHER COMPONENTS OF RDM

5.1 Preamble

It is beyond the scope of this training manual to give a detailed account of the role that groundwater plays in the environment, or how groundwater links to other components of RDM. Because of the importance of understanding the links, a range of recent publications on the topic are listed in section 5.6. Nonetheless, promulgation of the National Water Act (Act No. 36 of 1998) resulted in scrutiny of the role groundwater plays in sustaining ecosystems and satisfying basic human needs.

5.2 The role of groundwater in addressing basic human needs

Early San hunter-gathers who roamed southern Africa relied on rivers and springs for fresh, potable water. The Khoi probably dug the first water wells in the area, as a number of water wells reportedly thousands of years old are located in close proximity to cave paintings. Following the pastoral revolution some 2 000 years ago, water and grazing became key drivers in migration patterns, with springs playing an important role in areas without rivers or with ephemeral and seasonal rivers.

The majority of the 10 million South Africans that have been provided with water since 1994 have been supplied from groundwater resources. The Reconstruction and Development Programme (RDP) instituted a programme of drilling, testing and equipping boreholes. Because groundwater is generally found near the point of need, boreholes drilled close to villages and rural settlements could be used to establish basic water supplies. There are indications that 14 000 rural villages could be served from groundwater. In the Eastern Cape alone, the water supply to more than 80% of the 5 700 communities in the province could be groundwater-based.

The Constitution of South Africa recognises that everyone has a right to have access to sufficient food and water, and the state must take reasonable legislative and other measures within its available resources to achieve the progressive realisation of these rights. A basic supply of water is one of only two rights to water enshrined in the National Water Act. Groundwater is now recognised as a strategic resource that can play a major role in the fight against poverty and in easing the burden of women in rural areas. The sustainable use of groundwater is paramount in attaining the goal of each South African having access to at least 25 ℓ/cap·d of water.

5.3 Groundwater-dependent ecosystems

In addition to recognising the right to a basic water supply, the National Water Act (Act No. 36 of 1998) recognises the need to set aside water for aquatic ecosystems. Groundwater is generally interpreted as falling outside the definition of aquatic ecosystems, except where groundwater discharges and sustains surface water bodies. However, groundwater provides an important linkage between terrestrial ecosystems and aquatic ecosystems (Parsons, 2003).

For example, springs are an expression of subsurface water discharging at surface. In addition to providing the groundwater contribution to river flow, they play a critical role in providing fauna and flora with a source of water. Unique ecosystems develop around springs in response to the permanency of available water.

Similarly, the hyporheic zone is contained within the land–water ecotone and is functionally a composite between surface and groundwater ecosystems. It provides a number of ecologically important services, including thermal, temporal and chemical buffering, habitat, flow augmentation and refugia. The zone may be significantly different from the overlying surface water body and the underlying aquifer system. Brown et al. (2003) noted that upwelling (or discharge) of groundwater creates patches of high productivity in the hyporheic zone and aquatic ecosystems, supporting greater animal densities and diversities when compared to non-upwelling situations.

Case study: Doring river

Groundwater plays a crucial role in providing refugia during dry periods. In summer, fish survive in groundwater-fed pools when surface flows cease in the Doring River. It was recently observed that indigenous fish only use pools fed by a fresh groundwater source, while alien fish were found in all pools.

(Brown et al., 2003)

Riparian zones – especially in arid and semi-arid areas – are important for maintaining biodiversity, offering refugia and habitat to a variety of organisms not able to survive in adjacent terrestrial and aquatic ecosystems (Brown et al., 2003). They create a buffer between terrestrial and aquatic ecosystems, protect rivers from the effects of activities in adjacent terrestrial environments, and stabilise river banks. These zones are typically sustained by a combination of surface and subsurface water, with the contribution of groundwater being critical during dry periods.

Salt marshes in estuarine environments provide a further example of the important role of surface – groundwater interaction. While the marshes are regularly inundated by saline water, the continual discharge of fresh groundwater (often in small quantities) provides refugia for freshwater organisms by maintaining relatively low salinities.

The Australians first developed a system to classify groundwater-dependent ecosystems (Hatton and Evans, 1998; Sinclair Knight Merz, 2001). This was linked to a classification where groundwater-dependent ecosystems are ranked in terms of their conservation value, vulnerability to potential threats and the likelihood of these threats being realised. Colvin et al. (2002) and Colvin (2003) are currently researching this issue from a South African perspective. The groundwater-dependent ecosystem classification proposed by Sinclair Knight Merz (2001) is presented in the box that follows, while Colvin (2003) modified the classification to recognise the following groundwater-dependent systems:

- In-aquifer systems
- Springs and seeps
- Riverine systems
- Riparian systems
- Wetlands

- Terrestrial systems
- Estuarine and coastal systems.

While it is important to recognise the dependence of ecosystems on groundwater, it is equally important to recognise that not all aquatic or terrestrial ecosystems are groundwater dependent. Furthermore, demonstration of groundwater use does not necessarily equate to groundwater dependence while groundwater abstraction will not necessarily affect the supply of groundwater to groundwater-dependent ecosystems. In this context, it is also important to distinguish between facultative and obligate systems, since the former should readily adopt if groundwater is not readily available.

Key Note: Grouping of groundwater-dependent ecosystems

- *Terrestrial vegetation*: Vegetation communities and dependent fauna that have seasonal or episodic dependence on groundwater.
- *River baseflow systems*: Aquatic and riparian ecosystems that exist in or adjacent to streams that are fed by groundwater baseflow.
- *Aquifer and cave ecosystems:* Aquatic ecosystems that occupy caves or aquifers.
- *Wetlands:* Aquatic communities and fringing vegetation dependent on groundwater fed lakes and wetlands.
- *Terrestrial fauna:* Native animals that directly use groundwater rather than rely on it for habitat.
- *Estuaries and near-shore marine ecosystems*: Coastal, estuarine and near-shore marine plant and animal communities whose ecological function has some dependence on the discharge of groundwater.

(Sinclair Knight Merz, 2001)

It is also important to recognise the degree and significance of the dependency. A fundamental tenet of ecology is that ecosystems generally use a resource in proportion to the availability of the resource (whether it be water, light, nitrogen or some other resource), and the availability of the resource will be a significant determinant of the structure, composition and dynamics of an ecosystem (Tilman, 1988 as quoted by Brown et al., 2003). Where groundwater is accessible, ecosystems will develop some degree of dependence on it, and the degree of dependence is likely to increase with increasing aridity.

The current challenge facing geohydrologists is how to identify groundwater-dependent ecosystems and to distinguish between facultative and obligate systems. Few documented case studies exist in South Africa where groundwater abstraction has measurably impacted groundwater-dependent ecosystems. Some anecdotal accounts exist, few of which have been properly investigated. The only known study where it has been investigated in detail was the Sandveld. (Conrad et al., 2005)

Key Note: Degree of groundwater dependency

- *Entirely dependent:* ecosystems would collapse if groundwater fluxes were to diminish or be slightly modified. (Also referred to as obligate systems.)
- *Highly dependent:* moderate changes to groundwater discharge or water tables would lead to substantial decreases in either the extent or condition of ecosystems.
- *Proportionally dependent:* a unit change in the groundwater system would result in a proportional change in the condition of the ecosystem.
- *Facultative dependency:* changes to a groundwater system would have a minor effect on the condition of the ecosystem.
- *No dependence:* ecosystems are independent of groundwater.

(Brown et al., 2003)

Until the current research is completed, few tools are available for practitioners to use when trying to ascertain dependence and evaluate the extent, degree and nature of that dependency. Figure 5.1 presents a preliminary protocol presented by Colvin et al. (2002) to assess the dependency of vegetation on groundwater. Minor modifications will make it applicable to other groundwater-dependent ecosystems.

Dennis et al. (2002) developed a fuzzy logic-based ecological risk assessment tool to quantify the risk of using groundwater. When undertaking a risk assessment, one is required to ascertain whether groundwater contributes to baseflow, whether vegetation is groundwater-dependent and to identify potential impacts that could result from a change in groundwater quality. Quantification of risk provides a means of presenting a measure of assurance, and thereby allowing some integration with the surface water components of RDM.

5.4 The role of groundwater in supporting other components of RDM

Parsons (2003) describes the role of groundwater in sustaining rivers, lakes, wetlands, estuaries and the marine environment. Our abilities to quantify the groundwater contribution to surface water bodies and activities that impact on the interaction are also described. The role of groundwater and potentially impacting activities is summarised in Table 5.1

Table 5.1: Summary of the role of groundwater and activities likely to impact on groundwater-dependent ecosystems.

Role of Groundwater	Potentially Impacting Activities
Discharge of baseflow into rivers	Large-scale groundwater abstraction
Discharge of baseflow into wetlands	Infestation by alien vegetation
Discharge to springs	Planting of forests and other plantations
Discharge into estuaries	Contaminated groundwater discharging at surface
Discharge into the marine environment	Modification of surfaces in recharge areas
Supporting terrestrial vegetation	Lowering of the regional water table

In addition to addressing the groundwater components of RDM, one of the key roles of a geohydrologist in the RDM process is to provide insight to other specialists about how the groundwater system functions and the role it plays in supporting other components of RDM. For example, groundwater plays a key role in sustaining many wetlands. If Resource Quality Objectives are set without understanding whether a wetland is groundwater driven, the RQOs may be altogether ineffective for protecting that wetland, or they may fail the National Water Act by being too restrictive on groundwater abstraction when restrictions are not warranted.

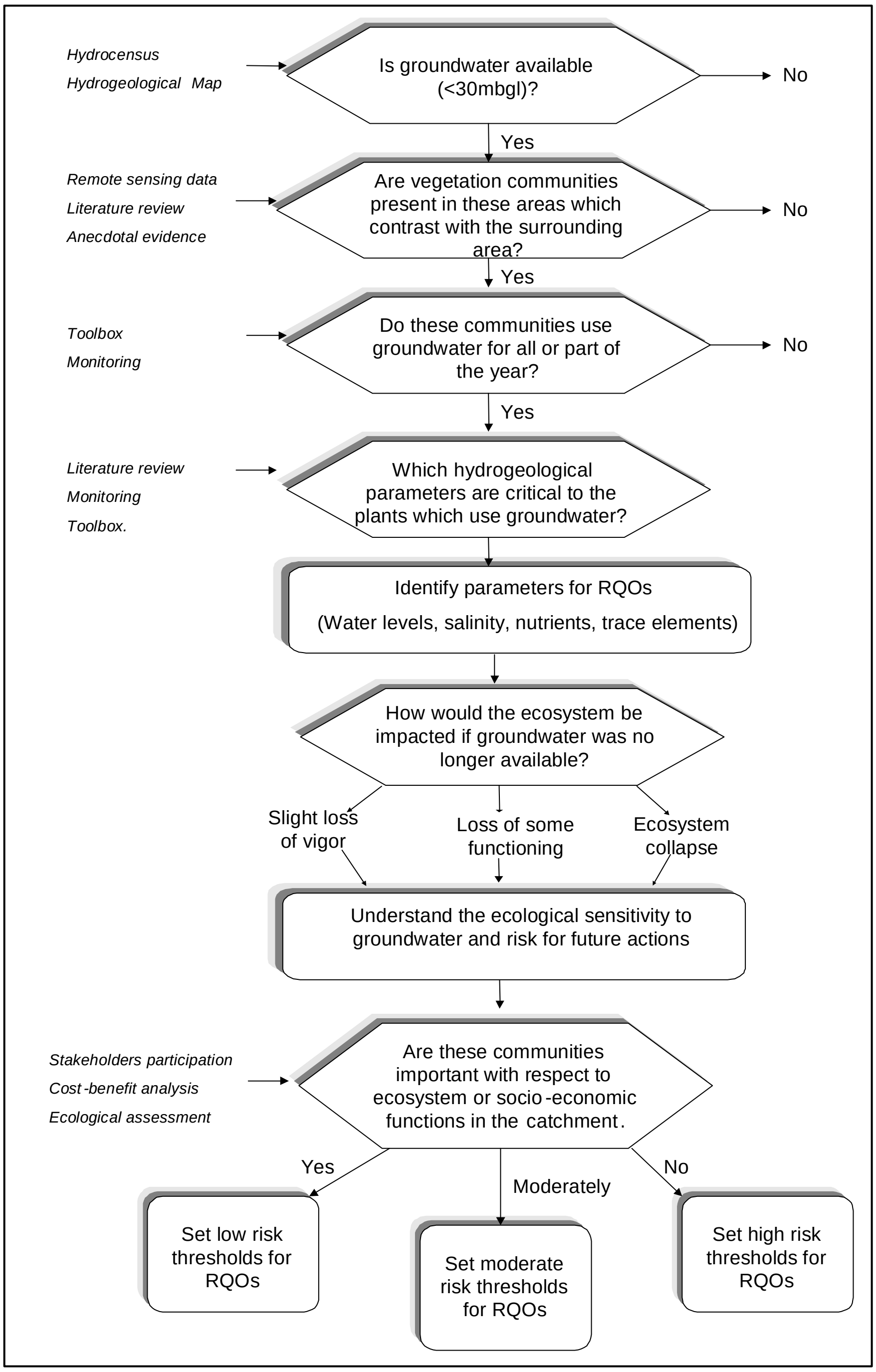

Figure 5.1: Preliminary protocol to identify groundwater-dependent vegetation and set RQOs (Colvin et al., 2002)

Case Study: Kammanassie springs

Using a spring classification developed by Kotze (2001), Cleaver et al. (2003) estimated 51% of springs in the Kammanassie area were Type 1 springs not dependant on groundwater as a source of water. These springs were all above the water table, and isotopic composition of the spring water showed them to be different from groundwater. These perched springs are not vulnerable to potential impacts by groundwater abstraction, but are susceptible to the effects of low rainfalls and drought. Thirty per cent of the springs were classified as Type 2 fed by groundwater and were considered potentially vulnerable to the effects of groundwater abstraction, and less vulnerable to periods of low rainfall. Nineteen per cent of the springs could not be classified, as an element of doubt exists with respect to their dependence on groundwater.

(Cleaver et al., 2003)

5.5 In summary

In response to the NWA, the role of groundwater in sustaining aquatic ecosystems is now starting to be understood. It has also been recognised that not all ecosystems are dependent on groundwater. Where a direct link exists between groundwater and aquatic or terrestrial ecosystems, protection mechanisms need to be put in place to ensure that groundwater abstraction does not negatively impact on ecosystems that are dependent on the groundwater. Such mechanisms need to take into account the degree of dependence and the risk of impact. Documented case studies of where groundwater abstraction negatively affected the environment are required to facilitate a better understanding of the cause and effect relationship.

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6. PREPARATORY PHASE

The purpose of this phase is to:

- Initiate a GRDM study
- Set the level of confidence of the GRDM assessment
- Appoint a GRDM assessment team.

6.1 Responsibility

A GRDM study can be initiated by DWAF Head Office as part of the compulsory licensing process, or by a DWAF Regional Office in response to a licence application. This is largely a DWAF management task undertaken by the RDM Directorate and the assigned RDM Study Manager, with specialist groundwater input being provided by DWAF personnel. When initiating a study:

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

The National Water Act (Act No. 36 of 1998) states that the Minister must determine the Reserve for all or part of every significant water resource, with the term ‘significant’ relating to the aerial extent of the resource and not to its importance. The basic unit of any GRDM assessment is the quaternary catchment, but the area undergoing compulsory licensing, or the scale or extent of the proposed application, usually defines the extent of the study.

6.2 Approach

As a means of initiating the study and setting the level of confidence required (and hence the Terms of Reference), a desktop GRDM assessment should be undertaken. This is done using the GRDM Assessment Software included with this manual. This assessment will provide an indication of recharge, basic human needs, baseflow and the groundwater allocation. If information is available regarding the volume of groundwater abstracted, then the Stress Index of a catchment can be determined (see section 9.2.3). The geohydrologist undertaking the assessment needs to be both experienced and familiar with the area of interest.

In some cases, a Scoping Study can be undertaken if information that is more detailed is required before the level of confidence can be set. The Scoping Study would aim to provide information about:

- 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
- aquifer stress (quantity and quality)
- geohydrological data and information available.

A key outcome of the Scoping Study is a recommendation regarding the level of GRDM assessment required for the study area.

As part of the preparation phase, the responsible geohydrologist is to identify and collect all available data and information for the area of concern. The extent of geohydrological work required is to be assessed in terms of the availability of data and the required level of confidence of the GRDM assessment.

A key factor 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.

Investment of both time and effort into the Terms of Reference is hence crucial. The Terms of Reference are to state clearly

- the extent of the study area,
- the level of GRDM assessment required,
- the key tasks to be completed,
- the key outcomes from the GRDM assessment,
- any specific methods or approaches that need to be followed and
- the schedule of the project.

As GRDM assessments are still in their infancy, and many assessments will have to be based on limited data, expert judgement and experience will play a key role in the assessment of an area. As a result, peer review and formal review of the outcome of an assessment are important for ensuring that the principles of the NWA are adhered to. 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.

6.3 Key outcomes

The four key outcomes of the Preparatory Phase are described as follows:

- Definition of study area – a map is to be produced at a suitable scale outlining the extent of the proposed GRDM assessment
- Level of GRDM assessment – the level at which the GRDM assessment is to be undertaken is defined (rapid, intermediate, comprehensive)
- Project Terms of Reference – Terms of Reference are to be compiled that clearly state the nature and extent of the GRDM assessment required.

- Appointment of study team – if the project team is to comprise members outside of DWAF, organisations capable of undertaking the assessment need to be identified and invited to tender for the work. The Preparatory Phase culminates with the signing of a contract between DWAF and the team appointed to undertake the work.

6.4 In summary

The Preparatory Phase is mostly a DWAF management task undertaken by the Directorate: Resource Directed Measures to define the area to be studied, set the level of GRDM assessment required, compile the Terms of Reference for the assessment and appoint a study team to undertake the assessment. In some instances, a Scoping Study can be commissioned to help the decision-making process.

