GROUNDWATER DEPENDENCE OF AQUATIC ECOSYSTEMS ASSOCIATED WITH THE TABLE MOUNTAIN GROUP AQUIFER

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A thesis submitted in fulfilment of the requirements for the degree Doctor of Philosophiae in the Faculty of Natural Sciences, Department of Earth Sciences, University of the Western Cape, Bellville.

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ABSTRACT

Bulk water supply from the Table Mountain Group (TMG) aquifer in the Western Cape Province was proposed in 1999. This sparked a heated debate on the sustainability of abstraction of water from the TMG aquifer, which is largely associated with the Cape Fold Mountains, home to one of six Floral Kingdoms of the world namely: the Cape Floral Kingdom. The aim of the study was to characterise the groundwater dependence of the aquatic ecosystems (streams, rivers, springs, seeps and wetlands) associated with the TMG aquifer.

The first hypothesis for the study was that discharges from the TMG aquifer are largely responsible for maintaining a natural flow regime in the mountain and foothill streams of the Cape Fold Mountains. Further that the flow regime will be affected by large scale groundwater abstraction from this aquifer system.

A second hypothesis linked to first, was that there are different types of so-called groundwater discharges that contribute to the flow regime in rivers and streams, particularly in the mountain and foothill areas where streams and rivers are associated with the TMG. These groundwater discharge types can be divided into two categories namely, real groundwater and non-groundwater discharges. It was essential to understand the mechanisms of groundwater discharge to surface resources and where in the landscape these discharges dominate.

The third hypothesis was that there are two primary areas of interaction between groundwater from the TMG aquifer and aquatic ecosystems. The first is located in the “TMG aquifer daylight-domain” where groundwater is discharged at or near the recharge area in the higher elevation mountain and foothill areas. The second is located in the “TMG aquifer surface water interface-domain”, which refers to discharges in the lowland settings closer to, or at the discharge end of the aquifer.

A fourth hypothesis was that it would be possible to generate a Geographical Information System (GIS) model, which integrates the conceptualised groundwater surface water interactions, to highlight aquatic ecosystem areas sensitive to groundwater use from the TMG aquifer.

After an intensive literature survey covering three disciplines namely, hydrogeology, geomorphology and aquatic ecology, a "Conceptual Model" was developed that demonstrated that there are two primary areas of interaction between groundwater from the TMG aquifer and aquatic ecosystems namely, the "TMG aquifer daylight-domain", and the "TMG aquifer surface water interface-domain". It also acknowledged that both real groundwater and non-groundwater discharges accounted for the flow in various degrees in streams and rivers associated with the TMG. The conceptual model indicated that the low flows of mountain and foothill streams and rivers associated with the TMG will be most vulnerable to groundwater abstraction from the TMG aquifer. The higher flows are less vulnerable to the use of groundwater from the TMG aquifer due to the increasing role of non-groundwater discharges under these scenarios.

Two case studies were selected to investigate the scientific soundness of the conceptual model, one in each of the two primary groundwater interface domains. The first case study, in the Kammanassie Mountain Complex (KMC), was done to scientifically validate the conceptualised groundwater discharges to the flow regime in mountain and foothill streams and rivers in the so-called "TMG aquifer daylight-domain". A comparative study between two adjacent river valleys investigated possible effects of altered groundwater discharge regimes on soil nutrient concentrations in the riparian strip next to mountain and foothill streams. Soil nutrient concentrations are known to show a response to groundwater discharges. The one river valley, the Vermaaks River had a known impact on its stream flow resulting from a groundwater well field that has been in operation since 1987. The adjacent river valley, the Marnevicks River served as the control site with no groundwater use taking place and a near natural flow regime. Both river valleys are similar in geology, soils, climate, aspects, gradient and vegetation.

The results from this study supported the postulated accumulation of ammonia, nitrate and phosphate in the riparian strip of the Vermaaks River due to the cessation or reduction of groundwater discharges to the river that has become seasonal.

The second case study was done in the southern part of the Western Cape, where two coastal wetlands, within a 10 km perimeter, were compared to assess possible groundwater contributions from the TMG aquifer, typically at the discharge end of the aquifer system in the "TMG aquifer surface water interface-domain". These wetlands were Groenvlei and

Van Kervelsvlei, both being endorheic. Piezometers were installed at pre-selected sites, based on hypothesized hydraulic gradients, where groundwater and surface water quality were measured. Vegetation composition and plant nutrient cycling in response to groundwater discharges were assessed for both wetlands, but was reported in a separate study.

Both the hydrochemistry and the vegetation data clearly demonstrated distinct differences between the two wetlands, and supported the postulated link between the TMG aquifer and Groenvlei and Van Kervelsvlei. This was further supported by the underlying geology and the hydrological gradient between Van Kervelsvlei and Groenvlei. The hydrochemistry and vegetation composition clearly showed a groundwater gradient between Van Kervelsvlei and the north-eastern side of Groenvlei.

Both case studies confirmed the validity of the conceptual model and the understanding of groundwater surface water interactions occurring in the two primary interface areas.

Finally the results of the study were used to development a GIS model highlighting the quaternary catchments containing sensitive aquatic ecosystems that would be vulnerable to groundwater use from the TMG aquifer. The vulnerability culminated from the TMG aquifers interface with surface waters in both primary interface areas. This model was developed through geospatial intersections of various existing GIS layers. After several geospatial intersections the sequence of layers, and the successive intersections, gave an effective “Sensitive Aquatic Ecosystem” layer.

The “Sensitive Aquatic Ecosystem” layer will enable water resource managers to review groundwater use applications and to know where conflict may exist between groundwater development and ecosystem health, particularly in the more sensitive aquatic ecosystems.

Results from this study enables a better understanding of groundwater surface water interactions in the TMG, particularly regarding aquatic ecosystems. It has also highlighted the necessity to do proper impact assessments before proceeding with bulk abstraction from this important aquifer. The results also demonstrated the importance of differentiating between real groundwater and non-groundwater discharge contributions to surface hydrology and where these interface areas are located.

With increasing pressure on water resources the search for sustainable groundwater alternatives will continue to increase. This study has highlighted the importance of looking at the full hydrological cycle when assessing water resource developments.

DECLARATION

I declare that ***'Groundwater Dependence of Aquatic Ecosystems associated with the Table Mountain Group Aquifer'*** is my own work, that it has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Wietsche Roets **Date: August 2008**

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GLOSSARY

Aquatic Ecosystem -	Any ecosystem that is dependent on water for it's functioning.
Aquifer -	Strata or a group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater via boreholes or springs.
Aquifer system -	A heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.
Biome -	Broad natural region, e.g. savanna, fynbos.
Ecosystem -	Any system in which there is an interdependence upon and interaction between living organisms (biota) and their immediate physical, chemical and biological environments.
Endemic -	Species having a restricted distribution, occurring in specific areas.
Endorheic -	No surface water inflow or outflow exists.
Exploitation potential -	Potential of an area to sustain large-scale groundwater abstraction.
Exploration potential -	Probability of drilling high yielding production boreholes for water supply with a high success rate.
Flow regime -	Variable flows in aquatic ecosystems that determine its characteristics.
Groundwater -	Water below ground surface, generally within the saturated zone below the water table, but includes water found in the capillary fringe and partially saturated vadose zone. The water occurs within joints, fissures, fractures, cleavage

	planes and faults as well as pore spaces in sedimentary rocks and unconsolidated sediments.
Hyporheos -	Substratum of river or stream (streambed).
Hyporheic -	Streambed processes.
Integrated management -	A management approach which serves to co-ordinate management of the environment as a whole, rather than individual components, integrating different aspects.
Phreatophytic vegetation -	Plants capable of obtaining groundwater from the zone of saturation either directly or through the overlying capillary fringe.
Recharge -	Process of accretion of water to the groundwater system by natural or artificial processes.
Vadose zone -	That part of the geological stratum above the saturated zone in which voids contain both air and water, but is not saturated.
TMG aquifer daylight-domain -	Domain where the TMG aquifer discharges at or near the recharge area in the higher elevation mountain and foothill areas.
TMG aquifer surface water interface-domain -	Domain located at or near the discharge end of the TMG aquifer in lowland or coastal settings.

ACRONYMS

CAPE	Cape Action Plan for People and the Environment
CFB	Cape Fold Belt
CFK	Cape Floristic Kingdom
CFR	Cape Floristic Region
DEM	Digital Elevation Model
DWAF	Department of Water Affairs and Forestry
DEAT	Department of Environmental Affairs and Tourism
EC	Electrical Conductivity
GIS	Geographical Information System
GPS	Global Positioning System
KKRWSS	Klein Karoo Rural Water Supply Scheme
KMC	Kammanassie Mountain Complex
KMR	Kammanassie Mountain Range
MAP	Mean Annual Precipitation
mamsl	Meters above mean sea level
NEMA	National Environmental Management Act
NWA	National Water Act
NO_3^-	Nitrate
NH_4^+	Ammonia
P	Phosphate
pH	Measure of Alkalinity or Acidity
RDM	Resource Directed Measures
TMG	Table Mountain Group

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CHAPTER ONE
Introduction

1.1. Integrating surface and groundwater supply

Water is the single most important substance on earth. It maintains all life forms due to its inherent properties and remarkable inter-connectedness with organisms on our extraordinary planet (Davies and Day, 1998). The colour of our "blue" planet reflects the fact that it is the only body in the solar system on which it is known that water exists freely. Exact amounts and distribution of water has not been determined. Neither it's movement and fluxes, or the full understanding of the hydrological processes at work on and near the earth's surface (Ward and Robinson, 1990).

From the earliest inception of human society fresh water has played an integral role in the functioning of all environments and societies. Fresh surface water bodies were viewed as vital resources and entire ancient 'hydraulic civilisations' developed on certain rivers. The most notable being the Tigris-Euphrates, the Nile and the Indus. Today human mankind is no less reliant on this fundamental natural resource. Until recently fresh surface water from lakes, rivers and wetlands, were the major supply sources (Middleton, 1999).

As water availability decreased in the last 5000 years, people started construction of dams to manage water resources. Although big dams have been successful in achieving their primary objectives, there are many negative sociological and ecological impacts associated with the building of dam schemes (Davies and Day, 1998; Middleton, 1999).

Water is a very important naturally occurring inorganic liquid, but its distribution over the globe is amazingly uneven (Ward and Robinson, 1990). Table 1.1 summarise the earth's water balance.

Table 1.1. Earth's water balance (National Water Act News, 2004).

Saline Water ~ 97.5%	Fresh Water ~ 2.5%
Sea water ~ 99.0% Saline groundwater and lakes ~ 1.0%	Ice and snow ~ 70% Groundwater ~ 30% Lakes and Rivers ~ 0.25% Soil, Wetlands and Biota ~ 0.1% Atmospheric Water Vapour ~ 0.04% Rivers only ~ 0.007%

The primary reason for the recent focus on groundwater resources, stems from the fact that 30% of freshwater occurs subsurface, with only 0.007% flowing down rivers.

World wide, and particularly in South Africa, water is the prime commodity for all of it's people. It is required for cooking, drinking, washing, mining, cleansing wastes, manufacturing, growing forests, producing electricity, cooling industrial processes, watering stock and crops, growing fish, fishing and recreation (Davies and Day, 1998). With the promulgation of the ***New National Water Act (NWA) Act No. 36 of 1998***, the ***National Environmental Management Act (NEMA) Act No. 107 of 1998,*** and ***Section 24 of the Constitution of South Africa (Act No. 108 of 1996)***, more pressure was placed on authorities to supply the long overdue supply of safe water to the most desperate communities. Far too many lives are lost due to poor sanitation and water supply.

The sub-continent of Southern Africa is notorious for its unpredictable rainfall. In South Africa this problem is exacerbated by the current population growth. In addition redistribution of water to those in dire need of basic water services is placing more pressure on the water resources. According to Davies and Day (1998), South African will at the lowest estimated population growth and water demand no longer be able to meet the water demand by 2020 if only surface water will be used, and by 2040 if both surface and groundwater is used. Under worst case scenario with the highest population growth and water demand all the fresh water supplies will be fully committed by 2015. Very strict water demand management strategies might add some years of grace (Davies and Day, 1998).

Unfortunately, not all water can be used from an aquatic ecosystem. Some is needed to sustain aquatic ecosystems functioning, as is recognised by the NWA. Currently, almost all water use in South Africa comes from rivers (aquatic ecosystems). Consequently, the greater the scarcity of water for human use become, the greater the impact will be on natural aquatic resources, particularly rivers (Davies and Day, 1998).

Principles in-trenched in the NWA imply a definite need to look at the integrated management of groundwater and surface water, and even more comprehensively to manage catchments in an integrated fashion. However, this requires a proper understanding of the full hydrological cycle. The Department of Water Affairs and Forestry (DWAF) recognised, in their newsletter "National Water Act News" (February 2004) that groundwater contributes to flow in springs and rivers and feeds coastal lakes, estuaries and wetlands, especially in the higher rainfall areas, such as the Western Cape. This newsletter reports on a recent discovery that some of the greatest ecosystem diversity occurs in mixing zones, called ecotones, where groundwater enters a river, lake or the sea.

The growing need for more safe water inevitably meant that the use of groundwater would be receiving more attention. The realization of the potential to supply water from groundwater resources in the Western Cape Province, home to one of six floral kingdoms of the world (Cape Floral Kingdom), sparked a fierce debate on the sustainability of abstraction of water from the Table Mountain Group (TMG) aquifer associated with the Cape Fold Belt. This made it imperative to properly understand the hydrogeology, and the possible link between groundwater and surface resources. To achieve this it required an integrated approach, bridging between the different disciplines of hydrogeology, geomorphology and ecology.

The aim of this study was to conceptualise and asses the groundwater dependence of the aquatic ecosystems (streams, rivers, springs, seeps and wetlands) associated with the TMG aquifer of the Cape Fold Mountains.

1.2. Hypothesis and objectives of the study:

The first hypothesis of this study was that discharges from the TMG aquifer are largely responsible for maintaining a natural flow regime in the mountain and foothill streams of the Cape Fold Mountains in varying degrees, further that the flow regime will be affected when large scale abstraction from this aquifer system is instituted.

Linked to this, the second hypothesis stated that there are different types of groundwater discharges that contribute to the flow regime in rivers and streams, particularly in the mountain and foothill areas where these streams and rivers are associated with the TMG. It was therefore essential to understand the mechanism of groundwater discharge to surface resources, and where in the landscape these discharges dominated. This would enable the assessment of areas where groundwater discharges might be affected if groundwater should be used from the TMG aquifer. It would also enable the prediction of whether the flow regime and ecology might be affected.

The third hypothesis was that there are two primary areas of interaction between groundwater from the TMG aquifer and aquatic ecosystems. The first is located in the "TMG aquifer daylight-domain" where groundwater from the TMG aquifer is discharged at or near the recharge area in the higher elevation mountain and foothill areas, and the second is located in the "TMG aquifer surface water interface-domain", which refers to discharges in the lowland settings closer to or at the discharge end of the aquifer. These TMG discharges would be indicated by the geology and stratigraphy, geological contact zones, aquifer boundary conditions, and piezometric surface position.

The fourth hypothesis was that it would be possible to develop a GIS model which will integrate the conceptualization of groundwater surface water interactions in the TMG and highlight aquatic ecosystem areas sensitive to groundwater use from the TMG aquifer. It would therefore be possible to determine the groundwater dependence of aquatic ecosystems (streams, seeps, springs and other wetlands) associated with the TMG Aquifer in the Cape Fold Mountains using a GIS model.

The **objectives** of this study were:

- To determine the ***mechanisms*** of the groundwater discharge to aquatic ecosystems associated with the TMG through a conceptual understanding.
- To determine the different ***groundwater*** 'discharge types', as recognised by hydrogeologists, and to distinguishing between real groundwater and non-groundwater contributions to surface resources.
- To establish ***where*** the interface between ***groundwater*** from the TMG aquifer and surface resources are located in the landscape.
- To establish ***which*** part of the flow regime of streams and rivers will be affected most by groundwater use from the TMG aquifer that would subsequently affect the ecological functioning of aquatic ecosystems.
- To ***develop a conceptual model*** by integrating the above information to explain the different groundwater 'discharge types' contributing to the flow regime in stream and rivers associated with the TMG indicating aquatic ecosystem groundwater dependence.
- To scientifically ***validate*** this ***conceptual understanding*** through two separate case studies.
  - The first case study had to be located in the "TMG aquifer daylight-domain", to test the conceptualised groundwater surface water interface.

  - The second case study had to be located in the “TMG aquifer surface water interface-domain”, to test the conceptualised groundwater discharges to surface resources at the discharge end of the aquifer.
- Finally to ***develop a GIS model*** that would highlight aquatic ecosystems sensitive to groundwater-use from the TMG aquifer. This aquatic ecosystem sensitivity had to relate to areas having both a high groundwater development potential and high groundwater dependence.

The results from this study clearly highlighted the importance of an integrated approach to groundwater development and planning. Such an approach will prevent major conflict and impacts to the aquatic ecosystems of the Western Cape. With the Cape Floral Kingdom, being one of the six plant kingdoms of the world, it is crucial to ensure the sustainable management of the full hydrological cycle. Ironically, the streams and rivers associated with the mountainous areas will be affected most by groundwater use, but are also the most important from a conservation point of view. These mountain and foothill streams comprise the tributaries of all major river systems and contain the last indigenous and endemic species associated with the different systems that are hanging in for dear life as fragmented populations.

CHAPTER TWO
Literature review

2.1. Hydrogeology

2.1.1. Defining groundwater

Subterranean water occurs in two principal zones, the unsaturated zone and the saturated zone. In the unsaturated zone, or vadose zone (Parsons, 2004), the spaces between the grains of gravel, sand, silt, clay, and cracks within rock contain both air and water. Although this might constitute a significant amount of water it cannot be pumped because of the strong capillary forces. In contrast to the unsaturated zone the saturated zone is characterised by being completely filled with water, and this is referred to as groundwater (Ward and Robinson, 1990). However, the distinction between saturated and unsaturated conditions is an artificial one because there are an essential unity between all types of subsurface water and indeed also between surface water and subsurface water (Ward and Robinson, 1990). For the purposes of understanding the interface between groundwater discharges from the TMG aquifer to surface resources, it was essential to distinguish between real groundwater and perceived, or non-groundwater discharges.

Surface water groundwater interactions can be quantified in one of two ways nl. recharge of groundwater by surface water, and secondly discharge of groundwater to surface water. The interconnected nature of surface and groundwater was also shown by Knezek and Krasny (1990), who stated that the best way of estimating regional groundwater resources was by doing groundwater runoff estimates. These statements relate well to the TMG aquifer by having been established in a fractured hard rock aquifer system in Czechoslovakia, namely, the Bohemian Massif consisting of largely late Paleozoic igneous, metamorphic and well-cemented rocks (Xu and Beekman, 2003).

Stream flow studies in Malawi and Zimbabwe have also indicated that base flow can be used as a means of providing a minimum estimate of recharge by calculating a ratio of rainfall contributing to stream flow. However, it was also suggested that the greater the relief, the steeper the piezometric gradients that can develop and the faster the groundwater flow and the lessor the volume of groundwater lost through evapo-transpiration on-route to the stream. This undoubtedly showed that other factors had to be considered too, like higher rainfall, greater stream density, thinner soil cover and differences in vegetation cover between mountainous and hilly country compared to flat terrain (Xu and Beekman, 2003).

2.1.2. Types of aquifers

Any geological formation comprising of rock or unconsolidated deposits that contain sufficient quantities of water is known as an aquifer (Ward and Robinson, 1990). Groundwater is stored and transmitted in voids (pore spaces or interstices) between individual sediment, soil or rock particles, and more water is able to move through large pore spaces than smaller pore spaces. Very little water would be able to flow through solid rock, where the interstices have been cemented together during the rock forming process. However, should this rock be transformed by weathering, folding, faulting or uplifting, as is the case in the TMG, groundwater will be able to move in the voids created by these alterations. These voids that were created during the transformation of the rock are referred to as *secondary openings* and gave rise to the concepts of *primary* and *secondary* aquifers. In primary aquifers, groundwater moves through the original pore spaces of the geological material, like quaternary deposits. A striking characteristic of secondary aquifers is the variability of aquifer parameters over short distances, where both the hydraulic conductivity and storativity of fractured rock aquifers can vary by several orders of magnitude over short distances (Parsons, 2004).

Most major aquifers are composed of sedimentary deposits formed from the erosion and deposition of other rocks. In contrast, igneous and metamorphic rocks, formed under conditions of high temperature and pressure, generally have less interconnected pore spaces and would mostly have low water-bearing capacities (Ward and Robinson, 1990). In South Africa it is estimated by DWAF in their newsletter (National Water Act News, 2004) that 90% of the country’s groundwater occurs in hard rock aquifers. Parsons (2004) state that almost 98% of aquifers in South Africa are classified as secondary aquifers, with only a few coastal primary aquifers.

In the literature reference is made about confined, semi-confined and un-confined aquifers. The geological condition determines the form of an aquifer, and the presence or absence of an overlying aquitard or confining layer would determine whether it is a confined or unconfined aquifer system. Aquitards are formations having lower permeability, and have a significantly lower hydraulic conductivity (Parsons, 2004), and can only transmit water at much lower rates than the adjacent aquifers (Ward and Robinson, 1990). Unconfined aquifers are normally known as the water table, which is the level at which the pore-water pressure is equal to atmospheric pressure. Depending on the texture of the material comprising the saturated zone the water table will be more or less horizontal (Ward and Robinson, 1990; Parsons, 2004). Confined aquifers are overlain by an aquitard which will prevent upward movement of the water table, resulting in an increase of hydrostatic pressure in the aquifer (See Figure 2.1). This result in an imaginary line connecting points of equal pressure inside the aquifer that is referred to as the piezometric surface (confined water table), and is the equivalent of a water table found in unconfined aquifers. These types of aquifers are also called artesian aquifers with examples of the Great Artesian Basin in Australia and the Uitenhage Artesian Basin in South Africa (Parsons, 2004).

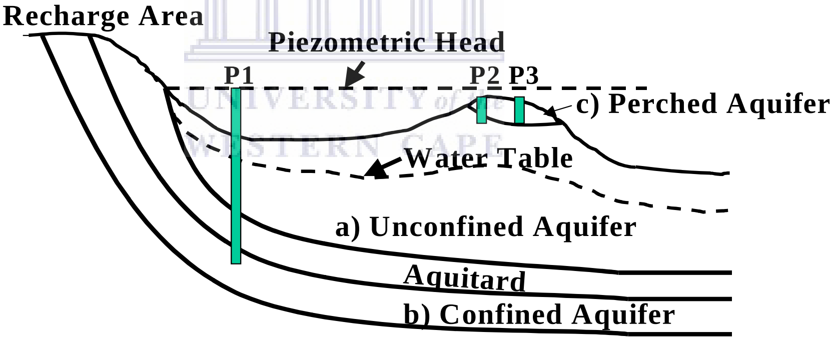

Figure 2.1. Diagrammatic relationship between unconfined aquifer (A), perched aquifer (C) and confined aquifer (B). Note that the piezometric levels may be different (adapted from Ward and Robinson, 1990).

Most confined aquifers have an unconfined area through which recharge of the groundwater system occurs by means of infiltration and percolation. The water table (piezometric head) in this case would be the upper surface of the saturation zone. Due to the fact that the water table in this unconfined groundwater area, where the recharge happens, is situated at a higher elevation than the confined area of the aquifer, is would cause the groundwater in the latter area to be under pressure. This pressure will be equivalent to the difference in hydrostatic level between the two. When tapping into a confined aquifer the water level will theoretically rise in the borehole or well to the height of the hydrostatic head, also called the piezometric head (Ward and Robinson, 1990).

Hydrogeologists also talk about semi-confined or semi-unconfined aquifers, specifically in South Africa where the secondary nature of aquifers results in relatively large differences in hydraulic conductivity over short distances. In these aquifers the differences in hydraulic conductivity retards the movement of water, thereby resulting in both lateral and vertical localised pressure differences. Most aquifers in South Africa fall into this semi-confined or semi-unconfined category (Parsons, 2004).

Perched aquifers are a special case of an unconfined aquifer in which the underlying impermeable or semi-permeable bed is not continuous over a very large area and is situated higher than the main groundwater body (Ward and Robinson, 1990; Parsons, 2004).

2.1.3. Hydrogeology of the Cape Fold Belt

Conceptualising groundwater movement is much more difficult than water in the atmosphere and on the land surface. Groundwater normally moves along flow paths of varying lengths from areas of recharge to areas of discharge. It generally starts at the water table and continues through the ground-water system, and ends in streams or other types of discharges. The water table receives water from infiltration of precipitation through the unsaturated zone. In unconfined (uppermost) aquifers, flow paths are near the stream and can be tens to hundreds of meters in length and have corresponding travel times of days to a few years. The longer deeper flow paths may be hundreds of metres to tens of kilometres in length, and the travel times may be from decades to millennia (See Figure 2.2). The different geologic units have different permeabilities that affect seepage and distribution patterns of groundwater (Winter *et al.*, 1999).

The TMG, as part of the Cape Super Group, form the backbone of the Cape Fold Belt that runs from Van Rhynsdorp in the west to Port Elizabeth in the east. As most rock formations, like the TMG, have low primary porosities, they only become good aquifers where fractured, folded and or faulted. It is therefore only favourable aquifers where the strata are strongly folded and faulted, which creates secondary porosity (De Beer, 2002; Kotze, 2002).

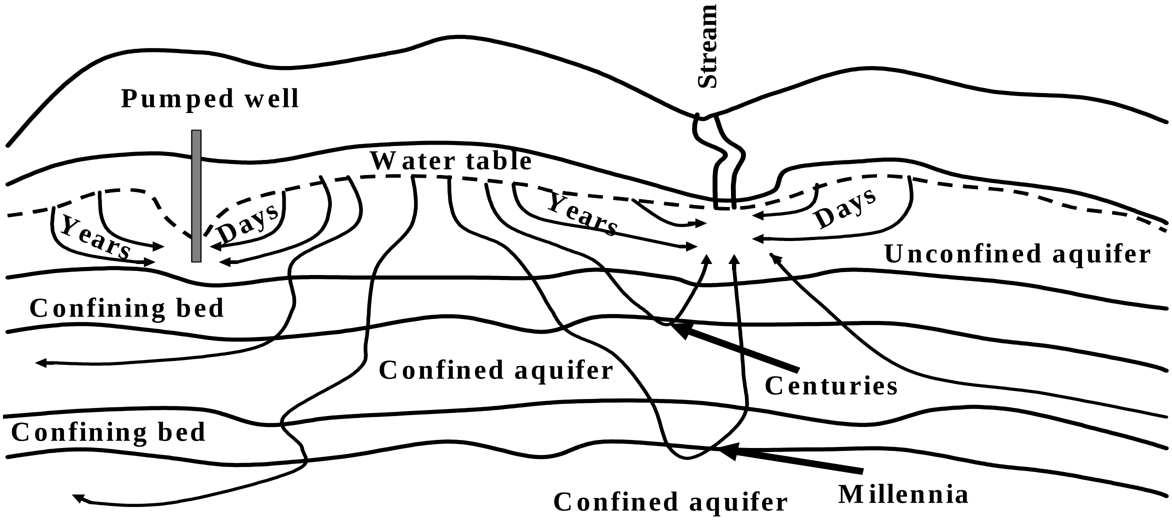

Figure 2.2. Schematic representation of the flow paths of groundwater in different time scales (local and regional) (Winter *et al.*, 1999).

2.1.4. The Table Mountain Sandstones (TMS) of the Table Mountain Group (TMG)

In the Western Cape Province of South Africa the Cape Super Group was deposited from the early Ordovician to early Carboniferous times (approximately 340 to 500 million years ago). This siliclastic dominated sequence is exposed along its entire length of the Cape Fold Belt (De Beer, 2002). According to De Beer (2002) the succession of quartz arenites, shales and siltstones, with minor conglomerate and thin diamictite unit, has been subdivided into the Table Mountain, Bokkeveld and Witteberg Groups (Du Toit, 1954; Rust, 1967; Theron, 1972; Theron and Loock, 1988; Broquet, 1992 all in De Beer, 2002). These sediments were deposited in shallow marine environments as well as in non-marine, braided-fluvial environments. Due to the medium to coarse grain size and relative purity of some of the quartz arenites, together with their well indurated nature and fracturing caused by folding and faulting in the fold belt, enhance both the quality of the groundwater and its exploitation potential (De Beer, 2002). Over time these layers became buried, eventually forming rock under the pressure and temperature increases. Due to continental movement these layers became squeezed into folds that buckled and fractured. This resulted in the fractures and faults in the brittle or competent layers e.g. the quartz sandstones, and extensive folding in the more pliable shale layers. Table 2.1 gives a summary of the Lithology (De Beer, 2002) and hydrostratigraphy (Hartnady and Hay, 2002) of the TMG.

Table 2.1. Lithostratigraphy[1] (De Beer, 2002) and hydrostratigraphy[2] (Hartnady and Hay, 2002) of the TMG (Thickness values apply mostly to the south-western outcrops).

Subgroup	**Formation**	**Lithology (Rock type)**	**Max. Thickness (m)**	**Hydro-stratigraphy**
Nardouw	Rietvlei/Baviaanskloof	Feldspathic sandstone	280	Aquifer (limited)
	Verlorenvalley	Shale		Mini-aquitard
	Skurweberg	Quartz sandstone	290	Aquifer
	Goudini	Silty sandstone, siltstone	230	Meso-aquitard
Peninsula	Cedarberg Pakhuis	Shale, siltstone Diamictite shale	120 40	Meso-aquitard
	Peninsula	Quartz sandstone	1800	Aquifer
	Graafwater	Impure sandstone, shale	420	Meso-aquitard
	Piekenierskloof	Quartz sandstone, Conglomerate, shale	900	Aquifer (limited)

[1] The sequence in which rock types are layered

[2] The sequence in which hydrological units (aquifers, aquitard) are layered

Since 1999 the Table Mountain Sandstones (TMS) of the Cape Fold Mountains have been identified, and subsequently targeted, for bulk water supply. The Water Research Commission has since then started funding research to ensure a proper understanding of the functioning of this aquifer system and to determine potential impacts on surface resources that might be expected when exploitation will start (Pietersen and Parsons, 2002).

2.1.5. Properties of TMG aquifer systems

De Beer (2002) stated that large fracture systems within the arenites of the TMG have the potential to be important water resources in future, due to its capacity to contain large quantities of water in flow paths of the fracture systems.

Most of the water in fractured rock aquifers like the TMG, occur in the preferential flow paths in the major fracture systems. The macro fractures are usually embedded in a porous matrix consisting of sandstone blocks or micro fissured quartzite blocks. Some water can be stored in the innumerable pores and micro features of this matrix, but it has a lower permeability than the fractures (Brown *et al.*, 2003).

One of the most striking hydrogeological features of fractured rock aquifer systems is its variable parameters, like the large magnitude of variation in the hydraulic conductivity or permeability and storativity. Strong preferential flow paths exist along fractures zones resulting in anisotropic flow. Fractures are also densely interconnected forming a fracture network characterised by a large storage capacity (Brown *et al.*, 2003). All the above properties of the TMG determine the hydraulic behaviour of this fractured rock aquifer.

When aquifers are utilised by pumping boreholes, standard equations as derived for primary aquifer systems, state that radius of influence increases with increased permeability and decreased storativity. In the case of fractured rock systems the fractures act as conduits of water with very high permeability, and can the radius of influence (cone of depression) easily extend several kilometres in the direction of the fractures set, while the radius perpendicular to the fractures reaches only several meters (Brown *et al.*, 2003). This has far reaching implications for groundwater use in the TMG, where buffer zones will have to be included around aquifer delineation, to include this extended drawdown patters that can develop.

In South Africa flow of groundwater in most of the fractured-rock formations is controlled by two types of fractures, namely: vertical and sub-vertical fractures (i.e. faults and fault zones caused by tectonic stresses; contacts along dykes) and horizontal or bedding-plane fractures (i.e. fractures formed by tension releases, uplifting and weathered zones) (Brown *et al.*, 2003).

In the tectonically folded TMG fractured rock system in the Western Cape the main geological and hydrogeological settings that are targeted for large scale abstraction are the *Skurweberg Aquifer* in the *Nardouw Subgroup* and the *Peninsula Aquifer* in the *Peninsula Subgroup*. Table 2.2 lists the main characteristics and differences between the Skurweberg Aquifer and Peninsula Aquifer (Brown *et al.*, 2003).

Water from the Peninsula formation of the TMG tends to be oligotrophic (low in nutrients), acidic and low in salinity (conductivity) due to the character of the TMS. Unlike the water from the Peninsula formation the water from the Nardouw formation generally has a higher salt and iron content. The general expected water chemistry characteristics for water abstracted from the Peninsula formation of the TMG is given in Table 2.3.

Table 2.2. Lists the main characteristics and differences between the Skurweberg Aquifer and Peninsula Aquifer (Brown *et al.*, 2003).

Characteristics	Skurweberg Aquifer	Peninsula Aquifer
Elevation of outcrops	Middle and lower ranges	High mountain ranges
Vegetation cover	Karroid shrublands, Renosterveld, Fynbos	Fynbos, often bare rock
Weathering	Highly weathered, fractured	Resistant, highly fractured
Confined/unconfined	Often confined, overlaid by Bokkeveld Shale	Mostly confined, overlain by Cedarberg Shale
Material	Sandstone, siltstone, shale layers	Sandstone, Quartzite
Bedding & jointing	Thin bedding, cross-bedding, small vertical fractures; medium fracture network	Thick bedding, dense vertical fractures; good fracture network
Storage capacity	Medium storativity due to less thickness and fracturing	High storativity due to thickness and dense fracture network
Recharge	Less rainfall and less recharge percentage	High rainfall and higher recharge percentage
Discharge	Seep zones, seasonal low flow springs	High elevation wetlands, perennial springs

Table 2.3. Typical water chemistry characteristics expected for water abstracted from confined TMG aquifer. All concentrations in mg/l unless otherwise indicated (Smith *et al.*, 2002).

	EC (mS/m)	PH	Na	Mg	Ca	Cl	SO_4	Alkalinity as $CaCO_3$	Si	K	Fe	ΔD (‰)	Δ^{18}O (‰)
Boreholes from Nardouw Subgroup													
Mean	30.0	6.0	30.8	5.8	10.2	56.2	27.6	42.8	6.4	5.1	3.3	-45.2	-7.3
Minimum	9.2	3.1	7.2	1.5	1.3	6.1	3.2	1.0	2.1	0.4	<0.1	-53.2	-7.9
Maximum	155.0	8.3	232.8	43.1	73.4	395.2	220.5	147.3	18.1	16.2	15.4	-27.7	-6.3
Boreholes from Peninsula Formation													
Mean	10.4	6.2	11.1	1.8	3.3	18.0	5.2	14.5	3.8	0.8	0.2	-42.8	-7.3
Minimum	2.6	4.3	2.0	0.9	0.4	4.5	1.0	3.5	1.4	0.2	0.1	-51.1	-7.7
Maximum	26.3	7.6	21.2	3.2	30.4	34.1	14.0	77.9	9.4	2.3	0.2	-35.5	-7.06

2.1.6. Groundwater surface-water interface

Until recently surface water and groundwater were treated as separate entities around the world. However, with the increase in water use it became apparent that development of either of these resources affects the quantity and quality of the other (Winter *et al*., 1999). This is also true for South Africa, and the change in the Western Cape Province came in 1999, when the Cape Folded Mountain Ranges, consisting of mainly Table Mountain Sandstones (TMS), where identified and targeted for bulk groundwater exploration and exploitation. This incited a debate by the biodiversity conservation agencies in the Western Cape Province because the province is home to one of six Floral Kingdoms of the World, namely the Cape Floral Kingdom (CFK). Many of the CFK communities are possible associated with these unique mountain ranges and many of them are said to be groundwater dependent. It was also postulated that most surface water, especially in mountainous reaches, originates from groundwater sources (Roets, 2002). Ward and Robinson (1990) agree that groundwater sustains stream flow during periods of dry weather and is the major source of water in many arid areas. Winter *et al*. (1999) also realized and described it as “Nearly all surface water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with groundwater”. Even floods in river systems can be mainly groundwater. According to Midgley and Scott (1994) less than 5% of storm flows (floods) comprised of direct runoff. They concluded through isotopic analyses (D and ^{18}O) of storm flows in the Jonkershoek valley near Stellenbosch, that most of the water in a storm flow response consisted of displaced groundwater (up to 95% of storm flow consisted of groundwater with less that 8.5% or less being rainwater). It was suggested that the rapid response of these streams to rainfall was mainly due to displaced groundwater associated well drained soils with high infiltration capacities. This was supported by findings from Richey *et al*. (1998) (in Parsons, 2004) on research in New Zealand, North America and Europe. This theory is also supported by the fact that South Africa has one of the lowest conversions of mean annual precipitation (MAP) to mean annual runoff (MAR) at 8,6% (Hewlett and Bosch, 1984; Davies and Day, 1998). Many of the authors in Xu and Beekman (2003) support this viewpoint.

Horton and Hawkins (1965) in Ward and Robinson (1990) investigated the mechanism of recharge by infiltration and described it as a process of displacement whereby the water during rainfall is not “new” rainfall but previously stored rainfall being displaced downwards by successive bouts of infiltration. This process was called translatory flow or piston flow and undoubtedly helps explaining the often rapid response of water tables to precipitation, even in low permeable material (Ward and Robinson, 1990). Winter *et al.* (1999) states that groundwater contributes to stream flow in most physio-graphic and climatic settings, where the portion of stream water that is derived from groundwater inflow varies across physio-graphic and climatic settings. Base flows in rivers are discharged groundwater in the absence of rainfall. This is especially true in valley bottoms where the capillary fringe is near to the ground surface and little water is required to saturate the soils. This can have two consequences, saturated-excess overland flow (SOF) is generated, and secondly the large rise in the water table can displace a pulse of groundwater towards the river creating a storm flow response consisting of mainly groundwater (Xu and Beekman, 2003).

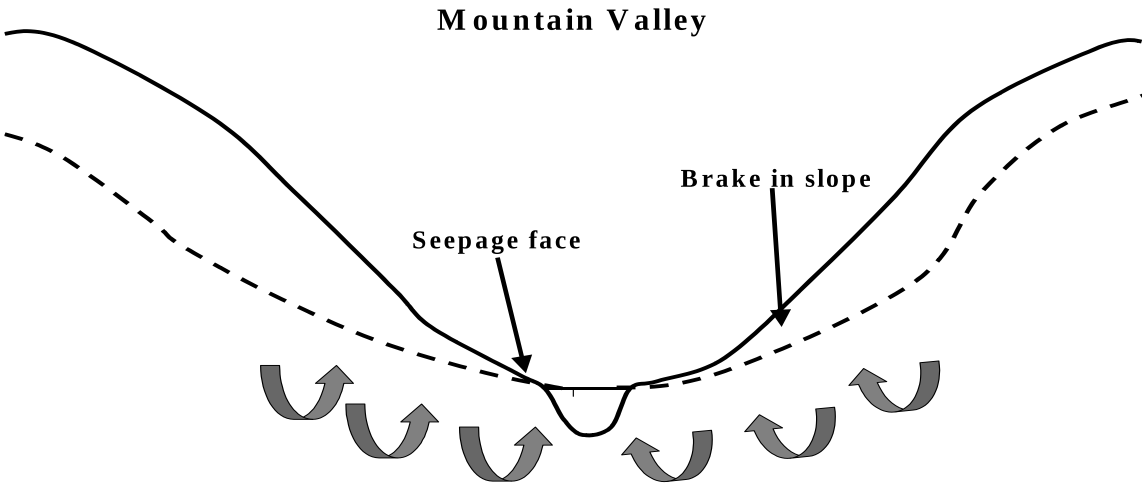

Figure 2.3. Schematic representation of groundwater discharges in a mountain valley.

Another very important aspect of groundwater surface water interaction is the hyporheic groundwater discharge and recharge as described by Winter *et al.* (1999). According to them the chemical reactions that take place where chemically distinct surface water meets chemically distinct groundwater in the hyporheic zone may result in a biogeochemical environment that in some cases could be used as an indicator of change in either terrestrial or aquatic ecosystems. Parsons (2004) refers to this interaction of groundwater and surface water in the hyporheos as being an important ecotone (Figure 2.5), or area of transition between different habitat types. The hyporheos as an ecotone provides a number of ecologically important services, including thermal-, temporal- and chemical buffering, habitat, flow augmentation, nutrient recycling and refugia (Parsons, 2004). This ultimately results in “unique” cocktails of species of aquatic fauna and flora reflecting the myriad of different environmental conditions caused by these discreet groundwater discharges, which is typical of the CFK.

Discharge of groundwater through the hyporheos also reset this zone and play an important role in the cycling of nutrients. Studies in North America suggest that nutrient processing in rivers is more complicated than initially meets the eye (Winter *et al.*, 1999). The flowing water represents only the ‘tip’ of a much larger body of water beneath the streambed. Up-welling through the streambed caused by groundwater infiltration or recharge, release rich nutrients back into the water column and reset the hyporheos (Figure 2.4). Cutting off this lateral exchange of water through its banks, and the vertical exchange with the hyporheos below the bed, through canalisation or groundwater interception will inevitable cause these rivers to cease to exist as true rivers (Davies and Day, 1998).

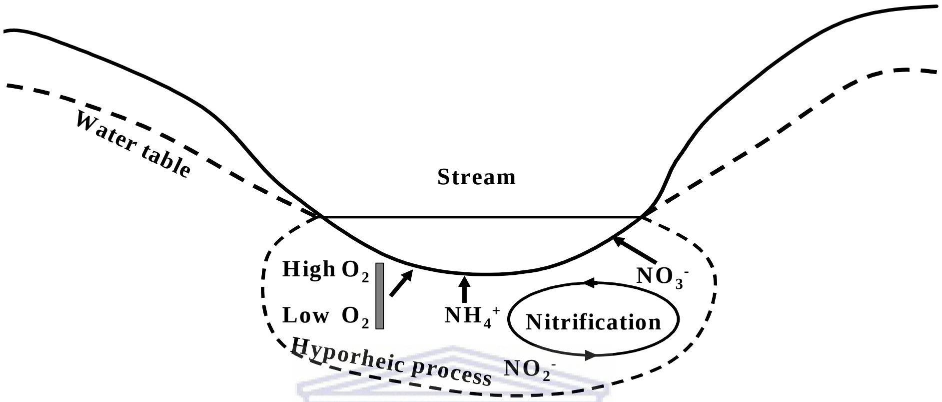

Figure 2.4. Hyporheic discharge of groundwater (Adapted from Winter *et. al*. 1999).

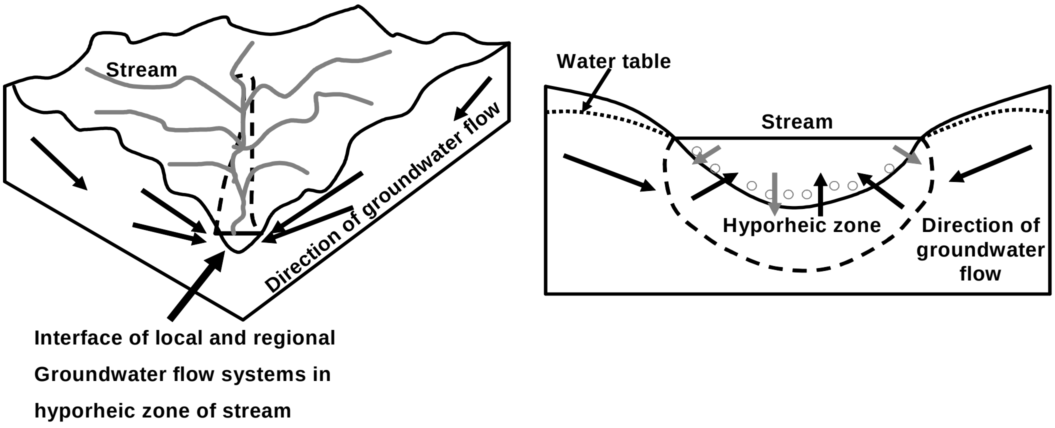

Figure 2.5. Schematic representation of hyporheic processes (Taken from Winter *et al.*, 1999).

Vegter and Pitman (1996) explain the relationship between groundwater and surface water more directly through the position of the piezometric surface (water table) in relation to the stream elevation (Xu and Beekman, 2003; Parsons, 2004). Table 2.4 summarise this approach proposed by Vegter and Pitman (1996).

Table 2.4. Summary of stream types associated with the different relationships of piezometric surface elevation to stream elevation (Vegter and Pitman, 1996).