7. DESCRIPTION OF STUDY AREA

The purpose of this phase is to:

- Collect existing geohydrological and related data for the study area
- Collect additional geohydrological data through appropriate geohydrological investigation
- Describe the study area in terms of its physical and geohydrological characteristics in detail appropriate to the level of GRDM assessment required
- Develop a conceptual understanding of geohydrological conditions in the study area and linkages to other components of RDM

7.1 Preamble

Previous approaches to GRDM assessments assumed that groundwater data were collected and interpreted in the process of undertaking the seven-step process (DWAF, 1999; Xu et al., 2003). It is now recognised that the GRDM assessment process may not be linear, and that the development of a sound conceptual understanding of geohydrological conditions is required before classifying a resource, determining the Reserve and setting Resource Quality Objectives. As a result, the second phase of the GRDM process entails data gathering and analysis typical of any groundwater resource assessment, but ensuring that the information is adequate to classify a resource, determine the Reserve and set Resource Quality Objectives in the manner prescribed in this manual and at the level specified in the project Terms of Reference.

It is beyond the scope of this training manual to train geohydrologists to undertake groundwater investigations or prepare reports. Because of the variety of methods, tools and approaches that can be used, it is also inappropriate to prescribe how geohydrologists must undertake their work. However, it is a prerequisite that an experienced geohydrologist lead the GRDM assessment and take responsibility for the work he or she undertakes. Listed below are potential sources of existing data and information, as well the type of information that needs to be included in a GRDM assessment report.

7.2 Data sources

A wide range of data and information can be used to characterise the geohydrology of an area. At desktop and rapid levels of assessment, national scale data sets may be the only sources of reliable information. These would then be supported by anecdotal information and the local knowledge and experience of the team undertaking the assessment. For intermediate and comprehensive GRDM assessments, site-specific data have to be collected. As much data as possible, and within the scope of the assessment, should be used. 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 7.1. This table excludes the data available through the GRAII project, since it is included in the software that accompanies this manual.

Table 7.1: Possible sources of data used during GRDM assessments

Data Needed	Data and Information	Source
Study area	Quaternary catchment boundaries	WR90
Population data	Population statistics	Central Statistical Services
Land Use		
Conservation areas		Department of Environment Affairs and Tourism
Water sources		DWAF
Physiography	Topographical maps - 1:250 000 - 1:50 000 (if needed)	Dir. Surveys and Land Information
Climatic data	Rainfall data Evaporation data	Weather Bureau WR90 SA Atlas of Agrohydrology and Climatology
Geology	Geological maps - 1:250 000 - 1:50 000 (if available)	Council for Geoscience
Geology Physiography	Remote sensing maps and data - satellite images - aerial photographs	Satellite Applications Centre Dir. Surveys and Land Information
Soils	Soil maps	Department of Agriculture Agricultural Research Council WR90
Drainage	Flow data Wetland inventory	DWAF Department of Environmental Affairs and Tourism WR90
Vegetation		National Botanical Institute WR90 Vegetation map
Geohydrology	Geohydrological maps - national groundwater maps - harvest potential map - groundwater vulnerability map - 1:500 000 geohydrological maps	Water Research Commission DWAF
Geohydrological data	Geohydrological data - national groundwater database - hydrochemical database - geohydrological reports	DWAF National Ground Water Data Base DWAF Regional Offices Water Research Commission Local authorities Consultants Other

The first step in collecting information is always to conduct a literature search and obtaining data from existing databases (e.g. National Groundwater Data Base - NGDB) is always the first step in collecting data. While published reports are usually relatively easy to find, a rich source of data exists in unpublished consulting reports and research projects not yet completed. Efforts to obtain these data and this information could benefit the GRDM assessment greatly.

A second very valuable source of data is a hydrocensus, although this is normally only warranted for studies at an intermediate or comprehensive level. This entails visiting landowners in an area and collecting as much geohydrological information as possible from them. This includes information pertaining to geology, drilling depths, borehole yields, groundwater levels, groundwater usage and other site-specific issues of relevance. During the visit, parameters such as depth to groundwater and quality (EC) may be measured, and water samples collected. This information, together with that from the literature and database surveys, can be used to compile a geohydrological model of the study area and be the basis for planning further fieldwork. Further geohydrological investigative work could include remote sensing, geophysical surveys, drilling and testing and chemical and isotope analyses. In the case of comprehensive GRDM assessments, numeric modelling may be warranted.

7.3 Report structure

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 to build a sound geohydrological conceptual understanding of an area is presented in Table 7.2. This list could also be used as a basic template for the geohydrological report to be prepared on completion of the study.

It is noted that the degree of detail presented in a report will vary from assessment to assessment. For example, the 'work undertaken' section in the introductory section would only be a few lines long in a rapid assessment, but in the case of a comprehensive assessment could entail a number of pages. It is in this section that details relating to the hydrocensus, geophysical surveys, drilling, pumping tests and other activities would be presented.

7.4 Key outcomes

The key outcome of this phase of the assessment is a draft report describing the study area in general, and the geohydrological conditions and conceptual model in particular. The report is to include as much of the information listed in Table 7.2 as possible, including tables and maps. Information used to prepare the report will then form the basis on which delineation of units, classification, Reserve determination and the resource quality objectives are based.

Key Note: GRDM assessment report

The geohydrological report will form the basis of the GRDM assessment report. The GRDM assessment report is to include the description of the study area as well as the outcomes of delineation, Classification and setting the Reserve and Resource Quality Objectives.

An area that needs to be given particular attention during this phase is the identification of ambient conditions (reference conditions) and those observed conditions that may be the result of abstraction or other anthropogenic activities. This information is used for defining the present status of a water resource (Chapter 9). To be able to make such an assessment, the assessor needs to conceptually re-establish natural conditions and compare these to conditions currently observed. This is done by considering historical data and/or extrapolating information from similar unimpacted resource units.

Table 7.2: Basic information required for a geohydrological description of a 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)
- 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) information (if available)
- Vegetation (map), including types and classification (e.g. Acocks, Low and Rebelo), riparian vegetation types and ecoregions (map)

4. Geology
- Stratigraphy and lithology (map, cross-sections)
- Weathering
- Structure (map, cross-sections)

5. 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
- Aquifer classification (sole source, major, minor, poor) (map)
- Aquifer vulnerability (map)
- Aquifer stress status (see Section 9.2.3)
- Conceptual geohydrological model of study area, including a water balance

7.5 In summary

This phase of the GRDM process entails data gathering and analysis typical of any groundwater resource assessment, but ensuring that the information is adequate to classify a resource, determine the Reserve and set Resource Quality Objectives in the manner prescribed in this manual and at the level specified in the project Terms of Reference. A draft report describing the study area in general, and the geohydrological conditions and conceptual model in particular, is to be produced. This will later form the basis of the GRDM assessment.

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8. DELINEATION OF RESOURCE UNITS

The purpose of this phase is to:

- Demarcate significant water resources in the study area
- Record the name and size of each resource unit on the GRDM assessment data sheet.

8.1 Preamble

The key outcome of this step is a map demarcating groundwater resource units, each of which is to be classified, a Reserve assessment undertaken and Resource Quality Objectives (RQOs) set. A geohydrologist performs this work. In delineating groundwater resource units, consideration must also be given to the role groundwater plays in the environment. Other components of the water cycle such as wetlands and rivers must be considered during the delineation process to assess possible interdependency and promote the integrated water resource management vision of the National Water Act. Before considering how to delineate resource units, we need to consider the meaning of 'significant water resource' as all significant water resources require in an RDM assessment.

8.2 Significant water resources

The National Water Act (Act No. 36 of 1998) recognises that water resources include watercourses, surface water, estuaries and aquifers. A watercourse means 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; and any collection of water which the Minister may, by notice in the *Government Gazette,* declare to be a watercourse. Reference to a watercourse includes, where relevant, its bed and banks.

The Minister of Water Affairs and Forestry is responsible for determining the Class, Reserve and Resource Quality Objectives for "all or part of every water resource considered to be significant". As in the case of 'water stress', the National Water Act refers to 'significant water resource', but does not define the term. The absence of a legal definition or official policy from DWAF may have considerable ramifications, as water resources not considered significant fall outside the protection afforded by Chapter 3 (sections 12–18) of the Act. This issue requires further consideration by DWAF. The current approach is that the term refers to the aerial extent of a water resource.

DWAF (1999) argues that 'significant', when used in the context of section 13 of the Act, does not relate to the importance of one water resource in comparison to another, and all water resources should be protected, not just those considered significant. 'Significant' relates rather to the geographic extent of the water resource for which a Class, Reserve and RQOs must be determined. DWAF (1999) further argues that it would not be reasonable or practical to determine RDM for water resources or parts of water resources that are very small, but neither would it be useful to determine a single Reserve for a whole primary or secondary catchment. It is considered necessary to delineate water resources in a way that is practical for water use planning, allocation and licensing purposes, but that is also at a scale that allows effective everyday management of the water resource itself. (The implication is then that a RDM assessment should be undertaken at a "significant" scale and that a GRDM assessment not be done at a very restrictive and local scale.)

Considering the purpose of the Act and the fact that significance relates to the size of a resource rather than its importance, water resource units that are sufficiently different from one another will warrant their own GRDM assessment and specifications relating to class, Reserve and resource quality objectives (DWAF, 1999). The geographic boundaries of each significant water resource unit hence need to be clearly delineated.

Key Note: Resource units

Water resources sufficiently different from one another are delineated into distinct units that have similar properties, with delineation being based on geohydrological, management or other criteria. Resource units can comprise part of a quaternary catchment, or a group of quaternary catchments.

8.3 Previous terminology

DWAF (1999b) introduced the terms 'homogeneous response units', 'geohydrological region types' and 'geohydrological response units', while Xu et al. (2003) refer to 'groundwater regions' and 'groundwater response units'. The term 'groundwater management unit' is also starting to emerge as a further mechanism of delineation. Part of the motivation for these terms was to allow direct comparison (and integration) with surface water components of the hydrological system and to provide some clarity regarding the basis for delineation.

In practice, it has been found that the terminology is unwieldy and confusing. This is particularly true in a field already overloaded with jargon. Also, other authors have used similar terminology. For example, Vegter (2001) defined 64 groundwater regions in South Africa based on dominant aquifer type, lithostratigraphy, physiography and climate. Considering terminology used by other components of RDM (DWAF, 1999; 2003), it is proposed that we only need to talk about 'groundwater resource units' (or 'groundwater units'). The other terminology ('homogeneous response units', 'geohydrological region types', 'groundwater regions', 'groundwater response units', 'groundwater management unit' etc.) can be used, but is not essential to the GRDM assessment. When using such terms, they need to be clearly defined.

Key Note: Groundwater resource unit

A 'groundwater resource unit' (or 'groundwater unit') is defined as a groundwater system that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit.

8.4 Delineation of resource unit

A three-tier system of delineation is used. Primary delineation is based on the default use of quaternary catchment boundaries and is usually only used for desktop and rapid assessments. More complicated and data-intensive delineation is undertaken for intermediate and comprehensive GRDM assessments.

8.4.1 Primary delineation

By definition, quaternary catchments are used as the primary delineation of water resource units in RDM assessments. In the case of desktop or rapid assessments, insufficient information will be available for refining resource units further, and most assessments will therefore be based on quaternary catchments. Basic information about quaternary catchments can be obtained from the GRDM Assessment Software or WR90 (Midgley et al., 1994)

8.4.2 Secondary delineation

When considering surface water, it is necessary to delineate zones of similar ecology within the study area. Typing is the first step in developing a conceptual understanding of a hydrological system and allows for extrapolation from one area to another. Methods to do this were developed by Kleynhans and Hill (1998) and were based on physical, hydrological and ecological characteristics. Groundwater resource units relate specifically to geohydrological characteristics, but may coincide with other significant water resource units or ecoregions, or parts thereof. In some instances, subsurface conditions could play an influential role in controlling hydrological and ecological conditions. This is particularly true in the case of effluent rivers and groundwater-dependent wetlands. Typing of the various components of the hydrological system should initially be conducted independently before the various specialists integrate and/or accommodate requirements from other component disciplines. Because of the number of factors to be considered, setting resource unit boundaries will probably be an iterative process requiring modification until all component requirements have been accommodated.

An example: Crocodile River

In the case of the Crocodile River, it was found that groundwater discharge from the dolomitic aquifer system accounted for about 60% of baseflow (DWAF, 1999). Because of the unique role groundwater played in the hydrological system, the dolomitic aquifers needed to be delineated as a distinct water resource unit.

When it comes to the groundwater component of RDM assessment, the second level of delineation is based on aquifer type (i.e. primary aquifer, secondary aquifer, dolomitic aquifer). Though these aquifers may be linked, the nature of subsurface flow in them is so different that they warrant obvious delineation. In some cases, it may be desirable to regroup these aquifer types into a single groundwater unit. This is considered and motivated during the third level of delineation.

8.4.3 Tertiary delineation

No formal methodology exists for delineating groundwater resource units beyond the second level of delineation. Until formal tools are available for this, expert judgement and local knowledge will be required. Here the conceptual understanding of the area developed during the description phase (Chapter 7) is used.

Three criteria are recognised that could be used as the basis for delineation, namely physical, management or functional criteria. The criterion could be used singularly, or in conjunction with other criteria. It is necessary to specify which criterion or characteristics were used in the delineation process, and motivate why that particular characteristic was considered the most appropriate.

When delineating a groundwater unit, it is worth remembering that a Class, Reserve and RQOs have to be set for each unit; linkages with other components have to be considered; and each unit will have to be managed. It is impractical to define a single unit within the area of a Catchment Management Agency; likewise is it not practical to divide quaternary catchments into a large number of groundwater units. The case study presented in this manual should be used as a guide to the delineation process.

8.4.4 Physical criteria

Typically, delineation based on physical criteria would consider one or more of the following:

- Geology
- Climate
- Topography and geomorphology
- Recharge
- Groundwater levels and flow directions
- Temporal hydrostatic response patterns
- Groundwater quality
- Groundwater use (and stress)
- Groundwater-dependent ecosystems.

A range of data and information sets is available to facilitate delineation (Baron et al., 1998; Midgley et al., 1994; Parsons, 1995, Vegter, 1995 and regional scale geohydrological maps), while geographic information systems (GIS) are recognised as a very powerful mapping and delineation tool. The extent of resource units must be presented on a map so that this information can be clearly and accurately conveyed to other specialists involved in RDM assessments.

8.4.5 Management criteria

The outcome of a GRDM assessment and aquifer management goals is key components of the National Water Resource Strategy. In some cases, it may be difficult to manage an aquifer on the basis of physical delineation considerations and it may be more practical and meaningful to use management criteria for delineation. Examples could include property, water user association, catchment management, water management and political boundaries.

8.4.6 Functional criteria

It may be useful to type areas in terms of the role groundwater plays in sustaining the environment. The purpose of this sort of typing is to identify components within the study area that play a unique role in the hydrological and ecological functioning of a water resource (Figure 8.1). Groundwater units could be grouped according to their chief role or function, i.e. maintaining system integrity, discharge integrity or ecological integrity. A rule was developed for each type to ensure that integrity is not compromised (Figure 8.1). These rules are then considered when setting RQOs and determining groundwater allocations.

Exclusion zones are used to maintain system integrity and drawdown limitations used to promote ecological integrity. In the case of river flow and spring flow, groundwater allocation is reduced by the low maintenance baseflow requirement set by the surface water specialist team. Maintaining the groundwater contribution to baseflow is an integral part of calculating the groundwater allocation (Chapter 10), while methods for determining the extent of exclusion zones and calculating drawdown limitations are described in Chapter 12. Nonetheless, the following general guidelines can be considered:

- A distance of 1 km from a particular feature can be used to demarcate exclusion zones, with the exact distance based on prevailing conditions and risk of impact.
- Exclusion zones or groundwater abstraction limitation zones can be demarcated around sensitive rivers and springs, if groundwater abstraction from such zones could significantly impact flow.
- Normally the entire low maintenance flow is assumed to be derived from groundwater, but this may be reduced in the case of influent streams.
- Drawdown and groundwater level limitations need to be based on site specific considerations.

It is worth noting that an area may be classified as more than one geohydrological type. For example, groundwater may sustain both river flow and riparian vegetation. In such cases, both rules apply when setting the groundwater allocation and RQOs i.e. reduction of groundwater allocation by low maintenance flow and setting of drawdown limitations.

8.5 Key outcomes

The key outcome of this phase of the GRDM assessment is a map demarcating significant groundwater resource units, each of which is to be classified, a Reserve assessment undertaken and RQOs set. This map will also help ensure that the RDM team has a common understanding of the study area.

In addition to producing a map, the name and aerial extent (in square kilometres) of each groundwater unit has to be recorded on the GRDM assessment data sheet. An example of a data sheet is presented in Table 8.1, as well as with the case study.

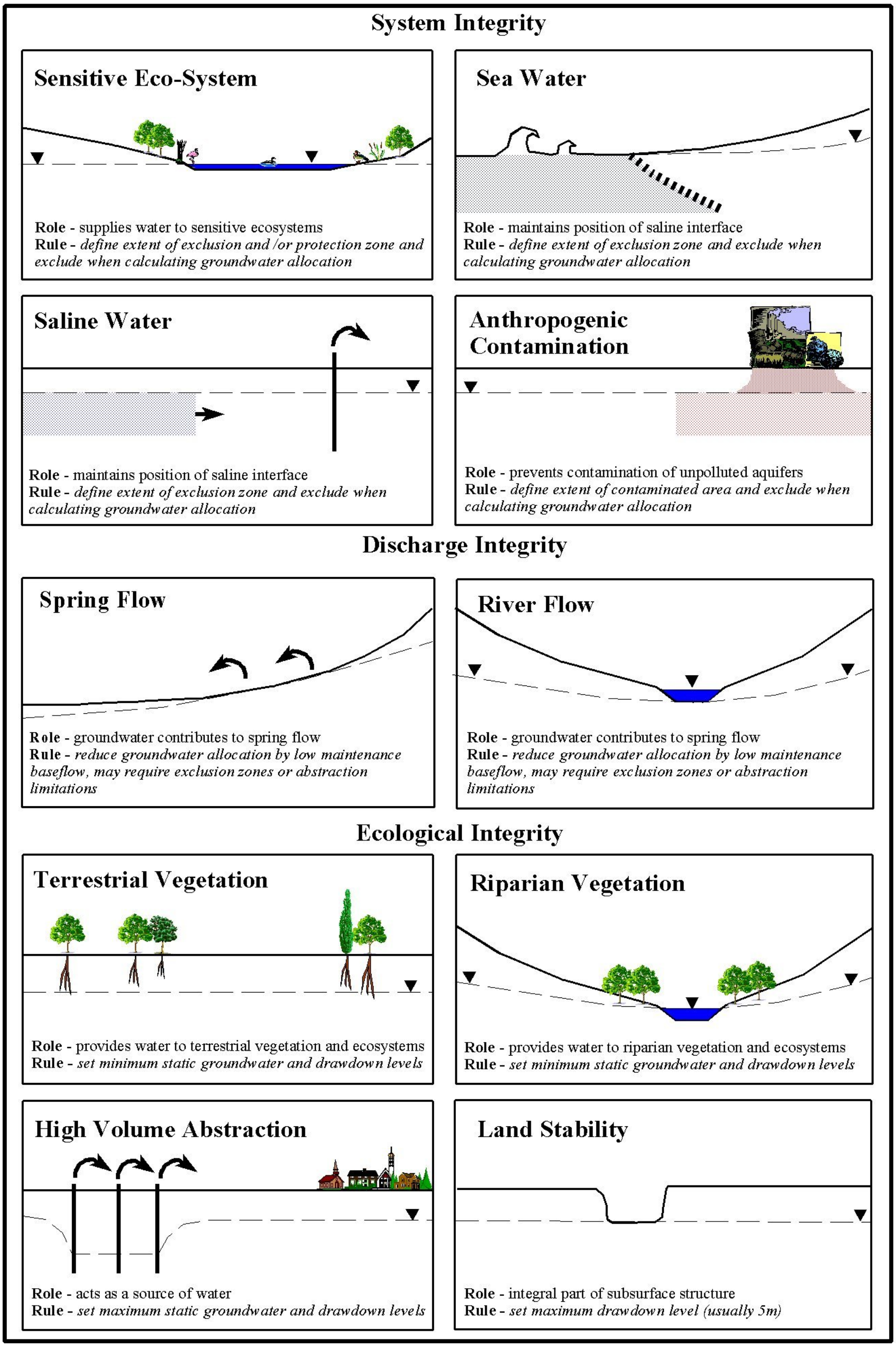

Figure 8.1: Groundwater resource unit delineation tool based on the role groundwater plays in sustaining the environment (DWAF, 1999)

Table 8.1: An example of the GRDM assessment data sheet

RESOURCE	**CLASSIFICATION**		**RECHARGE**			**RESERVE**			**ALLOCATION**	
Resource Unit	**Present Status Category**	**Resource Category**	**Total Area (km2)**	**Effective Area (km2)**	**Annual Recharge (Mm^3/a)**	**Groundwater Contribution Baseflow (Mm^3/a)**	**BHN Adjustment (Mm^3/a)**	**Reserve (% recharge)**	**Groundwater Allocation (Mm^3/a)**	**Current Groundwater Use (Mm^3/a)**

8.6 In summary

The purpose of this phase is to demarcate significant water resources in a study area. In the absence of a clear definition of a significant water resource, significance relates to size of a resource rather than its importance. Given the unwieldy and confusing terminology used previously regarding geohydrological delineation, it is proposed that we only need to talk about groundwater resource units (or groundwater units). Quaternary catchment boundaries are used to delineate groundwater units at a primary level, with aquifer type (primary aquifers, secondary aquifers, dolomitic aquifers) being used at a secondary level. When required and where sufficient data exist, further delineation can be based on physical, management and/or functional criteria.

8.7 Some useful references

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9 RESOURCE CLASSIFICATION

The purpose of this phase is to:

- Determine the present status category of each groundwater resource unit
- Define the water resource category of each resource unit in terms of natural, good, fair and poor
- Record the category of each groundwater resource unit in the GRDM assessment data sheet.

9.1 Preamble

Under Chapter 3 of the National Water Act (Act No. 36 of 1998), 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. Provision is made under section 14 of the Act for preliminary determinations of the Class and RQOs of water resources before the formal classification system is established. This allows for methods and tools to be developed simultaneously with implementation of the Act. As the classification system is still in a development stage, approaches described in this manual are still considered provisional.

Key Note: Preliminary assessments

Until a system for determining different classes of water resources has been prescribed by the Minister, all resource classes, Reserve determinations and Resource Quality Objectives are deemed preliminary. The preliminary status refers to a legal status of an assessment and not to the level of complexity or confidence of the methods used in the assessment.

Key Note: Classification process

Once a classification system is in place, DWAF will determine the Class of each significant water resource in the country, and with stakeholder consultation, a desired status category. This process will be undertaken over the next 10 to 15 years, starting in those areas where action is urgently required.

The overall objective of classifying a water resource is to define its water resource class (in terms of natural, good, fair and poor) and its management class (in terms of excellent, good and fair), as set out in Figure 9.1. The management class is set to ensure both long-term protection and management of our groundwater resources, as well as to promote development and use of the resource. The management class is also used to define the level at which the Reserve and RQOs must be set.

It is envisaged that the management class can only be set after consultation with stakeholders. However, the technical team undertaking the GRDM assessment can determine the Reserve categories and water resource classification using the tools provided. When setting the Reserve, two scenarios can be contemplated, namely if the class of a resource unit were to stay at its current level or if the class were to be set at the level of sustainability (i.e. fair) which allows for 65% of the estimated recharge to be abstracted.

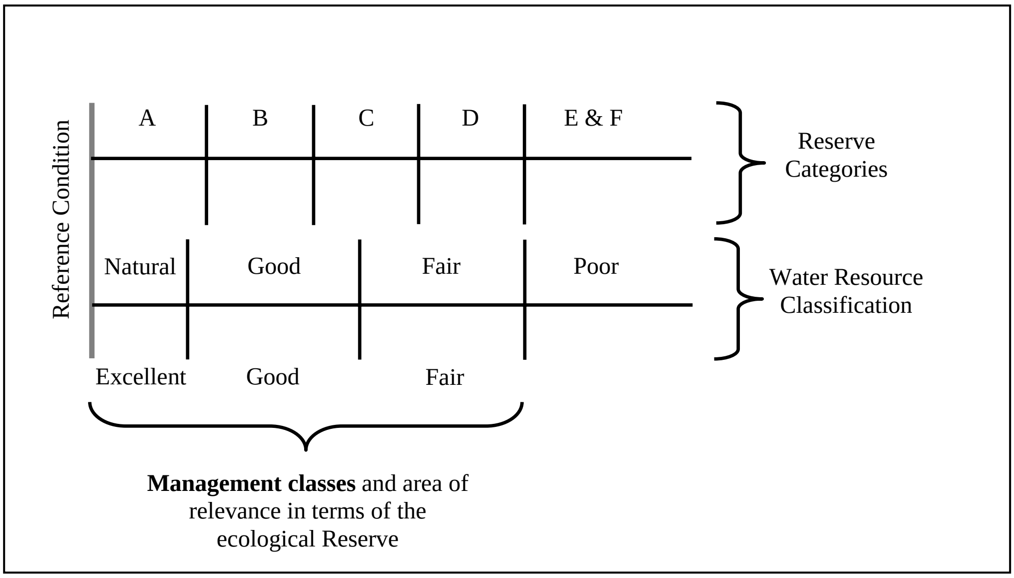

Figure 9.1: Relationship between various interim classification systems (DWAF, 2002b)

It is envisaged that the classification of water resources will include consideration of all components of the hydrological systems (surface water, wetlands, estuaries and groundwater) as well as the outcome of the catchment visioning process. The class of a resource is to be set by water resource managers, technical specialists and stakeholders in a catchment. In addition to water-related technical issues, consideration is also given to other factors such as social and economic factors during the catchment visioning and public participation processes.

Current practice in the RDM fraternity is to use the words ‘class’ and ‘classification’ to mean the management class of a water resource, as set through the public process. To avoid confusion, the word ‘category’ is used for all sorting or grouping prior to the public process. In other words, experts in a particular field base categorisation only on technical input. Classification implies both technical and public input into the classification process. In line with this, one should refer to a ‘water resource category’ instead of ‘water resource class’ indicated in Figure 9.1. This manual essentially addresses technical geohydrological issues relating to GRDM. Information from the categorisation process for groundwater is fed into the broader RDM assessment and the catchment visioning, public participation and classification processes, which has the ultimate aim of classifying a water resource into a management class (excellent, good, fair).

The classification of groundwater resources has typically not been practised at the level of Desktop or rapid Reserve determinations, nor is public input envisaged at these levels. Intermediate and comprehensive groundwater Reserve determinations typically make use of the categorisation process, as this is required to guide the setting of RQOs for groundwater resource units.

9.2 Present status categorisation procedure

9.2.1 Introduction

In terms of the overall groundwater categorisation process, and in order to be able to determine the class of a water resource, reference conditions need to be identified and present status assessed. A single present status category is assigned to each groundwater resource unit, and this is then used to assign a water resource category to each unit.

Reference conditions refer to the natural or ambient state of the groundwater system, while present status (also referred to as present ecological status category or PESC) relates to the current state of the groundwater system. A large difference between reference conditions and present state implies that a resource is in a degraded state and hence assigned a lower category. This stage of the GRDM assessment requires that information used to describe an area and develop a conceptual understanding of the geohydrology of that area (Chapter 7) be assessed to determine whether the groundwater is in its natural state or whether it has been modified through use or contamination. Where the resource has been modified, the significance of the modification needs to be appraised.

A series of tables has been prepared to guide the groundwater categorisation process. Both quantifiable and non-quantification parameters are used, but because data will be lacking in many instances, expert judgement will often be required during categorisation. While no rigorous step-by-step methods have been developed to categorise groundwater resource units, a three-phased approach has been developed, according to which a resource unit is categorised in terms of sustainable use (Table 9.1), in terms of levels of stress (Table 9.2) and then in terms of either usage or contamination (Tables 9.3–9.6).

9.2.2 Limits of sustainability

In considering appropriate classification procedures, it was assumed that the limits of sustainability would mark the difference between what would be considered acceptable use and unacceptable use. 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. Notwithstanding these problems, it was decided that those resources considered as being used at or about the limits of sustainable use should be assigned a ‘D’ category. In other words, those resources categorised as being either an ‘A’, ‘B’ or ‘C’ are considered as being used sustainably, while those categorised as either ‘E’ or ‘F’ are being over-utilised, and some corrective management action is required.

Indicators of unsustainable groundwater use include reduction in spring or river flow, vegetation die-off or reduced biodiversity, land subsidence or sinkhole formation or saline intrusion. For these to be good indicators, a causative relationship between groundwater abstraction and observed impact has to be established. While the work of Scott and Le Maitre (1997), Hatton and Evans (1998), SKM (2001) and Colvin et al. (2003) has been useful in helping to understand groundwater dependence, further work is required to provide practitioners with useful tools for establishing and assessing that dependence. A guide for assessing the status of groundwater units based on observed impacts resulting from groundwater abstraction is presented in Table 9.1.

Table 9.1: Guide for setting the present status category of a groundwater unit based on observed environmental impact indicators

PRESENT STATUS CATEGORY	**GENERIC DESCRIPTION**	**AFFECTED ENVIRONMENT**
A	Unmodified, pristine conditions	*No significant impacts observed*
B	Localised low level impacts, but no negative effects apparent	
C	Moderate levels of localised impacts – moderate or perceived impact on the environment	
D	Moderate levels of widespread impacts – limited but noticeable effect on the environment.	*Moderate to critical impacts to:* *- spring flow* *- river flow* *- vegetation* *- land subsidence* *- sinkhole formation* *- groundwater quality*
E	High levels of local impacts – serious effect on the environment	
F	High levels of widespread impacts – critical effect on the environment	

Using Table 9.1 and the conceptual understanding of the groundwater units in an area (Chapter 7), it needs to be assessed whether the resource is being used sustainably. If indicators of unsustainable use are observed (e.g. reduced spring flow, sinkhole formation, inducement of saline intrusion, etc.), then the resource unit is assigned either an ‘E’ or ‘F’ category. If no signs of unsustainable use are observed, then no category is assigned at this stage, and consideration is given to the level of stress. This approach is followed due to the complexity of defining natural conditions.

9.2.3 Defining stress

The concept of stressed water resources is addressed by the National Water Act, 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; or
- Where water resource quality is under threat.

To provide a quantitative means of defining stress, a groundwater stress index was developed by dividing the volume of groundwater abstracted from a groundwater unit by the estimated recharge to that unit. For example, if 5.2 Mm^3/a is abstracted from a unit recharged by 12.3 Mm^3/a, then the stress index is 0.42. Using Table 9.2 as a guide, the calculated stress index is used to define the level of stress of a groundwater unit. Units categorised as being either ‘E’ or ‘F’ are considered stressed or critically stressed and, under section 43 of the National Water Act, should be subject to compulsory licensing.

After calculating the stress index, the guide presented in Table 9.2 is used to set the present status category of each groundwater unit. Firstly, the stress index is used to check the category assigned using the sustainability indicators i.e. whether an ‘E’ or ‘F’ category is appropriate. If the stress index of a unit is more than 0.65, then the appropriate higher category is awarded (A, B, C or D). The lowest permissible category is D, since it is the lowest limit of sustainability.

Table 9.2: Guide for determining the level of stress of a groundwater unit

PRESENT STATUS CATEGORY	**DESCRIPTION**	**STRESS INDEX** **(abstraction / recharge)**
A	Unstressed or slightly stressed	< 0.05
B		0.05–0.20
C	Moderately stressed	0.20–0.40
D		0.40–0.65
E	Highly stressed	0.65–0.95
F	Critically stressed	> 0.95

9.2.4 General Categorisation

In many cases it is quite obvious when a resource is being over-used or is stressed, as these conditions manifest themselves as declining groundwater levels, worsening groundwater quality, reduced spring and baseflow, heightened levels of conflict in a catchment etc. Assessment of less impacted units can be more difficult as the signs of impact are less obvious. To assist in this assessment, a set of guiding tables has been prepared based on groundwater use (Table 9.3), observed contamination (Table 9.4) and expected contamination (Table 9.5).

The potential or expected groundwater contamination tool (Table 9.5) relates aquifer vulnerability to expected land use impact. If a site-specific assessment using DRASTIC (Aller et al., 1985) is not carried out, vulnerability as presented by Parsons and Conrad (1998) can be used. A table relating expected impact to land use was developed (Table 9.6). This table was based largely on the work of Foster and Hirata (1998). It can be modified in future to include approaches developed as part of the groundwater quality management strategy (DWAF, 1998). For example, a medium-sized sewage works located on a highly vulnerable groundwater system requires that the present status of that groundwater unit be set as ‘D’.

It is accepted not all impacts will be covered in the guiding tables (Tables 9.1–9.5). To accommodate other considerations, the generic descriptions used in Table 9.1 can be used to guide categorisation using factors other than those already accommodated. For example, if a few low-yielding springs in a small area have been shown to be impacted by groundwater abstraction, then a present status categorisation of ‘B’ may be appropriate. If the springs were to dry up and significantly impact sensitive ecosystems, a ‘C’ or lower category might be assigned.

In considering the present status category of a resource unit, the lowest category is assigned. If a unit can be assigned a ‘B’ category for usage and a ‘D’ for contamination, then the unit will be assigned a single present status category of a ‘D’. It is the responsibility of the geohydrologist to assign the most appropriate category to a resource unit.

Table 9.3: Present status category assessment based on groundwater usage

PRESENT STATUS CATEGORY	DESCRIPTION	GUIDE
A	Unmodified, pristine conditions	Very limited use (groundwater use is less than 5% of recharge)
B	Low volume groundwater usage, largely natural conditions, no negative impacts apparent	Stock watering, farm domestic water supply, rural water supply (use ranges between 5% and 20% of recharge)
C	Moderate volumes of groundwater usage, little or no negative impacts apparent	Small-scale irrigation, rural water supply, water supply for villages and small towns. (use ranges between 20% and 40% of recharge)
D	High volumes of groundwater usage, but with little apparent negative impact	Water supply for large rural communities, medium to large towns, large-scale irrigation. (use ranges between 40% and 65% of recharge)
E	Stressed system due to over-abstraction of groundwater or inappropriate land-use	High volume of major groundwater users (use ranges between 65% and 95% of recharge)
F	Critical over-abstraction of groundwater or highly sensitive hydrological environment	Very high volume of major groundwater users (groundwater use is in excess of 95% of recharge)

Table 9.4: Present status category assessment based on groundwater contamination

PRESENT STATUS CATEGORY	DESCRIPTION	GUIDE
A	Unmodified, pristine conditions	Natural groundwater quality conditions prevail
B	Localised, low levels of contamination, but no negative impacts apparent	Largely natural groundwater quality conditions prevail
C	Moderate levels of localised contamination, but little or no negative impacts apparent	Some localised contamination detected; may impact the purpose for which groundwater is used
D	Moderate levels of widespread contamination, which limit the use or potential use of the aquifer	Groundwater contamination is quite widespread but levels are relatively low; may impact the purpose for which groundwater is used
E	High levels of local contamination which render parts of the aquifer unusable	High levels of contamination detected in places; use of groundwater from impacted area to be restricted or prohibited
F	High levels of widespread contamination which render the aquifer unusable	Very high levels of contamination widespread throughout the aquifer. Groundwater use to be restricted or prohibited.

Table 9.5: Present status category assessment based on potential or expected groundwater contamination

	VULNERABILITY (see Parsons and Conrad, 1998)			
EXPECTED LAND USE IMPACT (see Table 9.6)		**Low**	**Medium**	**High**
	Low Impact	A	B	B
	Moderate Impact	B	C	D
	High Impact	C	D	E

Table 9.6: Expected impact assessment based on observed land use

EXPECTED IMPACT	LAND USE
Low impact	natural veld industrial area – (not chemical) pastures rural area – farms abattoirs irrigation – limited chemicals kraals rural area – low density
Moderate impact	sewage works – small (less than 1 Mℓ/d) spills – hazardous waste site – small industrial area – food processing irrigation – chemicals rural area – high density feedlots sewage works – medium waste site – medium (between 1 and 20 Mℓ/d)
High impact	industrial area – chemical mine dumps urban area waste site – large sewage works – large (greater than 20 Mℓ/d) underground storage tanks industrial area – metal processing power generation waste site – hazardous

9.3. Water resource categorisation

Once a single present status category has been assigned to each resource unit, then the groundwater resource category can be determined using Table 9.7 It must be remembered that the desired status of the resource and management class is not addressed here, but rather in the public participation and catchment visioning processes.

Table 9.7 presents the most recent approach to classification (DWAF, 2002b). Wherever possible, the approaches used by the different components of RDM should be closely aligned to promote integration and a common understanding.