Piezometric surface at all times below streambed level	Characteristic of ephemeral streams although not limited to them only. Two scenarios may occur: 1) The material between the streambed and piezometric surface is pervious – stream is influent (losing stream) with the piezometric surface sloping downward away from the stream – groundwater is recharged. 2) Intervening material more or less impervious – very little or no recharge of groundwater takes place.
Piezometric surface slopes laterally down towards the stream	Different scenario's may occur: 1) Groundwater emerges and discharge into streambed at all times – piezometric surface permanently above the stream stage – material between piezometric surface and stream is pervious, porous or fractured – stream is effluent (gaining stream) and perennial. 2) Groundwater from the catchment area emerges into stream at intervals only after recharge events – stream flow intermittent. During dry spells groundwater storage is depleted by effluent seepage and evapo-transpiration. Storm runoff may recharge local groundwater in the immediate vicinity of the stream, but in the absence of rechargeable alluvial deposits and/or porous decomposed rock, replenishment from storm runoff is of minor importance compared to the volume of water recharged over the total catchment area. 3) Groundwater may never reach the stream due to permanent dissipation along it's flow path towards the stream by evapo-transpiration.
Piezometric surface level fluctuates alternately above and below the stream stage	Piezometric surface fluctuates alternately above and below the stream stage. The stream may be underlain and bordered by alluvial deposits and/or porous decomposed rock, thus alternating between being in- and effluent. In this setting groundwater flow from the hard-rock catchment towards the stream generally is of minor importance. The inter-action between alluvium and stream is most prominent.
	Note: None of the above designations apply to the full length of a stream.

A fourth type of discharge proposed by the author of this thesis is bank storage which is recharged during a flood and discharged to the river or stream after the flood has receded. The bank storage will be mostly associated with alluvial deposits in the lowland river reaches of river systems. The local hydraulics and channel morphology are the primary determinants of the physical habitat, which itself controls ecosystem functioning (Heritage *et al*., 2000).

All the above suggest a fair amount of groundwater being discharged into streams, rivers and wetlands especially in the TMS of the Western Cape Province, and go a long way in explaining the rapid response to rainfall in the TMG. Understanding these interactions, which are complex and can vary quite a lot, is the biggest challenge for water resource managers in the 20th century.

2.1.6.1. Groundwater flow regimes in surface resources

The seepage relationship between surface and groundwater is very seldom static and will be changing with changes in the level of a stream or adjacent water table. It might therefore happen that in a matter of hours, effluent seepage (Figure 2.6) in a stream may supersede influent seepage (Figure 2.7) and *vice versa*, changing from a gaining to a losing stream (Ward and Robinson, 1990; Winter *et al.*, 1999). Where stream flow is generated in the higher elevation head waters, the changes in stream flow between gaining and losing conditions may be particularly variable (Winter *et al.,* 1999).

Xu and Beekman (2003) classified rivers from a hydro-geological perspective according to their vertical positioning, i.e. being at different elevations in relation to the underlying groundwater, and stream flow characteristics. Rivers can thus be *remote, perched* (Figure 2.6) or *connected* (Figure 2.7) depending on the landscape and geology. He further suggests that there is an interchange between surface and groundwater controlled by stream flow, water table configuration and geology. Some rivers can even switch between being perched or connected as the water table changes seasonally in response to recharge events.

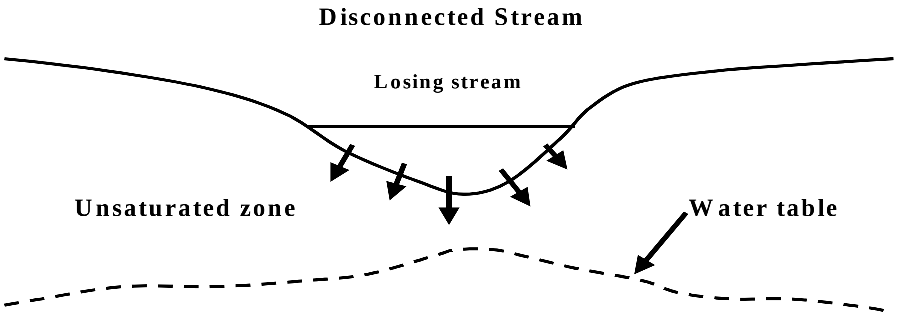

Figure 2.6. A stream disconnected from the water table, constantly loosing water to groundwater.

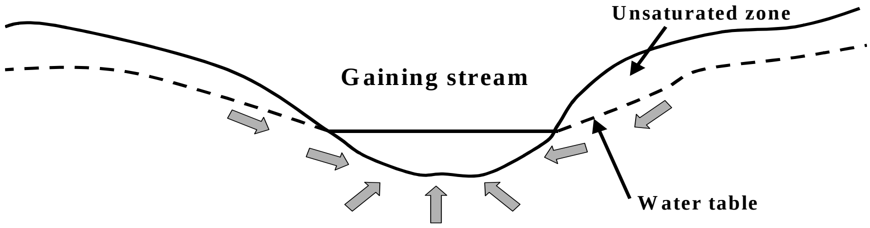

Figure 2.7. Water table higher than stream, groundwater discharged to the stream.

Stream flow characteristics separate rivers into two broad category's namely, ephemeral (event dominated) and perennial (continuous). The latter type rivers are normally connected to a water table, associated with groundwater discharge, wetter climates and larger catchments. Ephemeral rivers on the other hand are associated with dryer climates and are normally perched systems (Xu and Beekman, 2003). This classification is very appropriate for the Western Cape rivers systems, with the majority of rivers in the mountainous areas being connected and perennial and in the dryer parts, like the Klein Karoo and Karoo rivers being perched and ephemeral, with only the headwater streams being connected and perennial.

Since the flow regime in rivers play a very important role in the maintenance and functioning of in-stream processes it is evident that groundwater use could impact on the ecological integrity of river systems. Major floods flush accumulated debris, organic and other substances from rivers and floodplains resetting the system (Davies and Day, 1998). This flushing effect also maintains the river channel, bed structure and riparian vegetation which maintain habitat diversity. However, the low flows are essential for maintaining the river continuum and river integrity (Davies *et al*., 1993).

2.1.6.2. Runoff mechanisms

Conversion of rainfall to runoff is a combination of processes. Lerner (in Xu and Beekman, 2003) proposed that (a) overland flow or infiltration-excess overland flow (IOF) is generated when rainfall intensities exceed infiltration capacity. This is controlled by high rainfall rates and sealed surfaces such as bare rock, soils compacted by overgrazing, intensive agriculture, and with man-made coverings such as roads. The second mechanism (b) is saturation-excess overland flow (SOF) which occurs when soil becomes saturated from below and rainfall gets rejected. This is caused by through-flow from upslope that re-emerges on the surface. In this case SOF might occur at lower rainfall intensities than with IOF. The third mechanism (c) is unsaturated and locally saturated flows within slopes that are mainly related to layered permeability or the presence of macro-pores that form preferential flow paths. Such flows are characterised by rapid transmission of water to help saturate lower slopes that ultimately create conditions for SOF. The last mechanism (d) is subsurface storm flow (SSQ), which occurs below the main water table and provides the continuity of flows between rainfall events, and can even show a storm response (Xu and Beekman, 2003).

Water resource managers and water scientists need to understand this interaction of groundwater and surface water. If not, management of only one component of the hydrological system, such as a stream or an aquifer, would be only partially effective because each hydrological component is in continuous interaction with other components. Hence the need for the integration of the different disciplines into an ecohydrological understanding.

2.1.7. Managing the full hydrological system

To understand water resource management properly it is necessary to understand the full hydrological cycle (Winter *et al.*, 1999). This interdependence and continuous movement of water in all its different forms from one phase to another (Ward and Robinson, 1990), and cyclic through the atmosphere, lithosphere, hydrosphere and biosphere is referred to as the hydrological cycle (Middleton, 1999; Bergman and Renwick, 2002).

Each drainage basin (watershed or catchment) can be regarded as an individual system receiving quantifiable inputs of precipitation and converting this water as various flows and storages, into quantifiable outputs of evaporation and stream flow. In specific geological settings, leakages from deeper subsurface water may represent either an additional input or an additional output from the drainage basin system. Unfortunately drainage systems rarely operate completely un-impacted by anthropogenic influences, and it is therefore important to recognise these human induced modifications affecting virtually every component of the system (Ward and Robinson, 1990).

Ward and Robinson (1990) list the following as the most important anthropogenic impacts:

- Large-scale modifications of river flow and storage by means of, e.g. catchment modifications such as afforestation, deforestation, urbanisation, etc, all of which affect surface runoff and the incidence or magnitude of flooding.
- The indiscriminate development of irrigation and draining of land surfaces, and
- Large-scale abstraction of groundwater and surface water for bulk supply.

Artificial recharge of aquifers and inter-basin transfers of surface and groundwater are other very important human modification to the hydrological cycle in specific drainage basins.

2.1.8. Groundwater movement and recharge

The groundwater system is a three-dimensional flow field and it is therefore important to understand how the vertical component of groundwater movement affects the interaction of groundwater and surface water.

Actual flow fields are generally very complex and are of different sizes and depths, and can even overlie one another. Local flow systems are the most dynamic and mostly shallow flow systems, having the greatest interchange with surface water. These local flow systems can be underlain by intermediate and regional flow systems. The deeper flow systems have longer flow paths (see Figure 2.2) and longer contact time with the subsurface materials and would therefore generally contain more dissolved chemicals (Winter *et al.*, 1999). Flow in rivers is typically measured in metres per second, but groundwater flow is much slower and is expressed in metres per annum (Parsons, 2004).

It is important to recognise that it is not the movement of groundwater that controls the discharge of groundwater into surface water bodies, but rather the hydraulic pressure. Downward movement of water in soil is largely driven by gravitational forces in the unsaturated zone, while lateral flow may be induced by localised differences in the hydraulic properties of aquifer material. Downward movement of water cease when the matrix forces of individual soil or rock particles exceed that of gravity (Parsons, 2004).

By doing groundwater dating, it helps understanding the recharge rate and groundwater movement. Xu and Maclear (cited in Xu and Beekman, 2003) give calculated groundwater ages ranging from 1350 years at the Uitenhage Springs immediately east of the recharge area, to 28000 years at the Couga Kop discharge area near the sea. From this data it was calculated that the flow rate along the flow path in the Couga Artesian Basin is 0.76 m/yr. It was further estimated that the most recharge water discharge in the Uitenhage Spring at the edge of the unconfined area and that less than 3% of the total recharge flows into the confined section of the TMG aquifer to the east (Xu and Beekman, 2003). Xu and Maclear (cited in Xu and Beekman, 2003) applied the above data to a new method, the Auto Regression and Moving Average (ARMA), and found a time lag of 13 years between rainfall and spring responses. They concluded that pre-drilling recharged totalled 10% and increased to 11% post-drilling due to induced recharge, and accepted 3% of total recharge as the figure for recharge of the deep flow component of the confined aquifer in this basin. Groundwater yield is explained by the following simple water balance equation:

RECHARGE – OUTFLOW = STORAGE (RESOURCE)

Recharge in this equation includes all inputs to groundwater, rainfall, surface water and inter-aquifer flows. Outflow would include phreatophyte evapo-transpiration and discharge to surface water, which equates to the resource (Xu and Beekman, 2003). Under natural conditions, the water table position would reflect an equilibrium between aquifer recharge and discharge. However, a reduction in the recharge in response to reduced rainfall will result in a drop in the water table and a subsequent reduced discharge from the aquifer. A new stable water table level may develop reflecting the new equilibrium between recharge and discharge. Similarly, abstraction of groundwater will decrease the volume of water discharging from the aquifer, resulting in a shift in the water table until a new dynamic equilibrium is reached (See Figure2.9). This dynamic or changing water table level, whether by millimetres or a couple of meters, would clearly impact the amount of groundwater discharged to surface water bodies (Parsons, 2004). Xu and Beekman (2003) state that pumping an aquifer change the equation and the water balance to:

ADJUSTED RECHARGE – REDUCED OUTFLOW – VOLUME PUMPED = STORAGE LOSS (REDUCED RESOURCE)

This equation acknowledges that recharge may have increased and outflow decreased (surface discharges) in response to lowering the water table. For groundwater development to be environmentally acceptable and sustainable, these loses must be balanced against the beneficial use of the pumped groundwater (Xu and Beekman, 2003).

Recharge can be defined as the downward flow of water reaching the water table (piezometric surface), increasing the amount of water in the groundwater reservoir (aquifer) (Lerner *et al.*, 1990).

Xu and Beekman (2003) identified four modes of recharge:
(a) "Downward flow of water through the unsaturated zone reaching the water table"; (b) "Lateral and/or vertical inter-aquifer flow"; (c) "Induced recharge from nearby surface water bodies resulting from groundwater abstraction", and (d) "Artificial recharge such as from borehole injection or man-made infiltration ponds"

The downward flow through the unsaturated zone reaching the water table (Figure 2.8A) is the main mode of recharge, especially in arid and semi-arid areas. The main sources of recharge for this mode are rainfall, surface water bodies and irrigation losses (Xu and Beekman, 2003).

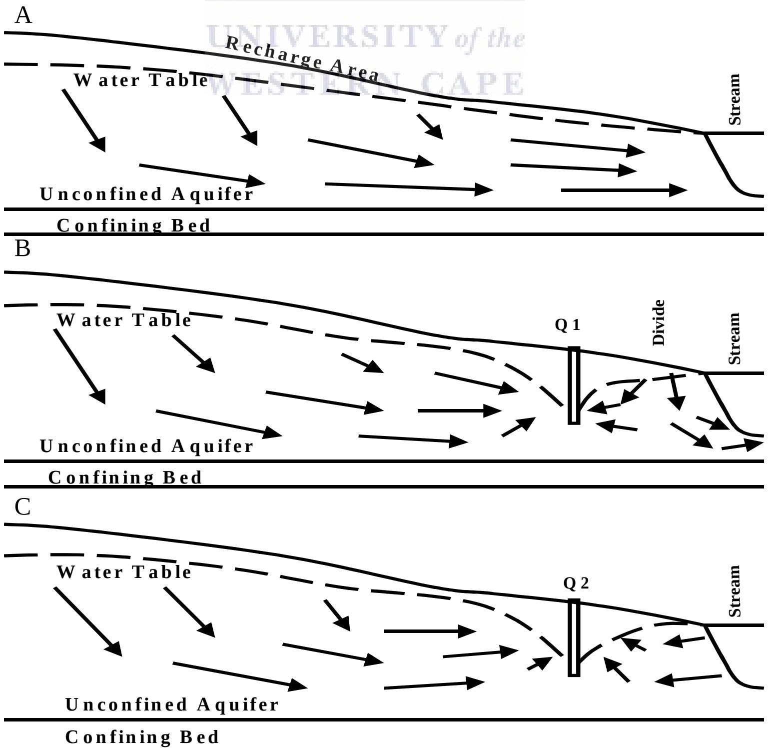

Figure 2.8. Diagrams showing an unconfined aquifer and cone of depression for different pump rates (A) no pumping, (B) Q1, pump rate does not cross the divide to reverse recharge from surface resource and, (C) Q2, pump rate induce recharge from surface resource (adapted from Winter *et al.*, 1999).

Xu and Beekman (2003) classified recharge as follows:

"I. Origin of water (Lloyd, 1986; Lerner *et al.*, 1990; De Vries and Simmers, 2002):

  a. direct / diffuse recharge: direct infiltration of precipitation and subsequent percolation through the unsaturated zone to a groundwater body, i.e. water added to the groundwater reservoir in excess of soil-moisture deficits and evapo-transpiration,
  b. indirect / non-diffuse recharge: percolated to the water table through riverbeds,
  c. localised recharge: accumulation of precipitation in surface water bodies, and subsequently concentrated infiltration and percolation through the unsaturated zone to a groundwater body.

II. Flow mechanism through the unsaturated zone:

  a. piston / translatory flow: precipitation which is stored in the unsaturated zone, is displaced downwards by the next infiltration / percolation event without disturbance of the moisture distribution,
  b. preferential flow: flow via preferred pathways / macro-pores, which are sites (e.g. abandoned root channels, burrows, fissures) or zones (e.g. stream beds) in the unsaturated zone with a relatively high infiltration and / or percolation capacity.

III. Area on which it acts:

  a. point recharge: recharge at a site, with no areal extent,
  b. line recharge: recharge from a line source, such as a drainage feature or river,
  c. areal recharge: recharge over an area.

IV. Time scale during which it occurs (for both episodic and perennial recharge):

  a. present-day recharge: recharge occurring within a time frame of days / months,
  b. short-term recharge: recharge covering a short period, in the past or predicted for the near future within a time frame of months / years,
  c. long-term recharge: recharge over a longer period, in the past (paleo-recharge) or predicted for the future (accounting for climate change) within a time frame of tens up to thousands of years.".

Recharge would include most elements of the hydrological system and the inter-related factors governing the frequency and extent of recharge in the TMG aquifer systems, these would include: rainfall (depth, duration, intensity); snowmelt; topography and altitude; lithology; depth and type of soil cover; vegetation type and density; fracture density, orientation and geometry; antecedent moisture conditions; depth to groundwater; regional groundwater flow patterns; and existing groundwater abstraction (Parsons, 2002).

Parsons (2002) reported that the recharge of the TMG aquifer system in the Western Cape mostly occurs in the mountainous areas were the precipitation (rainfall, snowmelt) is the highest, and where fractured rock are directly exposed. He also suggested that preferential flow in fractures is the key mechanism in the recharge process.

The groundwater movement towards the discharge zones occur through a series of local or regional interconnected fractures or fracture systems, either moving through the upper more localised aquifer or by means of deep circulation. Estimated recharge of the TMG aquifer system were found to be generally higher than expected, with recharge ranges from 5% of MAP in drier areas to in excess of 20% of MAP in higher lying areas with an annual rainfall greater than 600 mm/a. Rates of 35% of MAP can be considered in areas receiving more than a 1000 mm/a (Parsons, 2002).

Kirchner (cited in Xu and Beekman, 2003) states that in arid and semi-arid environment the water level in an aquifer drops during the year due to outflow, and the water level rise again during a normal rainy season. He suggests that it is only during the major rainfall events that occur every thirty-, fifty-, one hundred years and longer that the aquifer is fully recharged. In addition to this, the recharge, especially in semi-confined and confined aquifers, not only occurs in a vertical but predominantly in ± horizontal direction. This would imply that the water-level rise at a given point also depends on the distance from the recharge area, the aquifer transmissivity, and the storativity. This imply that there will be a high and immediate response of the water level near the recharge area and a delayed or lesser response further away. The lower part of the aquifer is therefore recharged months after the event (Xu and Beekman, 2003). The greater the aridity of the climate the smaller and potentially more variable is the recharge flux. This complicates groundwater management in arid areas.

In South Africa most aquifers are fractured rock aquifers, where the water is mainly stored in joints, fractures and faults. Permeability and storativity in fractured rock aquifers vary with depth and it has been found that the water-bearing capacity of most of these aquifers types decrease considerably when the water level is lowered by more than 20 – 30 m.

Apart from the natural recession of the water level, abstraction could cause and additional drawdown of the water level (Xu and Beekman, 2003). It also shows that the TMG aquifer is completely recharge dependent.

2.1.9. The role of hydrogeomorphology in the classification of streams in South Africa including those associated with the TMG

Classification of streams may be based on various criteria for different purposes. In the South African context it made sense to characterise streams by their geomorphic features for hydrogeological investigations to be in line with ecological reserve determinations as required by the National Water Act. Xu *et al*. (2001) adopted the following geomorphologic classification for the quantification of groundwater discharge towards streams (see Table 2.5), which relate well to river reaches associated with the TMG.

Table 2.5. Geomorphological classification of river reaches (Xu *et al*., 2002).

Upper catchment areas	▪ Steep profiles ▪ Deep incision ▪ Inflow from valley sides in humid areas ▪ Large bedloads
Middle courses	▪ Bedload deposition ▪ Braided channels near mountains ▪ Neotectonic uplift creates an incised convex profile downstream with riffle and pool sequences ▪ A few meandering rivers in stable areas in South Africa (e.g. Klip River)
Lower courses	▪ Neotectonic uplift causes incision, especially of old meanders ▪ In the arid west rivers are allogenic, with deeper bed deposits and thicker terraces ▪ In estuaries sea level changes resulted in deep infills with some saline intrusion ▪ Meanders on wide coastal plains (e.g. Pongola) ▪ Special cases of endoreic drainage into large pans (e.g. Okavango River).

Xu *et al*. (2002) went further and used the above classification to summarise groundwater interaction with streams (rivers) as follows:

For the upper catchment (Head water and Mountain reaches):

- Type a: Are streams without bank storage (e.g. braided rivers), most likely to occur in the mountainous areas. Stream flow velocities of sufficient energy to incise the stream channel resulting in cliffs on either side. At a local scale interflow could seep into the stream, but at regional scale these are recharge areas for groundwater.

For the middle reaches (Foothill areas):

- Type b: Streams are controlled by bed morphology (e.g. pool and riffle sequences), and is often associated with, but not restricted to, Type ‘a’ streams. Interaction with groundwater due to bed morphology alone is localised, but can regionally be significant. Both recharge and discharge to aquifers may occur. At a regional scale this is a groundwater runoff area, whereas at a local scale the interaction between groundwater and the river may be inter-changeable.

For lower reaches (lowland rivers):

- Type c: Streams characterised by bank storage (e.g. meandering rivers), often associated with topographically flat areas near regional base level. The fluvial erosion develops the terrain horizontally, and these areas may become a bank storage buffer for groundwater. This is generally the discharge area for regional groundwater system. However, bank storage is only significant for groundwater if the banks are composed of unconsolidated sediments with good storage coefficient.
- Type d: These are streams influenced by channel morphology and are often associated with, but not restricted to, Type ‘c’ streams. The interaction with groundwater due to channel morphology is at intermediate scale and is discharging to the regional groundwater system.
- Type e: These stream types are dictated by geological structures, especially those caused by neotectonic movement, and groundwater interactions with surface water are site specific.
- Type f: These streams have headwaters originating from allogenic sources and often occur in the drier western part of South Africa, with mostly ephemeral flows. Big floods recharge the aquifers.

The major advantage of the above classification method is that each stream type can be associated with a particular hydrogeological and geomorphological setting. It is also possible to derive flow boundary conditions and the ecological significance of these groundwater flows. However, a major disadvantage of this approach is that it is not in all cases applicable to confined aquifers like the TMG aquifer.

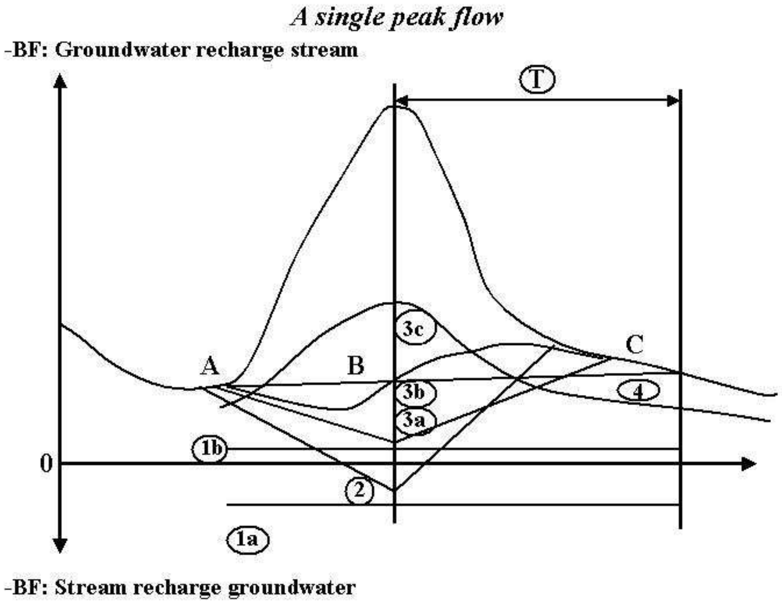

Figure 2.9. Typical scenarios of interaction between groundwater and streams (Xu *et al.*, 2002).

2.1.10. Hydrogeomorphological typing of interactions between groundwater and streams associated with the TMG

Xu *et al.* (2002) recognised four types of interactions between groundwater and streams which all apply to river reaches associated with the TMG.

- ***Type 1: Constantly losing or gaining streams***

  Mostly associated with the upper catchment (head water and some mountain streams) where the regional groundwater level is constantly below the stream stage as shown in Figure 2.9 (1a). It may also occur in places where the permeabilities of stream bed material are limiting the loss of water from the stream. Constantly gaining streams may also be found where the stream is fed by groundwater from confined aquifer systems (some mountain streams) (case 1b of Figure 2.9).

- ***Type 2: Intermittent streams***

  These stream types may be found in the middle (foothill) reaches where groundwater discharges towards streams during dry periods, while the river recharges aquifers during floods (bank storage). The base flow component would have a cut-off under the peak flow time as in case 2 of Figure 2.9.

- ***Type 3: Gaining streams with or without storage***

  This stream type is often observed in the lower (lowland) reaches where groundwater levels may be consistently higher than the river stage (mostly primary aquifer interactions). The base flow component would increase in an S-curve or straight line as a function of the presence or absence of bank storage. Figure 2.9 presents three possible cases: 3a – for porous media without bank storage; 3b – for fractured media without bank storage and 3c – for fractured media with bank storage.

- ***Type 4: Interflow-dominant streams***

Streams of this type occur in the upper catchment where interflow may be the dominant component of stream hydrographs, which is typical of mountain reaches of rivers associated with the TMG. Figure 2.9 shows that base flow displays similarities to the quick runoff in terms of their phase and amplitude. Figure 2.10 summarise the types of interactions between streams and groundwater.

Interflow would generally occur under the following conditions:

- Where the soil horizon acts as flow barriers, which hinder a direct downward percolation of precipitation
- Where partially saturated flow may be formed via a perched water table
- Where the unsaturated zone interflow occurs along preferential flow paths
- Where favourable geometric configurations of fractured networks may lead to formulation of interflow towards the river (Xu *et al.,* 2002).

It may also be dominant in areas with relatively steep slopes and alluvial deposits, like certain mountain and foothill reaches of rivers associated with the TMG aquifer.

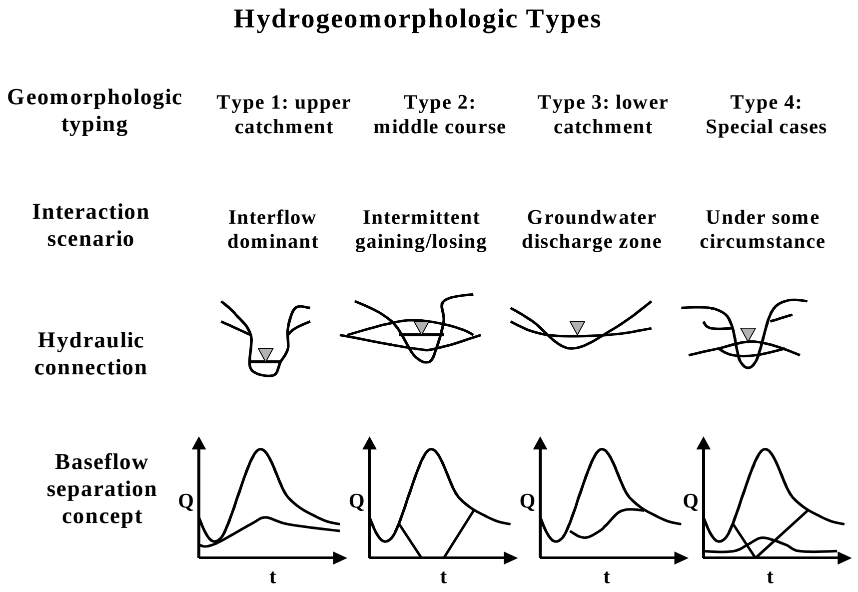

Figure 2.10. An illustration by Xu *et al.* (2002) showing the different relationships between rivers and groundwater.

2.1.11. Methods of estimating recharge from river flows

Many methods have been developed for estimating recharge. Recharge estimates in the context of rivers is the water that leaves a river and crosses the water table. This method of estimating recharge is often difficult, and many studies found it easier to estimate transmission losses, which is the water that leaves the river downwards. The variation in storage in the unsaturated zone, bank storage, evapo-transpiration, perched water table and shallow lateral flow can lead to large differences between recharge and transmission losses (Xu and Beekman, 2003).

Lerner *et al.* (1990) divide recharge estimate methods into five groups:

- Direct measurements,
- Correlation methods,
- Tracer techniques,
- Darcian approaches, and
- Water balances.

Xu and Beekman (2003) give as good summary of the different methods as proposed by Lerner *et al.* (1990), and conclude that few of these methods are useful, except for the water balance method. With the water balance method there are a variety of approaches:

- Channel water balance,
- Channel flow routing,
- Water table rise,
- Catchment modelling, and
- Aquifer modelling.

The **channel water balance and flow routing** use river flow data that is often the only good data available for catchments and if a good correlation can be established, recharge records can be extended from historical flow data (Xu and Beekman, 2003).

The **water table rise** method is an expected response to recharge events on ephemeral rivers and recharge periods on seasonal rivers. Recharge is then calculated from the volume of the rise and the specific yield, an approached widely used. However, there are problems associated with this approach, and the first problem is the choice of a specific yield. Often there are no relation between the values provided by pump-testing and those needed to simulate long term, regional groundwater flow. The short-term tests normally give a lower value (Xu and Beekman, 2003).

Catchment and aquifer modelling both estimate water balance. The advantages of these models are that they integrate all available data (hydrology, groundwater, geology), and being of use for predictive studies of resources (Xu and Beekman, 2003). This only confirms the link between the TMG aquifer and aquatic ecosystems.

2.1.12. Estimating groundwater discharge from river hydrographs

The alternative to estimating recharge is to estimate discharge to rivers. Xu and Beekman (2003) explain this alternative with the following equation for an exploited aquifer:

AVERAGE DISCHARGE = AVERAGE RECHARGE + RATE OF STORAGE DEPLETION

For this type of estimate it may be required to measure and aggregate the following components of discharge:

- Springs, which is discrete discharge points,
- Lakes and the ocean may receive diffuse or discrete discharges,
- Sabkas or saltpans are internal discharge drainage points (Darcian flow estimates of upward flow can be used),
- Evapo-transpiration by phreatophytes,
- Abstraction by wells,
- Rivers, which receives both point and diffuse discharges (Xu and Beekman, 2003).

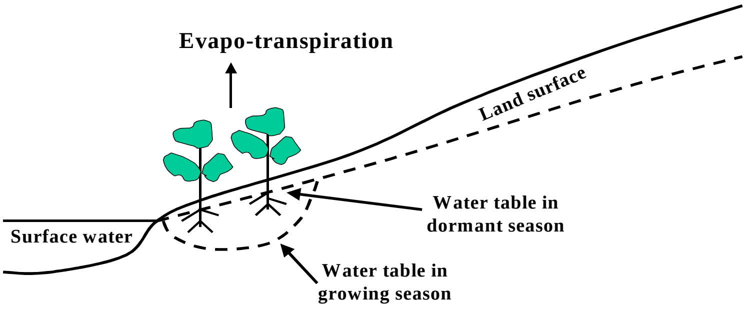

Figure 2.11. Diagram showing the localized draw down of the water table during transpiration in the growing season – evapo-transpiration by phreatophytes.

Alternatively the river flow hydrographs can be analysed to estimate the groundwater component called base flow. By applying this method it may be difficult to distinguish between surface runoff and the groundwater contribution to flow. Indications are that much of the storm flow response of a river is composed of groundwater by a displacement mechanism (Midgley and Scott, 1994; Winter *et al.*, 1999). This would apply to connected rivers, which will include any river that has a groundwater component in its flow. Base flow is water that has been part of the water table, and or part of the slow responding part of the hydrograph outside the zone of influence of the storm flow generation mechanism (Xu and Beekman, 2003).

In Xu and Beekman (2003) three approaches to base flow separation are listed namely: graphical separation, base flow rating curves, and recession-curve displacement. Each method is well described in Xu and Beekman (2003).

Vegter and Pitman (1996) state that recharge determinations are inadequate by themselves for estimating the development potential of groundwater resources. Again for the purposes of this study it just confirms the intimate link between the TMG aquifer and the flow regime of aquatic ecosystems.

2.1.13. Runoff process and hydrograph analysis

Runoff from precipitation, both rainfall and snowmelt, reaches the stream through several routes. Parsons (2004) recognises that runoff is generated by channel precipitation, quickflow (which include overland flow), interflow and groundwater flow. He further suggests that overland flow during storms is generated by two basic processes namely, saturation from above and saturation from below. According to the Horton runoff model, overland flow occurs when the intensity of rainfall is greater than the rate of infiltration (Parsons, 2004). It is commonly accepted that a rivers hydrograph consists of base flow (groundwater), interflow and direct runoff (Xu *et al.*, 2002). There is general recognition that there are four different components of runoff namely (Vegter and Pitman, 1996):

- Surface runoff, which is the water travelling over the soil surface as the residual after interception, surface ponding and infiltration. This runoff type occurs in any stream, perennial, seasonal and intermittent. This would be the water running off immediately after rains and occurs over relatively short distances to the nearest channel.

- Interflow is the water that infiltrate into the soil surface and drain laterally in the upper horizons until it discharges into a channel or returns to the surface down slope of where it infiltrated. In other literature there is also reference made to translatory flow or piston flow (Midgley and Scott, 1994; Winter *et al.*, 1999), which is the displacement of water of a previous recharge event.
- Groundwater follows a much more complex route or routes to the stream than any other component. Its flow originates from the groundwater table which is water that percolated through the unsaturated zone into the water table. Groundwater accreted from a particular storm is discharged into the stream over a long period of time.
- Channel precipitation is the water that falls directly on the water surfaces of lakes and streams.

The differing characteristics of the four components of runoff, and the relative proportions of each component present, determine the shape of the hydrograph. The complex flow composition resulting from local variations in rainfall, infiltration and antecedent conditions preclude any attempts to identify each component of runoff. The solution to this problem is to separate only two portions of runoff, by grouping surface runoff, channel precipitation and interflow into a single item designated as direct (storm) runoff or quick flow. The second group is groundwater, or base flow. In literature several procedures exist for separating the hydrograph into quick flow and base flow components (Xu and Beekman, 2003).

One of the products was the WR90 project (Midgley *et al.*, 1994), which included a time series of monthly flows for each of the approximately 2000 quaternary catchments of the study area. Each time series covered a 70 year period from 1920 to 1989. A simple method that was first developed to split the monthly flows into surface and groundwater components.

Base flow determinations indicated, that for South Africa as a whole, the base flow accounts for just over 20% of the total runoff of approximately $51x10^9m^3$. This amounts to less than 2% of the rainfall and this percentage is almost insignificant in the drier regions. The highest percentages were found in the well-watered regions of the western and southern Cape and the eastern escarpment. Areas underlain by dolomite showed the highest base flow contributions of almost 20% of the rainfall that amounts to roughly half of the total runoff (Xu and Beekman, 2003).

In the summer rainfall areas base flow ceased where the MAP dropped below 500 mm, whereas in the winter and year-round rainfall regions the threshold is somewhat lower. Rainfall of 300 mm will yield base flow in the steep mountain catchments, but elsewhere the cut-off is around 400 mm (Xu and Beekman, 2003).

Another characteristic of base flow is that it is far less variable from year to year than the quick flow component of runoff. In higher rainfall regions the variability of base flow and total flow is lower than in dryer areas (Xu and Beekman, 2003). Hydrogeologists see base flow separation as a useful tool for quantifying groundwater discharge to streams where there is hydraulic connectivity between the groundwater system and rivers (Parsons, 2004).

Three methods to determine the role of interflow in estimating recharge are described in Xu and Beekman (2003). It is suggested that interflow in mountainous catchments accounts for part of the base flow in rivers, and that the interflow component is important from an ecological point of view as this component of the hydrological cycle often sustain local ecosystems. The shallower weathered zone of the alluvial and slope deposits in the mountainous TMG areas, in which the interflow occurs, may serve as a reservoir for storing water during the rainy season while at the same time allowing for percolation to the deeper groundwater reservoir, often through a network of fractures. It is from this zone that interflow will contribute to the base flow component of the hydrograph. They concluded, for the catchments of the Kammanassie for which they did the modelling, the difference between including and excluding interflow in the calculation of recharge to be 1%, which equates to an overestimate of only 10% of recharge if one does not take into account the role of interflow (Xu and Beekman, 2003).

From these perspective listed above, it is again clear that hydrogeologists consistently agree on the intimate relationship between groundwater discharges from the TMG aquifer contributing to the flow regime in aquatic ecosystems, and it goes a long way in explaining the mechanisms involved, and how it differs in different positions in the landscape. This information enables a better understanding of the relationship between groundwater and aquatic ecosystems in the TMG, and highlight how and where these interface areas occur.

It also helps understanding which discharges are real groundwater and non-groundwater discharges. It further helps to demonstrate which discharges are of ecological significance relating to the flow regime, and the relative dependence of each component of the flow regime on real groundwater.

2.2. Hydrogeology and ecology

2.2.1. Groundwater discharge types to aquatic ecosystems

Generally groundwater discharges occur at springs, seeps, wetlands and in and around the riparian zones of streams and rivers, and through the hyporheos. The relative position of the water table in relation to the surface resource (river or stream) dictates whether the underlying groundwater system is hydraulically connected to the surface water resource or not (See Figure 2.6 and 2.7). However, this is only true for ‘real’ groundwater discharges, but exclude non-groundwater contributions such as interflow, translatory flow, bank storage discharges and channel precipitation. The latter are sometimes incorrectly perceived as groundwater discharges.

2.2.1.1. Discharges associated with springs and seeps

Springs are unique expressions of groundwater discharging at surface, and give rise to an important part of the ecological landscape because of the dependencies that develop around them. Many early settlements and towns developed around springs due to their important role in supplying water to people, animals and agriculture. Some hot springs have developed into popular tourism destinations like Goudini and Brandvlei (Parsons, 2004).

However, it must be understood that not all springs are fed by groundwater systems. Some springs are expressions of interflow in the vadose zone, which will dry up when rainfall is low. These springs are also referred to us *perched* springs by Cleaver *et al*. (2003). These springs are typically seasonal and occur above the regional groundwater table (Parsons, 2004).

Groundwater-fed springs are permanent in character with very distinct chemical and isotopic characteristics similar to the groundwater aquifer feeding them (Meyer, 2002). These spring types would be at a similar elevation as the regional groundwater table and would contribute to base flow in streams and rivers (Parsons, 2004). They would normally be expected at geological contact zones, at Shale-TMG contacts in particular.

Kotze (2001) gives the following classification for springs:

1. Type 1 – shallow seasonal springs and seeps emanating from perched water tables; these represent localised discharges of interflow, which is not connected to the groundwater flow system and will not be impacted by groundwater use from the deep flow systems.
2. Type 2 – lithologically controlled springs; these are often discharges at lithological contacts where the flow is more permanent and plays an important role in sustaining base flow. This spring type will be vulnerable to impacts of localised groundwater abstraction.
3. Type 3 – fault controlled springs that are permanent in character and may discharge either hot or cold water. These may or may not be impacted by localised groundwater abstraction, depending on the quantity of groundwater being used.

Spring discharges play an important role in aquatic ecosystems, not only around the spring itself, but by contributing to the flow regime and maintaining perennial flows of streams and rivers associated with the TMG.

2.2.1.2. Groundwater and wetlands

In recent years the value of wetlands has been widely recognised. Wetlands help prevent flooding, improve water quality, reduce sediments in rivers and provide important habitat to varies organisms, to name only a few of the free services they supply (Davies and Day, 1998). However, it is far less recognised that many wetlands are groundwater driven, and without understanding their drivers and functionality, it is difficult to manage and conserve this important component of the hydrological system (Parsons, 2004). Wetlands essentially act as the kidneys and liver of the environment.

The interaction between groundwater and wetlands is similar to that of streams, rivers and lakes, where some are connected to groundwater systems and others are not (Figure 2.12). Many wetlands have originated because of the availability of water from springs and seepages, and that many other wetlands receive at least a portion of their hydrological budget from springs (Le Maitre *et al.*, 2002; Parsons, 2004).

Wetlands are characterised by being permanently, frequently or seasonally wet, with distinct hydric soils that are usually saturated and under anaerobic conditions. These conditions favour the growth of hydrophytic plants that can tolerate flooded or saturated anaerobic conditions (Parsons, 2004). It is essential to understand the groundwater relationship in a particular wetland to be able to assess its ecological condition, significance and possible management interventions.

Generally low lying wetlands are connected to groundwater, but not all wetlands are located in the typical topographical low points or depressions in the landscape. Some wetlands are located on slopes and are fed by springs and seeps, which in turn might be fed by subsurface water, but not by groundwater. Only those springs that are 'connected' to deep groundwater systems may be impacted by groundwater use from the TMG aquifer (Parsons, 2004).

According to Hatton and Evans (1998), ecosystems will develop some degree of dependence on groundwater where it is accessible, and that dependence is likely to increase with increasing aridity of the associated environment. They also identified four kinds of ecosystem dependence on groundwater, namely: terrestrial vegetation, river base flow systems, wetlands and spring systems and aquifer and cave ecosystems (subterranean living organisms)(Hatton and Evans, 1998).

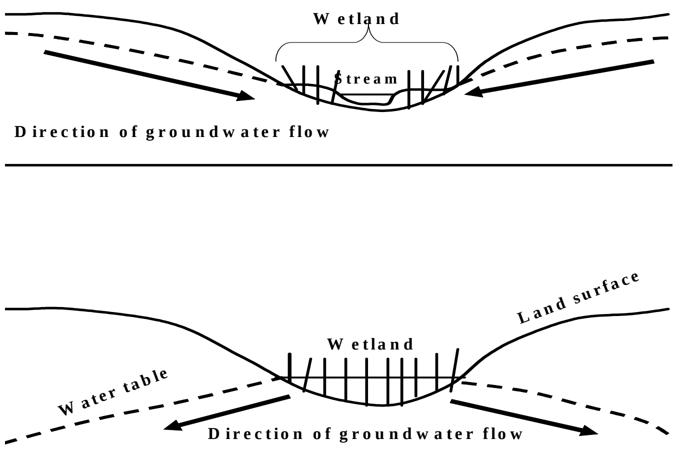

Figure 2.12. Schematic representation of wetlands and groundwater in (A) groundwater is discharging into the wetland and, (B) groundwater is recharged from the wetland.

Exploitation of groundwater resources can have a negative impact on both riparian and wetland communities, especially where wetlands depend on access to groundwater. The impacts can be subtle, by lowering water tables seedling recruitment can be prevented and ultimately vegetation dynamics can be altered, but with little impact in the short term (Scott and Le Maitre, 1998). Community responses can be delayed until droughts or high abstraction rates, or both, lower the water table to a point where it passes the threshold of community resilience and there is mass mortality (Scott and Le Maitre, 1998). It could also change the water quality in the wetland that could have devastating impacts on the viability of the wetland system.

However, this study aimed at determining whether any lowland wetlands, seemingly disconnected from the deep flow of confined aquifers, were connected directly or indirectly to the TMG aquifer, particularly at or near the discharge end of the aquifer.

2.2.1.3. Groundwater, estuaries and the sea

The groundwater-estuarine and groundwater-sea interactions have received little attention in the past, particularly in the TMG domain. The changing water level and chemistry as a result of tidal influence suggest a highly dynamic zone at the interface of these water bodies (Parsons, 2004). However, groundwater-estuarine interactions will be mostly related to primary aquifers, but deep TMG discharges may be possible. These deep circulating TMG aquifer discharges will occur at faults and fractures where geological layers, including aquitards, could be fractured or displaced due to folding and faulting. Discharges at these depths will be pressurised and could recharge shallower primary aquifers. This could be expected in the intermountain domain or lowlands close to the discharge end of the aquifer.

The deep diving synclinal nature of the TMG aquifer near the coast line dictates that groundwater inevitable should discharge into the marine environment. It is generally accepted that the hydraulic head of groundwater ensures that seawater cannot migrate landwards. However, over-abstraction can result in saline intrusion and deterioration in groundwater quality (Parsons, 2004). Marine discharges from the TMG aquifer will be expected to be through fractures and faults, by preferential flow paths. Groundwater use from the TMG aquifer to close to the sea, could therefore result in fast saline intrusion through the same preferential flow routes, if the groundwater use create a big enough asymmetric drawdown. Figure 2.13 gives two simplified diagrams illustrating the Ghyben-Herzberg hydrostatic relationship in (A) homogenous coastal aquifer and, (B) layered coastal aquifer (Winter *et al.*, 1999), which indicate saline intrusion potential.