Table 9.7: Relationship between present status category, desired status category and management class

Present Status Category	**Water Resource Category**	***Desired Status * Category***	***Management * Class***
A – unmodified natural	Natural	*A – Highly sensitive systems, negligible risk allowed*	*Excellent*
B – largely natural	Good	*B – Sensitive systems, small risk allowed*	*Good*
C – moderately modified		*C – Moderately sensitive systems, moderate risk allowed*	
D – largely modified	Fair	*D – Resilient systems, large risk allowed*	*Fair*
E – seriously modified	Poor		
F– critically modified			

Note: *only considered during public participation and catchment visioning processes

9.4 Key outcomes

The key outcome of this phase of GRDM is to set the water resource category for each groundwater resource unit (natural, good, fair, poor). When set, the information is to be recorded on the GRDM assessment data sheet.

9.5 In summary

The purpose of this phase of a GRDM assessment is to define the present status category of each groundwater resource unit based on levels of sustainable use, a Stress Index and other parameters. This requires an appreciation of the reference conditions of that unit and an assessment of the impact of anthropogenic activities on that resource unit. A single present status category is assigned to each unit. Once the present status of a groundwater unit has been assessed using a series of guiding tables, the water resource category of each unit is set using Table 9.7 and the outcome of the categorisation process recorded on the GRDM assessment data sheet.

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10. QUANTIFICATION OF THE RESERVE

The purpose of this phase is to:

- Quantify the groundwater component of the Reserve (Groundwater Allocation) for each resource unit
- Record the groundwater component of the Reserve on the GRDM assessment data sheet.

10.1 Groundwater component of the Reserve

The groundwater component of the Reserve is the part of the groundwater resource that sustains basic human needs and aquatic ecosystems. Because groundwater is far more widespread geographically than surface water resources, that component of the geohydrological system which sustains the Reserve is only a part of the greater system considered under GRDM. To be able to quantify the groundwater component of the Reserve, we need to be able to estimate the volume of groundwater needed to satisfy basic human needs (BHN) and groundwater discharged to surface water bodies. Groundwater can 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. (Please note that RQOs can be based on **both** the Reserve and Classification)

10.2 Some terminology issues

In response to the National Water Act (Act No. 36 of 1998), a host of new terminology has been and is being developed, much of which is used loosely or incorrectly. The Act only includes a limited number of definitions, and hence provides little guidance. As a result, we need to be careful in the way in which we use terms and ensure we have a common understanding of terminology, particularly when working in multidisciplinary groups. For convenience, refer to the extensive Glossary included in this manual.

10.3 Quantification process

To be able to quantify the groundwater component of the Reserve, the following relationship has to be solved:

$$GW_{allocate} = (Re + GW_{in} - GW_{out}) - BHN - GW_{Bf}$$

where: $GW_{allocate}$ = groundwater allocation
Re = recharge from rainfall
GW_{in} = groundwater inflow
GW_{out} = groundwater outflow
BHN = basic human needs
GW_{Bf} = groundwater contribution to baseflow

In essence, a combination of the groundwater contribution to baseflow and basic human needs met from groundwater is the volume of groundwater required to sustain the Reserve. However, because the Reserve bucket analogy is inappropriate for groundwater and the groundwater component of the Reserve is best represented by a groundwater level rather than a volume (DWAF, 1999), the concept of recording the groundwater component as a Reserve is problematic. It is preferable and more practical to determine *the volume of groundwater that can be abstracted from a resource unit without impacting the ability of groundwater to sustain the Reserve*. This is referred to as the Groundwater Allocation.

Key Note: Groundwater allocation

The Groundwater Allocation is that volume of groundwater that can be allocated for use after consideration of the Reserve and RQOs. The Groundwater Allocation has to be assigned to international obligations, Schedule 1 usage, General Authorisations and Existing Lawful Users before new licence applications can be considered. This allotment of the Groundwater Allocation is a post-GRDM activity (Figure 3.1).

Key Note: Groundwater quality

Groundwater quality issues are not addressed under the Reserve, but rather as part of resource classification and RQOs. Groundwater quality management is most effectively addressed under Source Directed Measures. We cannot in this manual provide a method for quantifying the groundwater quality component of the Reserve. The issue of a groundwater quality Reserve requires further research.

10.3.1 Recharge

Recharge is defined as the addition of water to the zone of saturation. Generally, this only includes contributions from precipitation, but leakage into the subsurface from rivers, dams and wetlands can be substantial under specific conditions. Aquifers can also be recharged by inflow from adjacent groundwater bodies. Subsurface inflow is addressed in section 10.3.2.

Recharge is one of the most important parameters in assessing the sustainable volume of groundwater that can be abstracted from an aquifer system. Unfortunately, it is also difficult to quantify because of rainfall variability and aquifer heterogeneities. It is beyond the scope of this training manual to provide training in methodologies used to quantify recharge, as this requires a high level of geohydrological expertise and judgement. However, guidance is given regarding where information can be obtained and which tools can be used for estimating recharge (section 12.1).

As a start, the national scale map of recharge prepared by Vegter (1995) (Figure 10.1) can be used to obtain an indication of recharge; while work by Kirchner et al. (1991), Parsons (1993, 2000), Bredenkamp et al. (1995), Woodford and Chevallier (2002), Sami (2003), Xu and Beekman (2003) and others provides estimates of recharge in various parts of the country. It is the geohydrologists task to provide the best possible estimate of recharge within the scope and level of GRDM assessment being undertaken.

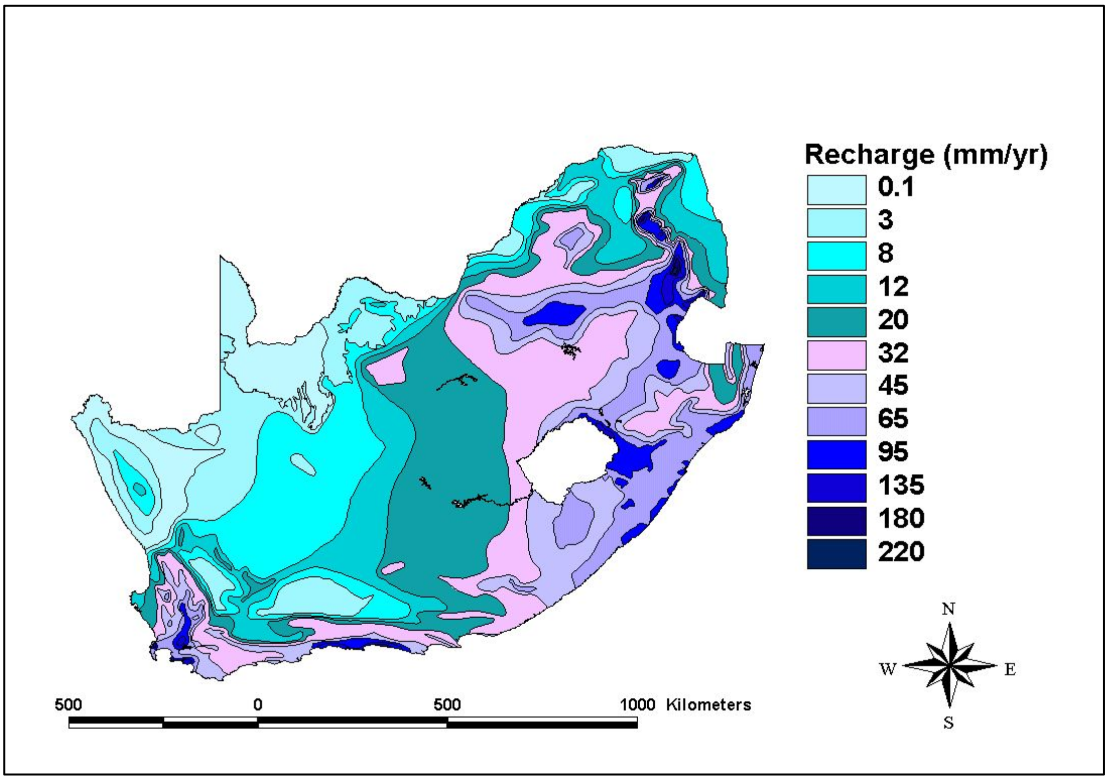

Figure 10.1: National scale map of recharge prepared by Vegter (1995)

In some instances, reserving the volume of groundwater discharged at surface is inadequate for ensuring that groundwater-dependent ecosystems are protected. Examples of this include wetlands, groundwater-dependent vegetation and the strip along the coast that is vulnerable to saline intrusion. By creating a protection or exclusion zone around these areas in which abstraction is prevented or restricted, the ability of the groundwater system to sustain these systems can be protected. The concept of exclusion zones was first addressed in section 8.4. However, it may become necessary during an assessment to consider the need for expanding protection or exclusion zones.

Sensitive ecosystems need to be delineated (in consultation with an appropriate specialist) and the area of the protection zone around them calculated. Methods for doing so are addressed in section 12.4 and included in the GRDM Software. The total area of the groundwater resource unit is then reduced by the area of the protection zone to yield an effective area of the groundwater unit. Recharge to the effective area has to be calculated and recorded on the GRDM assessment data sheet.

In addition to reducing the area of resource units, groundwater abstraction from a protection zone can be prevented or restricted. This approach forms part of setting Resource Quality Objectives (Chapter 11).

10.3.2 Groundwater inflows and outflows

Quantification of the Groundwater Allocation requires that groundwater inflows and outflows be calculated in addition to recharge from precipitation. While often small in relation to recharge to a quaternary catchment, subsurface inflows and outflows may be significant when dealing with smaller groundwater resource units or when dealing with artificial recharge. When undertaking desktop or rapid GRDM assessments, the quantification of recharge may suffice. However, when undertaking more detailed assessments, consideration of subsurface inflows and outflows is required. Methods for calculating inflows and outflows are described in section 12.2 and are included in the GRDM Software.

10.3.3 Basic human needs

Currently, basic human needs (BHN) are set by the Water Services Act (Act No. 108 of 1997) at 25 ℓ/p/d. The BHN component of the Reserve is readily calculated by multiplying the number of people living within the confines of a resource unit by 25 ℓ/d. To be correct, this volume should be multiplied by the ratio of people dependent on groundwater for their water supply. However, because the BHN component is generally very small (in relation to recharge), this correction is seldom necessary. The source of population statistics used for this calculation must be clearly referenced.

The definition of the Reserve refers to people who are now or who will - in the reasonably near future - be reliant on a resource for water. While no guidance is provided on what is meant by the reasonably near future, it is assumed that this is in the order of 5 years. As census data is seldom updated more frequently than this and because the basic human needs component is generally very small, use of the latest available census data will suffice when estimating this component of the Reserve.

10.3.4 Groundwater contribution to baseflow

One of the positive outcomes from the Reserve process to date has been an improved understanding of surface–groundwater interaction. An investigation by Parsons (2003) found that not all baseflow is derived from groundwater, and that inconsistent use (or misuse) of terminology contributed to a poor understanding of the interaction.

Baseflow is a non-process related term for low amplitude, high frequency flow in a surface water body during dry or fair weather periods. It is not a measure of groundwater discharged into a river or wetland, but it is recognised that both groundwater and interflow contribute to baseflow. The baseflow component of flow is determined using a variety of baseflow separation techniques (Herold, 1980; Smaktin and Watkins, 1997; Hughes and Munster, 1999). From this, a baseflow index can be determined. The baseflow index is a ratio of the mean annual baseflow in a river divided by total annual flow (mean annual runoff, or MAR).

Because of the realisation that not all baseflow is derived from groundwater, the use of baseflow in a river to provide an indication of recharge in a catchment must be used with caution. It may be possible to determine the groundwater contribution to flow by examining river flow characteristics during the latter part of the dry season. This approach was used on the Hex river (Papini et al., 2001) and Thukela river (Parsons, 2003), but requires further research. Hughes (2003) is in the process of incorporating a groundwater component into a rainfall run-off model that may provide a tool for quantifying the groundwater contribution to flow.

The GRDM Assessment Software includes a baseflow separation routine using the Herold method (Herold, 1980) and requires monthly flow data. While geohydrologists should be able to address the groundwater contribution to baseflow, it is strongly recommended that this be done in consultation with an experienced hydrologist. The geohydrologist can use the GRDM Software for desktop or rapid assessments, but hydrological input must be obtained for intermediate and comprehensive assessments. Typically, the low maintenance baseflow determined by the specialists undertaking the river quantity component of the Reserve assessment is used in the GRDM assessment.

The following approach can be used to assess the groundwater contribution to baseflow and the quantification thereof:

1. Using Figure 10.2, assess whether the baseflow in a river is likely to be fed by groundwater. Ephemeral or highly seasonal streams and those streams with a low baseflow index are unlikely to be groundwater fed.
2. If the river has a low probability of being groundwater-fed, then no further assessment of baseflow is required.
3. If the river has a moderate to high probability of groundwater sustaining baseflow (perennial rivers with a moderate to high baseflow index, say above 0.2) or significant perennial springs exist in a resource unit, then a baseflow separation assessment is required. In the case of intermediate and comprehensive assessments, this should be undertaken by an experienced hydrologist.

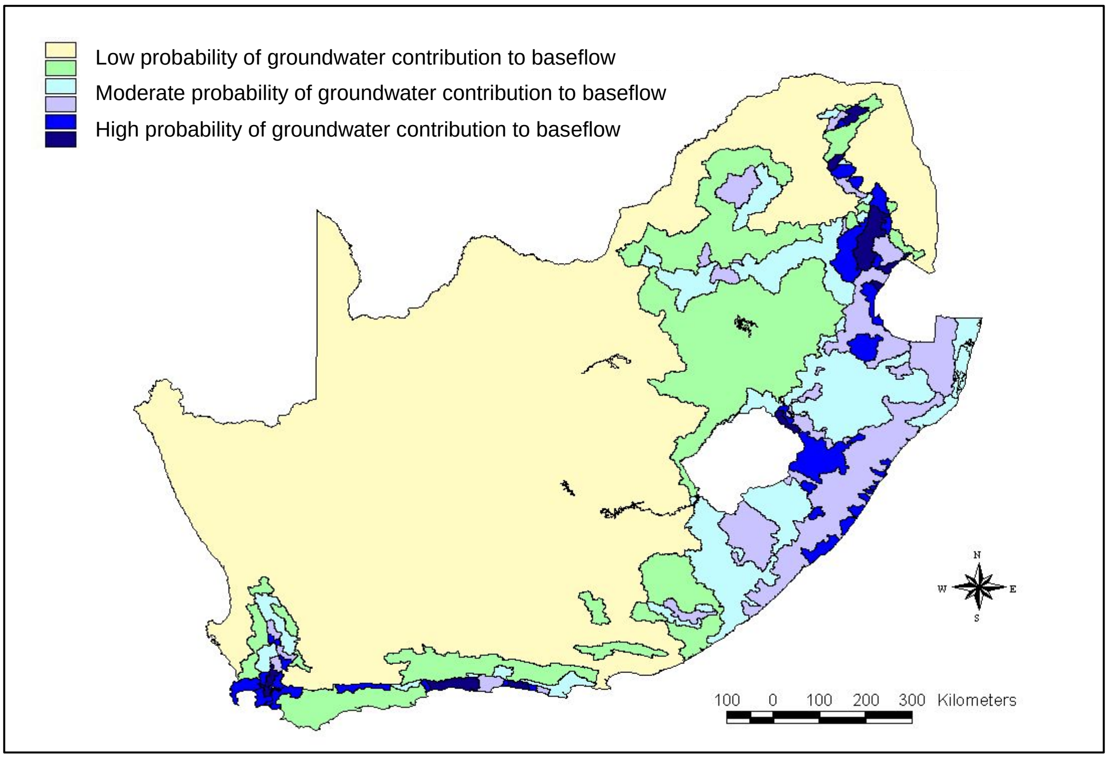

Figure 10.2: National scale map showing the relative probability of groundwater contributing to baseflow

10.4 Key outcomes

The key outcome of this phase of GRDM is to calculate the groundwater allocation for each groundwater resource unit and record the allocation on the GRDM assessment data sheet.

10.5 In summary

The purpose of this phase of a GRDM assessment is

- to calculate recharge to each groundwater resource unit,
- estimate the basic human needs to be supplied from groundwater and
- quantify the groundwater contribution to baseflow.

This information is used to quantify the groundwater allocation, which will form the basis for the allotment and apportionment of groundwater to current and potential users. The project geohydrologist is responsible for quantifying recharge, and may assess the groundwater contribution to baseflow for desktop and rapid GRDM assessments. However, an experienced hydrologist should provide this information for intermediate and comprehensive assessments.

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11. RESOURCE QUALITY OBJECTIVES

The purpose of this phase is to:

- Define RQOs for each resource unit
- Relate the RQOs to management objectives

11.1 Purpose of resource quality objectives

The Minister of Water Affairs and Forestry is required to determine the Class and Resource Quality Objectives of all or part of those water resources considered significant. The purpose of the Resource Quality Objectives is to establish clear goals relating to the quality of the relevant water resource. When setting Resource Quality Objectives (RQOs), 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. 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.

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. As is the case in the classification process, it is the task of the GRDM geohydrologist to provide RQOs from a scientific or technical perspective that can be fed into the catchment visioning process. RQOs are considered powerful tools for implementing groundwater protection for sustainable use.

From the NWA: Resource Quality Objectives

Under Section 13.3 of the National Water Act (Act No. 36 of 1998), Resource Quality Objectives 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 land-based activities which may affect the quantity of water in or quality of the water resource; and**
(h) **any other characteristic of the water resource in question**.

Note: RQOs in **bold** relate directly to groundwater.

11.2 What are Resource Quality Objectives

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:

- They set limits that are simple and measurable.
- They should reflect a balance between the need to protect and sustain a water resource on the one hand, and the need to develop and use them on the other hand.
- They provide goals within a management class and set the limits of acceptable impact.
- They may be numeric or descriptive.

RQOs should be set in consultation with stakeholders as part of the catchment visioning process, and can be implemented through catchment management strategies, source-directed controls, land-use planning and licensing conditions (Colvin et al., 2004).

From the NWA: Definition of resource quality

"Resource quality" means the quality of all the aspects of a water resource including:

(a) the quantity, pattern, timing, water level and assurance of instream flow;
(b) the water quality, including the physical, chemical and biological characteristics of the water;
(c) the character and condition of the instream and riparian habitat; and
(d) the characteristics, condition and distribution of the aquatic biota.