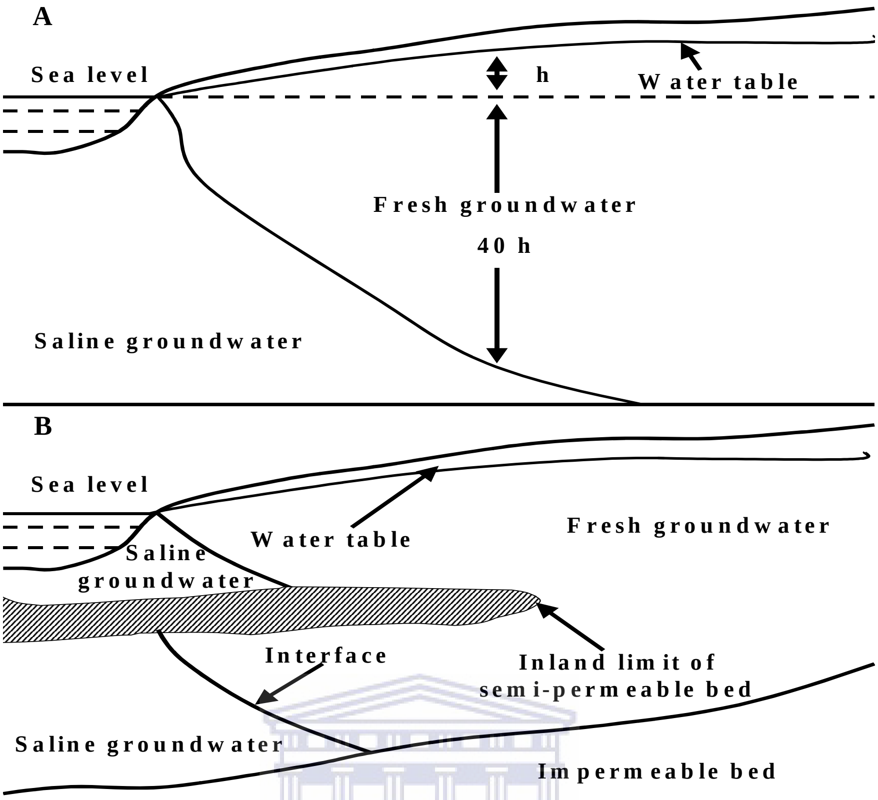

Figure 2.13. Simplified diagrams illustrating the Ghyben-Herzberg hydrostatic relationship in (A) homogenous coastal aquifer and, (B) layered coastal aquifer (Winter *et al.*, 1999).

2.2.1.4. Groundwater discharges and streams

Earlier sections of this chapter highlighted the widely acknowledged groundwater surface water (rivers, streams, lakes, wetlands, etc.) interactions that can sustain flow in surface resources during dry periods. However, not all surface water is fed by groundwater. Surface water on the other hand also recharges groundwater. This exchange of water between surface and groundwater bodies is controlled by the relative position of the water level in the river to that of the water table. Where the water table is lower than the surface water body water will flow from the surface water body into the groundwater body, if no aquatard or confining layer is disconnecting the two systems. Similarly, where the groundwater body is higher than the surface water body, there is a hydraulic connection with the surface water and groundwater will be discharged into the surface water. Figure 2.14 give a schematic illustration of the types of rivers, based on the connectivity with the underlying groundwater bodies. The terms to describe these interactions are influent stream (gaining stream) or effluent stream (losing stream) (Parsons, 2004).

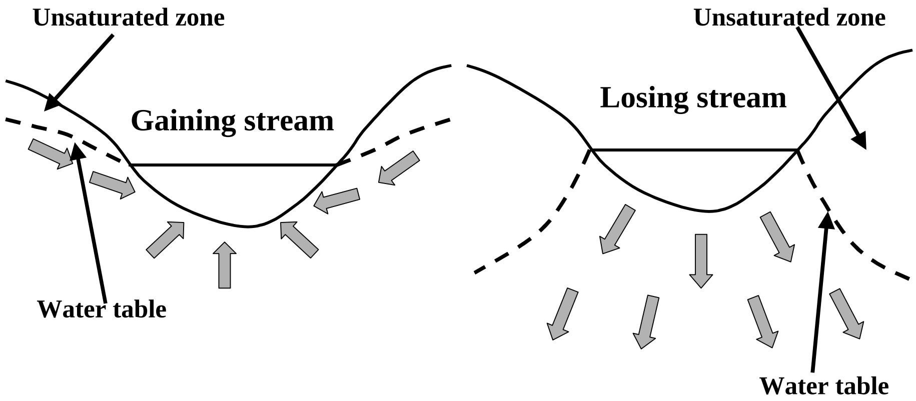

Figure 2.14. Illustrations indicating groundwater discharge to streams – gaining stream (left), and groundwater recharge from surface stream – losing stream (right).

Groundwater discharges from springs to surface water is widely recognised. Springs are in many instances maintaining the perennial flow and or base flow component in rivers, a view supported by Parsons (2004). The different types of springs feeding streams are discussed under 2.1.3 "Hydro-geology of the Cape fold belt", and 2.2.1.1 "Discharges associated with springs and seeps".

From this understanding it is clear that groundwater abstraction can impact gaining streams where groundwater is discharged to rivers. This would result from either the development of the cone of depression as a result of the pumping from the borehole, or a drop in the water table (piezometric surface). The depth and extent to which the cone of depression will develop will dependent on the rate and duration of abstraction and the prevailing hydrogeological properties of the aquifer (Parsons, 2004). However, a change in the hydraulic head (pressure) of the aquifer by a lowered water table or piezometric surface, will affect the retention time, transmissivity and hydrologic conductivity of the aquifer. In a confined aquifer, changes to the aquifers hydraulic head (pressure) will ultimately induce a new pressure gradient and flow pattern within the aquifer (induced recharge and reduced discharge scenario, and a new aquifer equilibrium). It is argued that the impacts will not just come from the development of the cone of depression, which can be highly asymmetric and take many years to develop to its full extent, but also due to the drop in the piezometric surface (water table level) which will affect the flow pattern to streams and recharge pattern of the aquifer. All of these aspects will manifest because of the modified aquifer recharge and discharge. Kotze (2002) and Parsons (2004) recognise that large-scale abstraction from well fields or multiple boreholes could significantly reduce flow in a surface water body on a regional scale. These effects may only be realised years after pumping has started, depending on the rate, volume and duration of groundwater abstraction and the distance between the river and the abstraction point (Parsons, 2004).

2.2.2. Groundwater and vegetation

Many plant species are groundwater dependent, and this dependency may vary across habitat types. Most notable will be riparian and spring vegetation because of their direct relation to groundwater discharge points.

According to Scott and Le Maitre (1998) the abstraction of groundwater may affect vegetation that is reliant on groundwater where it discharges in springs, streams, rivers or wetlands or where it occurs near the ground surface and is directly used by plants. Figure 2.11 clearly shows how vegetation can be dependent on groundwater.

The following generalised interactions between vegetation types and groundwater are relevant to the following biomes (Scott and Le Maitre, 1998):

- In the thicket biome groundwater interactions are probably limited to riparian situations, although many shrubs and trees are likely to be able to develop deep root systems where rocks are deeply weathered or fractured.
- In the fynbos biome, which is dominated by shrub species, shrubs are likely to be able to develop deep roots where possible but because groundwater resources are very limited in the shales, interactions with groundwater are probably minimal.

Riparian zones, especially in semi-arid to arid areas, are important for biodiversity as they offer habitat and refuge for a variety of organisms (Milton, 1990). In non-perennial riparian zones, many are supported by alluvial aquifers and the perennial systems receive a substantial proportion of local groundwater fed base flow (Colvin *et al.*, 2002). Winter *et al.* (1999) also states that riparian zones are particularly sensitive to changes in the availability and quality of groundwater and surface water because these ecosystems commonly are dependent on both resources. Changes to either water sources may cause changes in the riparian structure and composition, subsequently affecting its ability to provide aquatic habitat, mitigate floods and erosion, stabilise shorelines and process chemicals, including contaminants (Winter *et al.*, 1999). Exploitation of groundwater resources can also have a negative impact on wetland plant communities, especially where wetlands depend on access to groundwater (Scott and Le Maitre, 1998).

Soil nutrients and plants nutrient cycling have been used in many studies around the world to show groundwater relationships with surface resources, and to show groundwater dependency of plant communities. Recent studies in Belgium and Poland are examples of this (Wassen, 1995; El-Kahloun *et al.*, 2003; El-Kahloun *et al.*, 2005; Wassen *et al.*, 2005). The soil nutrient concentrations are known to be affected by groundwater discharge modifications that would result from groundwater use. In the TMG, and the associated Fynbos biome that are characterised by low soil nutrients, this may have far reaching effects. Reduced groundwater discharges could result in accumulation of soil nutrients that would cause vegetative changes in the long run.

Where groundwater is accessible, ecosystems will develop some degree of dependence on it and that dependence is likely to increase with increasing aridity of the associated environment (Hatton and Evans, 1998). There are examples where the ability of certain species to access groundwater maintains other species in that ecosystem (Colvin *et al.*, 2002). An example is “hydraulic lift” where deep-rooted plants absorb water during the day and then release it from their shallow root systems at night (Richards and Caldwell, 1987; Caldwell *et al.*, 1998). The additional water released into the surface soil layers may be critical for maintaining shallow-rooted plants and any other dependent organisms in this kind of system (Colvin *et al.*, 2002). According to Colvin *et al.* (2002) the loss of deep-rooted species through, for example, lowering of the water table, may therefore result in a collapse or major transformation of such ecosystems.

In order to prevent the collapse of ecosystems as a result of water stress it is important that plant water stress tests be undertaken in ecosystems where exploitation of water resources is taking place.

Plant water stress tests have been used to detect imbalances in the plant-water status of plants and are used to indicate the degree of plant water stress as a result of various impacts. A high plant water stress occur when a deficit of water exists in the plant either due to an un-replenished loss of water or the limited uptake of water by the plant. A number of factors are responsible for plant water stress in plants and under certain conditions this can reflect deficiencies in soil moisture due to groundwater abstraction. Long-term monitoring of plant water stress could therefore act as an early warning system to indicate water stress in ecosystems so that corrective steps can be taken timeously (Kemper, 1994; Cleaver, 2003).

2.2.3. Groundwater and soil nutrient cycling

The response of soil nutrients to groundwater movement has been studied by many authors (Wassen, 1995; De Mars *et al*., 1996; Clawson *et al.*, 2001; Eisele *et al*., 2003; El-Kahloun *et al*., 2003) in the European context. Soil nutrient concentrations is affected in two ways; 1) by soil water effects (mobilization and leaching) that result from groundwater discharge and recharge; and, 2) natural chemical cycling (i.e. nitrification, de-nitrification, ammonification, volatilization, adsorption, dissolution, mineralization and immobilization) (Farley & Fitter, 1999; Chapin & Aerts, 2000; Olde Venterinck *et al*., 2003; Hodge, 2004). Eisele *et al.* (2003) state that mobilization of soil nutrients depend on the water-runoff component, the soil characteristics and the chemical behaviour of each nutrient. Chemical cycling of soil nitrogen compounds will be affected by oxygen availability because nitrification is an aerobic process. Plant growth also plays a vital role in the cycling of nutrients in the soil by utilizing these compounds for growth and will have a seasonal effect on nutrient concentrations (Wassen, 1995; Clawson *et al*., 2001). Other physical and chemical soil properties, such as pH and calcium concentrations may also influence soil nutrient concentrations (El-Kahloun *et al.*, 2005).

Phosphate concentrations are known to vary steeply with season and to be less mobile due to the various reactions it has with other chemical constituents in soil and even adsorption to soil particles, all of which are pH dependent. In soil solution P occurs either as HPO_4^{2-} or $H_2PO_4^-$ depending on pH (Farley & Fitter, 1999; Eisele *et al.*, 2003; El-Kahloun *et al.*, 2003; Hodge, 2004; El-Kahloun *et al.*, 2005).

In the natural environment phosphorus occurs almost entirely as phosphate ions (PO_4^{3-}). Soluble Reactive Phosphorus (SRP) is seldom found in quantity in natural (non-polluted) water as a result of it being used by plants or being adsorped onto suspensoids or bonded to ions such as iron, aluminium, calcium and a variety of organics. Nitrogen on the other hand, occurs abundantly in nature and is an essential part of many biochemical processes. In water it occurs in the form of nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+) ions, and a wide variety of nitrogen containing organic compounds (Davies and Day, 1998).

The importance of soil minerals (Al, Ca and Fe) for the immobilization of phosphorus in wetland soils could be an important factor controlling P availability (Cooke, 1992; Boeye *et al.*, 1997). The capacity of these minerals to immobilize plant available P proved to depend on soil concentrations, pH, redox, soil organic matter and as such on eco-hydrological conditions (Gotoh and Patrick, 1974; Patrick and Khaled, 1974; Van Haesebroeck *et al.,* 1996). El-Kahloun *et al.* (2005) found that calcium rich groundwater reduce the orthophosphate concentrations because of the low solubility of calcium-phosphate complexes. Serious changes in hydrology (changes in ground- surface water flows) may result in an alteration of plant available P (Grootjans *et al.*, 1986) and plant available nitrogen. Microbial transformation of both nitrogen and phosphates are depended on soil water content and temperature (Roets *et al.*, in prep).

2.2.4. Groundwater and selected fauna

According to Winter *et al.* (1999) the environmental conditions caused by the interface between groundwater and surface water will be reflected by the type and numbers of organisms in a given reach of a streambed, in part, from interactions between water in the hyporheic zone and groundwater from distant sources. The chemical reactions that take place where chemically distinct surface water meets chemically distinct groundwater in the hyporheic zone may result in a biogeochemical environment that in some cases could be used as an indicator of change in either terrestrial or aquatic ecosystems. Groundwater discharges through the hyporheos or streambed, create micro-climate's or ecotone habitats that may be suitable for specific habitat specialists. Many indigenous fish species of the CFK have been observed selecting discreet groundwater discharges in streams as habitat.

When groundwater is abstracted from aquifer systems these discharges will be affected as indicated in earlier sections. Thus, in-stream biota may be affected in certain groundwater discharge scenarios where surface and groundwater is suspected to be connected. A change in the ecological integrity of groundwater dependent river systems (connected) can therefore be expected because the ecological functioning of rivers are hydrology (flow regime) driven. It is postulated that the hydrology of rivers are groundwater dependent thus affecting most ecological processes in rivers (Roets, 2002). Recent studies in the Kammanassie by Cleaver *et al.* (2003) and Department of Water Affairs have indicated that the current abstraction of water from the TMG aquifer in the Kammanassie, more specifically in the Vermaaks River valley has in fact contributed to the modification of flow regime in the Vermaaks River.

2.2.5. Flow regime as ecological driver of rivers and other aquatic ecosystems

The flow regime of a river is the primary driver for its ecological processes through its influence on the channel morphology and sediment movement, which determine the physical habitat availability, which in turn controls the ecosystem functioning. This is also true for wetlands. It is therefore essential to understand the mechanisms controlling the hydraulic parameters for any given area to be able to predict the effect of altering the flow and sediment regime on a river and or wetland (Heritage *et al*., 2000; King *et al*., 2000). Gilvear *et al*. (2002) agrees by stating that hydrology is a primary control on the ecological quality of a river system, through its influence on flow, channel geomorphology, water quality and habitat availability.

For sustainable use of aquatic ecosystems (like rivers and streams) they need to be managed holistically taking into account the full spectrum of flows, their temporal and spatial variability included, and how the flow regime influence the biological functioning of the aquatic ecosystem. To achieve this, a multi-disciplinary approach is necessary where hydrogeology, hydrology, hydraulics, fluvial geomorphology, sedimentology, chemistry, botany and zoology are all integrated in understanding aquatic ecosystem functioning. King *et al*. (2003) agree with this view.

With the focus on the intimate link between groundwater and surface water it is extremely important to relate groundwater discharges to aquatic ecosystem (like rivers and streams) functioning. Therefore it is required to understand how (mechanisms) and where in the landscape groundwater discharges contribute to the different components of the flow regime. It is also necessary to define the different components of the flow regime from an ecological perspective, and to conceptualise where and to what extent groundwater from the TMG aquifer contributes to each. Table 2.6 gives a summary of the different kinds of river flows and their importance to aquatic ecosystem functioning (King *et al.*, 2003).

The flow regime for rivers, including rivers associated with the TMG aquifer, can broadly be divided into the following components in terms of the parts of the flow regime recognised in Table 2.6:

- *The low flows:* the daily flows between high-flow peaks can be divided into:
  a) wet-season low flows; b) dry-season low flows.
- *The high flows:* the peak events of higher flow are allocated to one of the following:
  a) four size classes of intra-annual floods; b) floods with a return period of up to 2, 5, 10 and 20 years (After King *et al.*, 2003).

Table 2.6. Different kinds of river flow, and their importance to ecosystem functioning (all applicable to rivers associated with the Cape Fold Belt and the TMG aquifer) (King *et al.*, 2003).

Flow	Importance to ecosystem
Low flows	Daily flows that occur outside of high-flow peaks. These flows determine the basic hydrological nature of the river: its dry and wet seasons, and degree of perenniality. The variation in magnitudes of low-flow in the dry and wet seasons create more or less wetted habitat and different hydraulic and water-quality conditions, which directly influence the balance of species at any time of the year.
Small floods	Small floods are ecologically important in semi-arid areas in the dry season. These flows stimulate spawning in fish, flush out poor-quality water, mobilise and sort gravels and cobbles thereby enhancing physical heterogeneity of the riverbed, and contribute to flow variability. It also re-set a wide spectrum of conditions in the river, triggering and synchronising activities as varied as upstream migrations of fish and germination of riparian seedlings.
Large floods	The large floods trigger many of the same responses similar to smaller floods, but additionally provide scouring flows that influence the form of the channel. These floods mobilise coarse sediments, and deposit silt, nutrients, eggs and seeds on floodplains. These floods also inundate backwaters and secondary channels, and trigger bursts of growth in many species. Large floods also re-charge bank storage, inundate floodplains, and scour estuaries thereby maintaining links with the sea.
Flow variability	Fluctuating discharges down the river constantly change conditions through each day and season, creating mosaics of areas inundated and exposed for different lengths of time. The resulting physical heterogeneity determines the local distribution of species and the higher physical diversity enhances biodiversity.

Linking the flow regime to local hydraulic conditions is the vital link that allows river scientists to understand why river features and species occur where they do (King *et al.*, 2003). These flow regime characteristics are all applicable to river systems in the Western Cape, particularly those associated with the TMG aquifer.

Because of the intimate groundwater surface water interface it is logic to expect that altering groundwater discharges could alter the flow regime of rivers and thus the ecological functioning of aquatic ecosystems. Figure 2.15 explains the relationship between the catchment controls and ecological functioning.

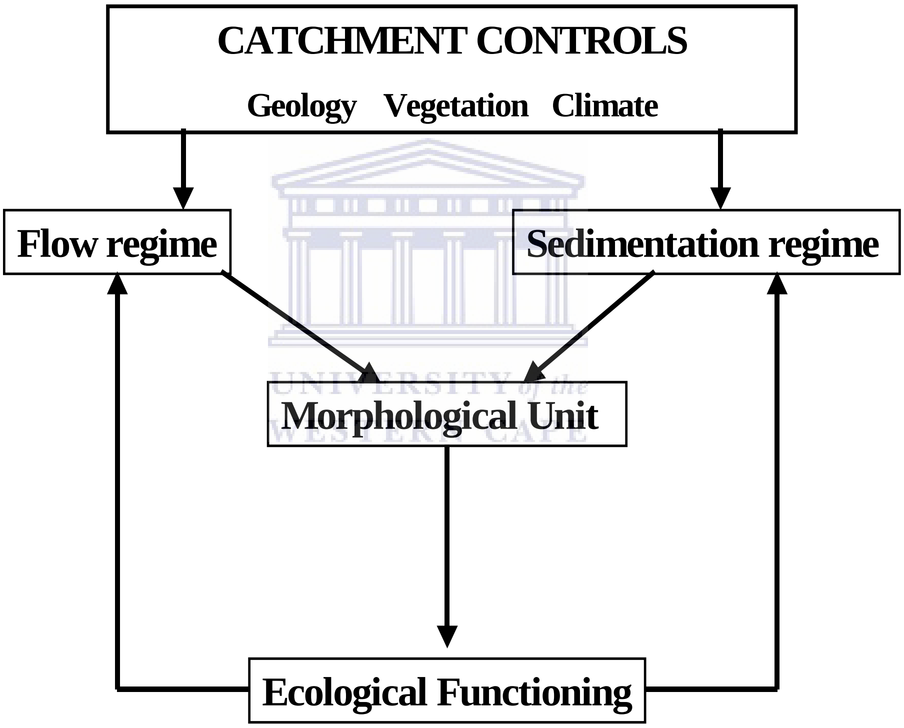

Figure 2.15. Link between catchment controls and ecological functioning (Heritage *et al.*, 2000).

Figure 2.16 (a) gives a schematic representation of the different components of the flow regime as conceptualised in a hypothetical cross-section of a river channel. The bottom picture (Figure 2.16 (b)) depicts the influence of the flow regime on the zonation in the riparian vegetation (King *et al.*, 2003). In both these schematic representations it is obvious that the flow regime, and the level of bank fill influence the availability and size of habitat types. This has a direct influence on the biological functioning and integrity of the river ecosystem.

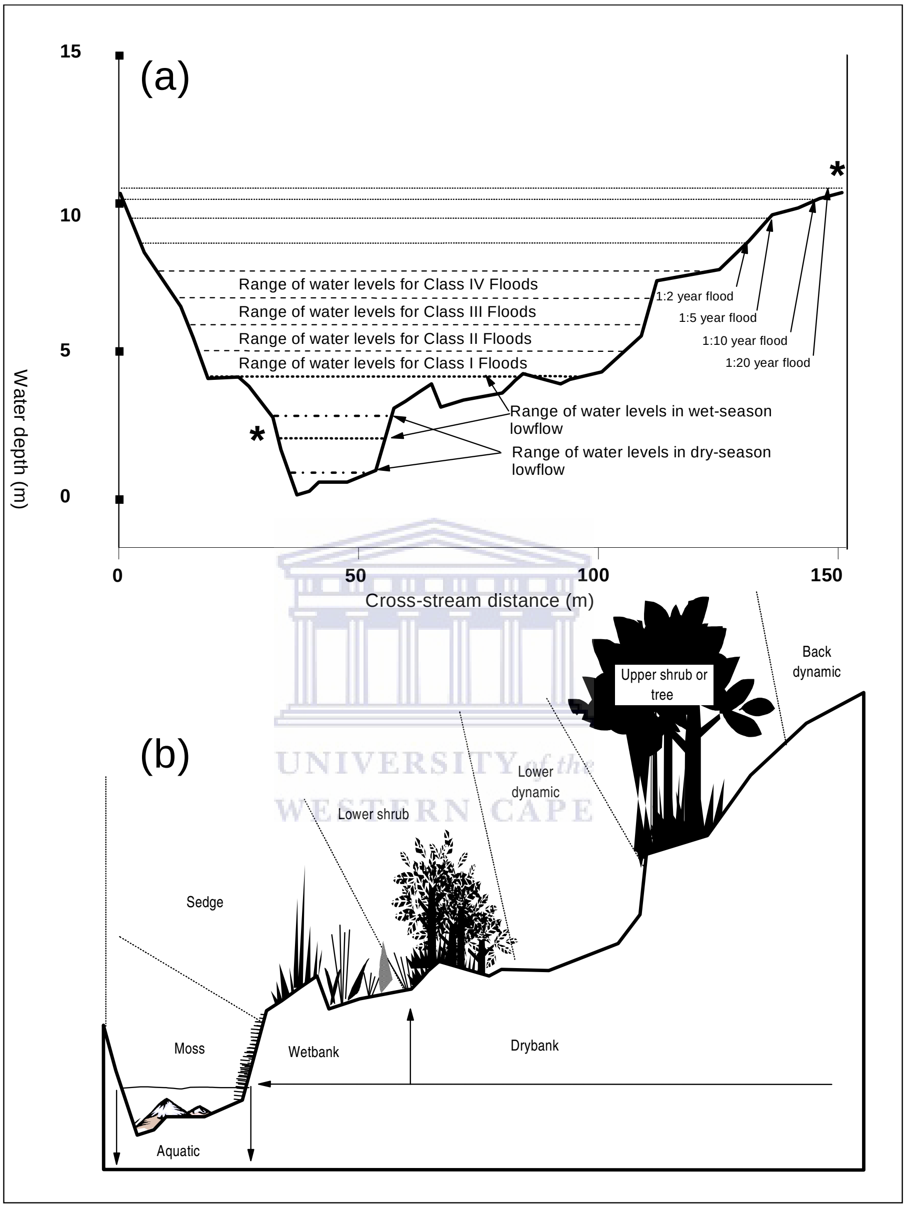

Figure 2.16. Schematic representation of the different components of the flow regime in a hypothetical river channel (King *et al.*, 2003).

According to Hughes and Műnster (2000) a reduction in the natural base flow directly impacts on the physical habitat template and availability of a river by changing the natural temperature regime, the abundance and proportion of marginal and in-stream habitat, the water availability to riparian vegetation, the sediment transport capacity and the water chemistry. These will all have secondary impacts on the natural environmental conditions required by invertebrates, fish, reptiles and mammals as well as the riparian vegetation. Another secondary impact of reduced base flows is the potential geomorphological consequence of a change in the physical channel structure resulting from a reduced ability to maintain suspended sediment mobility (Hughes and Műnster, 2000). From this understanding it is clear that affecting the natural base flow, which is by and large groundwater dependent, could have far reaching effects for the aquatic ecosystem.

Reduction of high flows will impact on flood plain processes and estuarine dynamics. Hughes and Műnster (2000) also hypothesized that sites at which connectivity between the active channel and the subsurface water is poor, it will have greater annual maintenance high flow requirements than sites where this connectivity is good. It will also affect bank storage if floods are reduced. King *et al*. (2000) state that many ecologists view the erosion and bed movement caused by major floods as a resetting mechanism that are periodically necessary for maintenance of the channel and its physical heterogeneity. They suggest that this may be true for smaller to medium floods with a return period of less than 1 in 5 years, and that larger floods do progressively more structural damage from which habitat and biota take longer to recover. Rowntree and Wadeson (1999) agree by stating that research has shown that events of moderate magnitude and relatively frequent occurrence control the erosion form of the channel, including size and shape. According to them observations of natural channels suggested that the channel shape as well as the dimensions of meandering rivers appeared to be associated with flows at or near bankfull stage (Small to medium floods). These bankfull flows recurred on average once every year or two years. The author of this document feels that the larger floods are important especially from an estuarine resetting point of view. However, the larger floods are less dependent on real groundwater discharges depending on the physio-graphic setting and river reach.

Although a lot of attention has generally been given on the disturbances caused by floods, it must be noted that the consequences of abnormally low flow, or cessation of flow is equally important. The natural variation and magnitude of flows is extremely important for the maintenance of productivity, nutrient cycling and spiralling, and decomposition. This very important disturbance regime is the most important feature of streams and is the dominant organising factor in stream ecology. The physical habitats are arguable the vital link between hydrology and the distribution and abundance of organisms in rivers (King *et* *al*., 2000). It is also in this part of the flow regime where groundwater is likely to have the largest impact.

2.2.6. Rivers as ecological corridors

Rivers are the arteries of the entire environment and form an important links between ecologically distinct regions. The variation in environmental conditions that exists naturally gives rise to diverse ecosystem types, but they are all linked in time and space. These ecologically distinct regions are all connected through a network of processes, pattern and corridors of which rivers play an important part (Davies *et al.*, 1993; Davies and Day, 1998). All the ecological regions are connected to a seamless environment through areas of transition or ecotones. However, many processes and regions are linked through rivers as their only connection.

Many of the global conservation initiatives also recognise this unique factor by using rivers as the backbone for many landscape conservation initiatives. In South Africa, and more specifically the Western Cape Province, there are two such landscape initiatives where the main rivers are the connecting corridor.

Rivers transport, animals, seed and form migration routes for many organisms, big and small. For these invaluable corridors to persist, the rivers ecosystems with their associated aquatic ecosystems, like wetlands, flood plains, estuaries etc. need to be in a healthy and functional state (Davies *et al.*, 1993; Davies and Day, 1998; Eisele *et al.*, 2003). With the current knowledge on the intimate link between groundwater and surface resources, groundwater use should take note off this important aspect.

2.2.7. Conservation importance of mountain streams

Regrettably the mountain streams of most of the river systems in the Western Cape Province, and elsewhere, are the most important river reaches from a conservation and ecological recruitment point of view. In most cases these mountain and foothill streams are home to the only remnant indigenous and endemic flora and fauna populations associated with a specific river system. These populations are the only pool of recruitment to maintain the ecological functioning of river systems, because in many foothill, and most lowland river reaches, these organisms are constantly wiped out by anthropogenic impacts. Mountain streams can be seen as the last outposts harnessing the fragmented populations of the indigenous biota. Springs, and other more discreet groundwater dependent ecosystems, are in most cases the only suitable habitat for habitat specialists, which are in most cases rare and or endangered endemics. Most of these habitats are suspected to be groundwater related (springs, wetlands and seeps) occurring in higher altitudes where discharges from the TMG is the main ecosystem driver (Hatton and Evans, 1998; Roets, 2000).

2.2.8. Groundwater discharges in the mountainous areas and vulnerability of mountain stream association with the TMG

Mountain stream and foothill reaches of rivers in the CFK are mostly associated with the TMG aquifer of the Cape Fold Belt as these are the areas where most rivers originate. It must therefore be assumed that in general rivers in the Western Cape Province have their head water, mountain stream and foothill reaches associated with the TMG aquifer. Stream flow in these reaches must be maintained by high altitude discharges from groundwater sources, either as perched aquifer discharges, TMG fracture or fault discharges, TMG geological contact zones (aquifer boundary conditions), TMG rejected recharge, or interflow (which will diminish under induced recharge conditions), bank storage discharges, translatory flow or TMG piezometric head discharges (real groundwater).

Most of these discharges are emanating from natural springs in the different hydrogeological settings. Some degree of overland runoff come into play straight after rainfall events in areas of bare rock and limited percolation due to the geology and soils. Most of the base flow and storm flow components have been proven to be groundwater discharges, both groundwater, interflow and translatory flow (Midgley and Scott, 1994; Winter *et al.*, 1999).

It is therefore safe to assume that changes to these different discharge regimes (spring discharges), due to abstraction of groundwater, can affect the stream flow of mountain stream and foothill areas in the “TMG aquifer daylight-domain”. Unfortunately, in most cases, the target areas for well field development are lineaments, or major fracture or fault lines, that generally coincide either with the main riverine valleys directly, or with preferential flow paths of the groundwater close to riverine valleys. Consequently conflict can be expected between the target areas, and the most important river reaches that maintain the perennial flows in most river systems. This would result from the effect of the development of the cone of depression near the borehole, or the pressure drop in the aquifer system, or in extreme cases a drop in the piezometric surface. The stream flows have been showed to be affected by groundwater abstraction in the Vermaaks Valley of the Kammanassie Mountain Range (Cleaver, 2003). Maclear and Woodford (1995) also found that spring flows were affected by groundwater use in the Uitenhage Artesian Basin (UAB) (Xu and Beekman, 2003). They also indicated that the Uitenhage spring flows recovered following the sealing of old artesian boreholes by DWAF in 1993.

As a consequence of alterations to the flow regime of mountain streams, it will logically be expected that the primary aquifers, in the lowland areas and other alluvial aquifers, will get less recharge from the losing streams or rivers. This chain of events will ultimately impact significantly on the availability of water in the environment and that which could be available for utilisation. It again emphasise the importance of understanding and managing the full hydrological system, rather than doing it independently.

2.2.9. Potential impacts of climate change on groundwater resources of the TMG

During the 9^{th} International Riversymosium in 2006 in Brisbane, Australia, renowned climate change experts shared their concerns about the effects of climate change. Amongst others were David Grey, Senior Water Advisor, World Bank, and Fred Pearce, author of “When the River Runs Dry”. The message for South Africa, and more specific the Western Cape, is short and concise: overall rainfall will decrease and rainfall intensity will increase. This has far reaching affects for water management in general, but much more so for potential future groundwater use development from the TMG aquifer.

Geological records have many examples of both warmer and cooler periods indicating that climate change is a reality of life on Earth. Future projections of the global climate indicate that precipitation patterns are changing. Because rainfall is a key factor in determining groundwater recharge, changes in the frequency, duration and intensity of rainfall events can have a significant impact on groundwater resources. Groundwater has a longer lag time response to rainfall compared to the corresponding hydrological response in surface water systems, generally smoothing the groundwater resource over the short term. This characteristic is normally a good buffer against the impacts of climate variability and provides a valuable resource to cope with short-term drought conditions. However, the presence of paleo-groundwater in several arid aquifers, illustrate that groundwater systems are not resilient to long-term climate change (Cavé *et al.*, 2003). Further to this the TMG aquifer will only give us some grace in water availability because of its characteristic recharge dependency and exposed recharge area.

It is estimated that a 20% decrease in mean annual rainfall volumes could translate to a 80% decline in recharge for areas that currently have a rainfall of 500 mm yr^{1}. Preliminary General Circulation Models (GCM) modelling over Southern Africa for the next 50 to 80 years indicates that the Western Cape is likely to experience an extended summer with a slight reduction in rainfall (possibly 10%). Rainfall patterns are likely to change to become more coastally focussed with less precipitation falling in the interior and more along the coast. Mean temperatures are likely to rise by about 2 ºC in the coastal areas, and in the interior it will be much more severe with temperatures in the Karoo rising to 40% (6 ºC). Rainfall in the Karoo could be reduced by 10 to 20% with summer convective rainfall events becoming less frequent, but more intense over the interior. The reduced rainfall will ultimately cause a decline in the annual groundwater recharge and lead to a lowering of the water table (Cavé *et al.*, 2003).

The estimated change in rainfall intensity will have a negative effect on recharge, because rainfall intensity may supersede the infiltration capacity of the TMG, resulting in more overland run-off and less percolation and interflow.

Changes to the precipitation will have significant impacts on water resources of a semi-arid country such as South Africa. It is postulated that it will induce changes to the botanical diversity and its distribution (Midgley *et al.*, 2002) resulting in spatial and temporal variation in evaporative losses and thus affecting contribution of rainfall to surface runoff and recharge. Reduced rainfall in the interior will decrease availability of surface water and place more pressure on groundwater resources (Cavé *et al.*, 2003).

Uncertainties still trouble quantitative assessments of climate change and the effects on groundwater recharge, but the fact remain that climate is changing, and that it will have an effect on water resources. Seward *et al.* (2006) support this view by highlighting the potential devastating effects that groundwater use may have if it is not properly understood, managed and used.

CHAPTER THREE
Study approach

3.1. Conceptual understanding of link between TMG aquifer and aquatic ecosystems

As stated in Chapter 1 (1.2.) the main objectives of this study was to conceptually understand and scientifically validate the mechanisms of groundwater discharge from the TMG aquifer to surface resources. This conceptualization had to be applicable to the full extent of the TMG aquifer, hence the aim to ultimately produce a spatially defined layer highlighting the quaternary catchments within the TMG domain, containing sensitive aquatic ecosystems that may be dependent on discharges from the TMG aquifer.

After an intensive literature survey, a conceptual model was developed. This highlighted the different groundwater ‘discharge types’ that contributed to the different components of the flow regime of streams and rivers associated with the TMG. The conceptual model also indicated the ecological importance of real groundwater discharges from the TMG to aquatic ecosystems as part of their flow regime. Clear distinction was also made between real groundwater and non-groundwater contributions. This included differentiation between the contributions of groundwater, translatory flow, quick flow (overland runoff) and interflow. It also indicated the two primary groundwater surface water interface areas where the TMG aquifer will be discharging to aquatic ecosystems (i.e. “TMG aquifer daylight-domain” and in the “TMG aquifer surface water interface-domain”).

Because of the location of the groundwater surface water interactions in two primary domains, a case study was selected in each of the respective domains. The purpose of both case studies was to scientifically substantiate the soundness of the conceptual model that was developed.

3.2. Selection of case study sites

Both case study sites were restricted to the southern branch of the structural domain of the TMG (see Chapter four) in the southern part of the Western Cape Province where use of groundwater is likely to happen in future.

The first case study sites were selected in two river valleys in the Kammanassie Mountain Complex (See Figure 3.1). These two river valleys namely, the Vermaaks- and Marnevicks valleys, presented a perfect opportunity for a comparative study on the impacts of groundwater use (Figure 3.2). The Vermaaks valley had an impacted groundwater discharge regime resulting from groundwater use from an existing well field. The Marnevicks valley with a natural groundwater discharge regime served as a control site. Both study sites are located in the “TMG aquifer daylight-domain”, which is associated with the mountain and foothill areas of the Cape Fold Mountains.

The sites for the second case study were selected in the coastal lowlands of the southern Cape in the “TMG aquifer surface water interface-domain”. Two unique coastal wetlands, namely, Groenvlei and Van Kervelsvlei, were selected to determine whether either or both were dependent on groundwater discharges from the TMG aquifer (See Figure 3.2). These wetlands are both endorheic which indicated their groundwater dependence.

3.3. Case studies

The ***first case study***, in the Kammanassie Mountain Complex, investigated the effect of groundwater discharges on soil nutrient concentration in the riparian soils of the Vermaaks and Marnevicks river valleys. Both river valleys have the same geology, soils, vegetation and climate which made it ideal for a comparative study. The Vermaaks River had a known altered hydrological regime resulting from a groundwater well-field that has been in operation since 1987 (Kotze 2002; Cleaver, 2003). Soil nutrient concentrations in aquatic ecosystems are known to show a response to groundwater discharge regimes (Wassen, 1995; El-Kahloun *et al.*, 2003). The Marnevicks River served as the control site with no groundwater use and a normal hydrological regime.

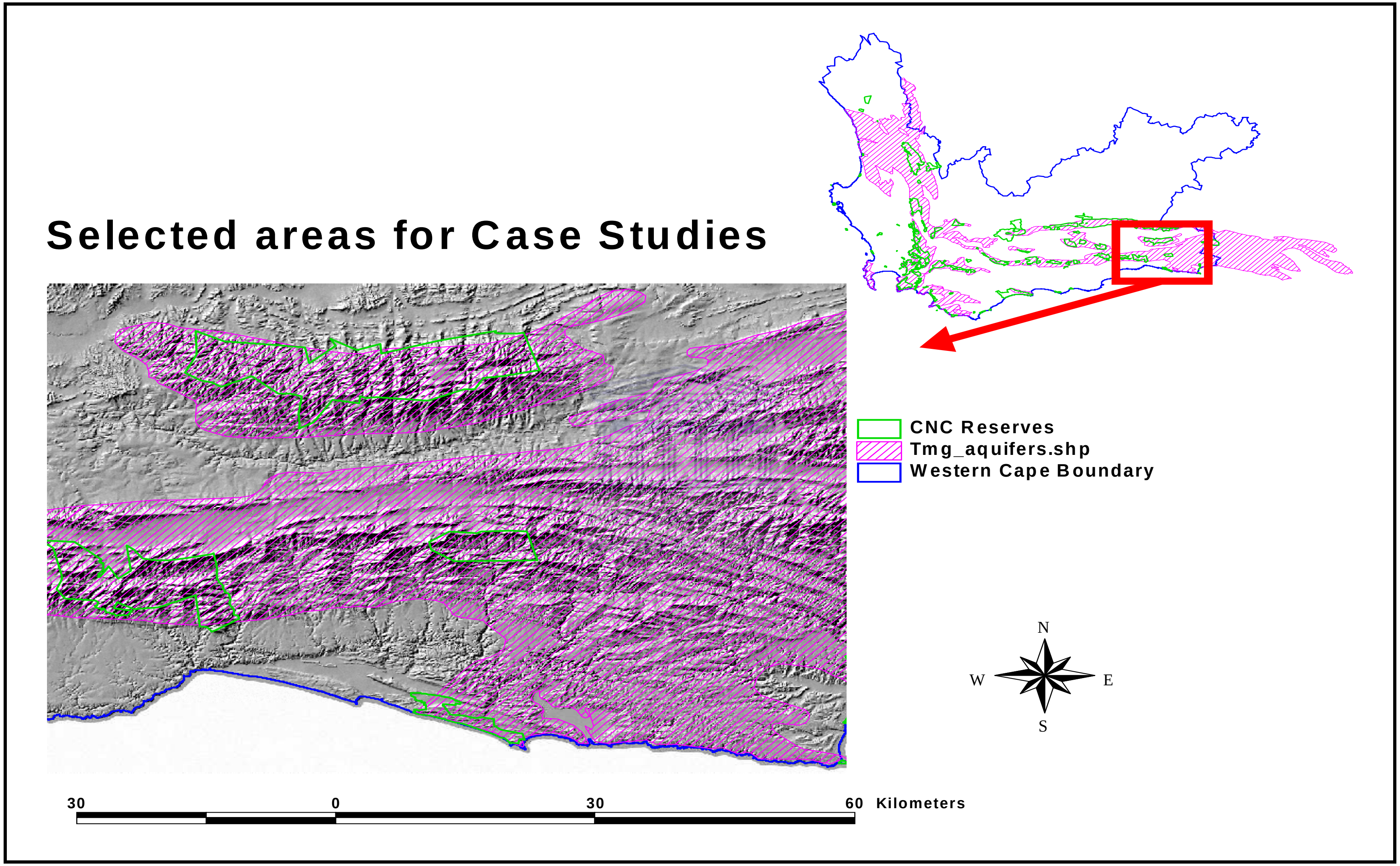

Figure 3.1. Showing the area in the southern Cape that was selected for the two case studies.

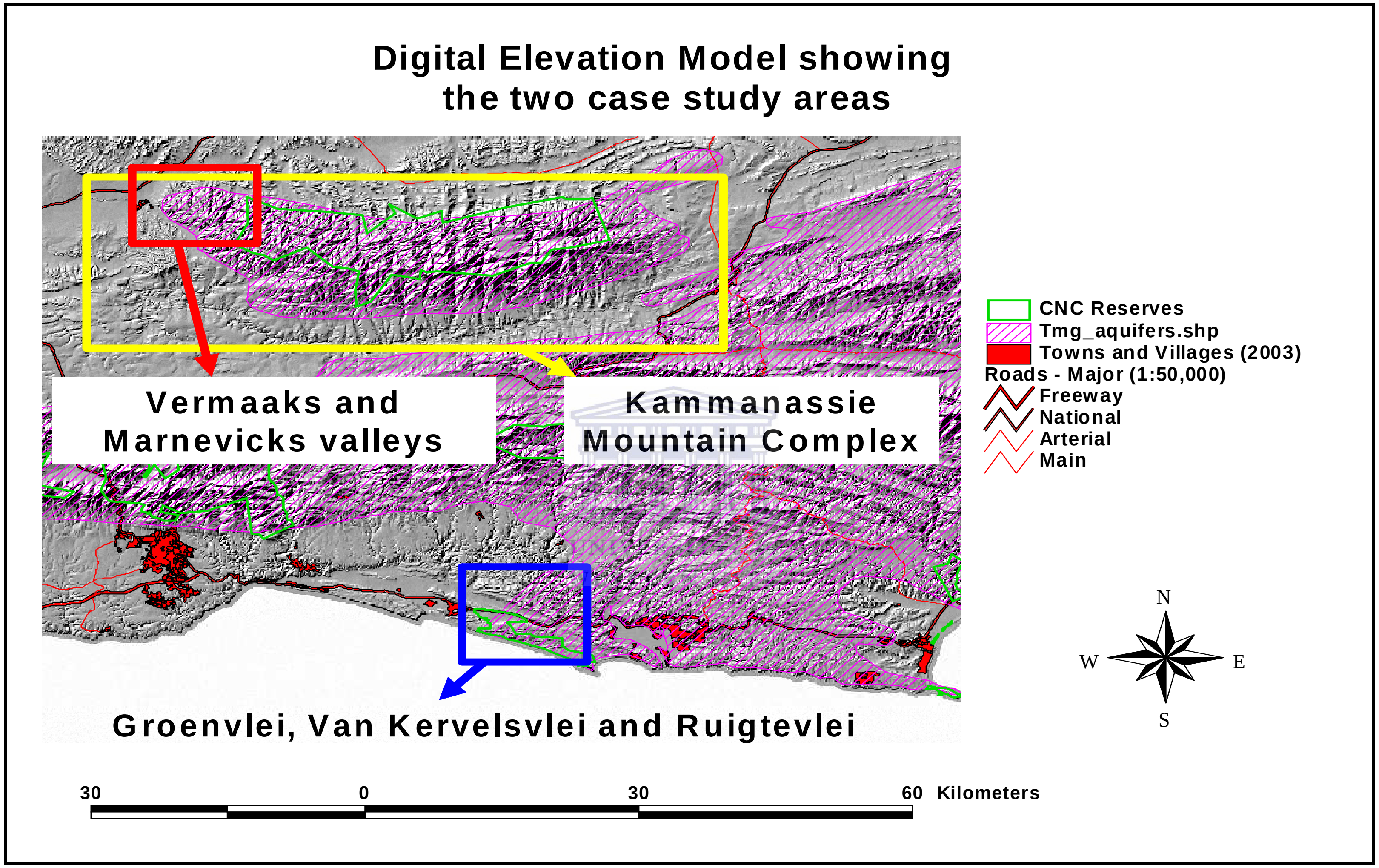

Figure 3.2. DEM showing the Kammanassie Mountain Complex (yellow square), Case study 1: Vermaaks and Marnevicks valleys (red square), and Case study 2: Groenvlei and Van Kervelsvlei (blue square).

The ***second case study*** investigated the possibility of groundwater discharges from the TMG aquifer to lowland wetlands in the "TMG aquifer surface water interface-domain". The very nature of the TMG aquifer dictates that discharges from this aquifer could be far from the recharge areas, even in marine environments. Groenvlei and Van Kervelsvlei, both endorheic coastal wetlands, with differing characteristics, were selected to establish whether any of them were dependent on groundwater discharges from the TMG. Physical and chemical water quality parameters (hydrochemistry), groundwater level data and underlying geology were the main indicators used to determine the origin of the groundwater sources feeding these wetlands. Hydrogeological data existed for Groenvlei, but little was known about Van Kervelsvlei.

3.4. GIS Model

In order to make the outcome of the study applicable to groundwater management, a GIS model was developed to highlight groundwater dependence of aquatic ecosystems associated with the TMG. This model had to highlight sensitive aquatic ecosystems associated with the TMG that could be vulnerable to groundwater use. Advances in GIS technology and spatial modelling techniques were used extensively to integrate a large number of existing GIS data sets. All existing and relevant information was used and collated into a GIS model and associated database. This was seen as a very cost effective method to develop a regional perspective of the variability of key parameters of the regional and local aquifers of the TMG and its association with the aquatic ecosystems of the CFK, a view shared by Semeniuk and Semeniuk (1994) and Commander (2000).

CHAPTER FOUR
Regional background and study sites

4.1. Physiography and locality

The study focused on the TMG aquifer that is associated with Table Mountain Group of the Cape Folded Mountains, covering most of the Western Cape Province and extending into the Eastern Cape Province. The GIS model that was developed at the end of this study covered the full extent of the TMG aquifer. This includes an area extending from 100 km north of Bergplaas on the west coast, down to Cape Town in the south-west and along the southeast coast to Port Elizabeth (Figure 4.1). The area covers over 116 000 km^2, which includes 90 000 km^2 of the Cape Floristic Region (CFR) (Goldblatt and Manning, 2000), and 314 Quaternary drainage regions (Figure 4.4) (Fortuin, 2004).

For the purposes of the two case studies the Kammanassie Mountain Complex in the Little Karoo, and the coastal wetlands of Groenvlei and Van Kervelsvlei near Sedgefield were the focal point (See Figure 4.1). The Kammanassie Mountain Complex is a prominent feature in the Little Karoo consisting of the TMG. The second case study focused on Groenvlei and Van Kervelsvlei. Both these wetlands are associated with the fixed dune fields in the Southern Cape, but having very different characteristics. Although these two wetlands form part of the 'Wilderness Lakes' historic embayment they are the only wetlands not connected to the sea or to each other. This prompted the investigation of the origin of the groundwater feeding both wetlands.

4.2. Geomorphological characteristics of the three structural domains of the TMG

The TMG forms part of the Cape Fold Belt (CFB) and is expressed as a mountain chain of about 1200 km along the south- and part of the western coast of South Africa. As a result of tectonic events, such as the Cape orogeny, the CFB was formed which resulted in three distinct structural settings or branches. It consists of the western branch extending along the western part of the CFB which is characterised by the Cedar Berg Fold Range. The southern branch extends along the southern section of the CFB characterised by the Outeniqua and Swartberg Ranges. Lastly the syntaxis formed at the junction of the western and southern branches is characterised by the Kogelberg and Hottentotsholand Mountains (See Figure 4.2). All the branches exhibit characteristic folding and associated fracture and fault networks. The geomorphology of the TMG reflects the folding, fracturing and faulting characteristics in these different structural settings of the CFB (De Beer, 2002) (See Plates A and B – pg 58-59).

De Beer (2002) described the characteristics of the TMG that is responsible for our current understanding of the general structure of the TMG. Table 4.1 summarises the characteristics of the TMG.

In general, *Anticlines* and *Synclines* form ridges and valleys respectively, where rocks in folded sequences are resistant. The TMG, being the lower most member of the CFB, forms most of the major ridges. The overlying Bokkeveld and Witteberg strata have been removed while synclinal valleys contain remnants of the once continuous Bokkeveld Shales and the ridges comprise anticlines either intact or breached. It is these TMG layers that form the significant reservoir of the TMG aquifer through the secondary porosity that developed through the folding and faulting.

The unique attributes of the TMG caused the evolution of unique vegetation types to be associated with it. Many ecosystems, especially aquatic ecosystems are dependent on water from the TMG aquifer.

Plate A. Shows a photo of a typical fault system in the TMG that clearly expose the folded nature of the TMG. Faults can be of different spatial scales. Large fault systems may form entire river valleys.

Plate B. Shows a photo of the typical folded nature of the TMG in the southern branch of the structural domain of the TMG.

Plates showing the fracturing and folding of the CFB.

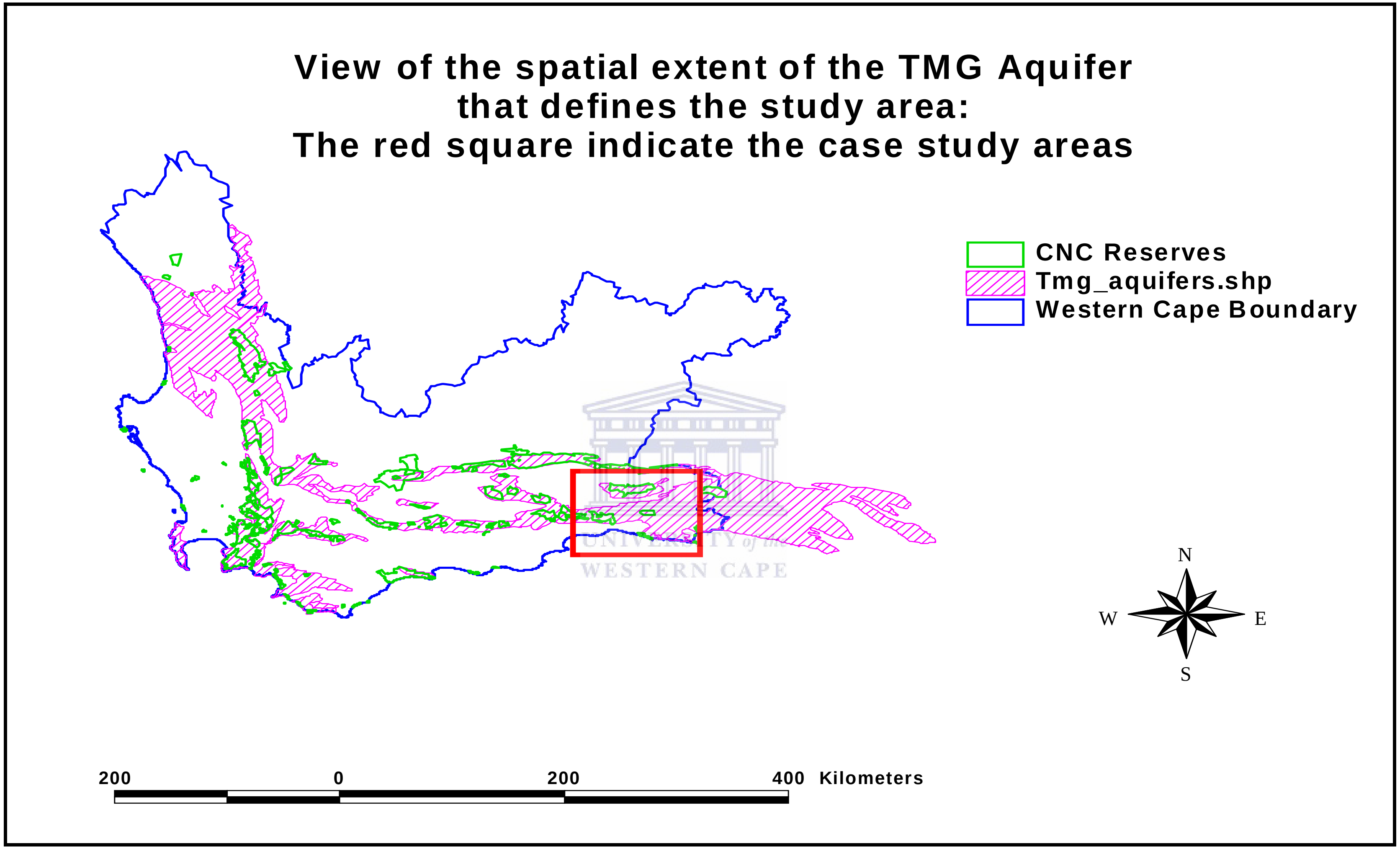

Figure 4.1. Spatial extent of the TMG aquifer that defines the study area. The red square depicts the area where the case studies were done.

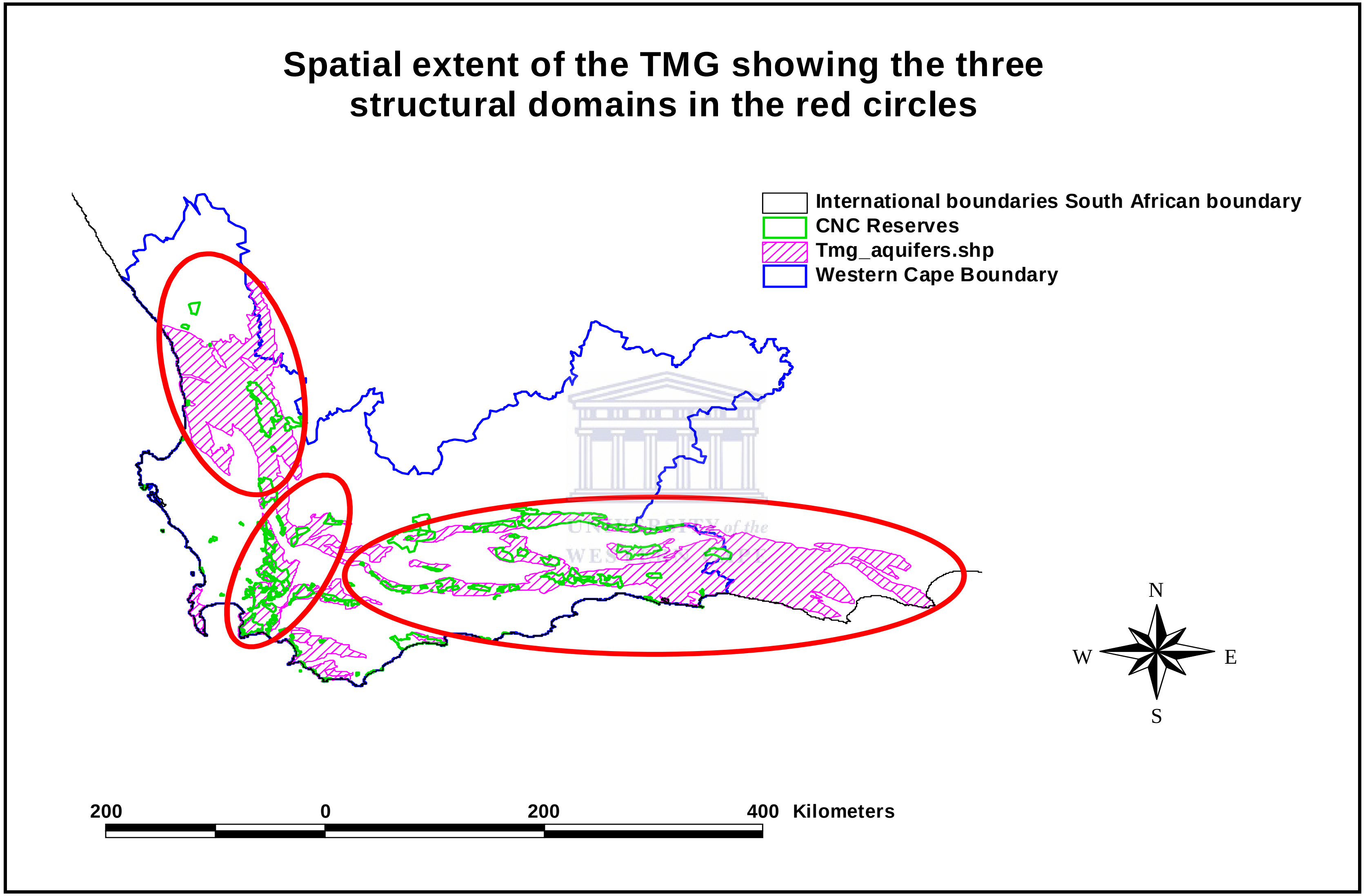

Figure 4.2. Extent of TMG with the red circles indicating the three structural domains.

Table 4.1. General characteristics of TMG structural settings (De Beer, 2002).

<table>
<tr><th></th><th colspan="2"><u>Folding</u></th><th><u>Fracturing</u></th></tr>
<tr><td><u>SOUTHERN BRANCH</u></td><td colspan="2">Intense folding
• Northerly verging often overturned
• Swartberg & Outeniqua fold ranges
• Abrupt changes in style & intensity of deformation separates branch into zones</td><td>• Sliced by normal faults & few thrust
• Due to differing deformational intensities associated intense fracturing</td></tr>
<tr><td><u>WESTERN BRANCH</u></td><td colspan="2">Gentle folding
• North-westerly fold trend
• Cedarberg fold range</td><td>• Faults trend north-westerly with some sets of transverse north-east-trending minor faults
• Well developed bedding & conjugate fractures</td></tr>
<tr><td rowspan="3"><u>SYNTAXIS</u></td><td colspan="2">Differing fold trends & shortening intensities
• Two separate domains on both sides of Hex River anticline (Northern & Southern Domain)</td><td rowspan="3">• Most fractured part of CFB
• Contains most components of western & southern branch faulting</td></tr>
<tr><td>Northern</td><td>Southern</td></tr>
<tr><td>• North, north-west, north-east & minor east-trending folds</td><td>• East & north-east trending folds</td></tr>
</table>

Based on geology, geomorphology and hydrogeology, Wu (2005) produced 19 hydrostratigraphic areas within the three structural domains, covering about 24 000 km^2 in the Western and Eastern Cape. However, for the purposes of this study, it was decided to keep to the three broader structural domains because of scale and detail required for the current investigation.

It should be noted that when applying hydro-geomorphological typing to streams at the catchment scale the structural setting should not be considered as a major influence on the interaction that would occur between groundwater and surface water but rather as a governing framework of distinct structural characteristics that would be expected in the study area.

4.3. Topographic characteristics

The physiographic setting of the bigger study area for the GIS model is extremely varied. The topography is dominated by very prominent mountain ranges, such as the Cedarberg and Hex River Mountains, separated by narrow cultivated intermontane valleys such as the Citrusdal and Koo Valleys. The syntaxis of the Cape Fold Belt (CFB), with its very high mountains, forms prominent water divides between major river systems. To the east of the syntaxis are the severely fractured and folded ranges of the Langeberge, Outeniqua, Swartberg and the Kammanassie Mountain Complex. The latter is the focus of this study.

4.4. Climate

The climate is predominantly Mediterranean in the south-western part of the Western Cape Province. However the relief largely influences the temperatures and precipitation. This region experiences a maximum rainfall during the winter months of May to August. The whole study area experiences mean temperatures ranging between 6 °C and 36 °C, but during winters the high mountains are usually capped with snow. Similarly, the rainfall varies from less than 250 mm in the north and northeast to more than 1500 mm in the mountainous areas (See Figure 4.3), and in some places more than 2500 mm. The rainfall pattern gradually changes from the west to east, with the southern Cape and Little Karoo (the focal area for the case studies) having all year rainfall with peaks in autumn and spring. The eastern extreme of the TMG experience a summer rainfall pattern.

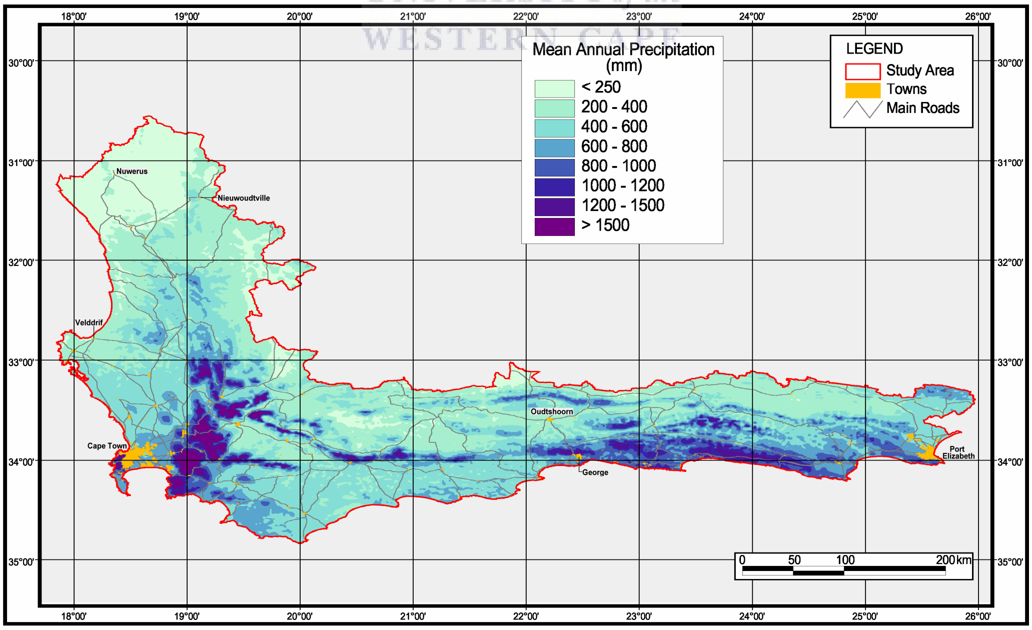

Figure 4.3. Mean Annual Precipitation (mm/yr) interpolated from the CWR1'X1'grid data (Schultze, 1997).

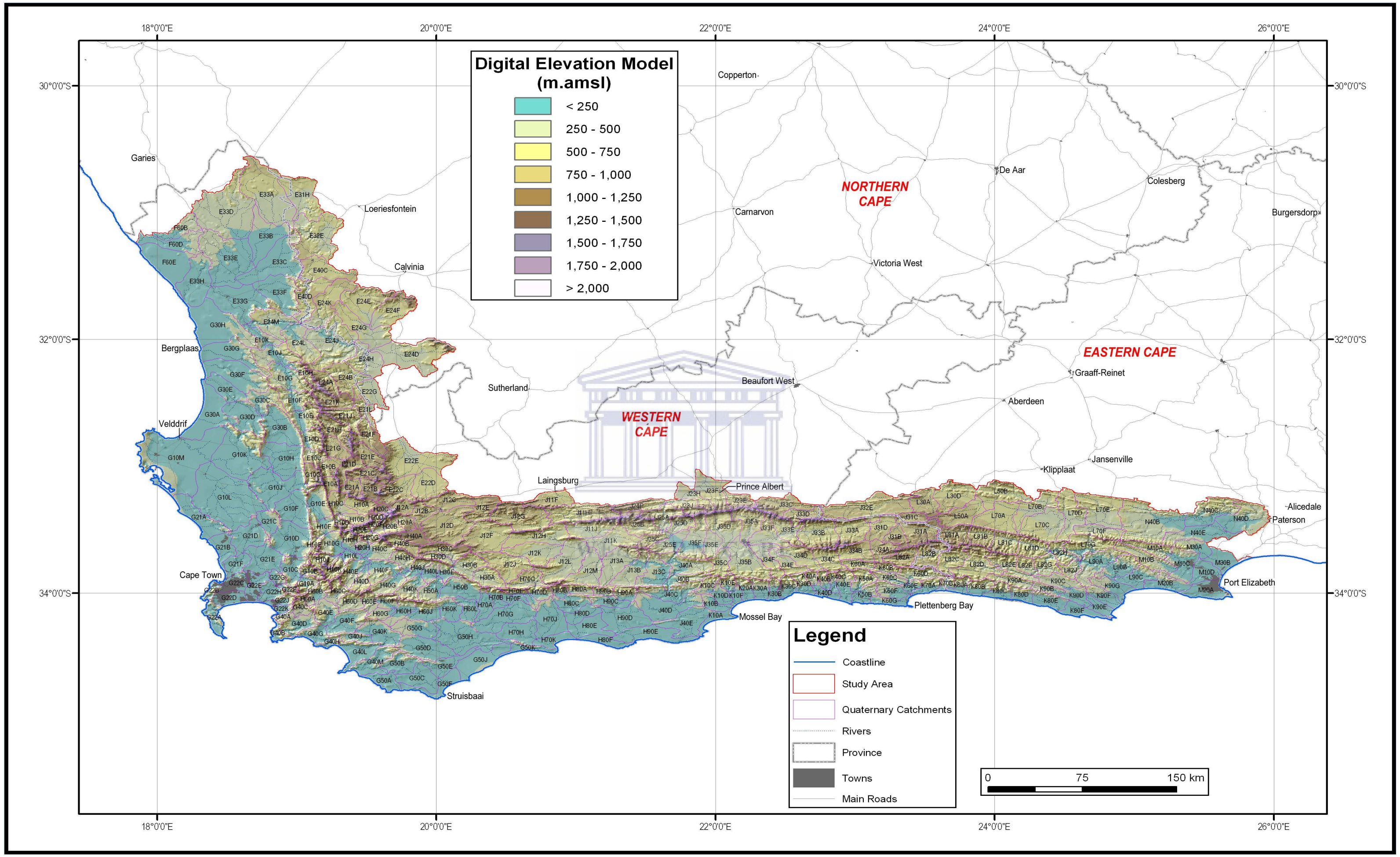

Figure 4.4. Physiographic setting of the study area (Fortuin 2004).

4.5. Vegetation

The Cape Floristic Region (CFR) is recognised globally as a floral kingdom in its own right (Goldblatt, 1978; Takhatajan, 1986; Cowling and Holmes, 1992). Botanically it is one of the richest regions in the world (Goldblatt and Manning, 2000). The CFR has 69% of its species being endemic (i.e. found nowhere else in the world). It is dominated by members of the *Asteraceae* (daisies); *Fabaceae* (peas); *Iridaceae* (irids); *Ericaceae* (ericas); and *Mesembryanthemaceae* (mesems or vygies). Five of South Africa's seven biomes namely, Fynbos, Forests, Thicket, Succulent Karoo and Nama Karoo (See Figure 4.5) and some 22 broad vegetation types are represented in the study area and are associated with the TMG (Low and Rebelo, 1996).

Vegetation types closely correlate with the geology in the CFR (Cowling and Holmes, 1992). Coupled with rainfall and other climatic variables these account for most of the variation and distribution patterns of vegetation within the region. The TMG aquifer system by definition is largely overlain by sediments of the TMG and dominated by sandstones, quartzites, conglomerates, and, to a lesser degree, finer textured mudstones and siltstones (Theron, 1983; Theron *et al.*, 1992). Generally this siliceous material produces soils that influence the vegetation in two ways. Firstly soils are acidic (Schloms *et al.*, 1983), deriving their acidity from the nature of the parent material and from leaching (Schloms *et al.*, 1983). Secondly they are oligotrophic, with low agricultural potential (Schloms *et al.*, 1983; Cowling *et al.*, 1992). Both these factors have contributed to the evolution of a flora, which is heath-like in character and is both species rich as well as possessing extremely high levels of endemism (Cowling and Holmes, 1992; Cowling *et al.*, 1992).

In general the vegetation associated with these soils is fynbos, although forest can develop in moist, sheltered ravines (Cowling and Holmes, 1992). At the lower end of the rainfall spectrum, Karoo vegetation becomes dominant (Cowling and Holmes, 1992).

Apart from the soils described above, there is a suite of substrates regarded as being moderately high in nutrients and generally finer textured. These border onto the TMG and include phyllite, schist, greywacke and shale of the Malmesbury and Bokkeveld Groups (Theron, 1983), whilst Cape Granite (Theron, 1983) also forms a more fertile and finer textured soil. Renosterveld dominate these soils types but can give way to fynbos at higher rainfall (Rebelo, 1996).

Along the entire coastal fringe another suite of soil types occurs, largely resulting from coastal processes and broadly divided into two categories, firstly calcareous sands and limestones, and secondly non-calcareous (neutral to acidic) sands. These soils support a number of coastal vegetation types such as Strandveld and Sand Fynbos (Mucina and Rutherford, 2006). It is with these soil types that the three southern Cape wetlands are associated.

The vegetation of the selected case study areas is described in more detail in the appropriate chapters. The Kammanassie Nature Reserve and Goukamma Nature Reserve that is part of the case study areas have well documented fine scale vegetation maps. For the purposes of the case studies, only the vegetation of the Vermaaks- and Marnevicks River valleys and the two wetlands in the southern Cape (see appropriate Chapters 6 and 7) are described.

4.6. Geology (stratigraphy) and hydrogeology

The geology of the study area is well described by Visser (1989) and comprehensively discussed in Fortuin (2004).

The Cape Supergroup, which is the main focus of this study within the study area were deposited from early Ordovician to early Carboniferous times, approximately between 340 and 500 million years ago (De Beer, 2002). This sequence is exposed along the entire length of the Cape Fold Belt, the 220-280 million year old orogenic belt straddling the west and south coasts of South Africa, starting from Vanrhynsdorp in the west to Port Elizabeth in the east. It is divided into three groups, namely the Table Mountain, Bokkeveld and Witteberg Groups (See Figure 4.6).

As stated earlier the TMG occurs within the Western and Eastern Cape Provinces of South Africa, extending from just north of Nieuwoudtville to Cape Agulhas and then eastwards to Algoa Bay, a linear outcrop distance of over 900 km. It attains a maximum thickness of 4400 m in the Western Cape Province, whilst the thickness decreases rapidly towards the north to 900 m in the vicinity of Nieuwoudtville. A large percentage of the TMG consists of quartzitic sandstones. The sediments of this group were deposited in a shallow, but extensive, intra-cratonic basin on a fairly stable continental shelf (Visser, 1989).

The TMG is divided into six units. Table 4.2 gives a summary of the lithostratigraphy of these units. The Peninsula Formation is the thickest unit in the TMG and together with the Nardouw Subgroup forms the high mountain ranges of the Western Cape. The Peninsula Formation comprises at least 50% of the TMG and it is composed of a monotonous succession of medium- to coarse-grained, thickly bedded, greenish grey sandstone, which weathers to a whitish colour.

The Nardouw Subgroup is similar to the Peninsula Formation, but is subdivided on small lithological differences into the Goudini, Skurweberg and Rietvlei Formations. The rocks of this Subgroup are generally weathered to a more brownish colour than that of the Peninsula Formation, whilst shale intercalations are more plentiful and they become more feldspathic toward the top (Visser, 1989).

The stratigraphy of the Bokkeveld Group and Witteberg Group is summarized in Table's 4.3. and 4.4. These groups are less permeable to water and act as aquatards in many areas, confining the TMG aquifer.

Table 4.2. Stratigraphy of the Table Mountain Group (De Beer, 2002).

SUBGROUP	FORMATION	MAXIMUM THICKNESS (m)	LITHOLOGY
Nardouw	Rietvlei	280	Light grey feldspathic sandstone, siltstone and micaceous shale bands
	Skurweberg	390	Light grey, massively bedded, quartzitic sandstone; thin lenticular conglomerate and grit beds
	Goudini	230	Red-brown weathering, thin bedded quartzitic sandstone; thin shale beds and places
	Cedarberg	120	Shale, aranaceous shale, tillite, grit and conglomerate
	Pakhuis	40	Grey-blue, massively bedded diamicite with erratics
	Peninsula	1800	Light-grey quartzitic sandstone with thin siltstone, shale and polymictic conglomerate lenses
	Graafwater	420	Thinly bedded sandstone, siltstone and mudstone; mainly reddish
	Piekenierskloof	900	Grey to reddish quartzitic sandstone with minor grit, conglomerate and reddish shale lenses

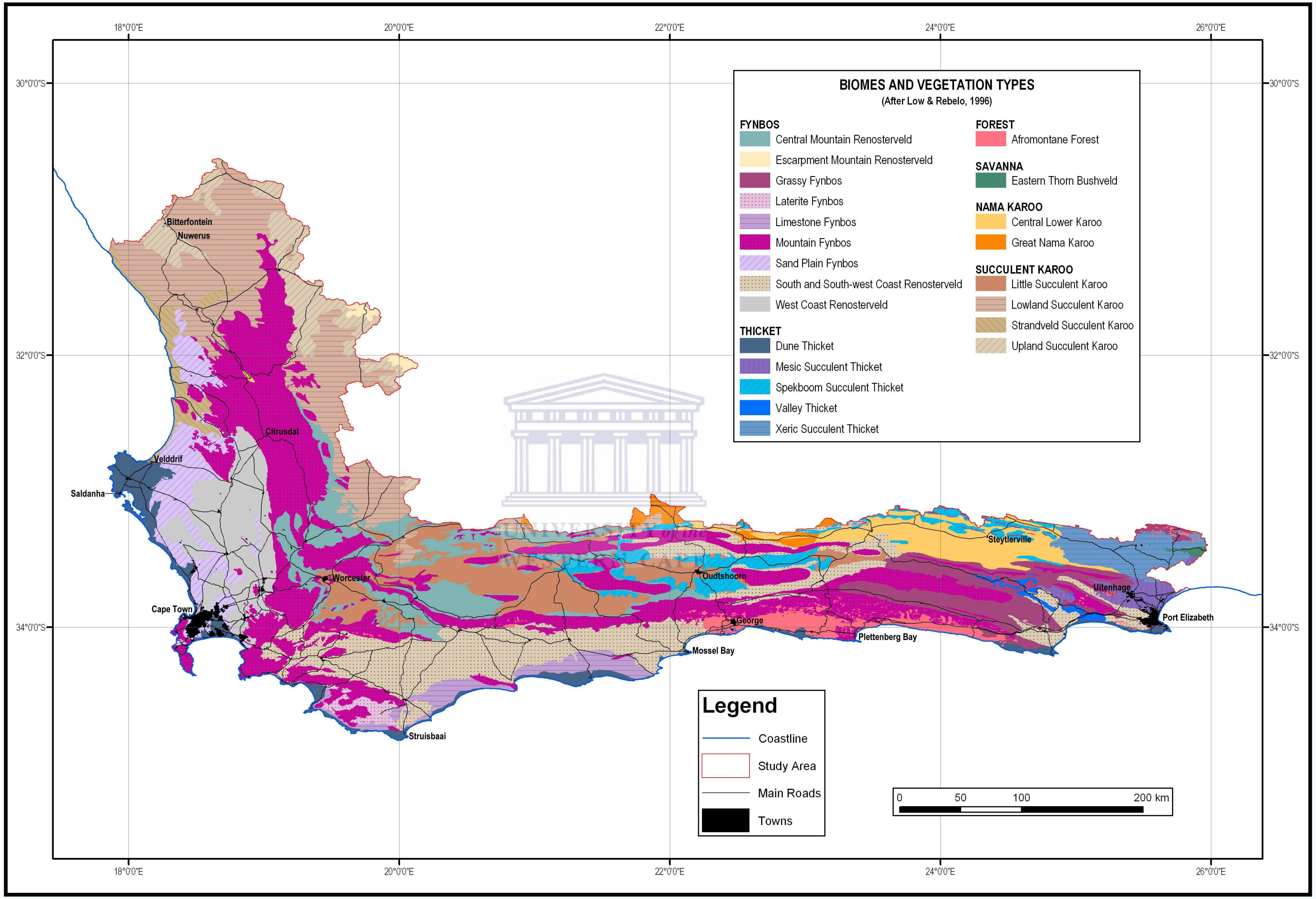

Figure 4.5. Biomes and vegetation of the study area (Low and Rebelo, 1996).

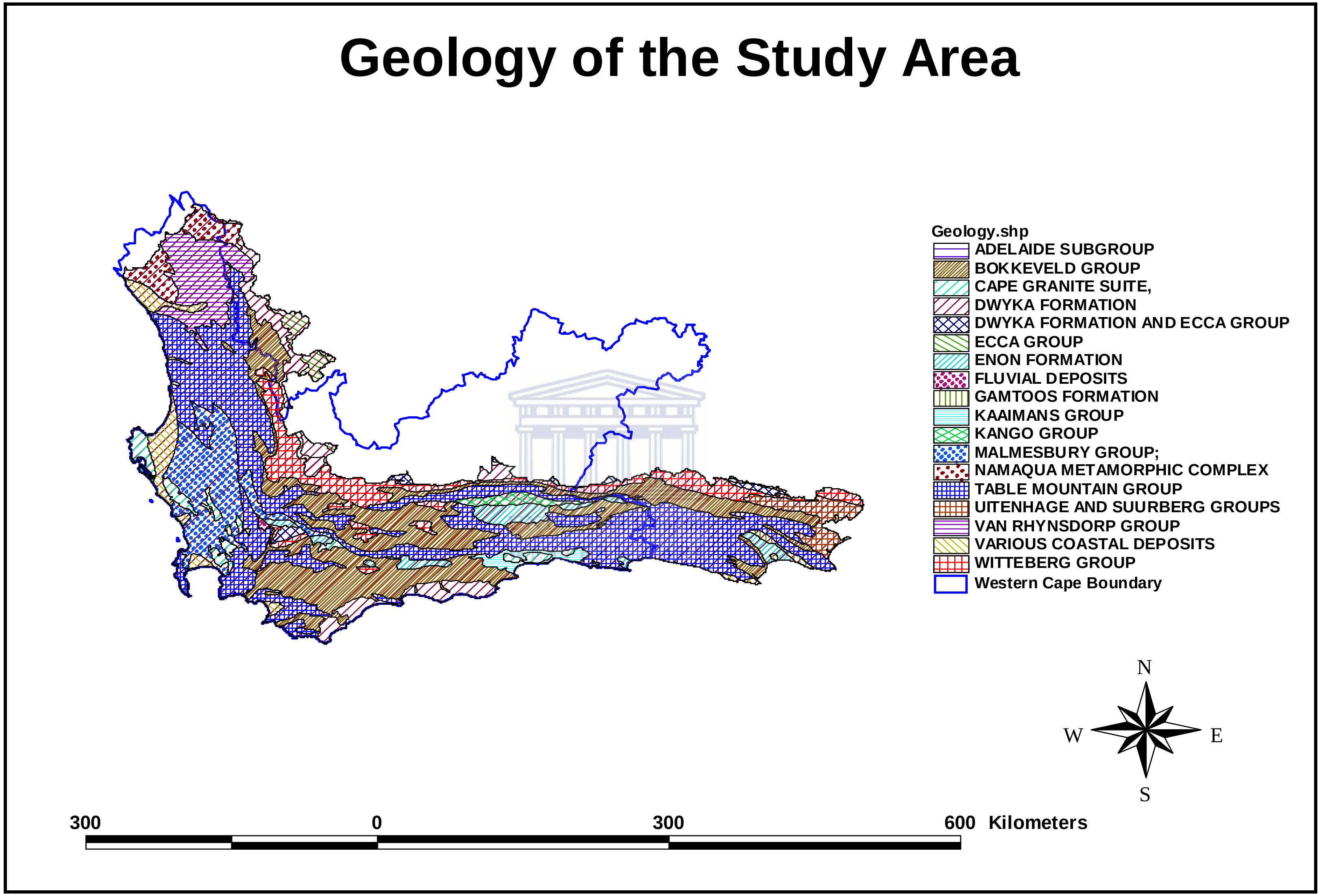

Figure 4.6. Geology of the study area (Council of Geoscience, 2001).

Table 4.3. Stratigraphy of the Bokkeveld Group (Visser, 1989).

WESTERN PART OF CAPE BASIN			EASTERN PART OF CAPE BASIN		
SUB-GROUP	**FOR-MATION**	**LITHOLOGY**	**SUB-GROUP**	**FOR-MATION**	**LITHOLOGY**
Bidouw	Karoopoort	Siltstone and orthoquartzite, with shale interbeds	Traka	Sandpoort	Reddish shale, siltstone and orthoquartzite
	Osberg	Feldspathic sandstone and orthoquartzite		Adoplhs-poort	Siltstone and orthoquartzite
	Klipbokkop	Mudstone, greywacke and subgreywacke		Karies	Shale, siltstone, orthoquartzite
	Wupperthal	Orthoquartzite, subgrey-wacke and siltstone			
	Waboom-berg	Siltstone, orthoquartzite, shale; black shale near top			
Ceres	Boplaas	Orthoquartzite, subgreywacke	Ceres	Boplaas	Feldspathic sandstone, orthoquartzite and mudstone
	Tra-tra	Mudstone, siltstone, subordinate sandstone		Tra-tra	Mudstone, siltstone, sandstone
	Hex River	Arkose, subgreywacke, orthoquartzite		Hex River	Subgreywacke, orthoquartzite, siltstone, mudstone
	Voorste-hoek	Siltstone, shale, fine-grained sandstone		Voorste-hoek	Siltstone, shale, fine-grained sandstone
	Gamka	Feldspathic sandstone, orthoquartzite, mudstone		Gamka	Feldspathic sandstone, orthoquartzite, mudstone
	Gydo	Black to dark-grey shale, siltstone and thin sandstone; fossiliferous		Gydo	Shale, siltstone, fine-grained sandstone

Table 4.4. Stratigraphy of the Witteberg Group (De Beer, 2002).

	WESTERN PART OF BASIN		EASTERN PART OF BASIN	
SUBGROUP	**FORMATION**	**LITHOLOGY**	**FORMATION**	**LITHOLOGY**
Kommadagga			Dirkskraal	Feldspathic sandstone, orthoquartzite
			Soutkloof	Mudstone, shale, varved shale
			Swartwaters-poort/Miller	Sandstone, diamictite
Lake Mentz	Waaipoort	Mudstone, greywacke	Waaipoort	Greywacke, mudstone, feldpathic sandstone
	Floriskraal	Feld spathic sandstone	Floriskraal	Shale, mudstone, orthoquartzite
	Kweekvlei	Black fissile shale	Kweekvlei	Shale, siltstone
	Witpoort	Orthoquartzite, rare shale lentils	Witpoort	Orthoquartzite, rare shale lentils
Weltevrede	Swartruggens	Siltstone, shale, interbedded sandstone	Weltevrede	Shale, siltstone, thick orthoquartzite
	Blinkberg	Orthoquartzites		
	Wagen Drift	Shale, siltstone, interbedded sandstone		

4.7. Structural geology – Folding/Fracturing/Faulting

The ability of rocks in the Table Mountain and Bokkeveld Groups to contain water is largely determined by the amount of fractures creating secondary porosity. Most of these rock types are remarkably densely packed with intense secondary overgrowths of quartz on grains within the arenites, and therefore need severe deformation and faulting to create such porosity.

Figure 4.7 shows the 9 regional structural – tectonic domains as proposed by De Beer (2002) of the Council for Geosciences. This covers the outcrop areas of the Table Mountain and Bokkeveld Groups within the Cape Fold Belt (CFB), based on their folding and fracturing characteristics. These domains are shown in (Table 4.5.). Folding during the Permo-Triassic Cape Orogeny and the fragmentation of Gondwana during the Mesozoic led to the extensive fracturing and strong enhancement of porosities within these rocks (De Beer, 2002).

The western branch (Figure 4.2) of the CFB encompass Domains 1 and 2, and Domains 8 and 9 the southern branch of the CFB outside the syntaxis domain. The Cape Peninsula is tentatively grouped into Domain 2 (i.e. the western branch) as a TMG outlier because it mainly displays North West – South East striking faults. Its North East – South West open folding, however, points towards its location within the syntaxis and elements of Domain 5 folding (Fortuin, 2004).

The syntaxis is made up of Domains 3 to 7, where Domains 3 and 5 still display many features of the western branch, and Domains 4 to 6 many of the characteristics of the southern branch. Domain 7 comprises the highly deformed and possibly thrusted sequences between Hermanus and Cape Agulhas (Fortuin, 2004).

The syntaxial area of the CFB (Domains 3 to 7) is subdivided by the Worcester Fault into two areas both with strong differences in the trend and intensity of faults. Domains 5 and 6 of the southern part displays interplay between North West – South East, East-West and North East – South West faults, most of which are major structures. This resulted in the southern syntaxis being the most intensely fractured part of the whole CFB. The Faults in Domains 3 and 4 trend West North West – East South East in harmony with the general trend of the Worcester Fault. The general absence of North East – South West faults in this areas implies that faults of this trend south of the Worcester Fault were formed either contemporaneous with the mega-fault, or later (Fortuin, 2004).

Domains 8 and 9, which are the part in which the case studies were done, are essentially the southern branches proper (See Figures 4.1 and 4.2), with zonal variations in shortening intensity and the presence of a major continent-wide normal fault system, the Kango Fault, within Domain 8. Shortening intensity reaches its maximum in the Outeniqua Mountain Ranges (70%) and thrusting is conspicuous within the mountain ranges north of Plettenberg Bay and Port Elizabeth (Fortuin, 2004).

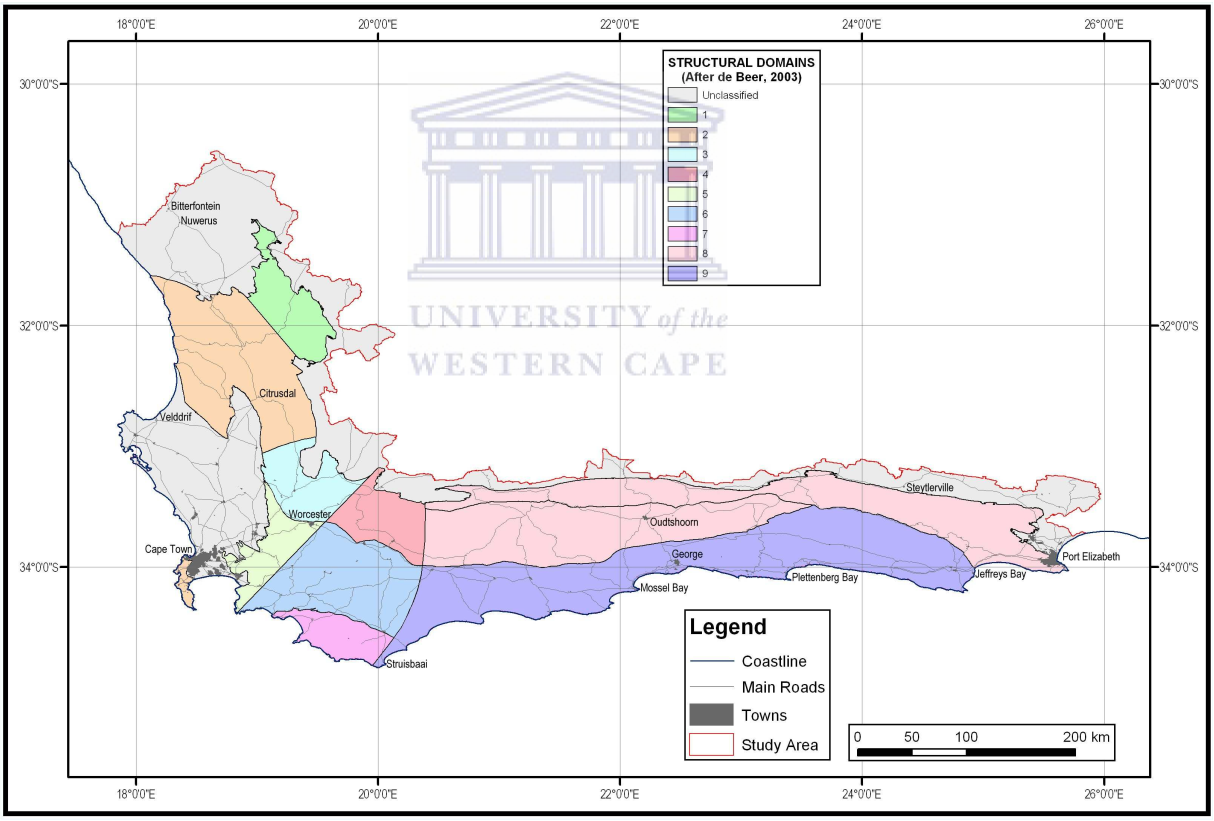

Figure 4.7. Structural – Tectonic Domains of the TMG and Bokkeveld Groups within the Cape Fold Belt (De Beer, 2002).

Table 4.5. Summary of the structural character of the Table Mountain and Bokkeveld Groups in the Cape Fold Belt (De Beer, 2002).