11.3 Setting Resource Quality Objectives

At present, no formal methodologies exist with respect to setting RQOs. The Water Research Commission initiated a study to develop guidelines (Colvin et al., 2004). Guidelines presented in this document, together with those presented by DWAF (1999) and Xu et al. (2003) have been used to form the basis for the methodology presented here. Because no formal methods exist, all RQOs are considered preliminary.

Setting RQOs requires an understanding of groundwater resources and their boundary conditions, uses of groundwater, the importance of various uses, the current degree of modification of the resource and the agreed degree of modification of the resource (Colvin et al., 2003). When setting RQOs, consideration must also be given to dependencies on groundwater and the consequences of modifying the geohydrological regime.

Stakeholder involvement is a key premise in the management of South Africa's water resources. It is a requirement that a formal public participation process form part of comprehensive RDM determinations, during which stakeholders will be included in the setting of RQOs. Furthermore, RQOs need to be published for comment and review. Other levels of GRDM determinations do not entail the same level of stakeholder involvement. In these instances, the responsible authority takes the leading role in setting RQOs i.e. DWAF and CMAs.

11.4 Types of groundwater RQOs

RQOs can include any objective or goal that may need to be met to ensure that the groundwater resource is maintained in a desired and sustainable state. Typically, they relate to:

- Groundwater levels and gradients
- Groundwater quality (the presence and concentrations of particular substances in water)
- Groundwater abstraction volumes
- Land use activities that may impact the quantity or quality of a groundwater resource
- Aquifer structure and integrity (see Figure 8.1).

It is important to realise that RQOs are nothing new, but are a new way of considering and articulating aquifer management goals and objectives. As a rule, the setting of RQOs will pertain to the following broad areas:

- Abstraction volumes
- Water levels and gradients
- Water quality
- Temporal hydrostatic response patterns
- Exclusion zones (abstraction rates and activities/land uses).

11.5 Considerations in setting RQOs

Groundwater conditions vary considerably across the country, making it difficult to set generic guidelines for RQOs. For example, groundwater quality in the north-western parts of South Africa can be very poor in places, with ambient EC levels being in excess of 1 000 mS/m. The quality of groundwater yielded by quartzitic sandstones in the southern and eastern parts of the country may be as low as 20 mS/m. Because of this variation, it is a rule that RQOs cannot be set at a level more stringent than reference conditions. If the natural groundwater quality is in the order of 450 mS/m, and the limit set for basic human needs is 300 mS/m, the RQOs for that particular significant water resource can be no better than 450 mS/m. The RQO could hence be that no groundwater quality degradation is permissible.

Key Note: Rule when setting RQOs

RQOs cannot be set at a level more stringent than reference conditions of a particular water resource.

Resource Quality Objectives provide a very useful mechanism for attaining a balance between protection and use. To be able to get the balance right, one has to consider groundwater dependencies, effects or impacts of use and the consequence of any effects resulting from that use. One also has to consider the sustainable limits of a resource. Initially, RQOs will mostly be set based on past experience and expert judgement, but proper monitoring is crucial to allow for the revision of RQOs based on aquifer performance. It is a requirement of the

National Water Act (Act No. 36 of 1998) that licences be reviewed. To ensure efficient and effective use of a resource, review has to be based on monitored data.

Key Note: Characteristics of good environmental indicators

- Have an agreed, scientific meaning
- Represent an environmental aspect of importance to society
- Its meaning is readily understood
- It has a sound and practical measurement process
- Helps focus information to answer important questions

(from Colvin et al., 2003)

11.6 Format of RQOs

In setting RQOs, one has to recognise that they need to be transparent, and that all calculations and assumptions made in the setting of RQOs need to be recorded. RQOs also need to be semi-quantitative in that they have to effectively combine expert knowledge, stakeholder values and measurable aquifer parameters. Importantly, they must be practical, implementable and measurable. It is pointless to develop a set of objectives that cannot be implemented or monitored to check whether the objective is not being exceeded. Each RQO should be defined in terms of:

- The resource attribute value, e.g. groundwater level, a specific water quality parameter
- The location or area of groundwater management to which it should apply
- Acceptable temporal and spatial range of values
- Frequency and density of monitoring to ensure compliance.

11.7 Procedure for setting RQOs

The setting of RQOs must be based on the conceptual understanding of groundwater resource units (Chapter 7), the category of resource that is to be sustained (Chapter 9) and the Reserve that has to be met (Chapter 10). The following procedure to be followed when setting RQOs was adapted from Colvin et al. (2003):

1. Define critical characteristics or attributes of the groundwater system to maintain the aquifer functionality in terms of GRDM. These could include groundwater levels and gradients, groundwater quality, discharge volumes into rivers and groundwater abstraction.
2. From the critical characteristics or attributes, select key measurable indicators that relate to the resource itself or land-use impacts. These should be based on the type of risk posed to the resource and uses. For example, if a groundwater resource is used to supply basic human needs and a cemetery is the hazard to pose a risk to the aquifer, then concentrations of nitrate, ammonium and phosphate might be appropriate key measurable indicators.

3. Define monitoring protocols to provide the data required to assess whether the RQOs are being met or exceeded, and to be used to review the GRDM assessment at some point in the future.

The RQOs developed during the GRDM assessment will be fed into the catchment visioning process. Depending on the outcome of that process, the technically-based objectives may have to be revised.

11.8 Examples of groundwater RQOs

The following are some examples of RQOs drawn from actual case studies:

- The groundwater level within 50 m of the river should not be lowered by more than 0.5 m during summer (October–March). Continuous monitoring (hourly) must be implemented by the abstractor to ensure that this RQO is not breached. Monitoring is to have an accuracy of ± 10 cm.

- The sustainable volume of groundwater abstractable from the significant water resource is 300 000 m^3/a. Abstraction is to be evenly distributed in both time and space. This RQO was based on low-confidence estimates of recharge and it was assumed 65% of the annual average recharge could be abstracted without inducing impacts that negatively influence the functioning and structure of the aquifer system.

- No groundwater abstraction is permitted within 150 m of the wetland. Furthermore, no land-based activity that could result in groundwater contamination is permitted in this zone.

- If mining is to lower the groundwater level, then the volume of groundwater discharging into the river during the dry season needs to be maintained by artificially discharging groundwater into the river. Ambient quality groundwater must be discharged into the river at a rate of 100 ℓ/s between April and November.

Special Case: Mining impacts

As mines are shut down and groundwater abstraction from the mine is reduced or halted, some mining areas in South Africa are experiencing rising groundwater levels as the levels revert back to their pre-mining natural state. This could have disastrous environmental consequences if accompanied by acid rock drainage or other groundwater quality problems. To address this potential impact, it might be necessary to develop RQOs aimed at reducing and/or maintaining groundwater levels *below* certain thresholds. This reversal of the more typical objective of maintaining groundwater levels *above* certain thresholds is an exception, but is becoming increasingly important as we come to grips with mining-induced impacts to the environment in general and the hydrological systems in particular.

11.9 Key outcomes

The key outcome of this phase of the GRDM assessment is a list of practical and implementable Resource Quality Objectives that will be monitored to ensure that the Classification of the groundwater unit is not compromised and that the ability of the groundwater system to sustain the Reserve is not impaired.

11.10 In summary

Resource Quality Objectives articulate goals that result from the catchment visioning process. They are considered powerful tools for implementing groundwater protection for sustainable use. As part of the GRDM assessment, the geohydrologist is to prepare a set of RQOs based on technical considerations, which are then fed into the catchment visioning process. RQOs may be numeric or descriptive, but need to be simple and measurable. **Furthermore, they can never be more stringent than natural or reference conditions.**

11.11 Some useful references

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12. METHODS, TOOLS AND DATA

This section describes some of the tools and methods that can be used to quantify various components of GRDM. A summary of methods and tools is presented in Table 12.2 at the end of the chapter. While undertaking a GRDM assessment requires a degree of experience and expert knowledge, new tools and methods are constantly being developed to address the challenges of the day. It remains the responsibility of the geohydrologist undertaking a GRDM assessment to use appropriate tools, methods and supportive software packages.

12.1 Quantifying 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, while the Excel-based RECHARGE spreadsheet prepared by Van Tonder and Xu (2001) is useful for quantifying recharge using a range of techniques. 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. Some recharge estimation tools and techniques are described below, but commonly used approaches include:

- recharge maps
- expert opinion
- chloride mass balance method
- springflow technique
- hydrograph or baseflow separation techniques
- saturated volume fluctuation method
- water table function method
- cumulative rainfall departure method
- isotope-based methods
- EARTH model
- numeric groundwater flow models.

12.1.1 Recharge maps

Three national scale maps of recharge are currently available. While preparing his geohydrological maps of South Africa, Vegter (1995) attempted to quantify recharge (Figure 10.1). Schulze (1997) prepared a similar map, but of the annual recharge of soil water into the vadose zone (Figure 12.1). While Figure 12.1 may not relate directly to the addition of water to the groundwater system below the water table, it supports the work by Vegter (1995). Recharge was recently reassessed on a national scale during the Groundwater Resource Assessment Phase II project (DWAF, 2005). The map prepared by Vegter (1995) is currently used in the GRDM software to provide initial values of recharge to quaternary catchments, but is being replaced in the latest version of the software by the updated GRA Phase II recharge map.

The 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.

12.1.2 Expert opinion

Often geohydrologists who have worked in a particular area or region for many years have a good understanding of recharge and how it varies with climate, geology, topography and other controlling factors. Contacting experts familiar with an area can result in a good indication of recharge to that area. Such an approach was used when quantifying recharge in the Hex River Valley case study, while Parsons (2002) consulted a number of experts regarding recharge to Table Mountain Group (TMG) aquifers (Table 12.1). When using this approach, it is important to record the name of the expert consulted and the basis on which their estimate of recharge was based.

Table 12.1: Expert opinion of estimates of recharge of TMG aquifer systems presented by Parsons (2002)

PARAMETER	RAINFALL (mm/a)		
	0–300	300–600	600+
Harmonic Mean (%MAP)	4.9	11.2	20.6
Average (%MAP)	7.1	12.9	22.4
Respondents (n)	8	9	11
Minimum (%MAP)	2	6	12
Maximum (%MAP)	15	25	43

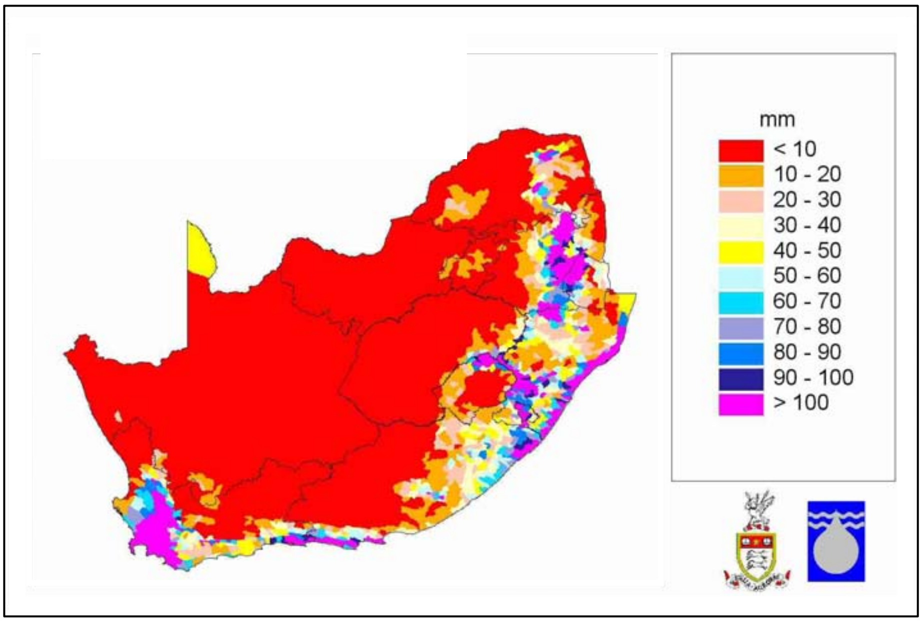

Figure 12.1: National scale map of mean annual recharge of soil water into the vadose prepared by Schulze (1997)

12.1.3 Chloride mass balance method

This method is based on the assumption of the conservation of mass between the input of atmospheric chloride and the chloride flux in the subsurface. Chloride is conservative by nature and hence is not readily precipitated out of groundwater by subsurface chemical reactions. The application requires a concentration of chloride in rainwater and in groundwater, as well as the mean annual precipitation in the area of interest. Recharge is calculated using the following relationship:

$$R_T = \frac{TD \text{ x } MAP}{Cl_{gw}}$$

where:	R_T	=	total recharge (mm/a)
	TD	=	total atmospheric chloride deposition (mg/ℓ)
	MAP	=	mean annual precipitation (mm/a)
	Cl_{gw}	=	harmonic mean of the chloride concentration in groundwater (mg/ℓ)

The chloride mass balance method has been used to evaluate recharge processes in a range of semi-arid environments. No sophisticated instrumentation or dependence on the measuring of specific runoff events is required. Also, estimates of recharge are independent of whether recharge is focused or diffuse. While easy to use and inexpensive, the method requires the concentration of chloride in rainfall. In addition to seldom being available, the low concentration of chloride in rainfall results in small differences in chemical analysis resulting in large differences in the computed recharge. For meaningful results, an accuracy and precision of 0.1 mg/ℓ chloride is required.

The method assumes that rainfall is the only source of chloride into the groundwater system. Where other sources of chloride exist (e.g. rocks deposited under marine conditions, mineralogical composition of rock contributes chloride to groundwater through dissolution or weathering, contamination etc.), the method becomes invalid and can no longer be used.

12.1.4 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:

$$S\frac{dh}{dt} = Recharge - \left(\frac{h}{DR}\right)$$

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.

12.1.5 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 (Figure 12.2). Bredenkamp et al. (1995) applied the method successfully in South Africa.

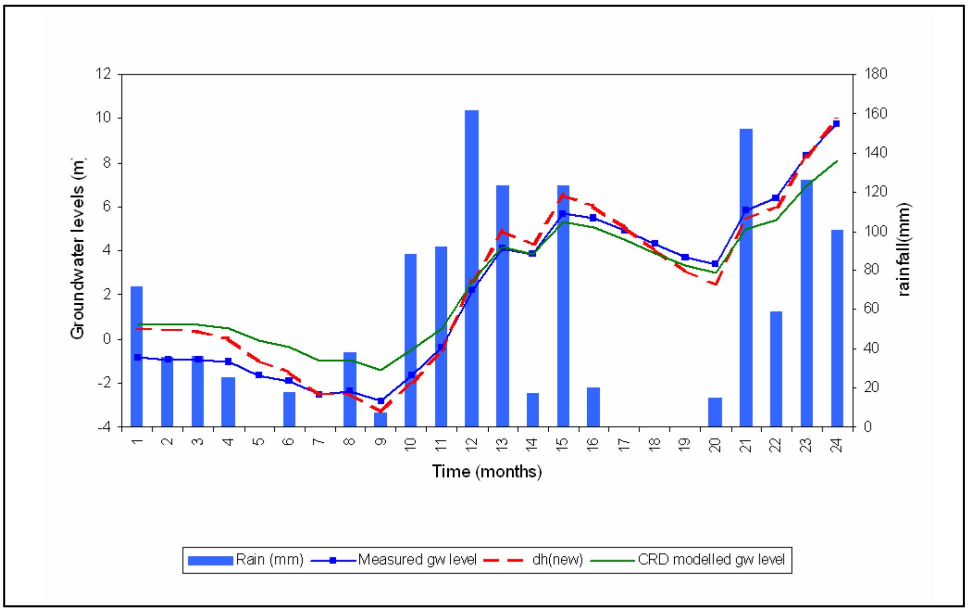

Figure 12.2: An example of the outcomes of the CRD method used to estimate recharge

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.

12.1.6 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 (Figure 12.3). 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 and 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.

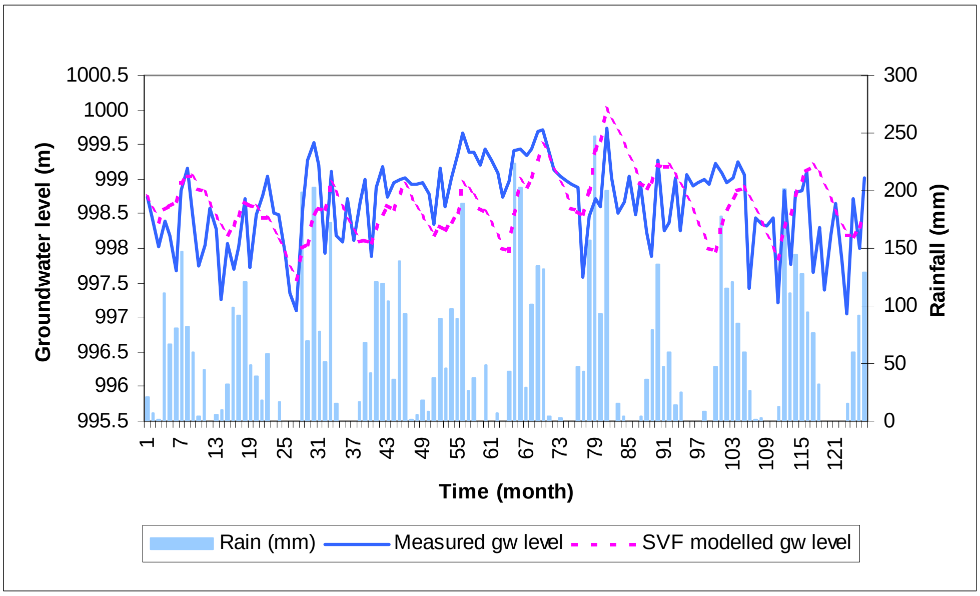

Figure 12.3: An example of the outcomes of the SVF method used to estimate recharge

12.1.7 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:

$$\Delta\delta = \frac{C}{\sqrt{Recharge}}$$

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:

$$\Delta\delta = \frac{20}{\sqrt{Recharge}}$$

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

12.1.8 Numerical groundwater flow models

The aim of groundwater modelling is to predict aquifer piezometry under different conditions, and as a result can be used to estimate recharge. Models are essentially sophisticated water balance methods that attempt to balance input, storage and output from an aquifer system.