DOMAIN	FOLDS	% SHORTENING	PELITE CLEAVAGE	METAMORPHISM	FAULTS
1	No discernable folding	Very low	None	Diagenetic	None
2	NW-SE, zonal development, kinks, λ= 40 km, open folding	Variable, < 15%	None	Lowest grades	Major NW-SE, shorter E-W and minor NE-SW faults
3	Major N-S and NE-SW folds, minor NW-SE, interference, λ= 20 km, open to tight folding, no overturning	Low, <25%	Weak to nonexistent, but strongly fractured	Lowest grades, little neoformed micas	WNW-ESE, slightly less major faults than Domain 1
4	E-W, local northwards overturning, minor NE-SW	>35%	Well-developed, axial planar	Low grade, abundant neoformed mica	WNW-ESE and WSW-ENE
5	NW-SE and NE-SW, open folding, no overturning	< 25%	Weak to non-existent	Lowest grades, little neoformed mica	Major NE-SW, lesser NW-SE
6	NE-SW and E-W folding, some overturning	>35%	Strongly developed, axial planar	Low grade, abundant neoformed mica	NE-SW and E-W
7	E-W, overturning common	>35%, thrusting	Strongly developed, often crenulations	Low grade	Curved thrusts, E-W normal faults
8	E-W, locally overturned	40-30%	Well-developed, axial planar	Low grade	E-W major faults
9	E-W, mostly overturned	70-40%	Well-developed, axial planar, crenulated	Low grade, quartz recrystallized, phyllites common	E-W major faults, thrusts

CHAPTER FIVE
Groundwater discharges to aquatic ecosystems associated with the Table Mountain Group (TMG) Aquifer: A CONCEPTUAL MODEL

5.1. Introduction

Rivers are an indispensable part of all ecosystems, which render many free services to the terrestrial environment. In spite of acting as corridors for many ecological processes, and creating linkages for ecological patterns, all aquatic ecosystems derive most of their characteristics from the catchments that they drain (Davies *et al*., 1993). However, for these functions to be maintained aquatic ecosystems need to be in a healthy and functional state (Davies and Day, 1998). Considering that most of the physical and biological attributes of river ecosystems are flow dependent, it is necessary for rivers to have the natural flow variability that they evolved with to maintain their ecological integrity (Davies *et al.,* 1993; King *et al*., 2003). Rivers therefore have to be managed in an integrated manner recognising the full hydrological system (Roets *et al.*, 2008).

As indicated in Chapter 1, a recent focus on large scale groundwater use from the Table Mountain Group (TMG) aquifer in the Western Cape Province of South Africa, and published information on the intimate link between surface water and groundwater (Ward and Robinson, 1990; Midgley and Scott, 1994; Winter *et al*., 1999), it became essential for ecologists to understand how, and to what extent groundwater discharges from the TMG contributes to the surface resources, particularly to the different components of the flow regime. The different groundwater discharge ‘types’ had to be conceptualised in the different river reaches, or locations in a landscape, and had to be linked to the flow regime (hydrology) which is the primary driver of aquatic ecosystems. This required the inclusion of geomorphological characteristics of the different river reaches in this conceptualisation (Figure 5.1). Gilvear *et al.* (2002) agree by stating that hydrology and geomorphology are intimately related and critical to the ecological quality of rivers. Aspects like river channel, cross-sectional geometry, bed material, size and level of bed, and bank stability are all controlled by the flow regime.

This chapter describes the conceptual model that was developed to link the different groundwater discharges to the various components of the flow regime, and indicate where in the landscape each would dominate (Roets *et al.*, 2008). This model will assist ecohydrologists in understanding the spatial occurrence of the different groundwater discharge 'types' contributing to the flow regime of rivers, and enable the mapping of areas in the Western Cape Province where groundwater use may impact on surface resources. With the unique characteristics of the rivers of the Cape Floral Kingdom, which is also associated largely with the Cape Fold Belt and the TMG aquifer, it is critical to understand these important linkages.

5.1.1. Components of the flow regime in rivers and streams associated with the TMG in the Cape Fold Belt

Many authors agree that the variable flows in rivers are responsible for creating ecosystem components such as channel type and pattern, water chemistry and temperature, habitat diversity and associated biota, zonation of riparian plants and associated wetlands (King *et al*., 2000; Gilvear *et al*., 2002). Diverse habitats are created through these dynamic geomorphological processes resulting from scouring, deposition and hydraulic sorting of sediments, gravel and cobble under the different flow conditions (King *et al*., 2003).

Realising the intimate link between groundwater and surface water makes it extremely important to relate groundwater discharges to aquatic ecosystem functioning. The starting point is clearly to define the different components of the flow regime from an ecological perspective, and to conceptualise where and to what extent groundwater from the TMG aquifer contributes to each component.

Ecological literature recognises that the flow regime consists of low flows and high flows, and that variable flows should be maintained to protect the ecological integrity any aquatic ecosystem (King *et al*., 2003). The low flows are the most critical for any river or stream with its associated aquatic ecosystems. Ironically this is also the time when water use from rivers is the highest. The low flows determine the basic hydrological nature of the river. The variation in magnitudes of low-flow in the dry and wet seasons create more or less wetted habitat and different hydraulic and water-quality conditions, which directly influence the balance of species at any time of the year.

The higher flows, that include intra-annual floods and large floods, are of particular ecological importance in semi-arid areas in the dry season. These flows stimulate spawning in fish, mobilise and sort gravels and cobbles, thereby enhancing physical heterogeneity of the riverbed, flush out poor-quality water and contribute to flow variability. It also essentially re-sets the river ecosystem. Large floods trigger many of the same responses as smaller floods, but additionally provide scouring flows. These scouring flows determine the form of the channel, mobilise coarse sediments, deposit silt, nutrients, eggs and seeds on floodplains, inundate backwaters and secondary channels, re-charge bank storage, inundate floodplains, and scour estuaries thereby maintaining links with the sea (King *et al*., 2003).

King *et al.* (2003) suggested a flow regime for streams and rivers that is directly applicable to rivers associated with the TMG aquifer. Table 5.1 shows how a rivers flow can be divided into its different components.

Table 5.1. Components of the flow regime (King *et al.*, 2003).

Flow regime	Types of flows	Frequency of occurrence
Low flows	Wet-season base flows	
	Dry-season base flows	
High flows	Intra-annual floods:	
	Class I	(6 times per year)
	Class II	(3 times per year)
	Class III	(3 times per year)
	Class IV	(2 times per year)
	Large Floods:	
	1 in 2 years	
	1 in 5 years	
	1 in 10 years	
	1 in 20 years	
	1 in 50 years	

Linking the flow regime to local hydraulic conditions is the vital link that allows river scientists to understand why river features and species occur where they do (King *et al.*, 2003). The flow regime characteristics listed above are all applicable to river systems in the Western Cape, particularly those associated with the TMG aquifer.

5.1.2. Precipitation may become runoff

The second aspect that needs to be understood is the routes that precipitation follow to become part of runoff, or to recharge the water table before being discharged to surface resources. It is clear from hydrogeological literature that precipitation that reaches the earths surface will infiltrate into the soil, some water may evaporate, some is taken up by bio-mass, some is lost through evapo-transpiration by plants, some move under gravity and percolate downwards to recharge the groundwater zone, or else flow laterally close to the surface as interflow. This equates to the water balance where the whole water cycle is taken into account.

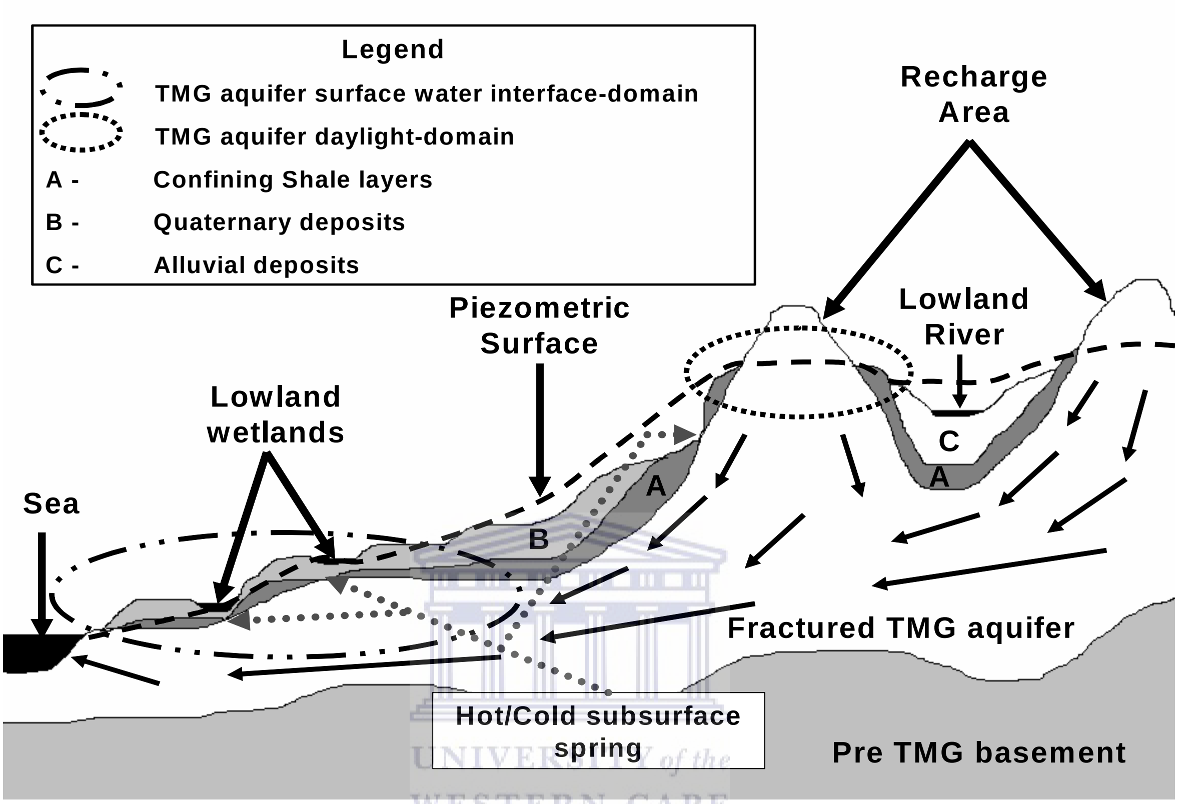

Figure 5.1. Illustration of how groundwater from the TMG aquifer interacts with surface resources in the "TMG aquifer daylight-domain" and "TMG aquifer surface water interface-domain" (Roets *et al.*, 2008).

5.1.3. Hydrogeological perspective on the mechanisms of groundwater and surface water interactions in the TMG

With the increasing demand for fresh water it became apparent that development of either surface or groundwater resources affects the quantity and quality of the other (Ward and Robinson, 1990; Winter *et al.*, 1999). Even floods in river systems can consist of mainly groundwater depending on the geological setting (Midgley and Scott, 1994). However, the percentage overland flow would vary greatly with rainfall intensity, slope, geology, soil types, vegetation type and antecedent conditions in soil moisture.

Groundwater discharges to surface resources as either point source discharges, like springs, or as diffuse discharges through the hyporheos. Understanding the discharge and recharge of groundwater through the hyporheos is important to fully understand and characterise groundwater discharge types to surface resources.

The groundwater discharge to and from streams is very dynamic and will be changing with changes in the level of a stream or adjacent water table. It might happen that in a matter of hours, influent seepage in a stream (gaining stream) may supersede effluent seepage (losing stream) and *vice versa*, changing from a gaining to a losing stream. In physiographic settings where stream flow is generated in the higher elevation head waters, as happens frequently with rivers associated with the TMG, the changes in stream flow between gaining and losing conditions may be particularly variable. However, there is broad consensus amongst hydrogeologists on the types of groundwater discharges that may contribute to surface resources.

5.1.4. Influence of geomorphology on types of rivers associated with the TMG

Understanding the link between groundwater and surface water makes it essential to know the role that the geomorphology plays in the rivers make-up or characteristics. Pool, riffle, rapid sequences, single or braided river beds, flat fluvial beds, flood plains, bed structure etc. are all determined by the geomorphology. With the variability of the flow regime, river gradient, geology, soils and hydraulic sorting of cobbles any river will have unique but divers habitat types and associated biota. This will also largely determine the type and quantity of groundwater that is discharging to the surface resource. According to Moon and Dardis (1988) it is a known fact that the underlying geological structure determine drainage patterns of rivers most notable.

Both *denritic* and *parallel* drainage patterns develop on uniform lithology and where there are no *controlling* joints or fractures. Where faults, joints, or other lineaments *control* drainage it will be *rectangular*, while alternating resistant or less resistant strata will promote the development of *trellised* drainage. In settings where updoming has occurred *annular* drainage patterns will be present, and in landscapes where tectonic activity is present, *radial* and *centripetal* drainage configurations will manifest. In any catchment one or several of these patterns may be present since these patterns are entirely dependant on the underlying structure (Moon and Dardis, 1988). These drainage manifestations will have far reaching effects on the type of groundwater discharges that might characterise certain sections of a river system, particularly those streams and rivers, and other aquatic ecosystems, associated with the TMG that is characterised by folding and faulting.

Taking the above into consideration, the Western Cape Province rivers associated with the TMG will mostly show dendritic (Figure 5.2.A), parallel (Figure 5.2.B) and rectangular (Figure 5.2.C) drainage patterns. The bigger river systems like the Gourits River would show characteristics of all the above drainage patterns as is traverse through it catchment.

Where mountain and foothill river reaches coincided with controlling faults, joints and other lineaments the drainage is rectangular. Even for lowland river reaches near the mountainous areas rectangular drainage dominated due to these lowland reaches coinciding with major faults or lineaments. Lowland river reaches show by and large a dendritic drainage pattern because of the uniform lithology and non *controlling* joints or fractures.

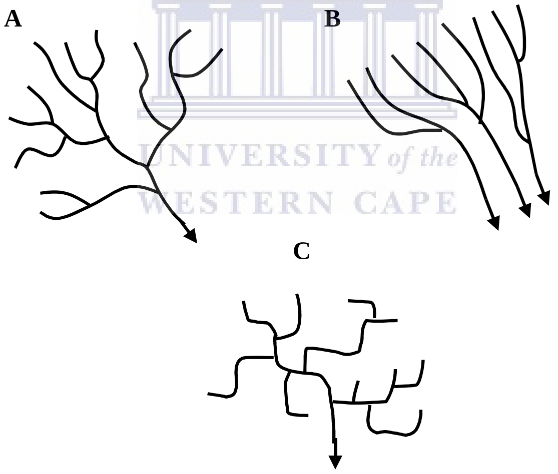

Figure 5.2. Drainage patterns in different structural settings: (A) dendritic, (B) parallel, (C) rectangular (Roets *et al.*, 2008).

5.1.5. Recognised groundwater discharge types to surface resources applicable to rivers associated with the TMG

Hydrogeologists recognise that runoff in rivers associated with the TMG are generated by channel precipitation, overland flow (surface runoff or quickflow), interflow (which include translatory flow) and groundwater flow. Overland flow may result from either infiltration-excess overland flow, which is generated when rainfall intensities exceed infiltration capacity, or saturation-excess overland flow which occurs when soil becomes saturated from below and rainfall gets rejected.

It is commonly accepted that a rivers hydrograph consists of base flow and storm flow. Hydrogeologists agree that base flow consists of mainly groundwater discharges and or interflow. Storm flows consist of direct runoff (Xu, *et al.*, 2002), translatory flow, interflow and in-channel precipitation (Winter *et al*., 1999; Xu and Beekman, 2003). Another important groundwater contribution to the hydrograph is bank storage discharges.

For the purpose of the conceptual model there was a definite need to distinguish between real groundwater discharges, and perceived groundwater discharges. Perceived groundwater discharges include interflow and translatory flow, because this water never became part of the groundwater table. By separating real- and perceived groundwater discharges, and conceptualising the relative proportions of each type contributing to each component of the flow regime distinguished for each river reach, it would enable the determination of the ecological significance of real groundwater discharges from the TMG aquifer.

The characteristics of the four components of runoff, and the relative proportions of each component present, determine the shape of the hydrograph in rivers associated with the TMG. Due to the complex flow composition resulting from local variations in rainfall, infiltration and antecedent conditions, it would be difficult to identify each component of runoff in a hydrograph.

5.1.6. Mechanisms of groundwater surface water interactions in mountainous areas associated with the TMG

Xu and Beekman (2003) suggested that interflow in mountainous catchments accounts for part of the base flow in rivers associated with the TMG. The shallower weathered zone of the alluvial and slope deposits in the mountainous TMG areas, in which the interflow occurs, may serve as a reservoir for storing water during the rainy season while at the same time allowing for percolation to the deeper groundwater reservoir, often through a network of fractures. This reservoir would then discharge to the streams base flow and cause continuity of flow. This would also apply to bank storage in certain physio-graphic settings. It is from this zone that interflow will contribute to the base flow component of the hydrograph in the TMG.

Groundwater surface water interactions for larger rivers that flow into alluvial valleys are spatially more diverse than it is for smaller streams. Groundwater discharges from regional flow systems may discharge to the river at various places across the flood plain. In these settings groundwater discharges is affected by the interchange between local and regional flow systems. Many of the larger rivers in the Western Cape would show similar characteristics in the lowland river reaches. However, all the headwater, mountain and foothill reaches of rivers, which are mostly associated with the TMG, will be associated with localised groundwater flow systems.

In the Western Cape Province the TMG aquifer is characterised by deep circulating flow systems that are confined to semi-confined with very little discharge directly to rivers beyond the mountain stream and foothill reaches. The lowland reaches could have discharges from the regional flow systems, unless these aquifers are semi-confined to confined. It is postulated that most of the direct groundwater discharge from the fractured TMG aquifer to streams and rivers manifest in the mountains and foothills before the confining shale layers come into play at the TMG shale geological contacts. Beyond the foothill zones most of the groundwater in the alluvial aquifers gets recharged by rivers and rainfall, with limited discharge from deep flow systems that can be possible (Roets *et al.*, 2008).

The semi-confined to confined nature of the TMG aquifer stems from its deep diving synclinal nature which is sealed of on the sides by the shale layers of the Cederberg Group (See Figure 5.1). Hence the postulation that the interface between the groundwater and the surface resources are largely located at the geological contact areas of the mountain and foothill zones of the Cape Folded Mountain ranges (Roets *et al.*, 2008). Discharges from the deep flow systems would generally occur as cold or hot springs eminating in the landscape at fractures or faults where confining layers are displaced or fractured, or in aquatic ecosystems at the discharge end of the aquifer in lowland settings, and marine environments.

5.1.7. Hypothesis and objectives

The hypothesis for this study was that groundwater discharges from the TMG aquifer contribute to surface resources in two primary areas, namely, contributions to the flow regime of mountain and foothill streams and rivers associated with the TMG in the "TMG aquifer daylight-domain", and secondly groundwater contributions to wetlands and other aquatic ecosystems, even marine discharges, all of which are located at the discharge end of the TMG aquifer in the "TMG aquifer surface water interface-domain".

The objectives of this study were:

- To conceptualise the different groundwater discharge 'types' contributing to the different components of the flow regime in the different river reaches, particularly in the mountain and foothill streams and rivers in the "TMG aquifer daylight-domain", located at the recharge areas.
- To highlight the difference between non-groundwater and groundwater contributions to the flow regime.
- To conceptualise the groundwater contribution to the lowland aquatic ecosystems in the "TMG aquifer surface water interface-domain", located at the discharge end of the aquifer (Roets *et al.*, 2008).

5.2. Methodology

After a thorough literature survey through hydrogeological, geomorphological and ecological literature applicable to the TMG, a *new integrated* conceptual understanding on groundwater interacts with aquatic ecosystems in the TMG was developed (Roets *et al.*, 2008). This conceptual understanding culminated in the formulation of a conceptual model that linked the 'acknowledged groundwater discharge mechanisms' in hydrogeological literature, to the 'acknowledged components of the flow regime' in ecological literature, to 'geomorphologically recognised river reach' (position in the landscape) (Roets *et al.*, 2008). This integration of three different disciplines during the conceptualisation process resulted in three basic steps that followed. These steps culminated in a new ecohydrological understanding of groundwater surface water interactions.

The *first step* was the compilation of a flow diagram showing how catchment precipitation results in the different groundwater discharges 'types' (i.e. real groundwater and non-groundwater) and how these contribute to runoff (Roets *et al.*, 2008).

The *second step* was the integration of the different components of hydrogeology, ecology and geomorphology by tabulating the information on the different drainage patterns, flow types, groundwater systems, geomorphological classes and the hydro-geomorphology of rivers associated with the TMG, and indicating the groundwater significance for the ecology (Roets *et al.*, 2008).

The *third step* was the design of a conceptual model that links the different groundwater discharge ‘types’ to the flow regime and to a particular position in the landscape (river reach). This was achieved by listing the components of the flow regime in the left hand columns of a matrix, with the different river reaches in the top rows of the tabulated matrix. The rest of the matrix was then populated with the different groundwater discharge ‘types’ expected for each component of the flow regime in each river reach. The conceptual model also distinguished between the two primary areas where interaction between aquatic ecosystems and groundwater from the TMG aquifer could be expected namely the “TMG aquifer daylight-domain” and the “TMG aquifer surface water interface-domain” (Roets *et al.*, 2008).

5.3. Results

Figure 5.3 gives the results of the *first step* on how precipitation (rainfall, snow and mist), within a particular basin or catchment, becomes part of channel flow through a) overland flow, b) in-channel precipitation, c) and after infiltration into the soil.

Infiltrated water (perceived groundwater) takes one or more of three different routes before it becomes channel flow (red and purple arrows). The first type of discharge is **interflow** that never became part of the water table (non-groundwater). **Rapid interflow** discharges would result from the presence of preferential flow paths or where the soil horizon acts as a flow barrier, which hinders direct downward percolation of water. It would also result from rejected recharge when the aquifer is fully recharged. **Delayed interflow** may result from partially saturated flow via a perched water table, or where geometric configurations of fractured networks lead to formulation of interflow. The onset of both will dependent on the antecedent soil moisture conditions. Soil moisture conditions influence transpiration, run-off generation, infiltration, water and nutrient uptake by plants.

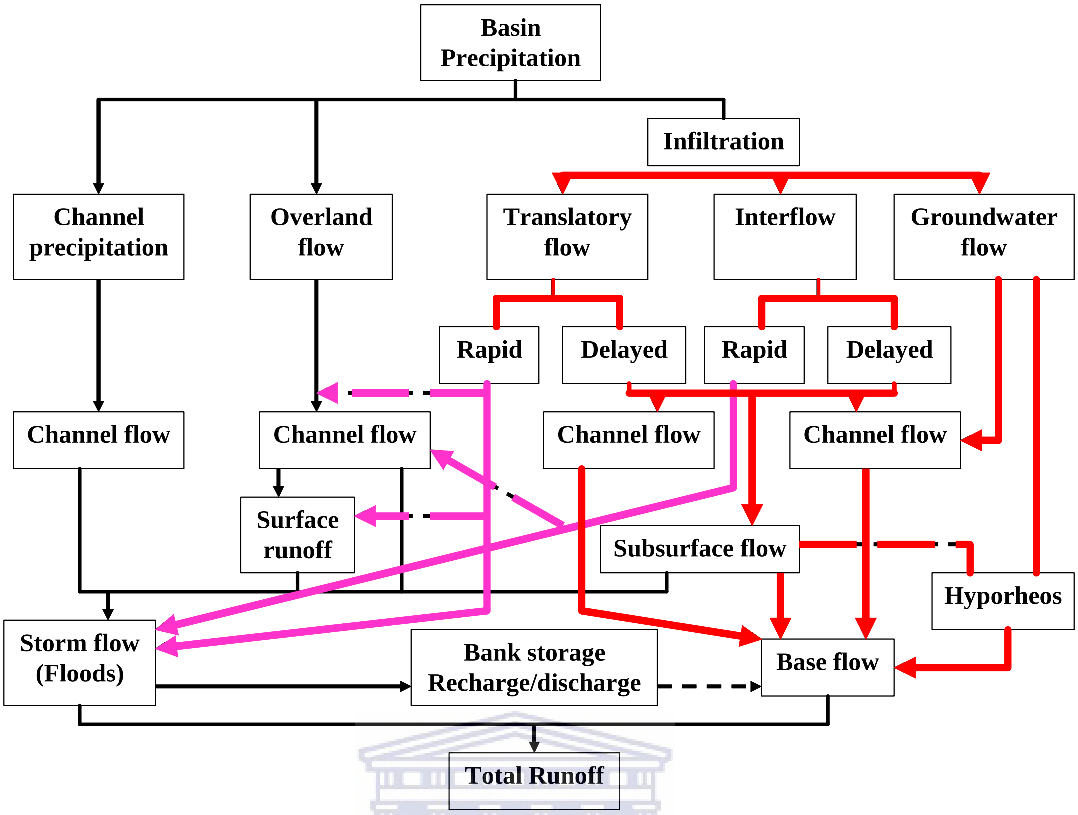

Figure 5.3. Schematic representation of the proposed groundwater contributions to the flow regime in rivers associated with the Table Mountain Group aquifer (Roets *et al.*, 2008).

Translatory flow will be discharged to streams and rivers in a similar geomorphological setting than interflow (also non-groundwater). The only difference is that translatory flow results from a previous recharge event that infiltrated into the soil, never became part of the water table, and are discharged laterally by a next recharge event through infiltration before it could discharge under gravitational forces. The difference between **delayed and rapid translatory flow** is similar to that of interflow and would happen under similar antecedent conditions (Roets *et al.*, 2008).

The third type of discharge resulting from infiltration is real **groundwater** discharges. This water recharged the water table (piezometric surface) before it gets discharged to the river or stream. These discharges may happen in different ways. The most common would be spring discharges, and or seeps, both of which are associated with geological contact areas or geological faults zones (Kotze, 2002). The geological groups that make contact will have different water permeabilities where the one acts as an aquatard. These aquifer boundary conditions will give rise to a semi-confined to confined aquifer that will discharge water at these geological contacts, or faults, provided that the piezometric surface (water table) is high enough or fully recharged. In this type of setting rejected recharge will be discharged as interflow. Groundwater discharges may also discharge in a diffuse manner through the hyporheos of a stream or river where these geological contact scenarios exists, or as a result of underlying faults or fractures (Roets *et al.*, 2008).

From Figure 5.3 it is clear that translatory flow, interflow, and groundwater discharges are mainly responsible for base flows in rivers and streams, depending on the stratigraphy of the area, the slope, geomorphology and antecedent conditions.

Channel precipitation and **overland flow** discharges (black arrows – Figure 5.3) will only occur under heavy precipitation events and contribute mainly to storm flows as small, medium and large floods. Under these conditions the river banks will be overflowed and be recharged to form the very important bank storage reservoir. Bank storage essentially reacts as an unconfined or primary aquifer, which would slowly release its water to the stream for as long as the streambed is lower than the water table. All of the above discharges ultimately equates to the total runoff for the catchment.

The *second step* under methodology culminated in Table 5.2, which summarise the cited literature on the different drainage patterns, flow types, groundwater systems, geomorphological classes and the hydro-geomorphology of rivers associated with the TMG, also indicating the groundwater significance for the ecology (Roets *et al.*, 2008).

From Table 5.2 it is clear that the dominant drainage patterns in the Western Cape Province are dendritic, parallel and rectangular, particularly in the TMG dominated mountain ranges. The dominant groundwater flow types for the four river reaches are: interflow dominating in the headwater and mountain river reaches, with some translatory flow and groundwater discharges (as base flow) from the TMG. Bank storage is unlikely to occur in these reaches. In the foothill reaches, the major groundwater discharge zone, groundwater discharges dominate base flow with some interflow. Storm flows and floods result from interflow, translatory flow, bank storage discharges, channel precipitation and surface runoff. The lowland rivers are getting most of their flow from the upper reaches with some surface runoff, channel precipitation and bank storage discharges. Lowland rivers could also get water from primary aquifers provided that the water table is higher than the stream level (gaining streams). This is the regional recharge and or discharge zone for the lowland primary aquifers (alluvial storage).

Geomorphologically the headwater and mountain river reaches vary from deeply incised, fracture and lineament controlled, to braided river flows consisting mainly of bed rock and cobble beds giving rise to dendritic and parallel drainage. In the foothill areas streams are controlled by bed morphology and alluvial fans resulting in dendritic and rectangular drainage. The lowland rivers meander as they traverse the flatter fluvial areas where the terrain developed horizontally into a dendritic drainage pattern.

Hydro-geomorphological characteristics for the four river reaches vary between constantly losing or gaining streams in the headwater and mountain reaches, to intermittent streams, alternating between gaining and losing sequences in the foothill reaches, and gaining streams with or without bank storage in the lowland reaches. In the headwater and mountain reaches the water table will be mostly below the stream stage, but in the foothill reaches it can be alternating from being above and below, and in the lowland reaches the water table will be mostly above the stream stage. However, it is important to note that the groundwater discharges to lowland rivers are by and large from shallow primary aquifers that are disconnected from the TMG aquifer (Roets *et al.*, 2008).

The ecological significance of the groundwater contributions from the TMG is therefore most significant in the foothill reaches, which are the primary groundwater discharge area for streams and rivers associated with the TMG. It can also be significant in the mountain reaches where the river or stream is connected to the TMG aquifer, or where there are significant groundwater discharges contributing to flow. It is particularly the important low flows that will be vulnerable. In the lowland river reaches the TMG discharges are unlikely to have a significant direct role to play in its flow regime other than it’s indirectly contribution to flows in these reaches. If flow of the upper reaches is significantly affected by groundwater use it will ultimately affect the lowland reaches by reducing the flows and subsequently the recharge of the primary aquifers associated with these rivers (Roets *et al.*, 2008).

Table 5.2. Summary of different drainage patterns, flow types, groundwater systems, geomorphological classes, hydro-geomorphology of rivers as described in cited literature, indicating the groundwater significance for the ecology (Roets *et al.*, 2008).

PARAMETER TYPE	***Headwater and Mountain reaches***	***Foothill reaches***	***Lowland reaches***
Drainage patterns	Dendritic, parallel	Dendritic, rectangular	Dendritic
Dominant flow type(s)	Interflow (IF) dominated on local scale. Surface runoff and preferential flow. Some translatory flow. Base flow in TMG (Perennial). No bank storage.	Base flow dominated but with interflow, some bank storage, surface runoff and channel precipitation.	Characterised by bank storage, Base flow increase with bank storage, Surface runoff, regional and local groundwater discharges possible - mainly alluvial storage.
Groundwater system (regional or local)	Local scale – interflow. Regionally - recharge area and may have local and regional groundwater discharge in the TMG.	Regionally a runoff area. Groundwater discharge is local but regionally significant. Discharge and recharge area (through hyporheos at pool-riffle sequences).	Regionally recharging alluvial aquifers. Local bank storage. May get groundwater discharge from regional and local groundwater systems.
Geomorphological classification	Braided, to single channel, deeply incised, fracture and lineaments controlled. High gradient, bedrock cobble bed.	Stream controlled by mainly bed morphology (pool riffle sequences).	Meandering, topographically flat areas, fluvial erosion develop terrain horizontally, alluvial deposits.
Hydro-geomorphological typing	Constantly losing or gaining streams. Regional groundwater level is constantly below the stream stage. Fed by confined aquifer and or local interflow.	Intermittent streams. Gaining and losing stream alternate at pool riffle sequences. Groundwater discharges towards streams during dry period and *vice versa* during wetter cycle. River recharges aquifers during floods (bank storage).	Gaining streams with or without bank storage. Groundwater levels consistently higher that the river stage. Base flow component increase in an S-curve or straight line as a function of the presence or absence of bank storage. Groundwater from TMG unlikely to play role directly.
Significance of groundwater contributions from TMG for ecology (Flow regime)	Significant where base flow from TMG is significant. Interflow may be affected by use from TMG because interflow is also a function of rejected recharge of TMG aquifer.	Highly significant. This is where groundwater discharge from the TMG is most likely and contributing significantly to the flow regime. Flows will be affected by piezometric head drop or development of the draw down cone (cone of depression).	Unlikely to significantly impact direct discharges from TMG aquifer. May affect discreet TMG regional flow discharges in specific settings because aquifer discharge will be impacted by use as given by: ADJUSTED RECHARGE – REDUCED OUTFLOW – PUMPING + STORAGE LOSS = 0

Table 5.3. "Conceptual model" showing groundwater discharge types contributing to stream flow for each river reach associated with the TMG (A and B represents the discharges in 'TMG aquifer daylight-domain' and 'TMG aquifer surface water interface-domain' respectively; Dark yellow – sensitive and heavily dependent on real groundwater, lighter yellow shades – reduced dependence on real groundwater; light green - perched systems not dependent on real groundwater (Roets *et al*., *2008*).

	FLOW REGIME	**FLOW REGIME COMPONENTS**	**HEADWATER REACH** *** Water Table below stream**		**MOUNTAIN REACH** *** Water Table below stream**	**FOOTHILL REACH** *** Water Table interchangeable**	**LOWLAND REACH** *** Water Table above stream**
			EPHEMERAL	PERENNIAL	(MOSTLY PERENNIAL IN TMG)	(MOSTLY PERENNIAL IN TMG)	(MOSTLY PERENNIAL IN TMG)
A	**LOW FLOW**	**Dry season base flow**	- Perched spring discharge - Interflow * (Interflow dominated reach)	- Groundwater (Perched springs) - Interflow * (Interflow dominated)	- Groundwater (TMG springs + seeps) - Interflow dominated in most settings (Interflow might increase as a function of rejected recharge to TMG aquifer in some settings)	- Groundwater from mountain reach (TMG springs) and other discharges (hyporheic) - Primary Groundwater discharge zone from TMG (Confined to semi-confined aquifer) - Interflow - Limited bank storage discharge possible depending on antecedent conditions	- Groundwater from Foothill reach and discreet TMG discharges (Hyporheic etc.) - Bank storage discharge depending on antecedent conditions - Water Table (Alluvial unconfined aquifer not confined to semi-confined TMG aquifer)
		Wet season base flow	- Perched spring discharge - Increased Interflow	- Increased spring flow - Increased Interflow * (Interflow dominated)	- Increased Base flow (result of increased TMG groundwater discharge) - Increased Interflow (Interflow might increase as a function of rejected recharge to TMG in some settings) - Possibility exists for some delayed translatory flow in some settings	- In creased Base flow (from mountain reach) - Primary Groundwater discharge throughout reach (Hyporheic) - Increased Interflow - Delayed translatory flow - Limited Bank storage discharge (depending on antecedent conditions)	- In creased Base flow (from foothill reach) - Water Table rise - Limited Interflow possible - Limited delayed translatory flow possible - Bank storage discharge (depending on antecedent conditions)
	HIGH FLOW	**Intra-annual floods (smaller floods)**	- Base flow - Increased Interflow - Surface runoff	- Base flow (recharge dependent) - Increased Interflow - Surface runoff	- Base flow component -High degree of Interflow (Rejected recharge to TMG aquifer) - Some degree of Translatory flow in some settings - Surface runoff	- Increased Base flow - Increased Groundwater discharge throughout reach (Hyporheic etc.) - Increased Interflow - Translatory flow - Surface runoff - Increased flow from mountain reach - Tributary discharges - Limited Bank storage recharge depending on antecedent conditions	- Increased Base flow - Water Table rise - Limited Interflow possible - Limited Translatory flow possible - Surface runoff - Increased flow from foothill reach - Tributary discharges - Bank storage discharge or recharge depending on antecedent conditions
		Large Floods	- Base flow - High degree of Interflow - Higher Surface runoff	- Base flow (recharge dependent) - High degree of Interflow - Higher Surface runoff	- Elevated Base flow - Very high degree of Interflow (Preferential flow paths) - High degree of Translatory flow possible in some settings - Higher Surface runoff	- Elevated Base flow - Increased Groundwater discharge throughout reach (Hyporheic) - Increased Interflow (Preferential flow paths) - High degree of Translatory flow - High tributary discharges - Bank storage recharge - High Surface runoff	- Elevated Base flow - High Water Table rise - Limited Interflow (Preferential flow paths) - Limited Translatory flow possible - Higher Surface runoff - High tributary discharges - Bank storage recharge - Channel precipitation
B	**Hot or cold springs discharging at faults or fractures at or near the discharge end of the TMG aquifer. This may recharge primary aquifers from the bottom or directly to wetlands, estuaries or even the marine environments.**						

Discharges from the TMG in the lowland reaches will be restricted to faults or fractures where deep flow discharges may be possible as hot or cold springs that may recharge primary aquifers from below. In the latter case these discharges may support wetlands, estuaries or even marine discharges. These discharges will occur at or near the discharge end of the aquifer in the "TMG aquifer surface water interface-domain" and will be ecologically significant (Roets *et al.*, 2008).

Table 5.3 represents the conceptual model that culminated from the *third step* mentioned under methodology. The conceptual model consists of a matrix where the top rows (left to right) of Table 5.3 lists the different river reaches, while the second left hand column list the different components of the flow regime (top to bottom), with the far left hand column showing the two primary domains within which the listed discharges occur. The rest of matrix between the upper and left axis of Table 5.3 were populated with the conceptualised 'groundwater discharge types' contributing to each component of the flow regime in each of the different river reaches. Geomorphological-, hydro-geomorphological-, and flow regime (hydrology and hydraulics) information were used in the compilation of the matrix (Table 5.3). The relative proportions of the four components of runoff (interflow, translatory flow, groundwater discharge and surface contributions) were conceptualised for each component of the flow regime (base flow or stormflow scenarios) in each of the river reaches to determine the importance and ecological significance of real groundwater from the TMG aquifer to each (Roets *et al.*, 2008).

In Table 5.3 the colours from dark yellow, yellow, light yellow and light green indicate the relative importance of groundwater discharges from the TMG aquifer to each 'river reach type' and each flow regime component. Dark yellow represents a very high importance of real groundwater discharges to maintain that component of the flow regime for that particular river reach. The lighter the colour gets (yellow to light yellow to light green) the less important real groundwater discharges become. Similarly, the more important the groundwater discharge is for each component of the flow regime in each river reach, the more important it is for the ecological functioning of the aquatic ecosystem. These same colours subsequently indicate the vulnerability of each component of the flow regime in each river reach to groundwater use from the TMG aquifer, and therefore the vulnerability of the ecological integrity of the aquatic ecosystem to the use of groundwater from the TMG (Roets *et al.*, 2008).

5.4. Discussion

The conceptual model clearly shows that the low flows (dry and wet season base flows) in the mountain and foothill reaches are highly dependent on groundwater discharges from the TMG aquifer. This applies to the "TMG aquifer daylight-domain". The important groundwater discharge types in these river reaches for these flow components consists mainly of interflow (normal and rejected TMG aquifer recharge), groundwater discharges from the TMG aquifer (springs, seeps and hyporheic discharges), some delayed translatory flow and limited bank storage may be possible in some geomorphological settings (See Table 5.2). All these discharges, groundwater and non-groundwater, are highly dependent on the TMG aquifer equilibrium and will be affected when the aquifer equilibrium is changed by groundwater use. Changing the aquifer equilibrium will affect both recharge and discharge of the aquifer. This changed equilibrium will affect both interflow and translatory flow, as both are a function of rejected recharge. If we take into consideration that the groundwater flow is localised in the mountain and foothill reaches, the use from this local aquifer is bound to have an effect on these groundwater discharges (Roets *et al.*, 2008).

However, under certain hydrogeological conditions the flow may even be regionally affected, if the use of groundwater is large enough. This may result from one of two effects due to the altered aquifer equilibrium, namely: (a) a drop in the piezometric surface, and (b) a subsequent drop in the pressure gradient of the aquifer that will affect the hydrological conductivity, and ultimately affect the discharges from the aquifer. The asymmetric draw down cone that can develop along preferential flow paths may extend kilometres away from the well field, having the same effect as in (a). This implies a reduction in the aquifer discharge that may take some time to develop, but it will have an effect. Under these conditions the "TMG aquifer surface water interface-domain" will also be affected as a result of a reduction in aquifer discharge to wetlands, estuaries and marine environments in the lowland settings far away from the recharge areas. These lowland discharges at the discharge end of the aquifer are all ecologically significant (Roets *et al.*, 2008).

The lighter coloured yellow dry and wet season low flows (Table 5.3) in the headwater river reaches stems from the fact that these streambeds are almost always disconnected from any groundwater table, and it is unlikely to have real groundwater discharges.

Groundwater discharges from perched springs may be possible, in which case it is un-related to TMG discharges. In headwater reaches the important base flow component is completely dominated by normal interflow (non-groundwater). Perennial flows in these reaches may result from recharge events that are spaced close enough to one another to maintain the interflow discharges (Roets *et al.*, 2008).

The conceptual model further indicates that higher flows will be less vulnerable to groundwater use. This results from non-groundwater discharges becoming more prominent and screening the low flow discharges that are highly vulnerable to groundwater use. Most of the groundwater discharges that contribute to high flows in all the river reaches are by this time recharged. However, if the groundwater use has significantly dropped the piezometric surface, it may take longer for the floods (temporal component of the flow regime) to develop and it might affect the flood peaks. This may affect the ecological functioning of the aquatic ecosystem in the long run, hence the yellow status (Table 5.3). In the headwater and mountain reaches interflow still dominates even under higher flows. The reason for the yellow status (Table 5.3) of the large flood component of the flow regime in the foothill river reach stems from the fact that this river reach is the primary groundwater discharge area and the ultimate link between the groundwater and surface water in the TMG (Roets *et al.*, 2008).

In lowland river reaches the most vulnerable part of the flow regime to groundwater use is the dry and wet season base flow, which will be indirectly related to the TMG aquifer. Base flow is the most critical flow for any aquatic ecosystem (Davies and Day, 1998).

The groundwater discharges from the TMG at the discharge end of the aquifer, as indicated in the model, would all be coloured dark yellow (Table 5.3) because of its ecological significance that is self-evident. These discharges will in all cases support groundwater dependent aquatic ecosystems and any reduction will affect the associated ecosystem negatively.

5.5. Conclusions

This conceptual model has clearly demonstrated which groundwater discharge ‘types’ are contributing to the different components of the flow regime in the different river reaches. It has also successfully shown the relative importance of real groundwater from the TMG aquifer for each flow component in each river reach. With the particular focus of this study on the groundwater interface of the TMG aquifer with surface water, it is clearly the ‘real groundwater’ discharges that will be mostly affected by groundwater use from the TMG aquifer. Reduced groundwater discharges resulting from groundwater use will be most notable in the mountain and foothill reaches of streams and rivers in the ‘TMG aquifer daylight-domain’. It will be the low flows in these reaches that will be most affected. Similarly groundwater discharges at the discharge end of the aquifer will be affected in the ‘TMG aquifer groundwater surface water interface-domain’, due to the fact that the TMG aquifer is confined to semi-confined and has deep circulation on mainly a regional scale (Roets *et al.*, 2008).

Local discharges in the “TMG aquifer daylight-domain” would be restricted to springs eminating from the TMG where faults affect the confining shale layers, and or at geological contact zones, but hyporheic discharges may be possible in certain settings (Roets *et al.*, 2008).

Similarly regional discharges from the TMG may be expected in the “TMG aquifer groundwater surface water interface-domain” where spring discharges may be hot or cold depending on how deep the flow system circulates. These discharges will affect wetlands, estuaries and marine environments (Roets *et al.*, 2008).

The reduced groundwater discharges in both domains will result from the potential drop in the piezometric surface, which will ultimately have an effect on the overflow and outflow areas in the mountains, and at the discharge end of local and regional aquifers with varying time scale coupled to that. A lower piezometric head will also cause induced recharge which will affect interflow and translatory flow components.

Table 5.3 clearly shows that the mountain and foothill areas are the most vulnerable to experience reduced base flow once groundwater is used from the TMG. This is of particular significance because of its essential role in maintaining the ecologically important low flow conditions (King *et al.*, 2000; Gilvear *et al.*, 2002; Eisele *et al.*, 2003). It also highlighted that importance of a natural flow regime that is clearly dependent on intact groundwater discharge regimes from the TMG aquifer. A natural flow regime with its variable flows is also crucial for aquatic ecosystem health through its role in the geomorphological processes. Under variable flow scenarios cobble, gravel, sand and mud gets hydraulically sorted to create the habitat diversity for an intact river ecosystem (Davies and Day, 1998; King *et al.*, 2000; Gilvear *et al.*, 2002; Eisele *et al.*, 2003)

This integrated understanding of the geomorphological, hydrogeological and ecological aspects as highlighted in this chapter shows the importance of integrated water resource planning considering the full hydrological cycle.

CHAPTER SIX

CASE STUDY 1: Soil nutrient concentrations in response to groundwater use in the Table Mountain Group (TMG) Aquifer - A comparative study in the Kammanassie Mountain Complex.

6.1. Introduction

Many scientists, both ecological (Le Maitre *et al.*, 1999; Le Maitre *et al.*, 2002) and hydrogeological (Winter *et al.*, 1999; Xu and Beekman, 2003), acknowledge the link between groundwater and ecosystems. However, few properly describe and interpret the intimate link between groundwater discharges and all hydrological contributions to aquatic ecosystems. So far assessments of groundwater surface water interactions mainly focussed on the influence of groundwater on riparian or wetland vegetation (Le Maitre *et al.*, 1999; Le Maitre *et al.*, 2002; MacKay, 2005). Substantial information underlines how important the link is between groundwater and flow within aquatic ecosystems (Ward and Robinson, 1990; Winter *et al.*, 1999; Xu *et al.*, 2002), and similarly how groundwater discharges affect soil and plant nutrient cycling (Wassen, 1995; De Mars *et al.*, 1996; Clawson *et al.*, 2001; Eisele *et al.*, 2003; El-Kahloun *et al.*, 2003).

The intimate link between surface water and groundwater, particularly in the Table Mountain Group (TMG) aquifer in the Western Cape Province of South Africa, necessitated understanding the "*how*", and to "*what*" extent groundwater from the TMG aquifer contributes to surface resources, and "*where*" the different discharge 'types' occur in the landscape as explained in Chapter 5 (Roets *et al*., 2008).

The objective of this study was to scientifically test the conceptual understanding that groundwater discharges, interflow and translatory flow discharge to surface flows in mountain and foothill streams in the "TMG aquifer daylight-domain". These discharges could affect soil nutrient concentrations in the riparian zone (Roets *et al.*, in prep). To this end, soil nutrient concentrations (NH_4^+, NO_3^- and Total extractable P) were comparatively assessed in the riparian zone of two adjacent river systems, the postulated primary groundwater discharge zone in the "TMG aquifer daylight-domain" (Roets *et al.*, in prep).

In the one river valley, the Vermaaks River, groundwater discharges to the mountain and foothill stream are known to have been reduced following a declining water table as a result of groundwater use since 1987 (Kotze, 2002), while the Marnevicks River had an untransformed groundwater regime (Figure 6.2) (Cleaver, 2003). The reduced groundwater discharges to the Vermaaks River has changed it from a perennial river to a seasonal stream. Cleaver (2003) also described the vegetation of the Vermaaks- and Marnevicks River valleys that are comparable. Her research also investigated and confirmed plant moisture stress in the riparian vegetation of the Vermaaks River resulting from the groundwater abstraction.

The groundwater discharges in the "TMG aquifer daylight-domain" were postulated to affect soil nutrients in the riparian zone of streams in the mountain and foothill areas through leaching and resultant higher soil water content which reduce oxygen availability. Reduced groundwater discharges could result in some degree of accumulation of soil nutrients, and possible higher nitrification success of ammonium to nitrate. Groundwater discharge and recharge in rivers and streams will manifest at or close to the water level or stream bed in the riparian zone. With the domination of interflow and groundwater discharge in the mountain and foothill reaches, these discharges through the soils and alluvial material where slope is still relatively high could have an effect on soil nutrients concentrations (Roets *et al.*, in prep).

Soil nutrient cycling, has been proven to show a response to groundwater discharges by being affected in terms of nutrient concentrations and mineralization (Wassen, 1995; De Mars *et al.*, 1996; Clawson *et al.*, 2001; Eisele *et al.*, 2003; El-Kahloun *et al.*, 2003). Soil nutrient concentrations can be affected in two ways; 1) by soil water effects (mobilization and leaching) that result from groundwater discharge and recharge; and, 2) natural chemical cycling (i.e. nitrification, de-nitrification, ammonification, volatilization, adsorption, dissolution, mineralization and immobilization – Figure 6.1) (Farley & Fitter, 1999; Chapin & Aerts, 2000; Olde Venterinck *et al.*, 2003; Hodge, 2004). Eisele *et al.* (2003) state that mobilization of soil nutrients depend on the water-runoff component, the soil characteristics and the chemical behaviour of each nutrient. Chemical cycling of soil nitrogen compounds are affected by oxygen availability because nitrification is an aerobic process. Plant growth also plays a vital role in the cycling of nutrients in the soil by utilizing these compounds for growth and will have a seasonal effect on nutrient concentrations (Wassen, 1995; Clawson *et al.*, 2001). Many other physical and chemical soil properties, such as pH and calcium concentrations may also influence soil nutrient concentrations (El-Kahloun *et al.*, 2005).

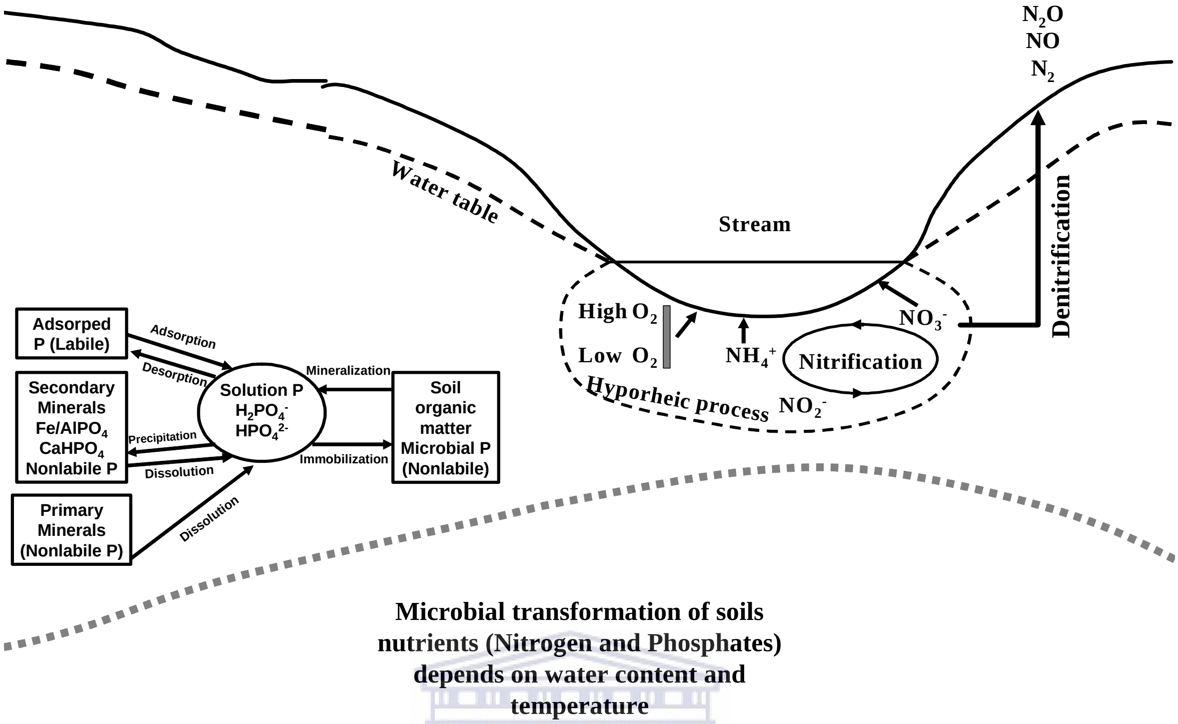

Figure 6.1. Soil nutrient processes – Altered groundwater discharges affect the water table, which affect leaching and oxygen availability for nutrient processing (Roets *et al.*, in prep).

6.1.1. Hypothesis for this case study

The hypothesis for this study was:

- That there is a natural progressive increase in water and soil nutrient concentrations (NH_4^+, NO_3^- and Total P) from mountain- to foothill- to lowland river-reaches under natural hydrological (flow regime) conditions (Davies and Day, 1998).
- Reduced groundwater discharges due to groundwater use will result in increased soil nutrient concentrations at groundwater discharge sites. This effect will manifest most notable in the riparian zone at the streambed or water level, which is the primary groundwater to surface water discharge zone in the "TMG aquifer daylight-domain" (Roets *et al.*, in prep).

The hypothesis was tested by the comparative assessment of soil nutrient concentrations in the riparian zone of mountain and foothill streams of two adjacent river systems, both associated with the "TMG aquifer daylight-domain" (Figure 6.2).

6.2. Study site selection

Based on the conceptualization in Chapter 5 (Roets *et al.*, 2008), groundwater from the TMG aquifer interacts with surface resources in the “TMG aquifer daylight-domain”. The mountain and foothill reaches of both the Vermaaks and Marnevicks Rivers in the Kammanassie Mountains are associated with the TMG aquifer in this domain. These two rivers offered an ideal opportunity for a comparative study (See Figure 6.2 and 6.3) because one of the rivers, the Vermaaks River, had a confirmed altered hydrological regime resulting from a well field that has been in operation since 1987 (Kotze, 2002). Many springs have dried up in the Vermaaks valley since the start of the abstraction project, many of which stopped flowing many years later (Cleaver, 2003). This has modified the Vermaaks River hydrology from a perennial stream to a seasonal stream and fragmented the river continuum (Davies and Day, 1998). The hydrology of the adjacent Marnevicks River has not been affected by groundwater use (Cleaver, 2003).

The well field in the Vermaaks River abstracts approximately 0.65 x 10^6 m^3/a water from 5 boreholes as part of the Klein Karoo Rural Water Supply Scheme (KKRWSS). A total of 4 production boreholes were drilled into the Peninsula Formation of the TMG aquifer on the Kammanassie Nature Reserve. According to the findings of Cleaver (2003) plant species composition, geology, soil, climate, aspect and altitude are similar for the Vermaaks, Marnewicks and Buffelsklip Valleys.

Both the Vermaaks and Marnevicks valleys are characterized by alluvial and slope deposits consisting of sand, gravel and other unconsolidated materials. These alluvial and slope deposits are distributed at the foot of the mountains and along the valley floors, having a thickness of up to 15 m (Kotze, 2002). It is with these deposits that the rivers and associated riparian zones are associated in both valleys.

The Kammanassie Nature Reserve, within which the largest part of these two river valleys fall, receives rain throughout the year with an average annual rainfall of approximately 450 mm. Drier periods are from November to February. Rainfall peaks occur in autumn and spring. The entire area is characterised by large diurnal and seasonal fluctuation in temperature. In addition, the Kammanassie Mountain Complex climate is highly variable, thunder storms in the hot summer months, contrasting with snow on the highest mountain peaks in winter until late spring. This results from the fact that this area is located some distance inland from the moderating influence of the ocean. Hot summer temperatures commonly reach 38 °C. On the other hand, during cold winter nights, temperatures can drop below 0 °C. Daily average minimum and maximum temperatures for summer and winter vary between 15 to 42 °C and -3 to 18.5 °C, respectively. The average maximum temperature is 29 °C and minimum is 2 °C. The coolest months are from May to August.

Average annual evaporation varies between 1760 and 2050 mm/a from west to east in the Little Karoo, and is 50% less (compared to summer figures) in the months of April to September each year. Evapo-transpiration losses reach a maximum from October to March, and are reflected by a drop in groundwater levels and a concurrent decline in spring flow. Temperatures and rainfall vary considerably from the high mountain peaks to the low-lying areas.

The main drainage direction in the region of the Vermaaks and Marnevicks Rivers are north-westward feeding into the perennial Olifants River that drains the northern side of the Kammanassie Mountain Range (KMR) (Figure 6.2 and 6.3). The perennial Kammanassie River collects water draining from the southern part of the KMR. Tributaries of the Olifants River arising on the northern slopes of the KMR include the Vermaaks, Marnewicks and Buffelsklip Rivers. The southern flanks are drained by the Huis, Diep, Klein, Klues and Mill Rivers that runs into the Kammanassie River. These relatively short tributaries are ephemeral in the steep upper reaches, with more sustained flow in the lower reaches.

These valleys are highly fractured and (Peninsula Aquifer or Nardouw Aquifer) have groundwater of good quality and yield, buffered by intermediate and regional flow systems. Kotze (2002) states that if groundwater is to be exploited from these aquifers this will clearly have to be at the expense of the base flow of mountain streams in local catchments and local lowering of water levels.

According to Kotze (2002) the Kammanassie Mountain Complex are postulated to represent an intermediate scale flow system, interconnected to the regional scale flow system of the Outeniqua Mountains at depth, along the folded strata of the Peninsula Aquifer. Tests conducted on the hydrochemistry and environmental isotope have confirmed that most recharge takes place in the higher altitudes where the Peninsula

Aquifer occurs and, to a lesser extent, where the Nardouw Aquifer outcrops at lower altitudes.

6.2.1. Location of the study area

The study sites were located in the Vermaaks- and Marnevicks River valley's which forms part of the north western end of the Kammanassie Mountain Complex (KMC). The Kammanassie Mountains is situated between the towns of Uniondale in the east and De Rust/Dysselsdorp in the north-west and west respectively. The mountain is an inselberg within the Little Karoo between the Swartberg and Outeniqua Mountains (Figure 6.2) (Cleaver, 2003).

The Western Cape Nature Conservation Board (WCNCB), trading as CapeNature, manage the Kammanassie Nature Reserve (KNR) which is situated between 33°33'50"S and 33°37'10"S and 22°27'29"E and 23°01'55"E and covers a total area of 49 430 hectares, of which 21 532 hectares are a privately-owned declared mountain catchment area. The remaining 27 898 hectares are state land, of which 17 661 hectares have been declared forest in terms of section 10(1) of the Forest Act No. 122 of 1984 (Cleaver, 2003). The largest part of the Vermaaks and Marnevicks River valleys form part of the KNR.

6.2.2. Geology, stratigraphy and hydrogeology

6.2.2.1. Geology of the Table Mountain Group sandstones

The TMG is subdivided into six formations, of which only the Peninsula Sandstone Formation, Nardouw Subgroup and the Cedarberg Shale Formation (C/S) are present in the study area. The Nardouw Subgroup is further subdivided into the Baviaanskloof, Kouga and Tchando Formations based on small lithological differences that relate to feldspar and shale content. For the purposes of background to this study it is sufficient to refer to the Nardouw Subgroup.

The Peninsula Sandstone Formation is mostly exposed along the mountain crests and make up two thirds of the total thickness of the TMG (1800 to 2150 m). It is composed of a uniform succession of medium to coarse grained, grey sandstones, thickly bedded, characterised by cross bedding. In places, thin layers of conglomerate may be present (Kotze, 2002).

The overlying Cederberg Shale formation comprises a 50 to 120 m thick shale layer. It is a good marker horizon that easily weathers deeply and to a smooth outcrop, which contrasts with the grey crags of the sandstones above and below (Kotze, 2002).

In the Nardouw Subgroup the rocks are, in general, more brownish on weathered surfaces and thin intercalations of shale are more plentiful than in the Peninsula Formation. Towards from the top, this layer becomes more feldspathic. Due to its higher shale content the Nardouw is less competent than the Peninsula Formation and deformation tends to be more ductile, giving rise to the spectacular fold geometries seen in the mountain road passes that cut through the Nardouw Subgroup (Kotze, 2002).

6.2.2.2. Stratigraphy

The stratigraphy of the Kammanassie region is summarised in Table 6.1 and shown in Figure 6.4. The Kammanassie Mountain Range (KMR) comprises almost exclusively the resistant quartz arenites of the Table Mountain Group (TMG), overlain on the lower slopes by the shales of the Bokkeveld group. The Cedarberg Shale formation (varying between 50 and 120 m thick) occurs as an important marker horizon within the TMG, separating formations of the Peninsula formation from the Nardouw Subgroup.

According to Kotze (2002) soils generally form a thin (<1 m) veneer of silty sands/sandy silts as a result of the steep slopes of the Kammanassie Mountains consisting of predominantly quartzitic rocks. Locally clayey soils occur in association with weathered shale horizons, and in particular the Cedarberg formation.

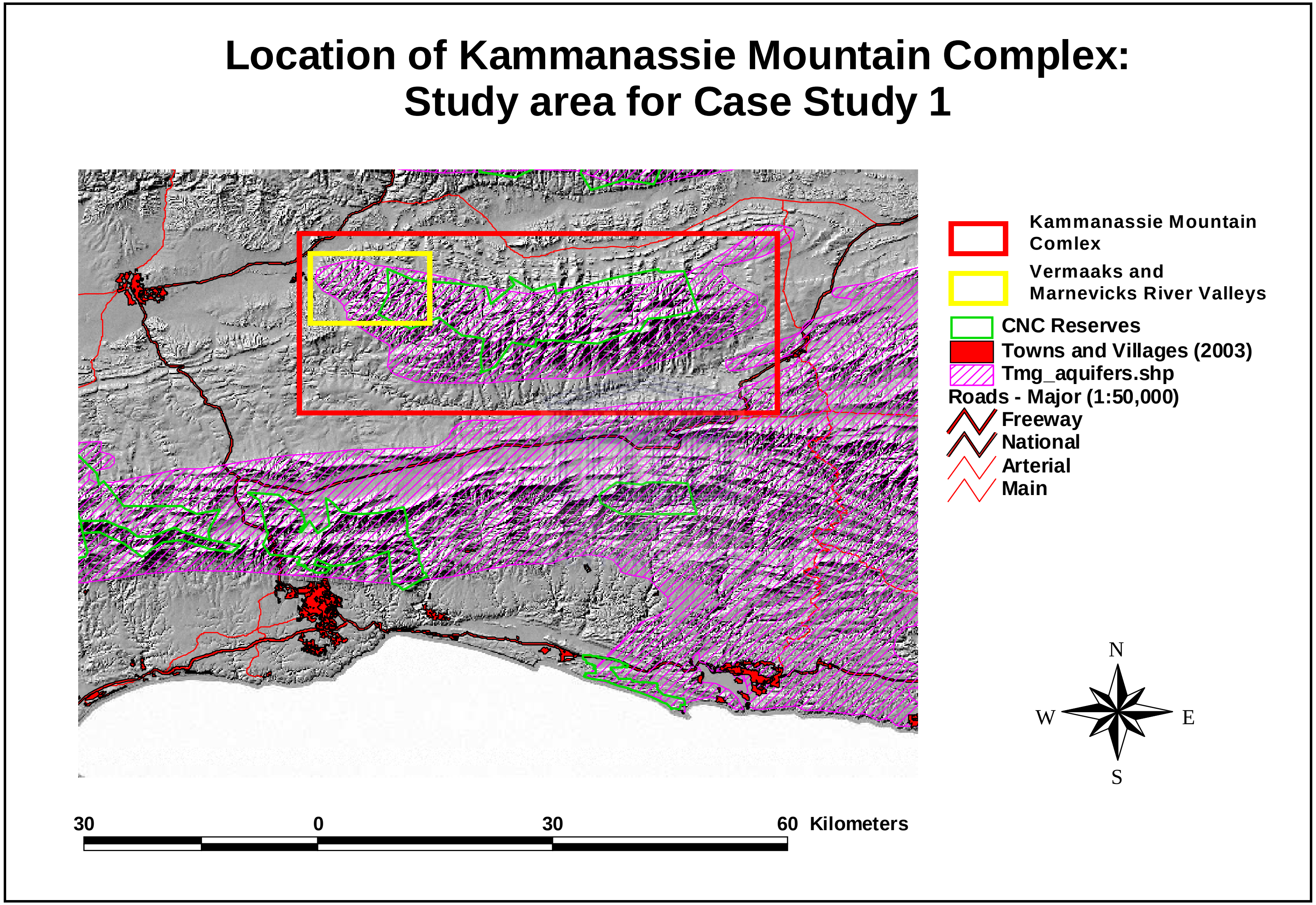

Figure 6.2. DEM showing the location of the Kammanassie Mountain Complex with the study site in the yellow block (Council of Geoscience, 2001).

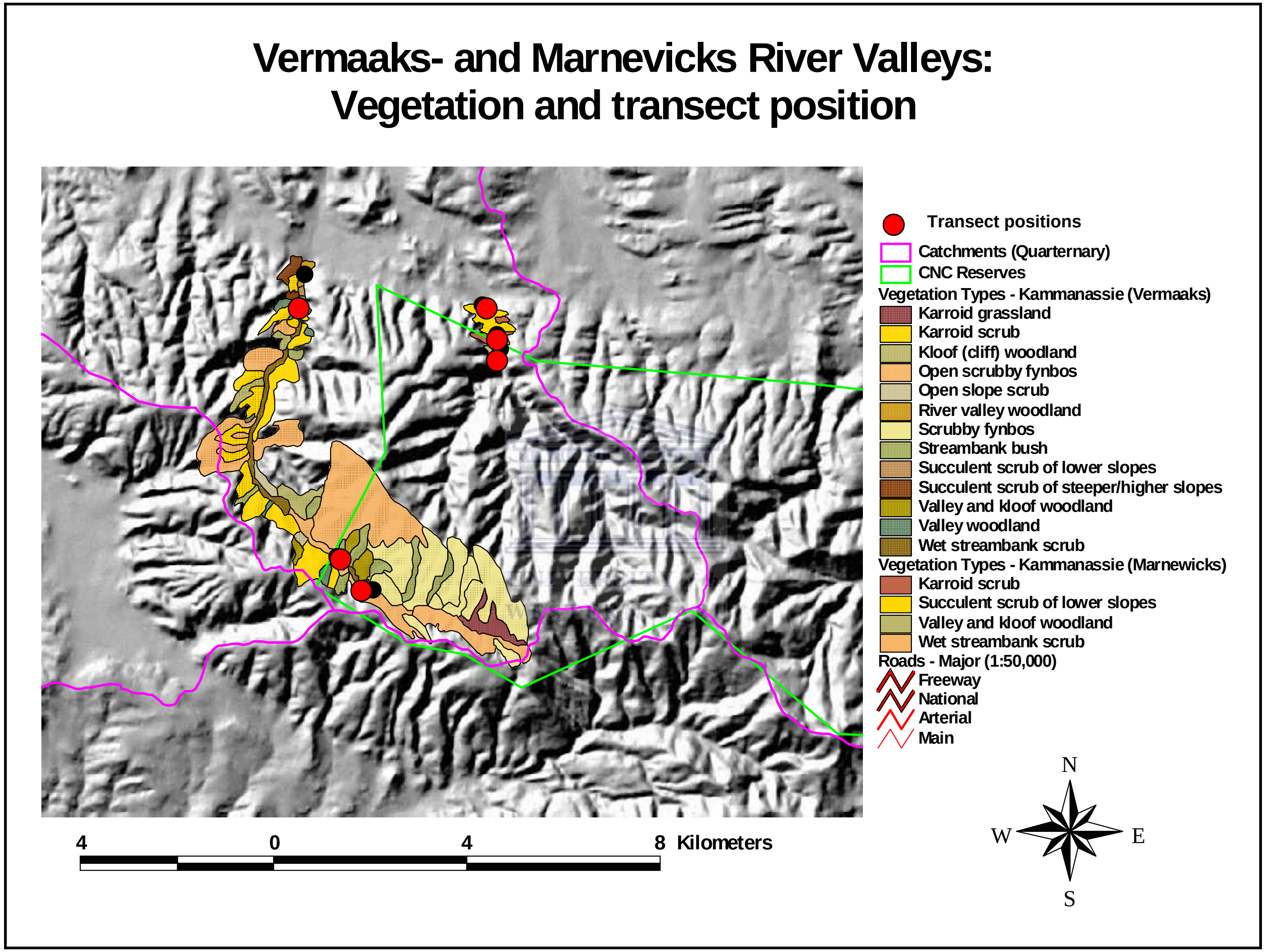

Figure 6.3. Map showing the vegetation types and transect positions of the Vermaaks- and Marnevicks River valleys.

Table 6.1. Geological succession of the Klein Karoo (De Beer, 2002).

SUPER GROUP	SUB-GROUP	GROUP	FORMATION		THICKNESS (m)	LITHOLOGY
						Alluvium, sand gravel and other unconsolidated deposits as well as calcrete
	Uitenhage		Buffelskloof			Conglomerate, thin sandstone, siltstone and mudstone
			Kirkwood			Conglomerate, siltstone, mudstone
			Enon			Conglomerate, thin sandstone, siltstone and mudstone
Karoo	Beaufort		Teekloof		1000	Mudstone and shale
			Abrahamskraal		2400	Mudstone, siltstone and sandstone
	Ecca		Waterford		800	Sandstone, minor siltstone and shale
			Fort Brown		1000	Shale, thin siltstone and sandstone
			Laingsburg/Rippon		1000	Sandstone, greywacke, siltstone/mottled grey sandstone, shale
			Vischkuil		100	Arenaceous shale, siltstone and thin sandstone
			Collingham		30	Siltstone, chert, sandstone, volcanic ash
	Dwyka				600	Diamictite and shale
Cape	Witteberg	Lake Mentz	Waaipoort		340	Shale, siltstone, thin sandstone
			Floriskraal		80	Sandstone, siltstone, shale and grit
			Kweekvlei		200	Shale
			Witpoort		850	Quartzitic sandstone, minor siltstone
		Weltevrede			800	Micaceous, purple to red brown siltstone, mudstone and shale
	Bokkeveld	Traka	Adolphspoort		1000?	Siltstone, shale, sandstone
			Karies		1200	Shale
		Bidouw	Waboomberg		200	Siltstone, shale
			Boplaas		100	Sandstone
			Tra-Tra		350	Shale, siltstone
			Hex Rivier		70	Sandstone, siltstone
			Voorstehoek/Swartkrans		300	Shale, siltstone
			Gamka		200	Sandstone, siltstone
			Gydo		600	Shale, siltstone
	Table Mountain		**Nardouw**	Baviaanskloof	300	Feldspathic quartz arenite
				Kouga	500	Quartz arenite
				Tchando	400	Brown-weathering arenite, minor siltstone, shale
			Cedarberg		50	Prominent shale marker
			Peninsula		1500	Quartz arenite

Disconformity (break in the geologic record)

Cango Group		Schoemanspoort	600	Grit, greywacke, subarkose, conglomerate
	Kansa	Schoongezicht	?	Conglomerate, greywacke, shale
		Gezwindskraal	?	Fine-grained greywacke, shale
		Uitvlugt	?	Cross-bedded greywacke, shale
	Goegamma	Vaartwel	?	Quartz-pebble and conglomerate
		Groendfontein	2400?	Grit, arenite, fine-grained greywacke, shale, limestone lenses
		Matjiesrivier	?	**Kombuys Member:** Limestone, siltstone and shale
			?	**Nooitgedagt:** Limestone, shale, greywacke and subarkose
Cape Granite				Gneissic granite
Kaaimans			85?	Feldspathic quartzite

6.2.2.3. Hydrogeology

The rocks of the TMG possess essentially no primary porosity, with groundwater flow restricted to fractures in joint and fault zones. Groundwater flow in these fractures is controlled by fracture characteristics and faulting that enhance secondary porosity.

Groundwater in the TMG is predominantly recharged in the highest topographic settings of the Kammanassie Mountains. Recharge is estimated to be about 14% of the mean annual precipitation (Kotze, 2002). Precipitation percolates into fractures and faults of varying orientation and scale. Where water accumulations in shallow fractures above localised aquitards it will result in the occurrence of perched springs and seeps. Migration of the groundwater under gravity into larger deeper fractures cause recharge of the water table/piezometric surface where it becomes part of the regional groundwater flow system, discharging toward the foot of the mountain where the groundwater table/piezometric surface daylights as springs, as well as base flow in river courses. Discharge in rivers occurs preferentially where there is good interconnection between fractures and the riverbed (groundwater discharges and interflow) (Kotze, 2002).

6.2.3. Flora

According to Lubke (1996) and Rebelo (1996) the Kammanassie Mountain Complex falls within the fynbos and thicket biome. Small pockets of the forest biome are present in valleys on the southern slopes (Lubke and McKenzie, 1996). The vegetation types for the Kammanassie Mountains are described in great detail in Cleaver (2003).

6.2.3.1. Vegetation of the Vermaaks River valley

According to Southwood *et al*. (1991), arid fynbos is found at the entrance to the Vermaaks River Valley, with kloof shrubland in the valley bottoms. The slopes of the valley are dominated by waboomveld. A small section of the Drier Protea community (southern aspects) is found in the upper most reaches of the Valley basin (Cleaver, 2002).

6.2.3.2. Vegetation of the Marnewicks River valley

Arid fynbos occurs at the entrance to the Marnewicks River Valley, with waboom veld dominating the valley slopes. The bottom of the river valley is dominated by kloof shrubland (Southwood *et al*., 1991; Cleaver, 2002).

6.2.4. Fauna

On the Kammanassie Nature Reserve, which comprises the largest part of the Kammanassie Mountain Complex, there is a population of 38 endangered Cape Mountain Zebra, *Equus zebra zebra* (Cleaver, 2002). Other game includes small populations of klipspringer, grey rhebuck, common duiker, grysbuck, kudu, mountain reedbuck and chacma baboon. Leopards also frequent the mountain but are seldom seen.

A total of 66 bird species have been recorded by Cleaver (2002). Raptors such as the well known black eagle and jackal buzzard are common.

Butterflies are abundant with at least 46 species recorded (Cleaver, 2002). The fairly recently discovered Kammanassie Blue (*Orachrysops brinkmani*) belongs to the same genus as the endagered Brenton Blue and Karkloof Blue.

The near threatened slender redfin (*Pseudobarbus tenius* – IUCN, 2006) is found in most of the rivers around the Kammanassie Mountain, including the Vermaaks, Marnewicks and Buffelsklip Rivers. Other indigenous fish species found in rivers around the Kammanassie Mountain include: Cape Galaxis (*Galaxias zebratus)* and Cape Kurper (*Sandelia capensis*). Frogs include: Common river frog (*Rana angolensis*), Cape river frog (*Rana fuscigula),* Clicking stream frog (*Strongylopus grayii grayii* and *Strongylopus grayii*), Ghost frog (*Heleophryne* species), Karoo toad (*Bufo gariepensis*), Raucous toad (*Bufo rangeri*), Sand toad (*Bufo angusticeps*), Tradouw's Mountain toad (*Capensibufo tradouwi*) and Bronze caco (*Cocosternum nanum nanum*). The River crab (*Potamonautes sidneyi and Potamonautes perlatus*) are common in the rivers around the Kammanassie Mountain.

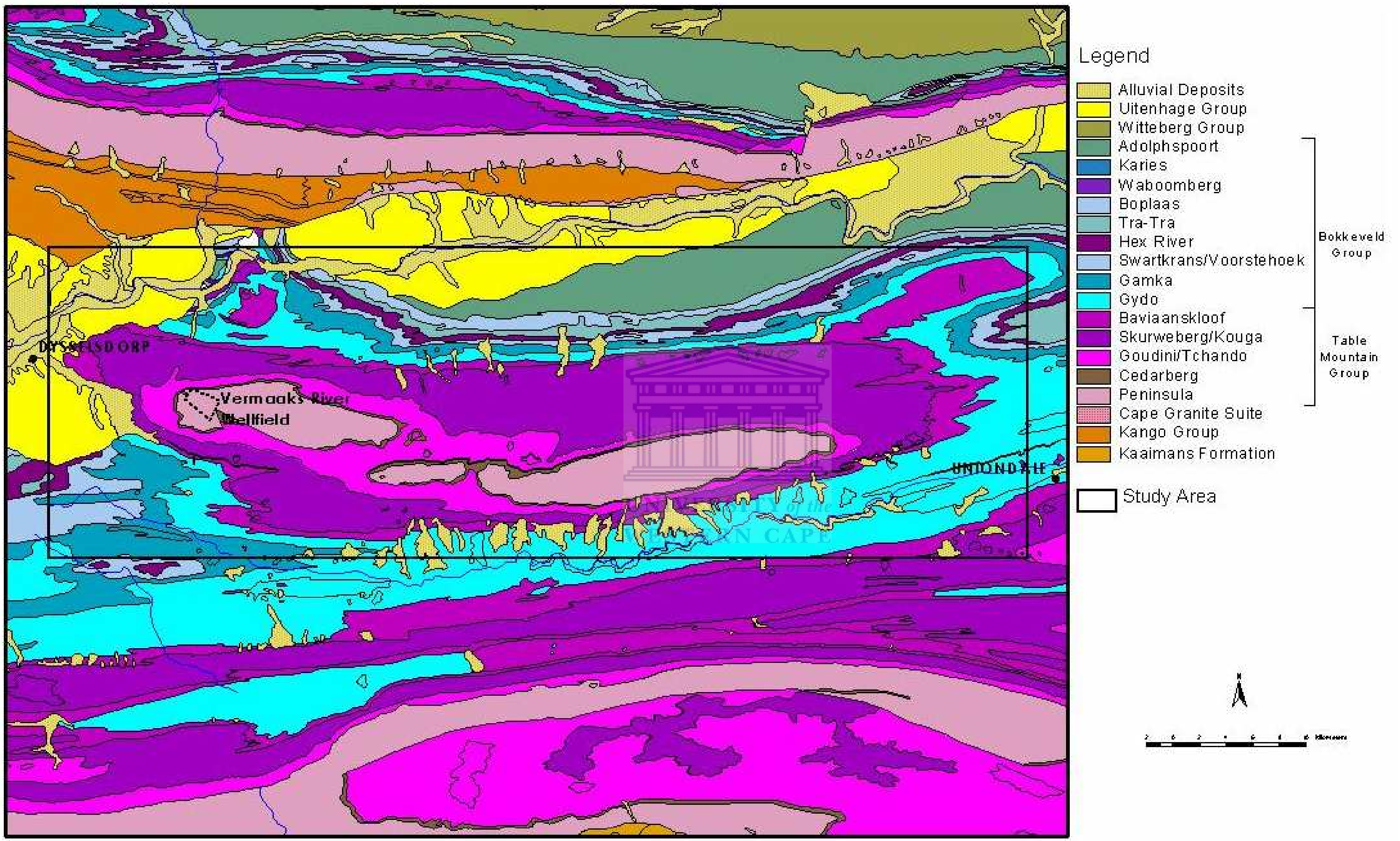

Figure 6.4. The stratigraphy of the Kammanassie study area (Cleaver, 2003).

6.3. Materials and methods

6.3.1. Transect selection

Three suitable transects with comparable geology, soils and vegetation were selected in the mountain- and foothill-river reaches of both the Vermaaks and Marnevicks River valleys. The first transect was selected in the lower mountain reach of the Vermaaks and Marnevicks Rivers, with the second and third transects located at representatives sites in the upper foothill reach, and lower foothill reach respectively for both rivers (See Fig. 6.2). Transect codes used in the data sets are: V(B) and M(B) representing the lower mountain stream reaches, V(M) and M(M) representing the upper foothill stream reaches and V(O) and M(O) representing the lower foothill stream reaches for each respective river. Transects were renamed in figures 6.5 a-c under results for easier interpretation. Vermaaks1 and Marnevicks1 represents the lower mountain reach transects, Vermaaks2 and Marnevicks2 represents the upper foothill stream transect, while Vermaaks3 and Marnevicks3 refers to the lower foothill stream transects. The GPS locations for the transects selected in the Vermaaks and Marnevicks River valleys were as follows: Vermaaks River: B – S 33^{o}37’06.4”, E 22^{o}33’14.9” , M – S 33^{o}36’48”, E 22^{o}32’52.7” , O – S 33^{o}33’57.9”, E 22^{o}32’16.7”; Marnevicks River: B – S 33^{o}34’40.5”, E 22^{o}34’57”, M – S 33^{o}34’32.4”, E 22^{o}34’56.5”, O – S 33^{o}34’08.4”, E 22^{o}34’44.2”.

At each of the three transects in both rivers (the Vermaaks and Marnevicks Rivers) six soil samples were collected during spring 2005 (early October), summer 2005 (middle December), autumn 2006 (middle March) and winter 2006 (middle June) (six samples - at three transects - in two rivers - over four seasons). The six samples were collected three on each bank (left and right) of the river next to stream bed or water level. All samples were collected in a linear fashion (about three meters apart) along each river bank at a depth of approximately 20-40 cm below surface. Groundwater discharge and recharge is expected to affect soil nutrient concentration in this soil horizon because this is where groundwater discharge and recharge would manifest in mountain and foothill streams (Roets *et al.*, 2008). A soil auger was used to collect the soil samples. Samples were stored in plastic bags in a cooler box and sent to a commercial laboratory (Bemlab, Somerset-West) by over night courier service for analysis for ammonium (NH_4^+), nitrate (NO_3^-) and extractable phosphate (P) (Roets *et al.*, in prep).

6.3.2. Soil analysis

Phosphate (P) was analysed as follows: 10 g of soil was suspended in 50 ml Aqua Regia and heated on a hotplate to boiling. The suspension was then filtered and the filtrate analysed for P with a Varian MPX ICP-OES (Olsen and Dean, 1965). Aqua Regia consists of 3 parts concentrated Nitric acid and 1 part Hydrochloric acid.

NH_4^+ and NO_3^- concentrations of the soil samples were measured as follows: 10 g soil was shaken for 1 hour with 50 ml 1M KCl. The suspension was filtered and the filtrate analysed for NH_4^+ and NO_3^- with an AutoAnalyzer (Bremner, 1965).

No water quality samples were taken because only the Marnevicks River had surface water to sample. The Vermaaks River has been changed from a perennial to a seasonal stream due to groundwater use (Cleaver, 2003).

The samples of the last two seasonal assessments, autumn and winter, were also analyzed for soil pH and electrical conductivity (EC). This was done to be able to compare soil pH and EC between the Vermaaks and Marnevicks Rivers, as these parameters could affects soil nutrient cycling (Roets *et al.*, in prep).

6.3.3. Statistical analysis

A factorial analysis of variance (ANOVA) was performed on the data with factors: two rivers Vermaaks (V) and Marnevicks (M) River valleys, and three transects (Lower foothill reach (O), Upper foothill reach (M) and Lower Mountain (B)). Soil nutrient samples were collected over the four seasons (spring, summer, autumn and winter). Seasons was considered as repeated measurements over time and were used as a sub-plot factor in the analysis of variance. Three samples were collected on both sides of the river giving a total of 6 samples per combination. Shapiro-Wilk's test was performed on residuals to test for deviations from non-normality (Shapiro and Wilk, 1965). Outliers for NH_4^+ and NO_3^- were identified and discarded until the residuals were symmetric or normal distributed (Glass *et al.*, 1972). Student t-LSD (Least significant difference) was calculated at a 5% significance level to compare means of significant effects (See Table 6.2) (Roets *et al.*, in prep). All data processing was performed with SAS statistical software (SAS, 1999).

The soil pH and Electrical Conductivity (EC) measurement data of the last two sampling runs were run in a Univariate analysis in SPSS to check for significant differences between the two river valleys.

6.4. Results

Previous research has confirmed a water table drop and altered hydrological regime (making the historically perennial stream a seasonal stream) in the Vermaaks River (Kotze 2002; Cleaver, 2003) that resulted from many springs that dried up.

From the ANOVA analysis clear evidence emerged for a three factor interaction, River by Transect by Season (RxTxS) for NH_4^+ (P=0.02) and NO_3^- (P<0.01). This was not evident for P (P=0.28) (See Table 1 and Figures 6.5a, 6.5b and 6.5c) (Roets *et al.*, in prep).

Table 6.2. Factorial analysis of variance with season as sub-plot factor for the three variables (Roets *et al.*, in prep).

	NH_4^+			**NO_3^-**			**Total P**		
Source	**DF**	**MS**	**P**	**DF**	**MS**	**P**	**DF**	**MS**	**P**
River (R)	1	21.36	0.11	1	125.42	<0.01	1	59514.04	<0.01
Transect (T)	2	50.26	0.01	2	216.03	<0.01	2	3777.87	0.04
RxT	2	38.27	0.02	2	88.87	<0.01	2	1470.09	0.26
Error (a)	**30**	**7.97**		**30**	**11.87**		**30**	**1057.55**	
Season (S)	3	523.47	<0.01	3	168.04	<0.01	3	53131.66	<0.01
RxS	3	3.52	0.60	3	24.56	0.05	3	6834.16	**<0.01**
TxS	6	19.04	<0.01	6	70.20	<0.01	6	1254.83	0.07
RxTxS	6	15.86	**0.02**	6	38.40	**<0.01**	6	777.66	0.28
Error (b)	**88**	**5.65**		**86**	**9.30**		**90**	**609.77**	
Corrected Total	141			139			143		
Shapiro-Wilk		P<W	0.16		P<W	<0.01		P<W	0.56

DF = Degrees of freedom, **MS** = Mean square and **P** = probability.

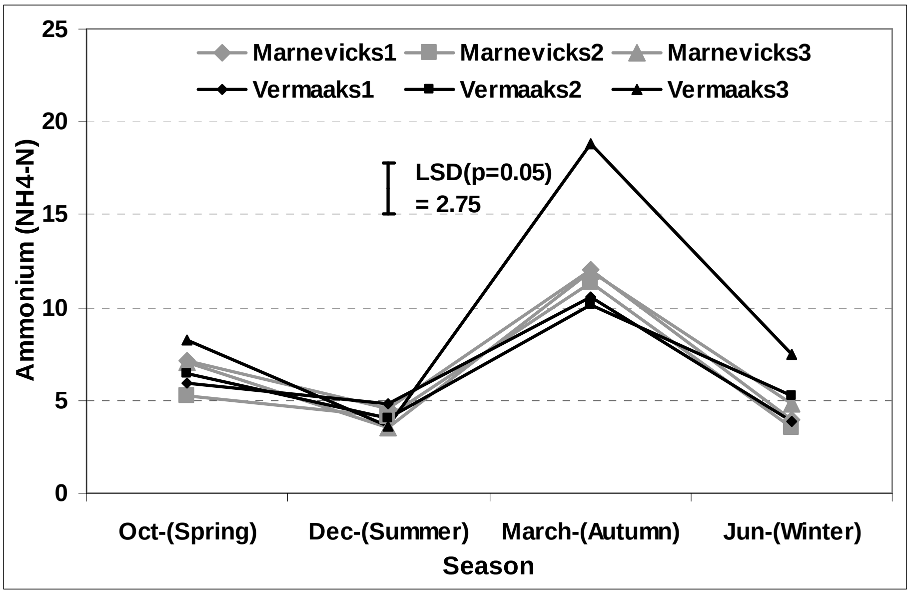

Figure 6.5a. Three factor Interaction for River by Transect by Season (RxTxS) for NH_4^+ (Roets *et al.*, in prep).

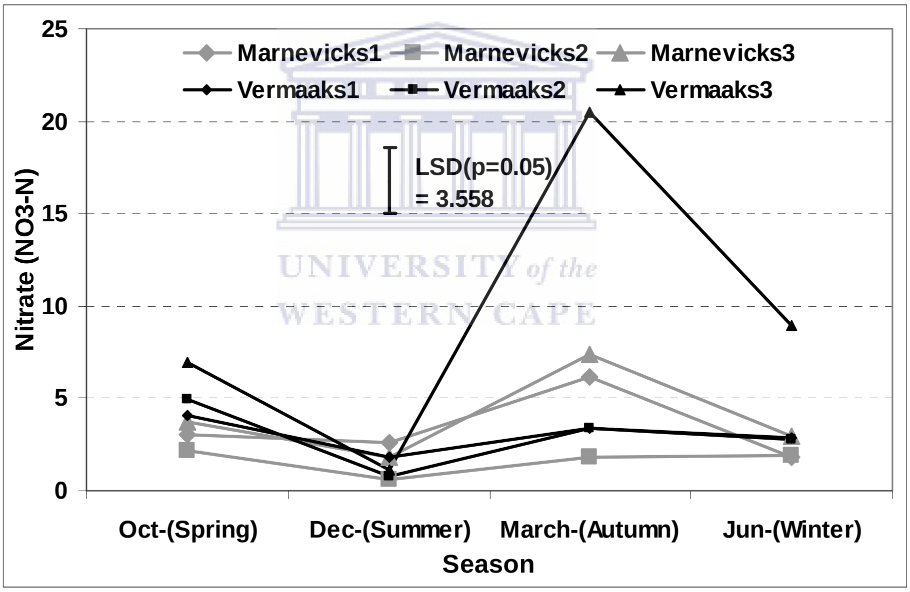

Figure 6.5b. Three factor Interaction for River by Transect by Season (RxTxS) for NO_3^- (Roets *et al.*, in prep).

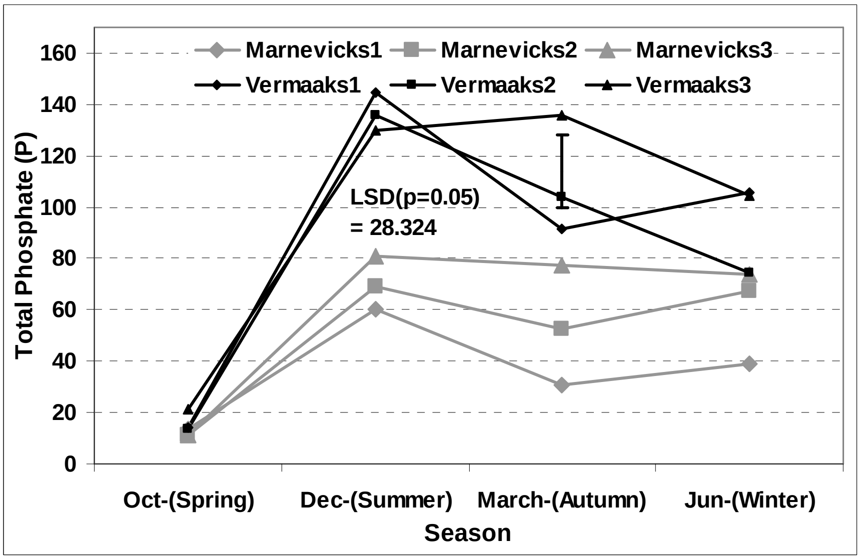

Figure 6.5c. Three factor Interaction for River by Transect by Season (RxTxS) for Total P (Roets *et al.,* in prep).

From Figure's 6.5a and 6.5b a clear seasonal pattern emerged. The Lower foothill reach (O) transect of Vermaaks (V) river showed significantly higher values for autumn and winter for both the NH_4^+ and NO_3^- and resulted in the three factor interaction to be significant. From these figures it is also clear that there is no significant river effect. This lead to a repeat of ANOVA for NH_4^+ and NO_3^- after discarding the data of transect (VxO) (See Table 6.3).

Table 6.3. Factorial analysis of variance with season as sub-plot factor for ammonium and nitrate after discarding data for transect (VxO) (Roets *et al.*, in prep).