When developing numerical models, the user creates a regular grid over the area to be modelled that subdivides the total model area into cells. Parameters, such as water level, transmissivity and recharge are assigned to each cell. Calibration takes place by comparing observed field data to simulated data. Parameters such as recharge are adjusted until the simulated and observed water levels coincide and provide a high degree of correlation.

A wide range of numerical flow models is currently available, including Visual Modflow, PMWin and others. To be able to develop and calibrate the models, data pertaining to aquifer geometry, aquifer properties, groundwater levels and recharge are required. In general, the models are data-intensive, are time-consuming to develop and calibrate, and require a proficient groundwater modeller to produce meaningful results. Moreover, the numerical solutions are not unique and are dependent on the aquifer parameters assigned in the model.

12.2 Quantifying other inflows and outflows

Darcy's Law can be used to approximate groundwater inflows into and outflows from groundwater units discussed in section 10.3.2. Darcy's Law 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. The following equation can be used to calculate both inflows into and outflows from a groundwater unit:

$$Q = T\ i\ w$$

where:	Q	=	discharge (m^3/d)
	T	=	transmissivity (m^2/d)
	i	=	groundwater gradient
	w	=	width of groundwater unit perpendicular to flow (m)

Estimates of transmissivity are obtained from aquifer tests or can be approximated from prevailing geology or borehole yields. Transmissivity near a borehole can be estimated from the following relationship:

$$T = 10\ Q$$

where:	Q	=	borehole yield in ℓ/s

The groundwater or hydraulic gradient can be determined from a groundwater level contour map or approximated from surface topography, while the width of the groundwater unit can be measured from the map showing the delineation of the units (Chapter 8).

The flux across a unit boundary can be calculated using the water budget option in a numerical model. Issues pertaining to models discussed in section 12.1.6 remain valid with respect to quantifying groundwater inflows into and outflows from groundwater units and are hence not repeated here.

12.3 Quantifying the groundwater contribution to baseflow

12.3.1 Baseflow maps

On the understanding that baseflow was an indication of the minimum recharge to an area, Vegter (1995) attempted to the groundwater contribution to baseflow (Figure 12.4). The map is used in the GRDM Software and provides an initial indication of the groundwater contribution to flow in rivers. As it is now recognised that not all baseflow is derived from groundwater, this map should be treated with caution, and more detailed and site-specific information should be used.

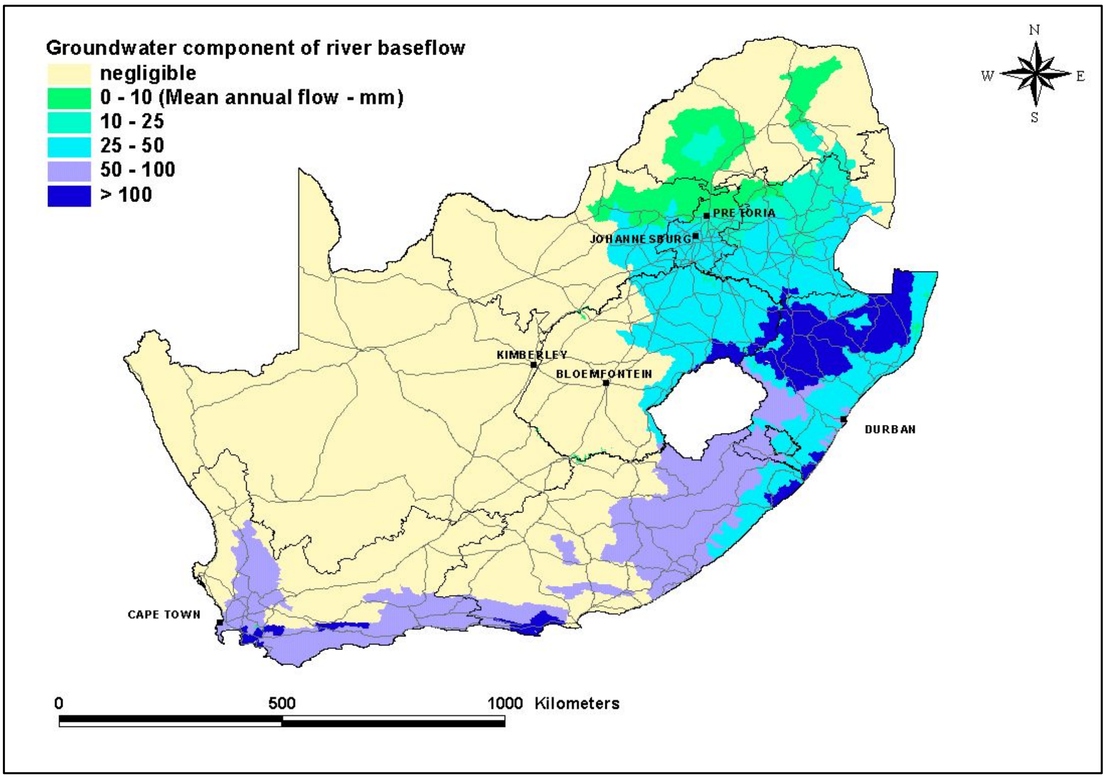

Figure 12.4: Estimation of groundwater contribution to river flow by Vegter (1995)

12.3.2 Herold method of baseflow separation

The Herold method (Herold, 1980) is used in the GRDM Assessment Software to determine the groundwater contribution to flow in a river. Vegter (1995) used the Herold method to separate monthly river flows into a surface runoff component and a groundwater contribution. Parsons (2003) challenged the contention that the baseflow component is derived entirely from groundwater, but recognised that with care, hydrograph separation techniques could be used to quantify the groundwater contribution to flow. Vegter and Pitman (in Xu and Beekman, 2003) explained the Herold method as follows:

$$Qi = QGi + Qsi$$

where:	Qi	=	total flow during month i	
	QGi	=	groundwater contribution	
	QSi	=	surface runoff	

The assumption is made that all flow below a certain value (called GGMAX) is groundwater flow, hence:

	QSi	=	Qi – GGMAX	(for Qi > QGMAX)
or	QSi	=	0	(for Qi ≤ QGMAX)
and hence	QGi	=	Qi – Qsi	

The value of GGMAX is adjusted each month according to the surface runoff during the preceding month and is assumed to decay with time, hence

$$GGMAX_i = DECAY.GGMAY_{i-1} + PG.QS_{i-1}/100$$

where: subscripts *i* and *i-1* refer to the current and preceding month.

DECAY	=	groundwater decay factor (0 < DECAY < 1)
PG	=	groundwater growth factor (0 < PG > 1)

An added constraint is that *GGMAX* may not fall below a specified value, *QGMAX*. Calibration of this model is achieved by selecting an appropriate value of *DECAY*, *PG* and *QGMAX* so that a realistic division between surface runoff and groundwater is obtained (Figure 12.5).

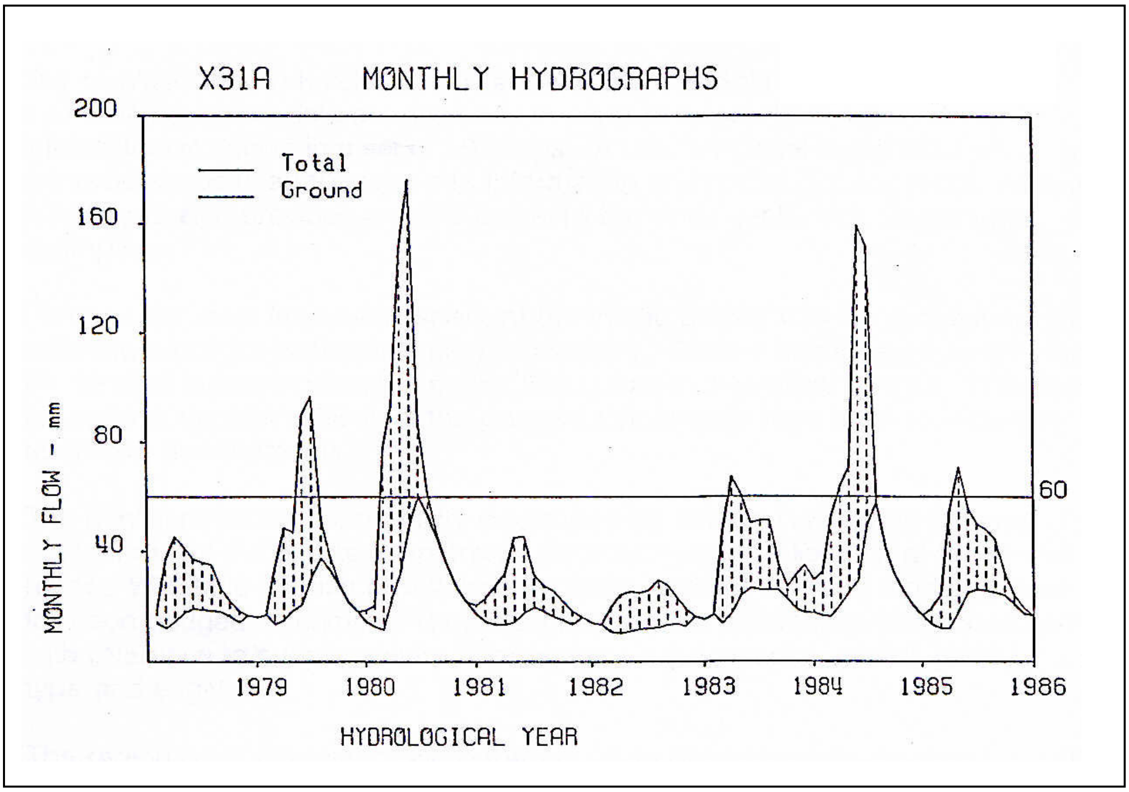

Figure 12.5: Graphic output of a hydrograph separation using the Herold method

Monthly flow data are required for the separation process. Naturalised monthly flow data from the WR90 data set is included in the GRDM Software for each quaternary catchment. Measured flow data can be downloaded from the DWAF website (www.dwaf.gov.za). The method has been included in the GRDM Assessment Software and is easy to use. However, the fitting of the separation curve is subjective, and the user has to decide which is the most appropriate fit when trying to quantify the groundwater contribution to river flow. It is strongly recommended that the separation be done in consultation with an experienced hydrologist. Nonetheless, when doing the separation, the following should be borne in mind:

- Groundwater will contribute very little to the flow in those rivers with a low baseflow index, ephemeral or strongly seasonal rivers. Consequently, the modelled groundwater contribution to flow should be small.
- Given that annual groundwater level fluctuations in a catchment are small in relation to the length or width of the catchment (and consequently that the hydraulic gradient varies very little), it is conceptualised that the groundwater contribution to flow in a river remains fairly constant. It is hence not possible that the groundwater contribution to flow will vary by orders of magnitude as suggested by conventional approaches to baseflow separation.

12.3.3 Rainfall-runoff modelling

Hughes (2004) and Sami et al. (2005) have being developing techniques to more accurately consider the groundwater contribution to baseflow using modified versions of the Pitman model. At present the methods require a high degree of hydrological modelling skills, but it is hoped that once further developed and tested can contribute to improving estimation of the groundwater contribution to baseflow.

12.3.4 Darcy's Law

The groundwater contribution to flow in a river 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. Assuming groundwater is discharged into the river from both sides, the following equation can be used to calculate discharge into the river:

$$Q = T\ i\ 2w$$

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

To be able to calculate the volume of groundwater discharged into a river, an estimate of transmissivity, the hydraulic gradient and the length of river into which the groundwater is discharged are required. The hydraulic gradient can be approximated from surface topography. Approximation of the transmissivity along the length of a river is far more difficult, as the hydraulic properties of fractured-rock aquifers can vary significantly over short distances. In addition to data from aquifer tests, transmissivity in the vicinity of a borehole can be estimated from the following relationship:

$$T = 10\,Q$$

where: Q = borehole yield in ℓ/s

By determining the harmonic mean of T determined from the yield of boreholes in a catchment, an indication of the lumped transmissivity can be obtained.
Estimating the length of river into which groundwater is discharged is also not as simple as it may seem. It is unlikely that the entire length of a river is effluent in character. Furthermore, it is likely that the lengths of river into which groundwater systems discharge vary seasonally. By preparing a groundwater level contour map of the groundwater resources and assuming that the river has an effluent character in those areas where the groundwater level is within (say) 2.5 m of the river bed, an approximation of the length of river can be obtained.
While the calculation of groundwater contribution using a Darcian approach may be simplistic in that it does not take into account the heterogeneous nature of most aquifer systems and localised variations in hydraulic properties, it does allow for an independent assessment against which the assessment obtained from baseflow separation can be compared.

12.3.5 Numerical groundwater flow models

The flux into a surface water body can be calculated using the water budget option of numerical groundwater flow models. Issues pertaining to models discussed in section 12.1.6 remain valid with respect to quantifying groundwater discharge into surface water bodies and are hence not repeated here.

12.3.6 Low maintenance flows

DWAF (1999) proposed low maintenance flows be used to determine the groundwater allocation. Low maintenance flows are determined in the RDM assessment process by the surface water specialists. In instances where rivers are not ephemeral and have a moderate to high baseflow index, this is considered a practical approach for an intermediate level assessment. However, a more considered approach is required for a comprehensive GRDM assessment, while the GRDM Assessment Software is adequate for desktop and rapid assessments.

12.4 Resource quality objectives

A number of tools and simple flow equations can be used when setting resource quality objectives. These include defining setback distances from line or point sources, quantifying drawdowns and determining the rate at which a borehole can be pumped so that it does not influence groundwater levels near protection zones.

12.4.1 Delineation of protection or exclusion zones

Areas around sensitive ecosystems may need to be protected. This is done by delineating protection zones around them. The flux necessary to maintain the ecosystem (Q_{ER}) can be determined using either Darcy's Law (section 12.3.3) or a baseflow separation procedure (section 12.3.2). The protection area around a line source to be protected (such as a river) can be determined using Q_{ER}:

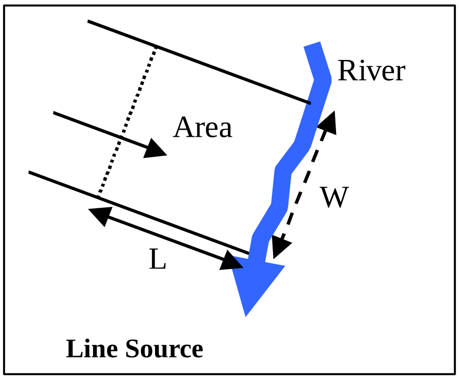

Figure 12.6: Determining the setback distance from a linear protection zone

$$A = \frac{Q_{ER}}{R}$$

where:

where:	A	=	area to be protected (m^2)
	Q_{ER}	=	flux (m^3/d)
	R	=	effective recharge within the protection area (m/a).

Then the setback distance from the line source (L) can be calculated using:

$$L = \frac{A\,.}{W}$$

where:	L	=	length from source (m)
	A	=	area of protection zone (m^2)
	W	=	width of protection zone (m^3/d)

The protection area for a point source such as a wetland or a borehole used to supply basic human needs can be calculated in the same way as that of a line source, except that the length of the protection area (L) is calculated as follows:

$$L = \sqrt{A\pi}\,.$$

where:	L	=	length from the point source (m)
	A	=	area of protection zone (m^2)

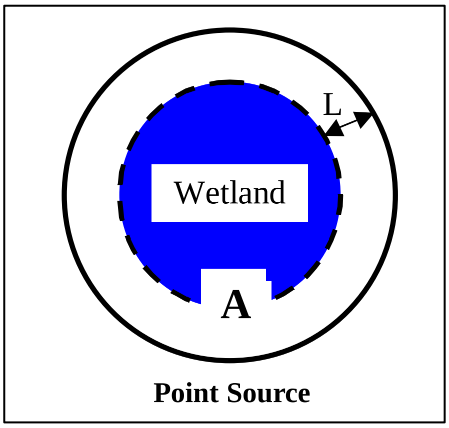

Figure 12.7: Determining the setback distance from a circular protection zone or point source

12.4.2 Calculating the radius of influence of a borehole

The maximum extent of the cone of depression – or the radius of influence (r_e) – of a borehole is independent of the rate of abstraction, but dependent on T, S and the duration (t) of abstraction. The radius of influence can be estimated using the following equation:

$$r_e = 1.5\sqrt{\frac{Tt}{S}}$$

where:	T	=	transmissivity (m^2/d)
	S	=	storativity
	t	=	time (d)

If a borehole is pumped continuously, the radius of influence increases at a rate proportional to the square root of time, i.e. the radius of influence increases 30% each year.

12.4.3 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 and 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.

12.4.4 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 12.x (b). 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.

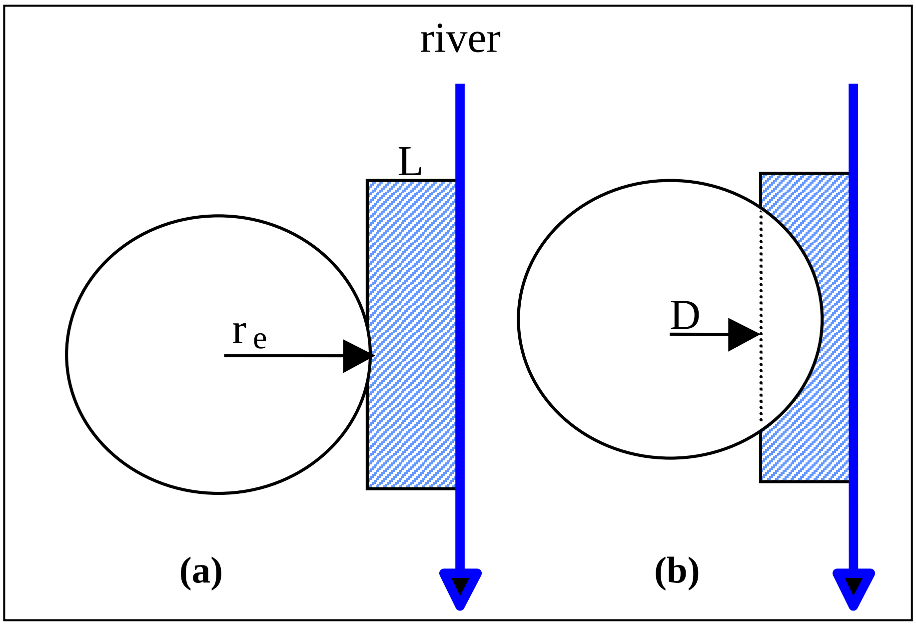

Figure 12.8: Graphical representation of the radius of influence (r_e) used to estimate the sustainable yield of a borehole (a) when the borehole does not influence the ecological protection zone and (b) when the borehole influences the ecological protection area

As indicated in Figure 12.8 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. 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 calculated using the following equation:

$$Q_s = BR$$

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)

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Table 12.2: Methods for calculating the components of the water balance

Component	Definition	Method	References/software
Groundwater inflow (I) and outflow (O) across catchment boundaries	Areas along the boundary where groundwater enters or leaves the catchment. Usually the catchment boundary acts as a groundwater water divide, and it is only in low-lying areas that groundwater will enter or leave the system.	Groundwater levels in an aquifer usually (in more than 95% of aquifers studied in South Africa) follow surface topography. As a result, Bayesian interpolation techniques can be used, and a groundwater contour map can be plotted. After constructing the Bayesian groundwater level contour map, there are two methods that can be used to estimate *I* and *O*, namely numerical flow models and Darcy's Law.	***Reference*** Darcy's Law can be obtained from Kruseman and De Ridder (1991). The transmissivity or hydraulic conductivity needed in the flow calculations can be obtained from literature (e.g. Kruseman and De Ridder, 1991) or pumping test data. ***Software*** TRIPOL (Van Tonder et al., 1996) can be used to perform the Bayesian interpolation. It is available on the IGS website: www.uovs.ac.za/igs PMWIN version 5 (Chiang and Kinzelbach, 1999), a numerical flow model, can be downloaded from the IGS website.
Groundwater abstraction	Withdrawing water from the aquifer, normally by means of a borehole	Databases, such as the National Groundwater Database (NGDB) and Water Resource Management System (WRMS), can be used. A hydrocensus would also give an indication of abstraction rates. If a useful database does not exist, information, such as land use maps (for estimating irrigation) and population maps (for estimating drinking and industrial uses) can be used to estimate the existing abstraction rates.	For more information concerning databases, refer to the DWAF website, www.dwaf.gov.za.
Recharge	Recharge is defined as the process by which water is added from outside to the zone of saturation of an aquifer, either directly into a formation, or indirectly by way of another formation.	Chloride method, saturated volume fluctuation method, cumulative rainfall departure method, isotopes and maps. For more information concerning the most commonly used methods, refer to Appendix A.	***Reference*** Bredenkamp et al. (1995) and Xu and Beekman (2003) discuss these methods in detail. ***Software*** An EXCEL-spreadsheet programme, RECHARGE (Van Tonder and Xu, 2000) can be used to determine the net groundwater recharge. Available from the IGS website, www.uovs.ac.za/igs. ***Maps*** Vegter's (1995) groundwater recharge map can be used

Component	Definition	Method	References/software
Flow from surface water bodies	Surface water bodies can recharge or discharge groundwater. The exchange rate of water is usually controlled by the difference in hydraulic heads (water levels) and resistance of the media between the groundwater and surface water bodies.	See groundwater inflow (I) and outflow (O) across catchment boundaries.	See groundwater inflow (I) and outflow (O) across catchment boundaries.
Basic human needs	The least amount of water required to satisfy basic water requirements; this is currently set at 25 ℓ/cap·d.	The amount of groundwater needed for basic human needs can be determined by multiplying the number of people dependent on groundwater by 25 ℓ/cap·d. Future changes in the groundwater-dependent population must also be considered.	***Reference*** Water Services Act (Act No. 108 of 1997).
Ecological requirements	The amount of groundwater needed to sustain aquatic ecosystems.	In the case of a line source (e.g. river) determine groundwater component of baseflow using the Herold method. It is important to note that these values must be scaled according to the various reaches within a river. In the case of a point source (e.g. wetland) determine the groundwater flow towards the source by means of Darcy's law or a numerical flow model.	***Reference*** Herold method (Vegter, 1995). Data needed to calculate baseflow can be obtained from WR90 (Midgley et al., 1994) or Hughes (2003) or field data. ***Software*** Base flow can be calculated using the reserve spreadsheet available from IGS website, www.uovs.ac.za/igs. For point sources, see flow across catchment boundaries.

13. CHALLENGES AHEAD

13.1 Data

- Unlike surface water, the groundwater sector is considered data-poor. A concerted effort is required to ensure National Groundwater Monitoring Programme data are captured into a national database, the national database is used to store ***all*** groundwater data collected in South Africa (including that collected by the state, local authorities, consultants and researchers) and the data are readily available to practitioners.

- The paucity of temporal data also makes it almost impossible to quantify all the parameters required in a GRDM assessment with a high degree of confidence. It should also be noted that in many instances, the Reserve *per se* does not create a suitable legal framework for the protection of groundwater resources. The concept of the Reserve was developed from a surface water perspective without considering the implications for groundwater. A more appropriate tool to use for resource protection and management is Classification. Even if substantial drilling is undertaken, it still takes years before meaningful time series data become available that can be used to quantify all the parameters required in a GRDM assessment.

  This should prompt a different approach to GRDM studies namely:

  - Undertake a GRDM assessment of a resource using all available information (and augment with field work if necessary).
  - From this, develop a conceptual model of the resource.
  - Quantify the main components of GRDM, placing an emphasis on Resource Quality Objectives that have been based on the classification of the resource units.
  - Relate the RQOs to a monitoring programme that can be used to update the management objectives of the resource.

  The advantage of this approach would be that the user will get access to the resource much sooner (albeit it with a higher risk of failure) and DWAF will not have to fund very expensive drilling and monitoring programmes.

13.2 Monitoring

- Guidelines regarding GRDM-driven monitoring and how it fits in the broader process of groundwater monitoring in South Africa are currently lacking. These guidelines are required by both water resource managers and practitioners and should address monitoring requirements and integration at all three levels.

13.3 Integration

- The integration of groundwater into the RDM procedure is required by law. In practice, however, this is not readily achieved. It is crucial to strive for the vision of integrated water resource management included in the National Water Act. This can partially be achieved if:

- All RDM assessments include a groundwater component
- A groundwater component is included in all hydrological, ecological and engineering tertiary education.

13.4 Methodologies

- Methods for GRDM assessments are new and still under development and review. It may be years before the methods attain complete and unequivocal acceptance. To facilitate improving the methods, the following actions are needed:

  - DWAF and others need to review the performance of the method after each GRDM assessment. This information is to be used to update the methods on a regular basis.
  - Manuals documenting currently approved methods for GRDM assessments need to be maintained by the RDM Directorate and made available to both authorities and practitioners when required.
  - GRDM training must form an integral part of groundwater tertiary education.

- As a general principle, an effort has to be made to keep GRDM methods simple and efficient, while clear and accepted terminology needs to be used. At present, the methods are disjointed, with excessive, undefined terminology. In developing and refining the GRDM methods, cognisance needs to be taken of the outcomes of GRDM assessments:

  - How much groundwater can be abstracted without impacting the Reserve and Classification requirements and still ensuring sustainability?
  - How should the groundwater resource be managed to ensure that the resource is used sustainably?
  -

- In essence, the GRDM assessment is quite simple. However, the components needed to undertake the assessment are often difficult to quantify with any accuracy. This is particularly true of recharge, groundwater use and the groundwater contribution to baseflow. New tools and approaches need to be researched and developed to improve our abilities in this regard.

- The groundwater quality component of GRDM assessments is poorly developed. Much of the focus has been on quantity issues, but the quality component may be just as important in certain instances. The ability to define a representative groundwater quality of a resource unit and quantifying the acceptable levels of change are extremely difficult issues that require appropriate consideration before a meaningful GRDM tool can be developed.

- Assessment methodologies also need to be affordable, cost effective and easily implementable. The challenge exists to develop simple and rapid tools that will allow for the rapid and efficient management of about 80% of groundwater resources that are being used in a sustainable manner. More complex and detailed investigations should only be required in instances where resources are being (or are thought to be) used in an unsustainable manner, are stressed or are the source of conflict between users. This will require that perspective be maintained between use and protection and maintaining a resource in its natural state and development.

13.5 Definitions

- The Minister of Water Affairs and Forestry is responsible for determining the Class, Reserve and Resource Quality Objectives for “all or part of every water resource considered to be significant”. As in the case of ‘*water stress*’, the National Water Act refers to ‘*significant water resource*’, but does not define the term. The absence of a legal definition or official policy from DWAF may have considerable ramifications, as water resources not considered significant fall outside the protection afforded by Chapter 3 (sections 12–18) of the Act. This issue requires further consideration by DWAF. The current interpretation is that the term refers to the spatial extent of a resource and not to its importance.

13.6 Beyond GRDM

- While much effort is being directed towards developing methodologies to perform GRDM assessments, there is a lack of tools and methodologies for allocating water. This situation is hampering the effective implementation of the National Water Act. Key to solving this problem is striking a balance between determining the Reserve and providing tools for equitable, sustainable and beneficial groundwater allocation, in tandem with appropriate compliance-monitoring measures.

14. E10 CATCHMENT PILOT STUDY

This case study is included for demonstration purposes only. It is intended to demonstrate how the manual is to be used and outcomes of an assessment. Not all information used in the assessment is included.

Flanagan LE, Parsons RP, Munch Z, Basson FC, Conrad JE and Wentzel J (2006) A Pilot Study for Setting Resource Directed Measures for Groundwater - Groundwater Atlas of the E10 Catchment. WRC Project 1427, Water Research Commission, Pretoria.

14.1 Preparatory Phase

Parsons and Associates Specialist Groundwater Consultants cc, in collaboration with DWAF, were awarded a project by the WRC to implement and test approaches and methodologies documented by Xu et al. (2003) for assessing the groundwater component of RDM. Because of planned groundwater exploration by the City of Cape Town, it was decided the research should focus on Table Mountain Group aquifers. The E10 Catchment was selected as the pilot study area on the basis of available data, its position in relation to the G30 Catchment (where DWAF were undertaking a RDM assessment of the groundwater component) and increasing use of groundwater in the area.

14.2 Description of Study Area

A detailed geohydrological investigation of the E10 Catchment was undertaken that included collection of available data and reports, a hydrocensus in areas with little or no data and identification of groundwater dependent ecosystems. In addition to data obtained from the NGDB, the WARMS database and the hydrocensus, data collected during the following previous investigations were also sourced and added to the project database:

- the CAGE study (Umvoto Africa and SRK Consulting, 2000)
- the Danida IWRM pilot study of the E10D, E10E and E10F catchments (GEOSS and SRK Consulting, 2003a)
- the Agter-Witzenberg valley research project (Weaver et al., 1999)

The data were analysed and presented in a groundwater atlas of the E10 Catchment that conformed to the format recommended in Table 7.2 of the GRDM Manual (Flanagan et al., 2006).

14.2.1 Background Information

The E10 Catchment is situated in the Western Cape Province, covering an area of some 2 900 km^2. It is a long and narrow catchment, orientated in a north-south direction. The catchment has a total length of some 165 km and a maximum width of about 40 km. Clanwilliam and Citrusdal are the only major towns in the study area. The small settlement of Trawal is located in the north of the study area; and a few small rural settlements are scattered throughout the catchment. The total population in the E10 Catchment was estimated at almost 12 000.

Much of the catchment is considered pristine, with about 80% remaining undeveloped and comprising of natural bushland and fynbos. Agriculture is the main economic activity in the area, with dryland and irrigated areas covering about 20 % of the E10 Catchment. Cultivated areas are confined to the river valleys and towards the flatter northern parts of the catchment. Important crops include citrus and deciduous fruit, wine and table grapes, vegetables and lucerne. In places, wild flowers are harvested.

Water for urban or agricultural use is obtained directly from the Olifants River or from the Clanwilliam and Bulshoek Dams. These storage dams form the cornerstone of the Olifants River Government Water Scheme that supplies water for irrigation and domestic purposes to areas west and north of the study area. Smaller farm dams have been built throughout the E10 Catchment for irrigation purposes. Groundwater is used for agricultural purposes and to supplement water supplies to Citrusdal during the dry summer months.

14.2.2 Physiography and Climate

The E10 Catchment comprises 10 quaternary catchments that vary significantly in size (E10A to E10K). Much of the area is rugged and mountainous with steep slopes. These areas are generally inaccessible.

The E10 Catchment experiences a Mediterranean climate with mild wet winters and hot dry summers. The majority of rain falls between May and September. Rainfall decreases towards the northern parts of the catchment, while evaporation increases in that direction. Rainfall in the valleys is in the order of 300 to 400 mm/a, and exceeds 1 500 mm/a in the mountains.

The Olifants River is the primary river draining the study area, with important tributaries including the Dwars, Boontjies, Heks, Elandskloof, Rondegat, and Jan Dissels Rivers. The Olifants River has its source in the Agter-Witzenberg valley and flows in a north-westward direction before discharging into the Atlantic Ocean west of Vredendal. It has a length of 184 km before the confluence with the Doring River at the northernmost boundary of the study area. The Olifants River is naturally seasonal in its upper parts, but changes to being ephemeral in character in the north. Mean annual runoff amounts to 472 Mm^3/a, of which about 6.8% is derived from discharging groundwater.

14.2.3 Geology

The E10 Catchment comprises rocks and sediments of the Vanrhynsdorp Group, Table Mountain Group, Bokkeveld Group, and the Sandveld Group. Hard quartzitic rocks of the Table Mountain Group cover about 90 % of the study area. The rocks have been extensively faulted and faulted, resulting in highly productive aquifer systems. Because of the underlying geology, thin sandy quartz-rich soils predominate. However, thick alluvial deposits are found in the central parts of the Olifants River valley in the vicinity of Citrusdal.

14.2.4 Geohydrology

Some 90 % of the catchment is underlain by fractured, secondary aquifers associated with the Table Mountain Group. Because of the highly fractured and faulted nature of the aquifers, it is likely that the different rock units act as a single aquifer system when considered on a regional scale. High yielding boreholes have been drilled in the Peninsula Formation around Citrusdal, with moderate to high yielding boreholes being established throughout the study area. It is only in the northern parts underlain by rocks of the Vanrhynsdorp Group that boreholes are generally low yielding and groundwater quality poor.

Recharge in the E10 Catchment was set at 165 Mm^3/a. Highest recharge occurs in quaternary catchments E10A, E10B and E10C. Recharge is higher in the mountain ranges flanking the eastern portions of the E10 Catchment. It was estimated groundwater use amounts to 17.8 Mm^3/a, about 88 % of which is used for agricultural purposes. Most groundwater is abstracted in quaternary catchments E10A (Agter-Witzenberg valley), E10E (Citrusdal) and E10F (north of Citrusdal). Little groundwater is abstracted from E10B and E10H.

The direction of groundwater flow was found to mimic that of surface water. Detailed analysis of groundwater flow data does not support the postulation by Umvoto Africa and SRK (2000), Titus et al. (2002), Kotze and Xu (2003), GEOSS and SRK (2003a), Nel (2004) and GEOSS (2004) that groundwater discharges from the E10 Catchment into the adjoining G30 Catchment.

14.3 Delineation of Units

Quaternary catchment boundaries were used as the primary delineation of groundwater resource units in a study area (Figure 14.1). The objective of delineation is to group significant water resources with similar characteristics. A 'groundwater resource unit' is defined as a groundwater body that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit. Typically, a GRDM assessment is required for each unit.

Consideration of geology, groundwater flow directions and patterns of groundwater use did not indicate any reason not to use quaternary catchment boundaries as the basis for delineation. While Primary Aquifers are located in and directly adjacent to the Olifants River channel in E10E, E10F and E10G, most of the study area comprises fractured and weathered secondary aquifers. As the aquifers are expected to be hydraulically connected, it was considered prudent not to delineate them separately. A secondary delineation of the quaternary catchments was hence not undertaken.

Other factors can be used to delineate resource units further. Tertiary delineation can be based on physical, management or functional criteria. A number of workers have postulated groundwater from the E10 Catchment discharges into the adjacent G30 Catchment, thereby providing a source of recharge to the latter (Umvoto Africa and SRK, 2000; Titus et al., 2002; Kotze and Xu, 2003; GEOSS and SRK, 2003; Nel, 2004 and GEOSS, 2004). While the geological structure of the area indicates this may be possible, analysis of measured groundwater levels between the two catchments suggests this is unlikely. Groundwater levels closely mimic surface topography, indicating the direction of groundwater flow would be similar to that of surface runoff. At least at the scale of the GRDM assessment being undertaken, the Aggenbachs and Swartberg Mountains act as a divide between the E10 and G30 Catchments. Research being led by the University of the Western Cape may shed light on regional groundwater flow patterns that could require this interpretation to be revised. Based on the assessment of conditions in the E10 Catchment, tertiary delineation was also not warranted.