	(NH_4^+)			(NO_3^-)		
Source	**DF**	**MS**	**P**	**DF**	**MS**	**P**
River (R)	1	2.15	0.51	1	0.011	0.96
Transect (T)	2	2.79	0.56	2	25.933	<0.01
RxT	1	8.29	0.20	1	18.697	0.03
Error (a)	**25**	**4.75**		**25**	**3.377**	
Season (S)	3	322.39	**<0.01**	3	47.949	<0.01
RxS	3	5.56	0.33	3	14.655	**0.02**
TxS	6	2.53	0.78	6	6.956	0.16
RxTxS	3	2.42	0.68	3	5.705	0.28
Error (b)	**74**	**4.755**		**73**	**4.396**	
Corrected Total	118			117		

DF = Degrees of freedom, **MS** = Mean square and **P** = probability.

The results in Table 6.3 show that for NH_4^+ only the season effect was significant ($P<0.01$) (Figure 6.6), and that values were significantly higher in the autumn than in the other seasons independent of the rivers.

The River (R) by Season (S) (RxS), two factor interaction elucidated significant differences for both NO_3^- (P=0.02) (Table 6.3) and P (P<0.01) (Table 6.2). These means are presented in Figure 6.7a and 6.7b.

For phosphate the Mean of the Vermaaks river (Mean =89.593) is almost double that of the Marnevicks river (Mean=48.934) and is highly significant (P<0.01).

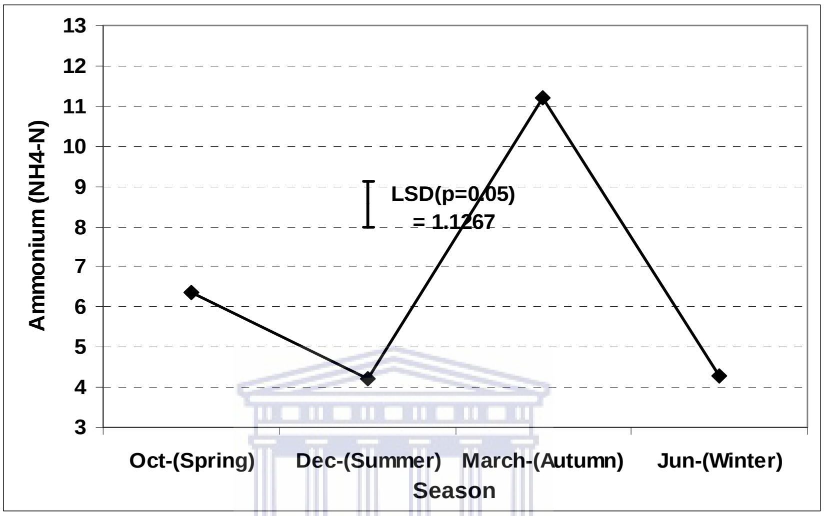

Figure 6.6. Season main effect means for NH_4^+ for both rivers without the lower foothill reach (O) transect of the Vermaaks (V) river (Roets *et al.*, in prep).

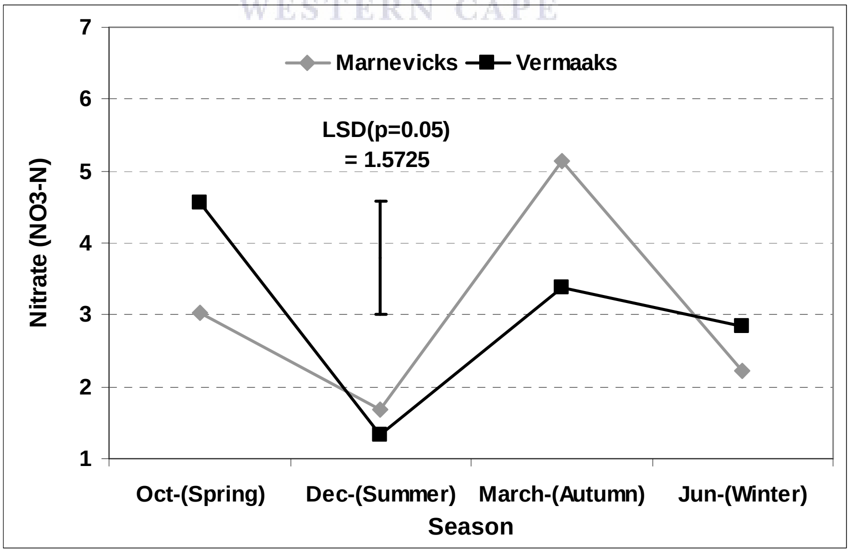

Figure 6.7a. Two factor interaction means for River (R) by Season (S) for NO_3^- without the lower foothill reach (O) transect of the Vermaaks (V) river (Roets *et al.*, in prep).

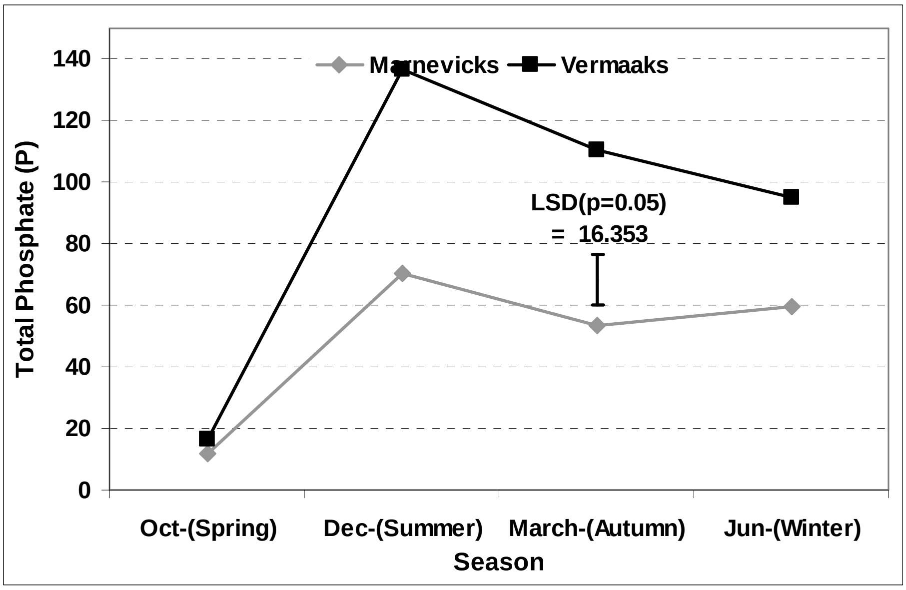

Figure 6.7b. Two factor interaction means for River (R) by Season (S) for Total P without the lower foothill reach (O) transect of the Vermaaks (V) river (Roets *et al.*, in prep).

The Pearson’s Correlation Coefficient for the NH_4^+:NO_3^- ratio (Figure 6.8) showed that the Vermaaks had a higher conversion of NH_4^+ to NO_3^-, with r = 0.766, compared to the Marnevicks with r = 0.567.

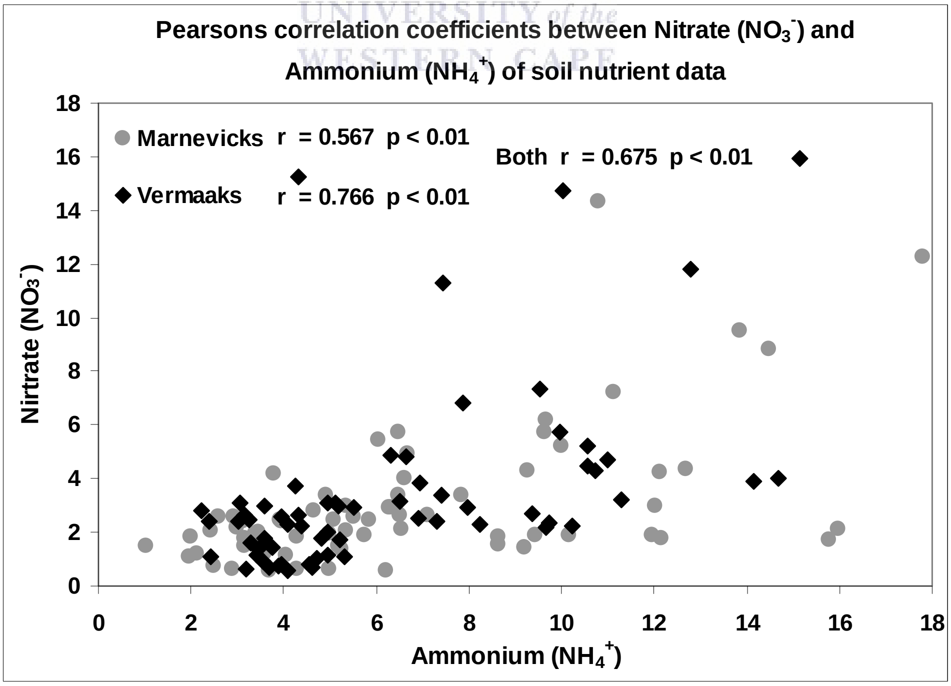

Figure 6.8. Pearson’s correlation coefficient between NH_4^+ and NO_3^- for each River and for both (Roets *et al.*, in prep).

The soil pH and electrical conductivity (EC) measurements of the autumn and winter sampling run, indicated no statistical significant differences between the Vermaaks and Marnevicks River valleys with P-values of P=0.131 and P=0.761 respectively.

6.5. Discussion

The research findings of Kotze (2002) and Cleaver (2003) confirmed a drop in the water table that altered the hydrological regime in the Vermaaks River. Cleaver (2003) confirmed plant moisture stress as a result of the declining water table. This transformed hydrological regime seems to have affected the soil water content close to the river bed in the Vermaaks River. The river is dry for most of the year with only seasonal flow under heavy precipitation.

The results from this study support these findings by showing higher soil nutrient concentrations that possible resulted from soil water effects (reduced mobilization and leaching) and natural chemical cycling (i.e. better nitrification, less de-nitrification, better ammonification, volatilization, adsorpstion, dissolution, mineralization and immobilization) (Farley & Fitter, 1999; Chapin & Aerts, 2000; Olde Venterinck *et al.*, 2003; Hodge, 2004) that was modified. Reduced groundwater discharges to surface resources may also result in an alteration of plant available P (Grootjans *et al.*, 1986) and plant available nitrogen, as both nitrogen and phosphates are depended by microbial transformation that is dependent on soil water content and temperature.

The data from this study showed a statistically significant difference between the Vermaaks and Marnevicks Rivers with regard to the soil nutrient concentrations collectively for all four seasons (Figure 6.5a-c). Based on the original data set, the Vermaaks Valley consistently showed higher soil nutrient concentrations for all three nutrients. Only NH_4^+ concentrations showed no statistically significant difference between the two river valleys at the 95% confidence level (See Table 6.2). This data support the hypothesis that soil nutrients accumulate in soils where the groundwater discharges, interflows and translatory flows have been affected and have changed the flow regime in the Vermaaks River. Nutrient concentration differences in response to groundwater discharges was also found by Wassen (1995), De Mars *et al.* (1996), Clawson *et al.* (2001) and El-Kahloun *et al.* (2003).

The statistical differences that emerged between the different transects for all nutrients within both the Vermaaks and Marnevicks Rivers collectively for all seasons, resulted from a progressive increase in nutrient concentrations moving downstream as more nutrients enter the stream from the tributaries and valley floor. Hence the highest nutrient concentrations recorded in the lower foothill transect. This is consistent with the first part of the hypothesis (Roets *et al.*, in prep).

After discarding outlier values for both NH_4^+ and NO_3^-, the three factor interaction (RxTxS), showed statistical differences for NH_4^+ and NO_3^-, but for the first factor River (R), NO_3^- and P emerged with $p<0.01$, but not for NH_4^+. This discrepancy was possible caused by the high values for NH_4^+ and NO_3^- recorded in the Vermaaks (V) lower foothill (O) transect for autumn and winter possible resulting from better microbial transformation as a result of soil water and temperature effects. Soil nutrient levels were expected to be lower in spring and summer as a result of the growing season for plants (Ward and Robinson, 1990; Davies and Day, 1998). Both Figure 6.5a and 6.5b show a good correlation over the seasons for both NH_4^+ and NO_3^-, which was expected due to both being depended on nitrification and de-nitrification. The higher nutrient values recorded in the lower foothill transect of the Vermaaks (V(O)), was also expected, as nutrients wash down any catchment and increase progressively downstream as more nutrients leach down (Davies and Day, 1998). The higher nutrient values in the Vermaaks River is consistent with an expected increase of nutrients resulting from reduced groundwater discharges that lead to the accumulation of NH_4^+ and NO_3^-, particularly in the lowest transect of the river where the cumulative effect of the reduced discharges will be most profound. Better aeration of soils also benefited microbial transformation of nutrients (Roets *et al.*, in prep).

After data for transect V(O) was removed, a two factor interaction emerged (RxS). This data indicate that NH_4^+ did not significantly differ between the two rivers. However, a clear significant difference was shown for both NO_3^- and P. Data further shows that the possible effect of reduced groundwater discharges on NH_4^+ and NO_3^- levels in the Vermaaks River's mountain and upper foothill zones were less pronounce than in the lower foothill area, which is the primary groundwater discharge zone according to Roets *et al*. (2008). These higher elevation mountain and upper foothill streams may be less dependent on groundwater discharges from the TMG aquifer due to their relative position to the water table.

For P a good correlation was present between the two rivers over the seasons. The steep dip in P concentrations in spring was expected due to the growing season when plants use a lot of P (Ryke, 1978). The P concentrations differences between the two rivers were statistically significant throughout, except for spring. No outliers were present and data showed a consistent difference between the two rivers. Because of the complex interrelationship among the various P fractions in soils these results may not be conclusive, but does support the hypothesis that P may have accumulated in the Vermaaks River valley as a result of reduced groundwater discharges affecting phosphate processing (microbial and chemical) in soils (Roets *et al.*, in prep).

Nutrient concentration differences between the two valleys could not have been caused by differing nutrient mobilities in soils as a function of pH and EC as indicated by El-Kahloun *et al*. (2005), because the soil pH and EC measurements for the two valleys did not show a statistically significant difference (Roets *et al.*, in prep).

Further support for the hypothesis is the fact that both river valleys have the same geology, soils, altitude, slope, aspect and vegetation types (Cleaver, 2003). The reduced groundwater discharges, both from the aquifer itself and reduced interflow as a function of rejected recharge, could have caused the accumulation of nutrients in the soils close to the stream of the Vermaaks River. The flow in the Vermaaks River has for many years been affected by a drop in the piezometric surface and springs drying up (Kotze, 2002). Riparian zone soil nutrient concentration differences between the two river valleys clearly are consistent with the hypothesis that reduced groundwater discharges and interflow will affect soil nutrients close to a river (Roets *et al.*, in prep).

The Pearsons Correlation Coefficient for the NH_4^+:NO_3^- ratio (Figure 6.8) clearly showed that the Vermaaks had a higher conversion of NH_4^+ to NO_3^- than the Marnevicks. This support the notion that reduced groundwater discharges in the Vermaaks Valley could have resulted in lower soil water saturation with a subsequent higher O_2 concentration that facilitated better nitrification success of NH_4^+ to NO_3^- (microbial transformation) (Roets *et al.*, in prep).

The surprisingly low concentrations of both NH_4^+ and NO_3^- in winter may have resulted from exceptionally high rainfall experienced during winter that leached the very mobile nutrients, or it could be attributed to soil water effects of microbial transformation of nutrients. The very high P concentrations recorded in summer probable resulted from high mineralization (microbial) resulting from organic breakdown of leaf litter during the summer heat.

Expected seasonal variation in soil nutrient concentrations caused by nutrient uptake by plants was clearly demonstrated by this data. Both river valleys showed exactly the same seasonal tendencies. The statistical differences in soil nutrient between the two river valleys can therefore not be attributed to plant nutrient uptake alone. Reduced groundwater discharges must have played a role.

The results of this study, and studies conducted by Wassen (1995), Goudie and Viles (1997) and El-Kahloun *et al.* (2005), confirm that soil nutrient concentrations show a response to groundwater. These findings support the conceptual model developed by Roets *et al.* (2008) that indicated that groundwater, translatory flow and interflow discharge to rivers and streams associated with the mountain and foothill reaches in the TMG.

6.6. Conclusion

The soil nutrient concentration differences between the Vermaaks and Marnevicks Rivers are consistent with the hypothesized progressive increase in soil nutrient concentrations from mountain- to foothill- to lowland river-reaches, and the affects of reduced leaching and altered microbial processing of soil nutrients (Roets *et al.*, in prep).

The study also found it highly plausible that these effect will manifest most notable in the riparian zone at the streambed or water level, the primary groundwater discharge zone (Roets *et al.*, 2008). Other research in the Kammanassie by Kotze (2002) and Cleaver (2003) clearly showed that the groundwater discharges was affected in the Vermaaks valley and that the current groundwater well field is using groundwater at the expense of the surface hydrology. The higher soil nutrient concentrations for the Vermaaks River, in comparison with the Marnevicks River, could well have resulted from the reduced groundwater discharges in the Vermaaks River valley, which resulted in reduced leaching of nutrients and by affecting microbial transformation of soil nutrients (Roets *et al.*, in prep).

Although it is extremely difficult to quantify the degree of accumulation of soil nutrients that may have resulted from reduced groundwater discharges close to a rivers streambed, the results of the study is consistent with the hypothesis formulated for the study. This elevation in soil nutrients may have far reaching affects in a nutrient poor environment like the fynbos biome, the Cape Floristic Kingdom (CFK).

However, during this study some weaknesses in the experimental design did emerge. Further research will be required before conclusive assumptions can be made on quantifying the effects of reduced groundwater discharges on soil nutrient cycling.

CHAPTER SEVEN

CASE STUDY 2: Determining discharges from the Table Mountain Group (TMG) Aquifer to wetlands in the Southern Cape - South Africa

7.1. Introduction:

Many authors worldwide have highlighted the importance of wetlands (Goudie and Viles, 1997; Davies and Day, 1998; Middleton, 1999), because they render many free services in terms of water quality and quantity management. Middleton (1999) states that wetlands provide benefits to human societies, from the direct resource potential provided by products such as fisheries and fuel wood, to the ecosystem value in terms of hydrology and productivity, up to a value on the global level in terms of the role of wetlands in atmospheric processes and general life-support. Unfortunately many wetlands worldwide have been destroyed and are currently being degraded due to anthropogenic activities (Roets *et al.*, 2008b).

With the ever increasing water demand, groundwater use in South Africa will increase and may compromise the integrity of groundwater dependent wetlands. It is therefore important to protect and manage wetlands as part of the bigger hydrological cycle to ensure their persistence. However, to achieve this we need to understand the functioning of wetlands, both from a hydrological and ecological perspective, including the interactions between both. Scientists agree that the main driving force of a wetland is the hydrology of the wetland, i.e. the duration and level of inundation that can result from surface flows, groundwater discharge and recharge, or a mixture of both (Goudie and Viles, 1997; Davies and Day, 1998; Colvin *et al.*, 2002; Le Maitre *et al.*, 2002). To manage the wetlands in a sustainable way it is important to know whether groundwater or surface water dominates as the ecological driver.

Groundwater discharges to wetlands are a common phenomenon (Hatton and Evans, 1998; Winter *et al*, 1999), but discharges to wetlands from the semi-confined to confined TMG aquifer in South Africa were to date generally predicted to be associated with seeps, wetlands and mires at higher elevation (Scott and Le Maitre, 1998; Colvin *et al.*, 2002; Brown *et al*., 2003; Sieben, 2003). However, the conceptual model developed in Chapter 5 (Roets *et al.*, 2008), describes the groundwater interface between the TMG aquifer and aquatic ecosystems in two primary areas, namely, in the high elevation "exposed TMG" recharge areas, the so-called “TMG aquifer daylight-domain”, and at the discharge end of the TMG aquifer in the lowlands in the so-called “TMG aquifer surface water interface-domain”. The discharge end of the TMG is located far away in the lowlands resulting in deep groundwater circulation to either hot or cold springs in the landscape, or marine environment, a view supported by Kotze (2002). Major faults or lineaments on the low lying land parallel to mountain ranges may result in deep pressurised TMG aquifer discharges ultimately feeding, or recharging shallower primary aquifers (See Figure 7.1). This is of significance because 90% of the aquifers across the world are hard rock aquifers. Fractures are one of the most abundant structures in geology found in almost all rocks and soils at or near the earth’s surface (Barton and Hsieh, 1989). Goudie and Viles (1997) list many countries around the globe where hard rock aquifers have been affected by groundwater use.

7.1.1. Hypothesis and objectives:

The hypothesis for this study was that the TMG aquifer could be discharging to lowland wetlands where aquatards have been displaced, even as close to the coast as Groenvlei and Van Kervelsvlei. These wetlands are both located at or near the discharge end of the TMG aquifer in the “TMG aquifer surface water interface-domain”. Previous reports showed that Groenvlei and Van Kervelsvlei were getting all their freshwater from the surrounding dune systems (Parsons, 2005a, and 2005b).

The objective of this study was to determine whether Groenvlei or Van Kervelsvlei were dependent on groundwater discharges from the TMG aquifer. In a parallel study (Roobroeck *et al.*, in press) the relationship between vegetation and groundwater quality in Groenvlei and Van Kervelsvlei was assessed to determine possible groundwater discharge gradients. Confirmation of groundwater contributions from the TMG aquifer to these two wetlands was necessary to understand their ecological integrity and sensitivity to groundwater use, and to scientifically validate the conceptual model developed in Chapter 5 (Roets *et al.*, 2008).

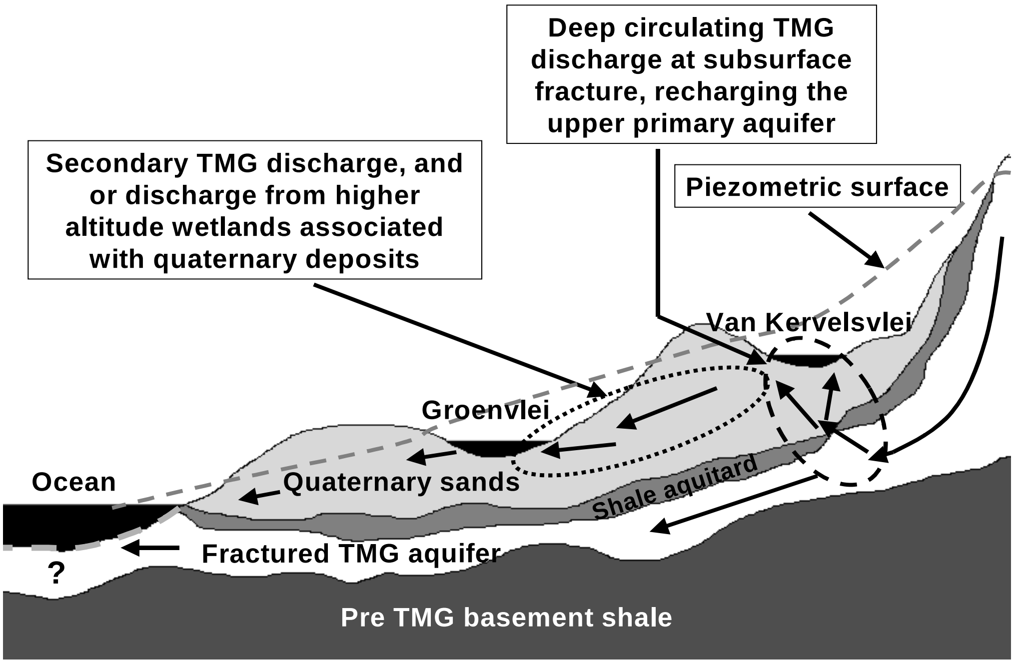

Figure 7.1. Hypothetical cross section through southern Cape coastal belt (adapted from Roets *et al*., 2008) showing groundwater surface water interactions between the TMG aquifer and coastal wetlands (Roets *et al.*, 2008b).

7.2. Study site

7.2.1. Site selection

The southern Cape is characterised by a large number of coastal wetlands, many of which are estuarine systems. All these wetlands are associated with a historic embayment running parallel to the Outeniqua Mountains fringing the coastline. Wetland sites for this study were selected on the basis of their endorheic nature, indicating their dependency on groundwater, with no inflow, or outflow, or connection to the sea. These study sites also had to be located in the "TMG aquifer surface water interface-domain". The geological setting of the area offered an ideal opportunity for a comparative study.

7.2.1.1. Geological characteristics

Groenvlei and Van Kervelsvlei are lowland wetlands associated with a major east-west running fault-system located to the south of the Outeniqua Mountains. Parsons (2005a) refers to it as a historic embayment, or wave cut platform. Both endorheic wetlands are isolated from rhinotrophic (river flow) input, but show very different geological characteristics at depth. They are both associated with the same tertiary to quaternary sands, fixed dunes and aeolianite (dune rock), with alluvial deposits in the low-lying valleys from ground level to an unknown depth (Parsons, 2005a; Parsons 2005b) (Figure 7.2 and 7.3), but are underlain by different geological formations at depth (Council of Geoscience, 2001).

Van Kervelsvlei is possible underlain by the Table Mountain Group (TMG) aquifer, with the TMG (Arenite and Quarzite) outcropping very close to it in the north-east (Figure 7.3)(Council of Geoscience, 2001). According to a TMG aquifer shape file developed by (Fortuin, 2004), Groenvlei's eastern half is underlain by the TMG aquifer, and the western half underlain by the Kaaimans Group (Figure 7.2).

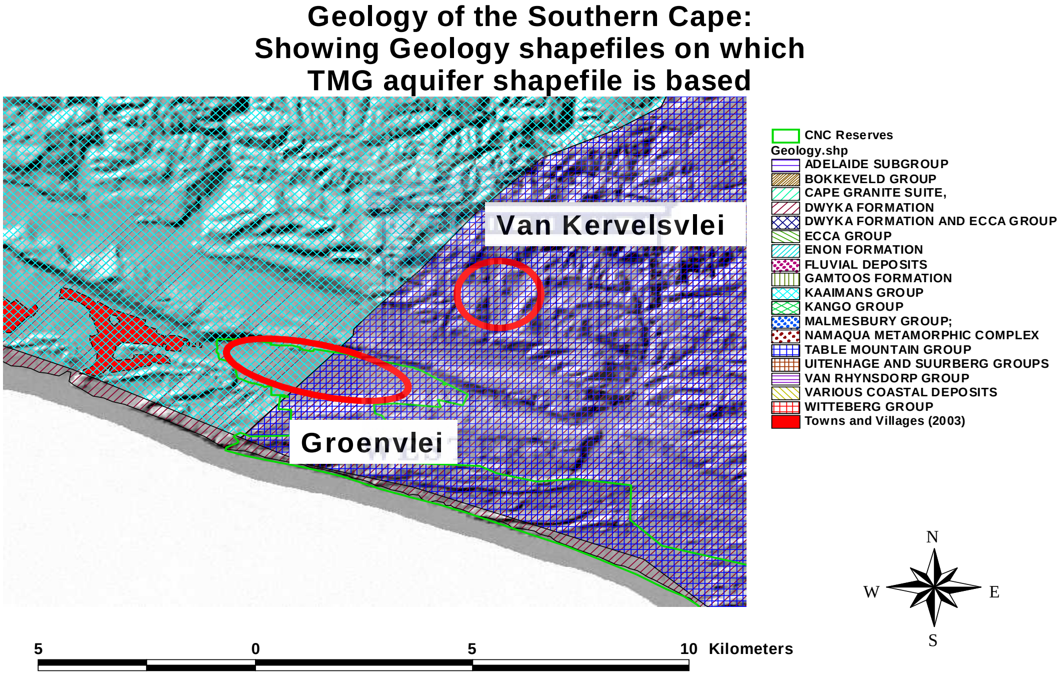

Figure 7.2. GIS layer showing the geology of the area on which the TMG aquifer was based by Fortuin (2004). This map shows the deep layers of the geological units, and does not show the upper outcrop layers (See Figure 7.3).

Rosewarne (2002) also described this coastal plain domain of the Southern Cape as comprising a wave-cut platform, bounded inland by foothills of coastal mountain ranges where there is usually a covering of quaternary sands and calcrete, with which shallow groundwater is associated. This is in line with Parsons view that also points towards the possibility of deep circulating TMG discharges in the underlying Intermontane Domain. Rosewarne (2002) also states that groundwater in the Coastal Domain have a longer residence time than that associated with the Intermontane Domain, which gives rise to water collecting various chemicals, and indirect recharge from the overlying sediments. This result in EC values ranging from 50-100 mS/m to as high as 5-819 mS/m in Port Elizabeth. According to him the groundwater quality can also vary significantly over short distances.

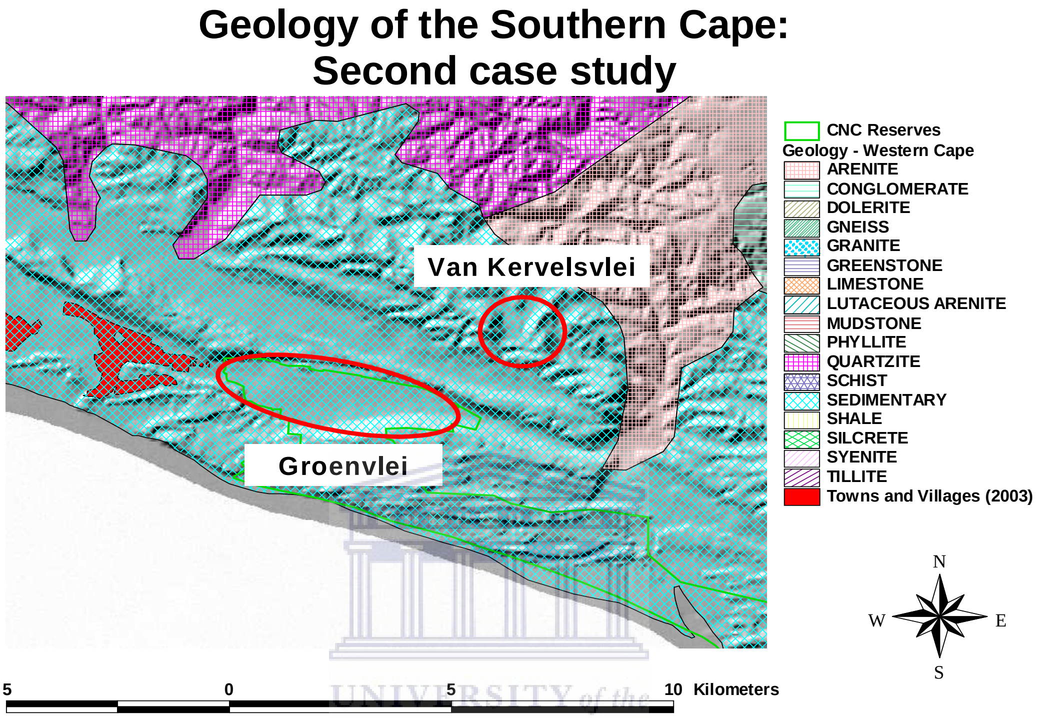

Figure 7.3. Geological *components and outcrop areas*, with the *Arenite and Quartzite containing TMG* located just north-east of Van Kervels and Groenvlei (Council of Geoscience, 2001), indicating the close proximity of the TMG aquifer (Roets *et al.*, 2008b).

7.2.1.2. Climate

Both Groenvlei and Van Kervelsvlei are within a 10 km radius of each other and have a mild and temperate climate with rain falling throughout the year. Slightly higher rainfall peaks are experienced in autumn and spring, which is typical of the Southern Cape. Fijen (1995) give an average rainfall figure of 655 mm/anum, and an annual evaporation 1130 mm/anum for Groenvlei. Minimum and maximum temperatures are typically influenced by the temperate effect of the ocean that is close to both wetlands, with frost-free winters and mild summers.

7.2.1.3. Topography

Figure 7.2 and 7.3 were generated on a Digital Elevation Model (DEM) for the study area which clearly shows that Groenvlei is situated in a low-lying area (+- 2.5 meters above mean sea level) with prominent fixed dune systems to the south that can reach elevations greater than 100 meters above mean sea level (mamsl). All the wetlands in this area, Swartvlei, Groenvlei, Ruigtevlei and the other lake systems to the west, are associated with the linear east-west embayment or wave cut platform (Rosewarne, 2002; Parsons 2005a). Van Kervelsvlei is located in the undulating landscape caused by fixed dune rock and alluvial valley deposits to the north-east of Groenvlei, at about 149 mamsl.

7.2.1.4. Vertebrate fauna of Groenvlei

Groenvlei is a popular tourist destination and very famous amongst freshwater anglers catching bass. Unfortunately the fish of Groenvlei is dominated by five exotic species namely: Common Carp *Cyprinus carpio*, Mozambican Tilapia *Oreochromis mossambicus*, Bluegill Sunfish (*Lepomis macrochirus*), Mosquito Fish (*Gambusia affinis*) and Largemouth Bass (*Micropterus salmoides*). The only two indigenous fish that is on record in Groenvlei are the Estuarine Round-herring (*Gilchristella aestuaria*) and Cape Silverside (*Atherina breviceps*) (Skelton, 1993), the only fish to survive after Groenvlei was presumable cut off from the sea. These two species have over the years adapted to this modified freshwater system. Groenvlei is also home to at least one breeding pair of Cape Clawless Otter *Aonyx capensis*. Many water birds are resident on Groenvlei including some migratory birds.

7.2.1.5. Vegetation of Groenvlei and Van Kervelsvlei:

Groenvlei is surrounded along its entire perimeter by different species namely, *Phragmites angustifolia*, *Juncus kraussi, Typha capensis, Cladium mariscus, Thelypteris palustris, Hydrocotyle verticillata*, *Senecio helenifolia*, *Scirpus sp.* and *Scrophulariacea* (Martin, 1960; Van Der Merwe, 1979; Goldblatt and Manning, 2000).

Van Kervelsvlei is a peat wetland dominated by reeds, sedges and other wetland species namely: *Typha capensis, Cladium mariscus, Thelypteris palustris, Juncus kraussi* and *Carex clavata* (Martin, 1960; Van Der Merwe, 1979; Goldblatt and Manning, 2000), with no open water. The fixed dune system surrounding Van Kervelsvlei has been intensively planted with *Pine* sp. plantations.

7.2.2. Site description

Both wetlands are close to the Southern Cape coastline and are surrounded by the same fixed dune system (See Figure 7.2 and 7.3).

Groenvlei has a surface water area of 2.5 km^2, with a length of about 3.7 km and a width of 0.9 km. The water level in the wetland fluctuates between 2.2 and 3.43 m (mean of 2.76 m) above mean sea level (Parsons, 2007), and the open water has a perimeter of 10.3 km. The average depth of the open water is 3.7 m with a maximum depth of 6 m, and a catchment area of 13.8 km^2 (Fijen, 1995). Only three small shoreline areas are present which limits the bird species visiting the lake. It is one of CapeNature’s Nature Reserves and is therefore statutory protected and viewed as an ecologically sensitive aquatic ecosystem being the only endorheic coastal lake in South Africa.

Van Kervelsvlei is one of very few and unique *Sphagnum* peat wetlands in South Africa and covers an area of about 50 hectares. Van Kervelsvlei has no open water but the plant roots and tussocks are permanently inundated with water. The peat is in access of 10 meters deep (Irving and Meadows, 1997). Van Kervelsvlei is classified as a floating bog, a rare and interesting landform in Africa, and is located in the fossil dune fields at 34° 0'71''S 22° 54' 22''E in the southern Cape (Irving and Meadows, 1997). The surface is covered by a mat of sedge vegetation to a depth of 2m below the surface. The water body is also endorheic and isolated from rhinotrophic input.

7.3. Materials and methods

Groundwater and surface water quality, and groundwater level data, were measured at pre-selected sites in the wetlands, to characterise the origin of groundwater feeding these wetlands.

Pre-selected sites were determined along hypothetical hydrological gradients that could indicate a link between the TMG aquifer and both wetlands individually and collectively. Piezometers of different depths were installed at these sites to determine groundwater level and quality. Surface water assessments were done at piezometer sites in both wetlands, where it was present to enable comparing groundwater and surface water (Roets *et al.*, 2008b).

7.3.1. Surface water quality

The electrical conductivity (EC) profile for Groenvlei was assessed to develop a three-dimensional (3-D) interpolation for the lake. This was achieved by using sampling points generated in GIS (Arcview 3.3), which was overlaid on digital aerial photograph of Groenvlei. The GIS grid divided the lake into blocks by north-south (gridlines 300 meters apart) and east-west running transects (gridlines spaced at 150 meters) dissecting each other perpendicular. At each point where transects intersected on the open water, sampling points were selected. Measurements were performed at each of the 53 points. At each sampling point conductivity, temperature, pH and depth was measured as the Yellow Springs Instruments (YSI) 6600 probe was submerged. The YSI 6600 probe was set to measure the parameters at a two second interval (Roets *et al.*, 2008b).

Because Van Kervelsvlei did not have open water like Groenvlei, the conductivity, temperature, pH and depth measurements were taken at the piezometers and open surface water where present.

7.3.2. Groundwater levels and water quality

Piezometers were installed at pre-selected points in both wetlands. The sites were selected based on the direction of underlying geological contacts, and expected groundwater discharge gradients (Figure 7.1). At each site selected for the study of plant nutrients by Roobroeck *et al.* (in press), two shallow piezometers were installed at depths of 0.5 m and 1 m. EC measurements were performed at six different times during a period starting mid winter until mid summer.

Figure 7.4 shows all the pre-selected study sites in both wetlands. The study sites were selected based on the direction of underlying geological contacts, and expected groundwater discharge gradients (Figure 7.3).

The location of all piezometers near the Groenvlei CapeNature office is given in Figure 7.4. Two were installed at 11m and 2m depth respectively, GVBH site. Others were installed on the western side just inside the open water and on the sand beach (11 m depth, GVWWa site), and three at the eastern side (11 m, 7 m, 5 m depth, GVE site). Similarly piezometers were installed at Van Kervelsvlei (VKA and VKB). At site VKA (north western site) a piezometer was installed to a depth of about 8.2 m, while at site VKB (south eastern site), two piezometers were installed, at respectively 5 m and 11 m depth. Existing piezometers for groundwater studies at LPG and LPST were included in the assessment (Roets *et al.*, 2008b).

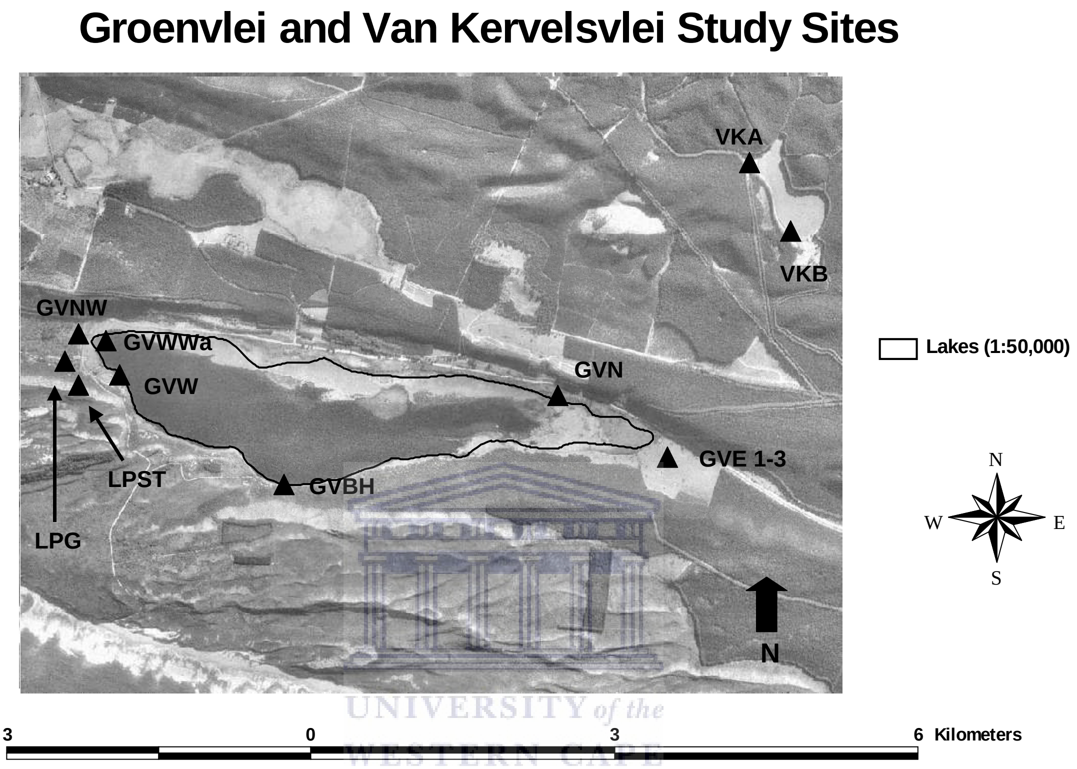

Figure 7.4. Aerial photo showing the location of study sites for Groenvlei and Van Kervelsvlei (Roets *et al.*, 2008b).

At all piezometers water level and water quality variables were measured *in situ*. Variables included pH (for initial assessments only), EC and temperature of fresh groundwater. A water sample collected in the piezometers was also send to a commercial laboratory for analysis of pH, EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-}, B, Mn^{2+}, Cu^{2+}, Zn, P, NH_4^+-N and NO_3^--N. Only pH, EC, Na^+, Fe^{2+} and Cl^- were used for the characterisation of TMG aquifer water (Roets *et al.*, 2008b).

7.3.3. Statistical methods

All the EC and temperature data collected at the different piezometer locations, at different depths and at different dates were statistically analysed using SAS statistical software (SAS, 1999). Not all the combinations were measure on the different dates, therefore the data were treated as an incomplete block design with the different dates as blocks. The treatment design was factorial with factors 10 locations (GVBH, GVW, GVWWa, GVNW, LPG, LPST, GVE, GVN, VKA and VKB) and 10 Depths (0.5 m, 1 m, 2 m, 6.5 m, 3 m, 5 m, 6 m, 7 m, 8.2 m and 11 m) replicated in 6 blocks (30/7, Blab, 19/7, 12/10, 27/10 and 29/9). The EC and Ln(EC) transformed data were subjected to a two factor analyses of variance. A Shapiro-Wilks test was performed on residuals to test for deviations from non-normality (Shapiro and Wilk, 1965). Student t-LSD (Least significant difference) was calculated at a 5% significance level to compare means of significant effects (Roets *et al.*, 2008b).

Furthermore a multivariate cluster (using EC and temperature means) was based on the distance between clusters, using the centroid method. As the distance between clusters increased the cluster groupings decreased (Roets *et al.*, 2008b).

7.4. Results:

7.4.1. Surface water quality

The 3-D interpolation of the data generated during the 3-D assessment of the EC profile for Groenvlei is given in Figure 7.5. pH measurements showed the same distinct gradient as EC, suggesting freshwater discharges into Groenvlei from both the west and the east. The eastern end was distinctly fresher. Throughout Groenvlei an east-west gradient could be determined with a strong indication of freshwater discharges located to the eastern and western side of the open water. None of the sampling points elucidated a north-south gradient. The eastern side consistently had the lowest EC values ranging between 444 mS/m and 456 mS/m. The western side showed EC values ranging between 447 mS/m and 465 mS/m, with the lower values measured relatively localised and not consistent with the higher values. The freshest discharges on the west were determined at depth (Roets *et al.*, 2008b).

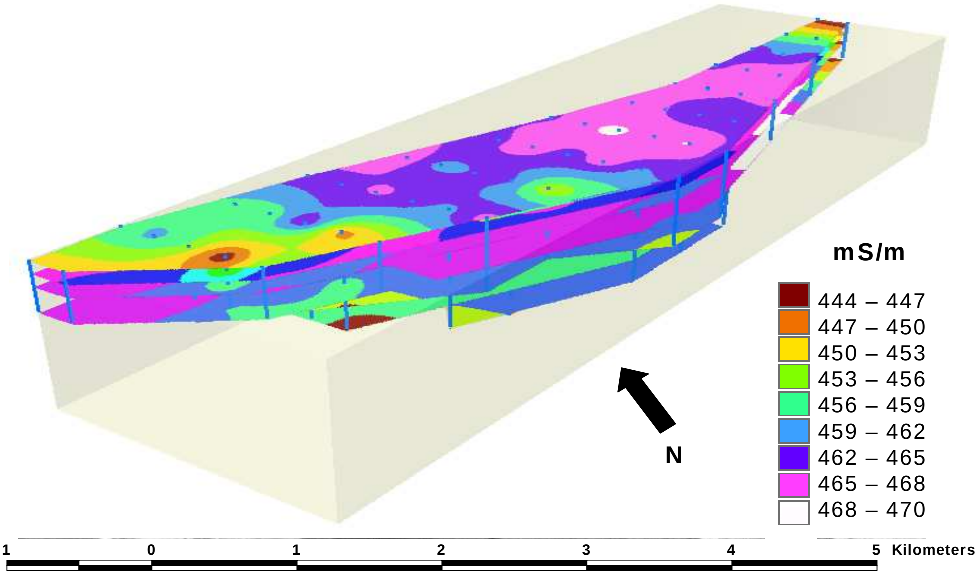

Figure 7.5. The 3-dimensional interpolation of the EC regime in Groenvlei (Roets *et al.*, 2008b).