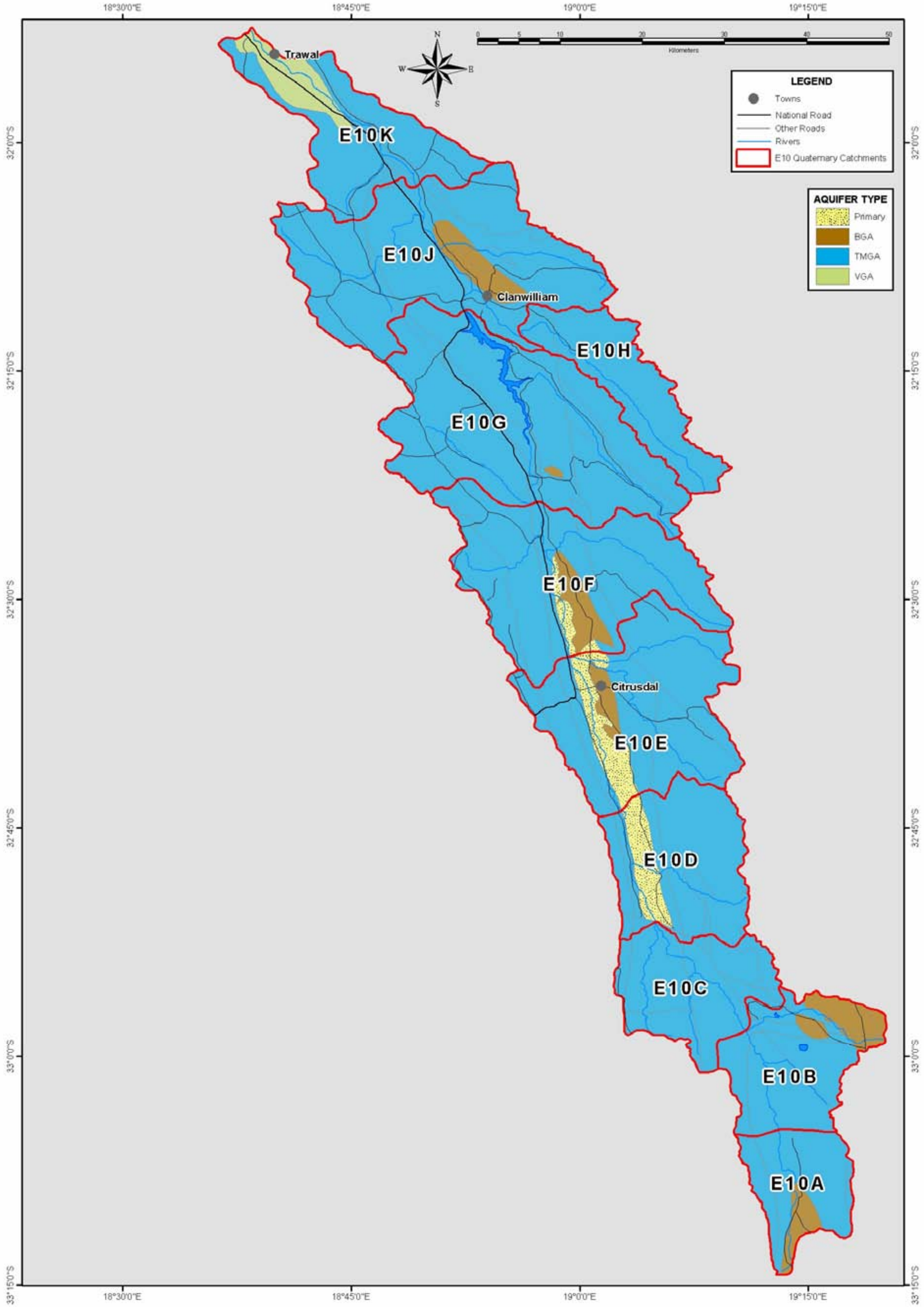

Figure 14.1: Delineation of resource units in the E10 Catchment.

14.4 Resource Classification

The National Water Act (Act 36 of 1998) requires all water resources be classified. A category can be set using generic descriptions in terms of levels of impact, a stress index based on the volume of groundwater abstracted in relation to annual recharge or observed or expected groundwater contamination. In the case of the E10 Catchment, comparison of the volume of groundwater abstracted to estimated recharge was considered the most appropriate method to determine the category of each resource unit (Table 14.1). The stress index is calculated by dividing groundwater use by recharge. The index is then used to classify the resource in terms of its present status (Table 9.2) and water resource category (Table 9.7).

Table 14.1: Classification of resource units in the E10 Catchment.

Resource Unit	**Groundwater Use (Mm^3/a)**	**Recharge (Mm^3/a)**	**Stress Index**	**Classification**	
				Present Status Category	**Water Resource Category**
E10A	5.70	22.5	0.25	C	Good
E10B	0.30	25.6	0.01	B	Good
E10C	0.60	15.3	0.04	A	Natural
E10D	1.05	14.2	0.07	B	Good
E10E	4.70	16.5	0.28	C	Good
E10F	2.80	16.7	0.17	B	Good
E10G	1.50	20.5	0.07	B	Good
E10H	0.10	13.6	0.01	A	Natural
E10J	0.60	15.9	0.04	A	Natural
E10K	0.40	4.6	0.09	B	Good
Total	**17.75**	**165.4**			

Various attempts have been made to quantify groundwater use in the E10 Catchment, including those by Umvoto Africa and SRK (2000), Titus et al. (2002) and DWAF (2005). Groundwater use in the E10 Catchment is in the order of 17.8 Mm^3/a, with most abstraction occurring in E10A, E10E and E10F. A number of estimates of recharge to the E10 Catchment have been made, most of which were regional in extent. Estimates range between 106 and 193 Mm^3/a, with an average of 165 Mm^3/a. It was decided an average of previous estimates would be used for the GRDM assessment.

Based on available data, the quaternary catchments are relatively unstressed (Table 14.1, Figure 14.2). Abstraction for irrigation in the Agter-Witzenberg valley (E10A) and abstraction for irrigation and municipal supply in the vicinity of Citrusdal is reflected in the stress indices for these two catchments. The low stress indices are supported by an absence of apparent groundwater-related problems (conflict, declining groundwater levels) in these areas. It must be noted that the stress index is determined for the catchment or resource unit as a whole. Most groundwater abstraction occurs in the central parts of the Olifants River valley. It is possible stress indices may be higher than those indicated when considered at a local scale.

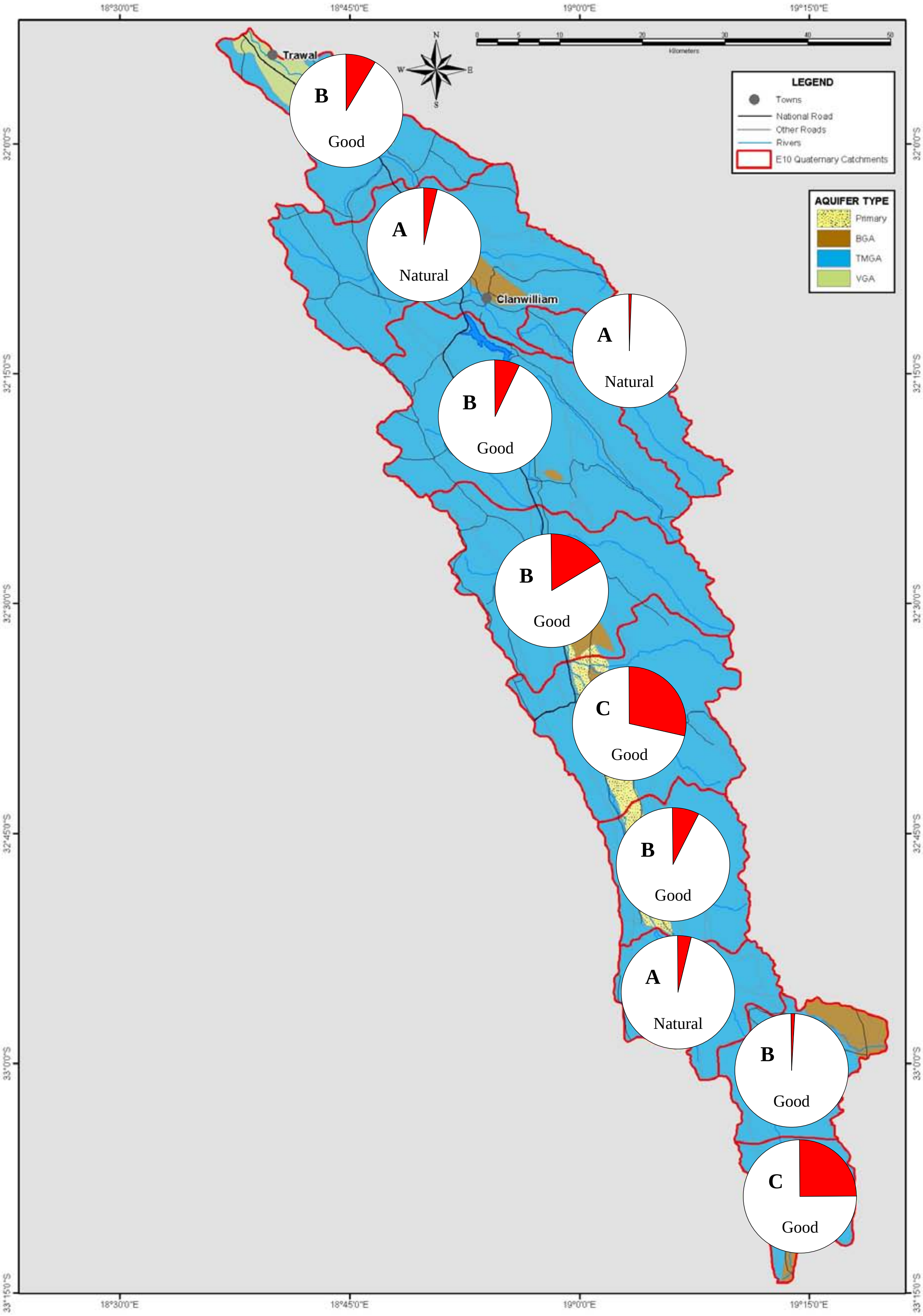

Figure 14.2. Classification of resource units in the E10 Catchment.

14.5 Quantification off the Reserve

The GRDM assessment process requires resource units be delineated, classified, the Reserve calculated and the allocatable groundwater in each unit specified. Information presented in the description of the study area was used to complete the GRDM assessment sheet of the E10 Catchment (Table 14.2). It was not deemed necessary to define protection or exclusion zones in the study area. As a result the effective area remains the same as the total area assessed. Recharge in the E10 Catchment was set at 165.4 Mm^3/a.

Determination of the groundwater contribution to baseflow in the Olifants River is hampered by a lack of run-of-river hydrological records for any location in the catchment. As a result, naturalised flow data in the WR90 data set was used to estimate the groundwater contribution to baseflow. Three different methods were used to estimate the groundwater contribution to baseflow, including the Herold method included in the GRDM Software and the modified Pitman Model approaches being developed by Hughes (2005, *pers.comm.*) and Sami (2005, *pers.comm.*). Unfortunately, there is a degree of difference between the results. In the absence of measured flow data and given the degree of modification of the river through abstraction and the construction of farm dams, it was decided to use the average of the estimates. It was estimated 6.8 % of the total naturalised MAR from the E10 Catchment is derived from groundwater.

It is of interest to note that the maintenance low flow at EWR Site 1 during December through to March was set at 0.1 m^3/s (or 3.16 Mm^3/a) by Brown et al. (2005). This is similar to the cumulative groundwater contribution to baseflow in resource units E10A through to E10F calculated using the Herold method, but is an order of magnitude less than that calculated by Sami (2005, *pers.comm.*). While the GRDM assessment protocol allows for use of maintenance low flows in the assessment, it was decided to base the GRDM assessment on the average estimated groundwater contribution to baseflow, as this was a more conservative approach.

Calculation of basic human needs (BHN) in a resource unit is a simple task, where each person living within the boundaries of the resource unit is allocated 25 L/p/d. The total population of the E10 Catchment is relatively small and is in the order of 12 000 people. Using 2001 hydrocensus population data for magisterial districts, the population of each quaternary catchment was estimated. If it is assumed the entire population is dependent on groundwater as a source of supply and using a basic human need of 25 L/p/d, then the basic human need of the E10 Catchment is 0.11 Mm^3/a.

The GRDM assessment indicates only a small part of the groundwater resources in the E10 Catchment are currently used; and large volumes remain available for allocation. In general, the Reserve accounts for about 20 % of estimated recharge. Based on the assessment undertaken, some 133 Mm^3/a can in theory still be abstracted from the E10 Catchment. However, large parts of the catchment are mountainous and cannot be accessed. Most groundwater abstraction currently takes place in the central valley, and it is expected this scenario will continue. This has two obvious ramifications:

- Large volumes of groundwater are held in storage that cannot readily be accessed and which readily replenish the abstraction zone. Because of this, any impacts resulting from groundwater abstraction are probably localised and of short duration.

Table 14.2: GRDM assessment data sheet of the E10 Catchment

RESOURCE	CLASSIFICATION		RECHARGE			RESERVE			ALLOCATION	
Resource Unit	**Present Status Category**	**Resource Category**	**Total Area (km^2)**	**Effective Area (km^2)**	**Annual Recharge (Mm^3/a)**	**Groundwater Contribution Baseflow (Mm^3/a)**	**BHN Adjustment (Mm^3/a)**	**Reserve (% recharge)**	**Groundwater Allocation (Mm^3/a)**	**Current Groundwater Use (Mm^3/a)**
E10A	C	Good	133.73		22.50	4.83	0.00	21.46	17.67	5.70
E10B	A	Natural	201.96		25.60	3.76	0.00	14.70	21.84	0.30
E10C	A	Natural	192.46		15.30	2.75	0.01	18.00	12.55	0.60
E10D	B	Good	234.91		14.20	3.02	0.01	21.31	11.17	1.05
E10E	C	Good	365.78		16.50	5.17	0.02	31.50	11.30	4.70
E10F	B	Good	385.78		16.70	3.35	0.01	20.13	13.34	2.80
E10G	B	Good	508.34		20.50	4.40	0.01	21.55	16.08	1.50
E10H	A	Natural	162.16		13.60	1.59	0.00	11.74	12.00	0.10
E10J	A	Natural	468.33		15.90	2.48	0.03	15.80	13.39	0.60
E10K	B	Good	235.34		4.60	0.98	0.01	21.54	3.61	0.40
TOTAL			2888.79		165.40	32.34	0.11	19.62	132.95	17.75

- The true groundwater allocation is probably significantly less than that indicated. Assuming 50 % of the study area is inaccessible, the groundwater allocation is thus more likely to be in the order of 75 Mm^3/a.

14.6 Resource Quality Objectives

Xu et al. (2003) noted RQOs provide goals within a management class, or goals to aim for and state RQOs must maintain a balance between the need to protect water resources and the need to use them. RQOs include any requirement – numeric or descriptive – required to ensure a water resource remains in a desired state. It is specifically noted RQOs must be set in consultation with stakeholders.

The stress index – as related to the management class – is a useful regional scale RQO. If the desired management class of each resource unit is set at the current resource category, then 20.22 Mm^3/a (in addition to the current 17.75 Mm^3/a groundwater usage) can be allocated for abstraction in the E10 Catchment [1]. However, if stakeholders of the E10 Catchment decide all resource units can be used to their sustainable limits and management class be set as "Fair" then 89.76 Mm^3/a in addition to current use can be allocated for groundwater use.

It does not appear possible to set RQOs at a regional scale. This is particularly true in the E10 Catchment where most groundwater abstraction takes place (and is likely to continue to take place) in the valleys. While some general aquifer management philosophies can be specified, detailed RQOs needed to be set on a site specific basis and may have to set per license application. A philosophy of good management of groundwater resources is aimed at ensuring groundwater resources are used sustainably. Potential sustainability indicators include groundwater levels, groundwater quality, vegetation die-off and emergence of groundwater related problems (Vrba et al. 2005; Parsons and Wentzel, 2005). Monitoring is required to assess when sustainable limits are being approached or exceeded.

- Groundwater levels – groundwater levels cannot display declining trends over the long term, with the rest groundwater level measured at the start of the hydrological year remaining constant. Continually declining groundwater levels indicate sustainable levels are being exceeded.
- Groundwater quality – quality must remain relatively constant over the long term. Declining groundwater quality suggests sustainable limits are being exceeded.
- Change in vegetation or vegetation die-off in the vicinity of large-scale groundwater abstraction may indicate a causal relationship. In such instances, appropriate investigation must be initiated.
- Increased incidence of groundwater conflict or emergence of specific groundwater problems (such as decreasing borehole yields) – may indicate sustainable limits are being exceeded. In such instances, appropriate investigation must be initiated.

Because of the ever-growing use of groundwater in the E10 Catchment, the responsible authority needs to establish a groundwater monitoring system in the catchment. The following specific requirements need to be implemented as part of the management of groundwater resources in the E10 Catchment:

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1 This is calculated by multiplying the estimated recharge of a particular resource unit by the upper limit of the stress index of a particular management class. If a "fair" management class is selected, then the recharge of a resource unit is multiplied by 0.65.

- A regional-scale monitoring network needs to be established to monitor ambient groundwater level and quality trends in the E10 Catchment.
- As part of all future licensing applications, groundwater dependent ecosystems that may be impacted by groundwater abstraction must be identified in accordance with Colvin et al. (2005), and protection zone considered in the case of "entirely dependent" or "highly dependent" systems. In these instances, set back distances and limitations on drawdown and pumping regimes may be appropriate.
- All groundwater users in excess of 1 L/s are required to monitor groundwater abstraction and groundwater levels on a weekly basis and chemistry on a quarterly basis. Users of groundwater in excess of 5 L/s need to install data loggers and monitor groundwater levels on a 2 hr basis. The monitored data needs to be submitted by the groundwater users to the responsible authority in the form of an annual groundwater use and monitoring report.

Table 14.3: Quantification of groundwater allocation based on current management class.

RESOURCE	**CLASSIFICATION**		**ALLOCATION BASED ON CLASS**			
Resource Unit	**Present Status Category**	**Resource Category**	**Management Class**	**Groundwater Allocation (Mm^3/a)**	**Current Groundwater Use (Mm^3/a)**	**Remaining Groundwater Allocation (Mm^3/a)**
E10A	C	Good	Good	6.75	5.70	1.05
E10B	B	Good	Good	7.68	0.30	7.38
E10C	A	Natural	Excellent	0.61	0.60	0.01
E10D	B	Good	Good	4.26	1.05	3.21
E10E	C	Good	Good	4.95	4.70	0.25
E10F	B	Good	Good	5.01	2.80	2.21
E10G	B	Good	Good	6.15	1.50	4.65
E10H	A	Natural	Excellent	0.54	0.10	0.44
E10J	A	Natural	Excellent	0.64	0.60	0.04
E10K	B	Good	Good	1.38	0.40	0.98
Total				**37.97**	**17.75**	**20.22**

Table 14.4: Quantification of groundwater allocation based on "fair" management class.

RESOURCE	**CLASSIFICATION**		**ALLOCATION BASED ON CLASS**			
Resource Unit	**Present Status Category**	**Resource Category**	**Management Class**	**Groundwater Allocation (Mm^3/a)**	**Current Groundwater Use (Mm^3/a)**	**Remaining Groundwater Allocation (Mm^3/a)**
E10A	C	Good	Fair	14.63	5.70	8.93
E10B	B	Good	Fair	16.64	0.30	16.34
E10C	A	Natural	Fair	9.95	0.60	9.35
E10D	B	Good	Fair	9.23	1.05	8.18
E10E	C	Good	Fair	10.73	4.70	6.03
E10F	B	Good	Fair	10.86	2.80	8.06
E10G	B	Good	Fair	13.33	1.50	11.83
E10H	A	Natural	Fair	8.84	0.10	8.74
E10J	A	Natural	Fair	10.34	0.60	9.74
E10K	B	Good	Fair	2.99	0.40	2.59
Total				**107.51**	**17.75**	**89.76**

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