7.4.2. Groundwater levels and water quality

Average EC values of surface water for both wetlands are given in Figure 7.7. Surface water EC values showed two distinct groupings, with the Groenvlei north site (GVN), Van Kervelsvlei site A (VKA) and site B (VKB) in the same grouping. Groenvlei west (GVW+GVWWa) and Groenvlei south (GVBH) surface water clearly had much higher EC values and grouped together. The EC values of the groundwater measured in the piezometers showed a similar picture, with piezometers on the western and southern side close to Groenvlei, GVW, GVNW, GVWWa, and GVBH showing the highest average EC values, ranging between 450 mS/m and 800 mS/m (Figure 7.6). The LPG and LPST sites, located on the western side of Groenvlei at least 500 meters from the open water, also measured lower EC values around 53 to 83 mS/m. Both VKA and VKB sites, two of the three GVE sites, and GVN sites had the lowest EC values, ranging between 16 to 88.5 mS/m (Roets *et al.*, 2008b).

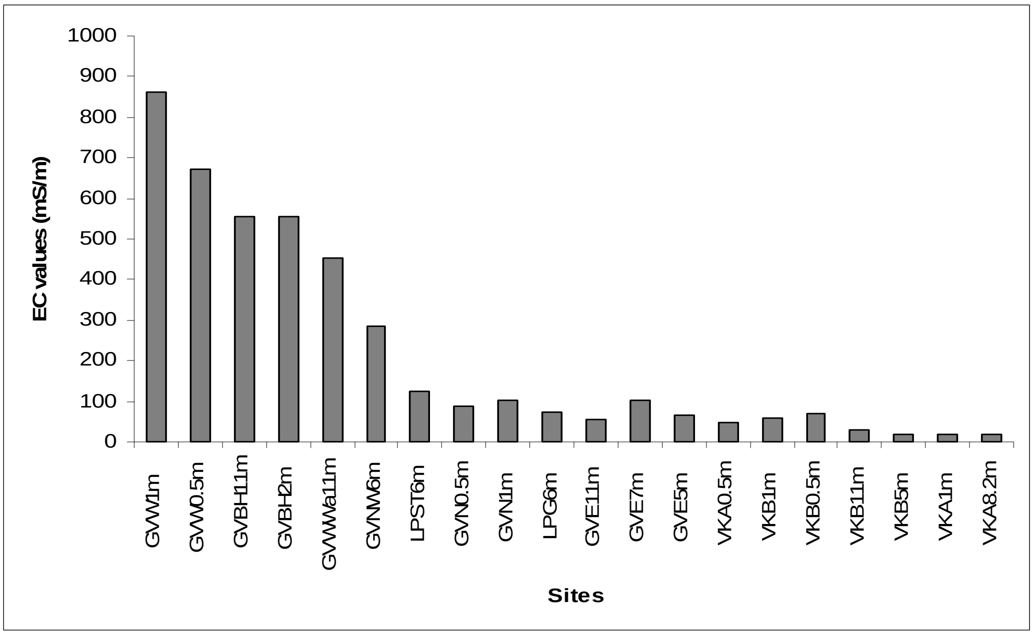

Figure 7.6. Averages of EC values measured in the piezometers of both wetlands on 29 September 2006, 12 October 2006 and 27 October 2006 (Roets *et al.*, 2008b).

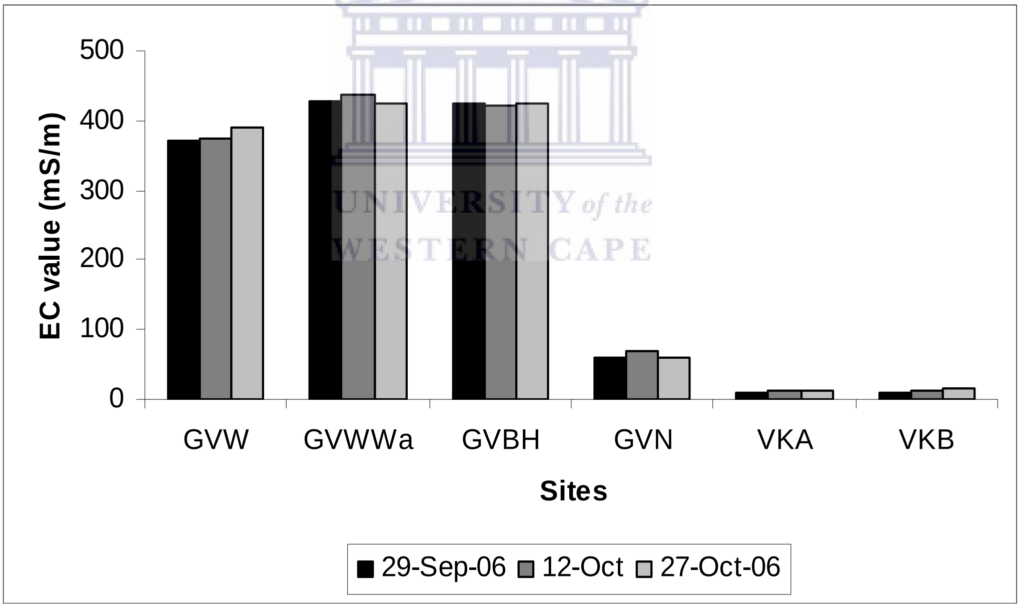

Figure 7.7. Averages of EC values measured in surface water of both wetlands on 29 September 2006, 12 October 2006 and 27 October 2006 (Roets *et al.*, 2008b).

Both the original EC-values and Log transformed values showed significant evidence of non-normality during statistical analysis. The kurtosis for EC residuals was 6.78 and the skewness 0.59, and for the Log transformed data both values decrease with the kurtosis 2.53 and skewness -0.14 but not enough to make the Shapiro-Wilk test non-significant (Shapiro and Wilk, 1965). Deviations from normality were due to kurtosis and not skewness, Therefore, interpretation of the untransformed data was continued (Glass *et al*., 1972).

Table 7.1. Two factor analysis of variance for EC and log-transformed EC data for both wetlands (Glass *et al*., 1972; Roets *et al.*, 2008b).

	EC-VALUE			**LN(EC-VALUES)**		
SOURCE	**DF**	**MS**	**P**	**DF**	**MS**	P
Block	5	881960.0	0.1313	5	0.6156	**0.0308**
Location	9	66803249.9	**<0.0001**	9	15.4130	**<0.0001**
Depth	6	473930.8	0.4711	6	0.9169	**0.0018**
LocxDep	4	1626647.4	0.0158	4	0.6401	**0.0358**
Error	95	504790.5		95	0.2381	
Corrected Total	119			119		
SHAPIRO-WILK	**P < 0.01**			**P < 0.01**		

***DF** = Degrees of freedom, **MS** = Mean square and **P** = probability*

The results from the univariate analysis (Table 7.1) clearly showed statistically significant differences for piezometer locations (P<.0001), and for piezometer location and depth combined (P=0.0158) (Roets *et al*., 2008b).

Table 7.2. Mean values for EC measurements indicating "Location" as main effect (Roets *et al.*, 2008b).

Location of Piezometer	**Number of Replicates**	**Mean values**	**Standard Deviation**	**t - Grouping**
GVW	8	7673.8	1789.21	**a***
GVBH	12	5550.9	616.77	**b**
GVWWa	5	4530.4	291.17	**c**
GVNW	3	2831.3	2030.32	**d**
LPST	16	1252.4	886.25	**e**
LPG	14	739.4	127.53	**ef**
GVN	8	957.0	91.47	**ef**
GVE	18	744.5	740.33	**ef**
VKA	14	290.0	214.11	**f**
VKB	22	438.0	312.05	**f**
LSD(p=0.05)		**683.19**		

* *Mean values with the same letter or letters do not differ significantly at the 5% level*

Table 7.2 clearly shows that LPG, GVN, GVE, VKA and VKB separated statistically from the rest of the piezometer locations. GVW, GVBH, GVWWa and GVNW clearly had no statistical similarity with each other or with the rest of the grouping. LPST seems to be the only outlier but showed similarity to LPG, GVN and GVE (Roets *et al*., 2008b).

Data presented in Table 7.3 show the similarity between EC measurements based on the piezometer position and depth for both wetlands. All the Van Kervelsvlei (VKA and VKB), Groenvlei north (GVN), Groenvlei east (GVE), and some localised Groenvlei western (LPG and LPST) piezometers show statistical similarity, with the Groenvlei west "proper" (GVW, GVWWa and GVNW) and Groenvlei south (GVBH) piezometers being separated on their own with no statistical similarity to each other or the rest of the groupings (Roets *et al.*, 2008b).

LPST was again an outlier but showed similarity to the fg-grouping. VKA (1 m and 8.2 m) and VKB (5 m and 11 m) separated but still showed similarity to the fg-grouping (Roets *et al.*, 2008b).

Results from the multivariate cluster analysis, using EC and temperature measurements of the water in the piezometers of Groenvlei and Van Kervelsvlei, clearly elucidated distinct difference between specific sites for both wetlands (Figure 7.8). Groenvlei east sites (GVE 5 m, GVE 7 m), and Van Kervelsvlei sites (VKA 0.5 m, 1 m and 8.2 m, and VKB 5 m and 11 m) clustered together. The shallow piezometers of Van Kervelsvlei site B (VKB 0.5 m and 1 m), Groenvlei north sites (GVN 0.5 m and 1 m), Groenvlei east (GVE 11 m) and the LPG and LPST sites clustered together. Piezometers in Groenvlei south and west, GVBH (2 m and 11 m) GVW (0.5 m and 1 m), GVNW (6 m), and GVWWa (11 m) had the highest EC values and cluster together. Figure 7.8 shows distinct similarities between the Van Kervelsvlei sites and Groenvlei's northern and eastern sites by clustering together (Roets *et al.*, 2008b).

Table 7.3. Mean values of EC measurements showing "Location by depth" interaction (Roets *et al.*, 2008b).

Location of Piezometer	Number of Replicates	Mean values	Standard Deviation	t - Grouping
GVW1m	4	8627.0	635.4	**a***
GVW0.5m	4	6720.8	2154.8	**b**
GVBH11m	6	5540.7	700.5	**c**
GVBH2m	6	5561.2	588.1	**c**
GVWWa11m	5	4530.4	291.1	**d**
GVNW6m	3	2831.3	2030.3	**e**
LPST6m	16	1252.4	886.2	**f**
GVN0.5m	4	876.3	18.2	**fg**
GVN1m	4	1037.8	42.4	**fg**
LPG6m	14	739.4	127.5	**fg**
GVE11m	6	546.8	107.6	**fg**

Location of Piezometer	Number of Replicates	Mean values	Standard Deviation	t - Grouping
GVE7m	6	1021.7	1234.4	**fg**
GVE5m	6	665.0	425.9	**fg**
VKA0.5m	5	483.6	248.2	**fg**
VKB1m	5	577.8	267.0	**fg**
VKB0.5m	6	693.3	385.8	**fg**
VKB11m	6	281.0	90.9	**g**
VKB5m	5	180.4	35.8	**g**
VKA1m	5	191.8	118.6	**g**
VKA8.2m	4	170.7	13.6	**g**
LSD(p=0.05)		**879.04**		

** Means with the same letter or letters do not differ significantly at the 5% significant level*

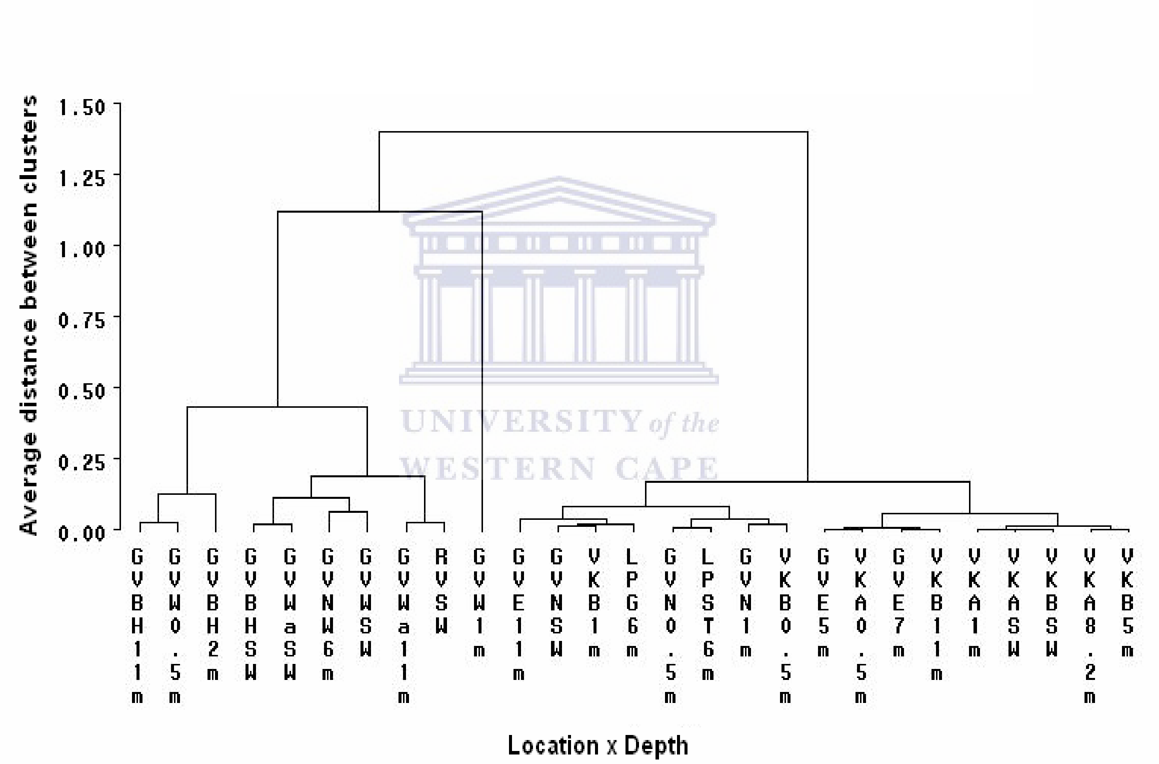

Figure 7.8. Multivariate cluster analysis using variables EC and water temperature: average distance method dendrogram for similarities. Dendrogram shows data of measurements taken in piezometers and surface water for both wetlands (Roets *et al.*, 2008b).

Table 7.4 lists the values of the water quality parameters measured at piezometer sites for both wetlands, showing those falling within the ranges characteristic of TMG aquifer water (The underlined values falls outside the ranges characteristic of the TMG).

Table 7.4. Chemical data for water samples collected on 30/7/2006 at all piezometers. Underlined values fall outside the concentration ranges typical of water from the TMG aquifer (Roets *et al.*, 2008b).

Water quality parameter	**pH**	**EC**	**Na^+**	**Fe^{2+}**	**Cl^-**
Piezometer Sites		**mS/m**	**mg/l**		
GVE 5 m	7.0	121	173.2	0.66	299.6
GVE 7 m	6.5	48	60.3	3.92	115.4
GVE 11m	7.5	72	71.6	0.00	127.8
VK A 1m	6.6	33	23.4	10.28	42.3
VK B 0.5m	6.0	20	19.1	9.49	34.4
VK B 1m	5.3	21	34.0	6.96	59.0
LPST 2	7.4	101	123.8	0.02	172.7
LPG	7.4	72	72.6	0.15	170.1
VK A 0.5m	6.3	72	41.0	22.68	75.8
VK B 11 m	5.7	16	31.9	382.23	132.2
GVBH 11 m	7.3	586	542.6	0.33	1106.8
GVBH 2 m	7.1	605	818.9	0.60	1569.4
GVBH Wa	8.1	474	727.0	0.00	1299.7
LPST 1	7.3	362	530.4	0.07	906.7
GVNW	7.8	464	699.7	0.06	1237.2

Very low EC values (below 35 mS/m) were recorded in piezometers in Van Kervelsvlei (Site VKA and VKB), and Groenvlei east (GVE 7 m and 5 m). EC values remained low throughout all the piezometers that elucidated water quality showing TMG aquifer characteristics. Only the Van Kervelvlei sites (VKA and VKB), Groenvlei sites (GVE 7 m and 11 m), LPST 2 and LPG showed values for EC, Na^+, Fe^{2+} and Cl^- falling within ranges characteristic of TMG aquifer water. Parameter values for TMG aquifer water range as follows: EC 9.2-155 mS/m (average: 30 mS/m), Na^+ 7.2-232.8 mg/l (average: 30.8 mg/l), Fe^{2+} <0.1-15.4 mg/l (average: 3.3 mg/l) and Cl^- 6.1-395.2 mg/l (average: 56.2 mg/l) within the Nardouw Formation, and EC 2.6-26.3 mS/m (average: 10.4 mS/m), Na^+ 2-21.2 mg/l (average: 11.1 mg/l), Fe^{2+} 0.1-0.2 mg/l (average: 0.2 mg/l) and Cl^- 4.5-34.1 mg/l (average: 18.0 mg/l) for the Peninsula Formation (Brown *et al*., 2003).

The altitude differences between Van Kervelsvlei (148 m) and Groenvlei (2.15 m) above mean sea level (msl) can support a hydraulic link. Table 7.5 gives the altitude of the piezometer positions above msl, and the water level measured inside the piezometers at each site on the same day (Roets *et al.*, 2008b).

Table 7.5. Altitude of piezometer positions above mean sea level (msl), and average water level above msl at each piezometer site (m) (Roets *et al.*, 2008b).

Site code of Piezometer	Piezometer altitude (m) above msl	Water level in piezometer, or surface water level where applicable
VKA	148.63	148.6 surface water level
VKB	148.89	148.8 surface water level
GVE	6.36	-3.27
GVN	2.15	2.15 surface water level
GVBH	2.17	2.16 surface water level
GVW	2.4	2.16 surface water level
LPG	6.59	-4.14
LPST1	1.76	-0.2
LPST2	1.68	-0.2
LPST3	3.19	-0.89
Groenvlei water level	2.16	

The water levels recorded in the piezometers during the follow up measurements, clearly show that the water level in the piezometers to the east of Groenvlei, at GVE sites, can support a hydraulic gradient between Groenvlei east (which is on the watershed) and Groenvlei water level. The piezometer water level was recorded at around 3.2 m below ground level, with ground level at 6.36 m (Table 7.5). This means the water level in the piezometers was at 3.09 m, about 1m higher than the water level in Groenvlei open water (Roets *et al.*, 2008b).

However, the piezometer levels above msl, and water levels at LPST1 and LPST2 indicated that the water level in the piezometers were lower than the water level on the western side of Groenvlei.

7.5. Discussion

7.5.1. General hydrological characteristics

All the data presented, along with the 3-D interpolation of EC for Groenvlei, points towards a difference in groundwater quality, discharge regimes and groundwater sources for both wetlands. These distinct differences are elucidated because of the unique characteristics resulting from the underlying geology and aquifers (Figure 7.2 and 7.3) (Roets *et al.*, 2008b).

The hydrochemical data of the groundwater from this study suggest that Groenvlei and Van Kervelsvlei are dependent on groundwater from the TMG aquifer. Both the clustering of EC and Temperature values, the statistical differences elucidated on piezometer location, piezometer location combined with depth, and the potential hydaulic gradient between Van Kervelsvlei and Groenvlei support this view. Based on the water quality data, the southern and south-western side of Groenvlei is clearly more saline. The clear clustering of EC and Temperature values (Figure 7.8), and the t-test grouping of the north-eastern part of Groenvlei and Van Kervelsvlei clearly supports a shared groundwater source feeding both (Roets *et al.*, 2008b)**.**

This link was further supported by the water quality parameters listed in Table 7.4, which give the parameter values distinctive of TMG aquifer water. This grouping of piezometers included both Van Kervelsvlei site A and B (VKA and VKB), and the two deepest piezometers of Groenvlei East (GVE 7m, and 11m) (Roets *et al.*, 2008b).

Van Kervelsvlei and Groenvlei are both hydrologically isolated from rhinotrophic water. Topogenous discharge is the only supply to their prevalent water regime. The strong limnotrophic (groundwater) input noted within both Van Kervelsvlei and Groenvlei by Roobroeck *et al*. (in press) also strongly suggests a connection of these systems to the TMG aquifer. The thalassotrophic (saline) nature of the western and south-western side of Groenvlei could be attributed to the fact that this is a typical ‘flow-through’ system that got fresher after being cut off from the sea around 5000 years ago (Parsons, 2007).

The hydrological link between the TMG aquifer and Groenvlei and Van Kervelsvlei is further supported by the findings of Roobroeck *et al*. (in press) who found that the GVW site showed a much higher EC compared to those of the GVE and GVN sites. The EC of samples taken at the GVW largely exceeded that of samples taken from Van Kervelsvlei, while the EC measured at the GVE and GVN levelled those of Van Kervelsvlei. They also reported a clear difference in pH between both locations. Samples from Van Kervelsvlei (VKA and VKB) generally showed a lower pH than those from Groenvlei (GVE and GVN) (Roobroeck *et al*., in press).

Results by Roobroeck *et al*., (in press) on vegetation composition showed that the vegetation composition at the eastern side of Groenvlei (GVE) was remarkably similar to that of the southern part of Van Kervelsvlei (VKB) with *Cladium mariscus* occurring at both. They state that the hydrologic, as well as floristic assets indicate that both Groenvlei and Van Kervelsvlei receive water from a similar groundwater resource (Roets *et al.*, 2008b).

7.5.2. Van Kervelsvlei

Water quality data collected from Van Kervelsvlei clearly show characteristics of TMG aquifer water with low EC (16-100 mS/m), low pH, low Fe^{2+} concentrations, low Cl^- concentrations and low water temperatures. Site VKB (11 m) was the only exception and measured a high Fe^{2+} concentration (382.23 mg/l). This could be attributed to the presence of the Nardouw Formation at this end. The groundwater chemistry as well as the nutrient limitation (especially phosphorus) (Roobroeck *et al.*, in press), elucidates the major limnotrophic nature of Van Kervelsvlei. Its relatively high bicarbonate content is most probably caused by the presence of peat, known to be carbonate-bearing (Almendinger and Leete, 1998). Fens and mires with exclusive groundwater discharge often have very low P-inputs, as PO_4^{3-} is adsorbed onto aquifer bedrock (Boeye *et al.*, 1997; El Kahloun *et al.*, 2005; Wassen *et al.*, 2005).

Roobroeck *et al.* (in press) also report that the tussocks formed by *Carex clavata, Juncus krausii* and *Cladium mariscus*, are a rare strategy to escape anaerobic conditions and increase the nutrient availability. This strategy was also found by El Kahloun *et al.* (2000; 2003; 2005) in P-limited fens in Belgium and in the Biebrza valley in Poland. The same specific hydrochemical conditions in Van Kervelsvlei are responsible for the occurrence of this specific vegetation composition. The “Cape Action Plan for People and the Environment (CAPE): The conservation of freshwater ecosystems in the Cape floral Kingdom” (Cowling *et al.*, 1999) reports *Carex clavata* as an endemic species, relying on a threatened habitat (Roets *et al.*, 2008b).

7.5.3. Groenvlei

Although the EC gradient elucidated in the 3-D EC interpolation profile from west to east is not steep (varying between 444 and 470 mS/m), it does indicate the discharge of fresher water from the west, and even more pronounced from the east. This was quite surprising considering that the water-shed to the east of Groenvlei is very close to its eastern extreme. There is a very steep drop in the landscape from the watershed eastwards down to the Goukamma River, which is at sea level, showing tidal exchange under open mouth conditions. The river level is therefore clearly below the Groenvlei water level, which is at 2.16 m above msl (Roets *et al.*, 2008b).

EC measurements in the piezometers in the reeds on the north-eastern end of Groenvlei (GVN) clearly indicate freshwater discharges from north-east. This north-south gradient was not picked up during the 3-D interpolation probable because it exists in the less mixed wide vegetated perimeter of the wetland in particularly the north-eastern end.

The thalassotrophic nature of Groenvlei water, as explained earlier, must results from the fact that Groenvlei is a flow-through system discharging water to the sea (Parsons, 2007). Roobroeck *et al*. (in press) found considerably high concentrations, as well as partial molar charge fractions, of calcium and bicarbonate in deep piezometers, indicating a limnotrophic source. However, it is the eastern part of Groenvlei that showed more lithotrophic conditions indicating more freshwater discharge from the north-east. The Groenvlei north site (GVN) showed low EC values (between 60.6 and 88.5 mS/m) confirming freshwater discharges coming from the north-east. On the southern side of Groenvlei (GVBH) no freshwater discharges could be established. A borehole drilled by Parsons in early 2006 on the southern side of Groenvlei, measured a high EC around 400 mS/m, and the water level indicated outflow of water from Groenvlei to the sea (Parsons, 2007).

The data found at the LPG and LPST sites are exactly in line with data collected by Parsons (2005a, 1992), showing possible fresh water discharges from the fixed dune system on the western side of Groenvlei. Storm water discharges from the town of Sedgefield close to this site could influence the freshness of the water. The cluster analysis (Figure 7.8) confirms this trend. Parsons (2007) also found the hydraulic gradient in this region to be very flat (0.0009).

The origin of the consistent fresh water influx from the west that was also found by Parsons (2005a) cannot be explained, except for the storm water discharges. However, slightly higher EC values were recorded at LPST and LPG. The sites on the western and southern side of Groenvlei (GVW and GVBH) had the highest EC values that were close to or even higher than the Groenvlei surface water EC values.

The 3-D interpolation generated for Groenvlei further supports the notion that the eastern side of Groenvlei is getting fresher water (EC values around 444 mS/m). Although not conclusive on where the fresher water is coming from, it is also pointing towards TMG aquifer discharge from the north-east coinciding with the geology of the area and data presented above (Roets *et al.*, 2008b). Some fresh water is also discharged from the west from the fixed dune system as was confirmed by Parsons (2005a).

7.6. Conclusion

The similarity in hydrochemical properties and vegetation composition between Van Kervelsvlei and the eastern side of Groenvlei, indicate a connection between both systems. Their groundwater dependency and the interconnection make them sensitive to hydrological disturbance at a local and regional scale. With the ever increasing possibility of intensive water abstraction in the vicinity of Groenvlei, it will probably have a direct local effect, increasing its thalassotrophic state. This will also have an indirect regional effect that could alter the hydrological regime of Van Kervelsvlei that will affect the valuable endemic vegetation in this threatened habitat. With the increasing demand for more water in the Sedgefield area, authorities should take this into consideration when planning to use groundwater in the Groenvlei region (Roets *et al.*, 2008b).

Further research on the hydrogeology of the area will be necessary to determine the amounts of freshwater being discharged from the TMG aquifer to Groenvlei and Van Kervelsvlei. A better understanding of the groundwater flow directions and gradients on the north-eastern side should receive urgent attention.

The complexity of the interactions between groundwater and surface resources highlight the importance of an integrated approach towards water resource planning globally. Many aquatic ecosystems may be far more groundwater dependent than originally conceptualised, particularly where fractured rock aquifers, both confined and unconfined, dominate.

CHAPTER EIGHT

A Geographical Information Systems (GIS) model highlighting groundwater dependence of aquatic ecosystems associated with the TMG aquifer.

8.1. Introduction

In order to give effect to the conceptual understanding that was developed in Chapter 5 on the groundwater discharges that contribute to the flow regime in streams and rivers associated with the TMG aquifer in the “TMG aquifer daylight-domain”, and the discharges associated with the “TMG aquifer surface water interface-domain” (Roets *et al.,* 2008), it was essential to develop a tool by which this understanding on the intimate link between groundwater and surface water, could be put into practice. This has never been done before for aquatic ecosystems associated with the TMG.

In the early 1980’s, most publications on groundwater surface water interactions did not look at the dependency and potential vulnerability of selected ecosystems on groundwater, although many publications clearly recognised the relationship (Alpin, 1976; Bestow, 1976; Arnold and Wallis, 1986). It was only later that researchers started concentrating on the identification and classification of groundwater dependent ecosystems (Semeniuk and Semeniuk, 1994; Commander, 2000).

With regard to the use of GIS for this purpose, Heywood *et al.* (2002) state that GIS has become an accepted tool for the management and analysis of spatial data in the twentieth century. Semeniuk and Semeniuk (1994) and Commander (2000) also identified the use of GIS as the most effective means of combining, synthesising, comparing and correlating various databases in an attempt to identify groundwater dependent ecosystems. This was also done very effectively by Fortuin (2004), when she specifically looked at potential conflict between ecosystems and groundwater use from the TMG aquifer.

Fortuin *et al.* (2004) successfully demonstrated that by using GIS technology and spatial modelling techniques, spatial data layers could be developed to highlight areas that have a high groundwater development potential and high conservation priority for the protection of sensitive ecosystems in the TMG of the Cape Fold Belt.

In this study advances in GIS technology was used to develop different GIS layers in order to map areas where TMG aquifer discharges can be expected, and where these discharges can be expected to have an ecological effect in the landscape, particularly with regard to aquatic ecosystems. The development of suitable GIS layers linking the conceptual model of Chapter 5 (Roets *et al.,* 2008) to spatially defined areas will enable decision makers to know where the aquatic ecosystems are located that may be vulnerable to groundwater use from the TMG aquifer.

The major difference between the approach followed in this model and that developed by Fortuin (2004), was that the Fortuin model looked at sensitive ecosystems from a botanical point of view, while this model focused on the sensitivity of aquatic ecosystems. TMG aquifer discharges have been confirmed to aquatic ecosystems associated with the TMG (Roets *et al.,* 2008; Roets *et al.*, 2008b; Roets *et al.*, in prep) and had to be included.

Le Maitre *et al.* (1999) also found that the effects of the artificial lowering of the water table on plants and vegetation communities can be divided into two inter-related groups, namely:

- Groundwater dependence of riparian vegetation resulting from groundwater flowing into or out of the river system (influent or effluent streams); and
- Groundwater dependence of wetlands.

Although the statement by Le Maitre *et al.* (1999) is true, the major shortcoming in this approach is that a change in water table would affect the functioning of the whole aquatic ecosystem by affecting the flow in the stream or river, not just the riparian vegetation. The effects on the riparian vegetation and or wetlands would result mainly because the hydrology (flow regime) has been affected by groundwater use (Roets *et al.*, 2008).

The approach during the development of this model was to use existing GIS data layers developed by Fortuin (2004) and Cape Action Plan for People and the Environment (C.A.P.E.) (Cowling *et al.*, 1999, Impson *et al.,* 1999), and to geospatially intersect these layers to produce a new layer highlighting sensitive aquatic ecosystems associated with the TMG aquifer. The objective of this approach was to link the conceptual model (Chapter 5 - Roets *et al.*, 2008) to a management tool for implementation by water resource managers.

8.1.1. Hypothesis and objectives

The hypothesis for this study was that it will be possible to develop a new GIS model highlighting areas in the TMG having both a high groundwater development potential and a high conservation value for aquatic ecosystems. This could be achieved by geospatial intersections of existing GIS data layers. The resultant layer could be geospatially linked to quaternary catchments containing aquatic ecosystems of varying sensitivities and or dependences on groundwater (Roets *et al.*, 2008).

The objective of this model was to produce GIS layers answering these vitally important questions. To achieve this objective the study had to:

- Collect and collate all existing and relevant data sets and other information into a Geographic Information System (GIS) and associated database.
- Identify shortcomings in the GIS layers and information, and where possible, adjust information and add additional information.
- Evaluate GIS datasets to determine key parameters required to characterize the geographical variability of the TMG aquifer systems and associated aquatic ecosystems.
- To link the Conceptual Model developed in Chapter 5 (Roets *et al.*, 2008) to the GIS model.

8.2. Materials and methods

Arcview 3.3 was used as the GIS software to develop this model, and all the data were in the WGS84 format. The computer (hardware) that was used consisted of a Pentium 4 Prescot processor, with 512 MG RAM, 80G hard drive and on line graphics. An accompanying USB dongle was used to activate Arcview 3.3. Existing GIS layers were used, and through geospatial intersections new data layers were developed. Each data layer was selected after careful consideration of the criteria to develop the necessary outcome.

8.2.1. Data layers used

A key component of this model was the use of GIS datasets developed by Fortuin (2004) as part of a model to identify Table Mountain Group Aquifer ‘Type Areas’ of Ecological Importance. Only a few datasets of this model that had reference to this study was used. The layer that was not used was the Ecological Sensitivity layer. Although this data layer was well developed, it had a very strong bias towards groundwater dependence of vegetation only, particularly in terms of each vegetation type's ecological sensitivity. Her model analysed a number of key parameters – area of vegetation type, transformation, fragmentation and ecological processes/gradients. Aquatic ecosystems were mentioned but not really considered in the model. Mainly lowland areas were subsequently highlighted because these were the areas mostly transformed (See Figure 8.5).

Fortuin (2004), amongst others, developed a groundwater 'Exploitation-' and 'Exploration Potential' Map for the TMG aquifer systems covering the entire TMG area. The Exploitation Potential Map considered the resource and recharge to show the potential of an area to sustain large-scale abstraction. Rainfall was used to estimate the mean annual effective recharge using raster-based grid analysis. The methodology used by Fortuin (2004) was based on the Maxey-Eakin empirical method but had been adjusted to consider other critical factors such as lithology and slope. The results showed that high recharge coincided with TMG outcrop areas in mountainous regions, but that the accessibility to these regions could be problematic where the slope was in excess of 15%. Fortuin (2004) then checked and verified the resulting recharge using the 'Harvest Potential' map developed by DWAF. She also considered borehole citing because it may not always be possible to find suitable drilling targets to site production boreholes capable of delivering the required yields. The Exploration Potential Map developed by Fortuin (2004) assessed the accessibility and drilling success of a borehole according to a reclassification of Vegter's Borehole Prospects map.

Fortuin (2004) then geospatially intersected the 'Exploitation-' and 'Exploration' potential maps and produced a Groundwater Development Potential Map (Figure 8.4), showing a qualitative rating for the development of large-scale abstraction schemes. This GIS layer was used as the baseline for the current model. Other existing layers used included a TMG aquifer shape file (developed by Fortuin, 2004), a DWAF layer containing quaternary catchments, and an existing C.A.P.E. (Cowling *et al*., 1999) layer, which highlighted aquatic ecosystem importance for fish conservation. The C.A.P.E. layer was based on identified catchments containing hotspots for threatened and endemic fish richness, where recruiting and strong populations of several indigenous fish were present (Impson *et al.*, 1999). The high to low categories on this layer were Critical, Very High, High, Medium and Low.

8.2.2. Study area

The entire extent of the TMG aquifer was covered by this model. The TMG which is part of the Cape Supergroup, forms the backbone of the Cape Fold Belt running from Van Rhynsdorp in the west to Port Elizabeth in the east (De Beer, 2002.).

Although the datasets are covering the entire spatial extent of the TMG, the focus for the purposes of this study is on those areas within the Western Cape provincial boundary (Figure 8.1).

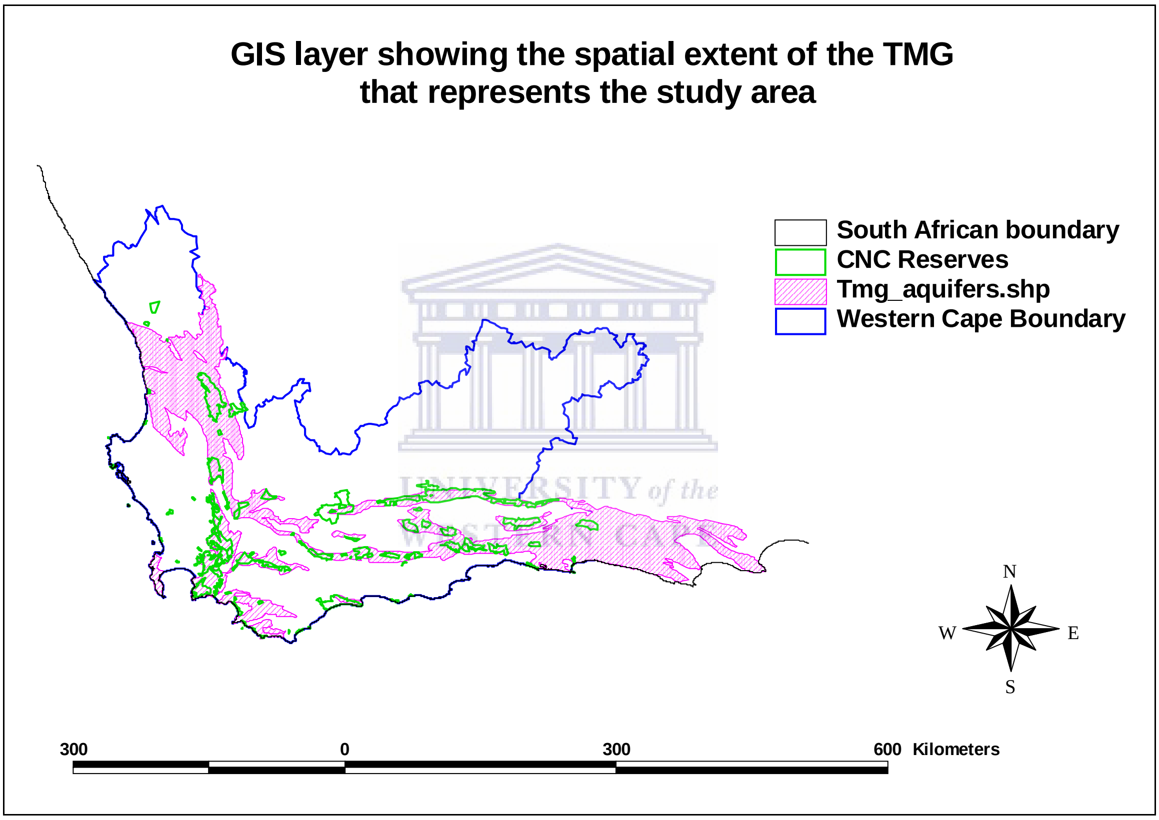

Figure 8.1. Study area covering the full extent of the TMG aquifer.

8.2.3. Methodology

For the purposes of developing a GIS model highlighting sensitive aquatic ecosystems associated with the TMG aquifer, it was necessary to obtain spatially defined information on aquatic ecosystems associated with the TMG, and that could indicate their ecological sensitivity. Further to this, and for it to be applicable and relevant, this GIS layer had to take cognizance of the DWAF defined quaternary catchments of the Western Cape Province.

All the existing GIS data layers, mentioned under 8.2.1, was used during several well planned geospatial intersections. These geospatial intersections were executed by following two basic steps.

The first step (Figure 8.2) was the geospatial intersection of the TMG aquifer shape file (developed by Fortuin, 2004), with the existing DWAF layer containing quaternary catchments. The resultant layer was then geospatially intersected with an existing C.A.P.E. (Cowling *et al*., 1999) layer, which highlighted aquatic ecosystem importance for fish conservation. Details of the criteria used for the generation of this C.A.P.E. layer is described in detail in Impson *et al.* (1999). This was followed by geospatially intersecting the resultant layer with the 'Groundwater Development Potential' layer of Fortuin (2004)(Figure 8.4), which culminated in a GIS layer showing all quaternary catchments having both a high groundwater development potential and varying degrees of 'Sensitive Aquatic Ecosystems' associated with the TMG (Roets *et al*., 2008). The 'Sensitive Aquatic Ecosystems' layer was thus based on the criteria used to show quaternary catchments sensitivity from a fish conservation perspective (Impson *et al*., 1999) (fish as indicator of ecosystem vulnerability) and on the criteria for developing 'Groundwater Development Potential' (Fortuin, 2004).

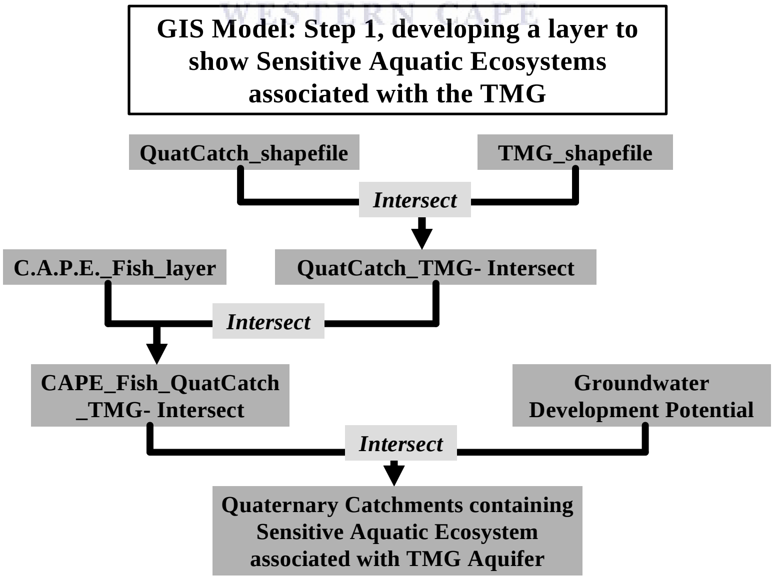

Figure 8.2. Diagram showing the development of the GIS model to show the Sensitive Aquatic Ecosystems associated with the TMG (Roets *et al.*, 2008).

However, the 'Sensitive Aquatic Ecosystems' layer did not include any buffer areas around the TMG aquifer. As a second step (Figure 8.3) a buffer area around the TMG aquifer shape file was included. This was achieved by using a buffer function in Arcview 3.3, which inserted a buffer area around the entire TMG aquifer shape file. This polygon was defined to extend 10 km away from the outside perimeter of the TMG aquifer. Xu *et al.* (2002) proposed a realistic range of influence when abstracting water from the TMG aquifer between 3 km and 10 km from the point of abstraction. The 10 km buffer shape file was geospatially intersected with the quaternary catchment shape file. The resultant intersection was then geospatially intersected with the C.A.P.E. fish conservation layer (Cowling *et al*., 1999; Impson *et al.*, 1999) that resulted in a layer showing the quaternary catchments containing sensitive aquatic ecosystems in the 10 km buffer area around the TMG aquifer (Roets *et al*., 2008).

The latter layer was then geospatially merged with the ‘Sensitive Aquatic Ecosystem’ layer to give the final spatial view of all the quaternary catchments that contain sensitive aquatic ecosystems associated with the TMG aquifer, including those in the vitally important buffer area (Roets *et al*., 2008).

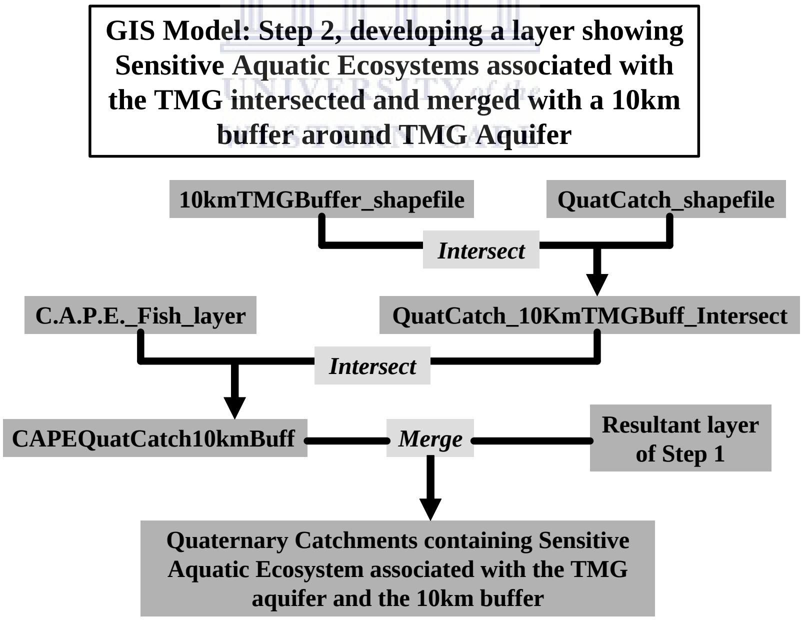

Figure 8.3. Diagram showing the development of the second step in the GIS model to show the Sensitive Aquatic Ecosystems associated with the TMG after inclusion of Quaternary Catchments in the 10 km buffer around the TMG aquifer (Roets *et al.*, 2008).

8.3. Results

The GIS layer shown in Figure 8.6 culminated from the geospatial intersection process as given in Figure 8.2. This layer clearly shows all the quaternary catchments containing sensitive aquatic ecosystems in the TMG aquifer that is vulnerable to groundwater use in varying degrees. The 'Critical' sensitive quaternaries are the most vulnerable to groundwater use, followed by the others from 'Very High' to 'Low' (Roets *et al.*, 2008).

Table 8.1 gives the statistics for the 'Sensitive Aquatic Ecosystem GIS layer', showing the number of quaternary catchments (represented as polygons), and the percentage of quaternary catchments containing each of the Sensitivity Priority Groupings. The 'Sensitive Aquatic Ecosystems' layers was based on the same criteria used to indicate quaternary catchments sensitivity from a fish conservation perspective, with fish as indicator of ecosystem vulnerability, and on the same criteria used to developing 'Groundwater Development Potential' (Impson *et al.*, 1999; Fortuin, 2004).

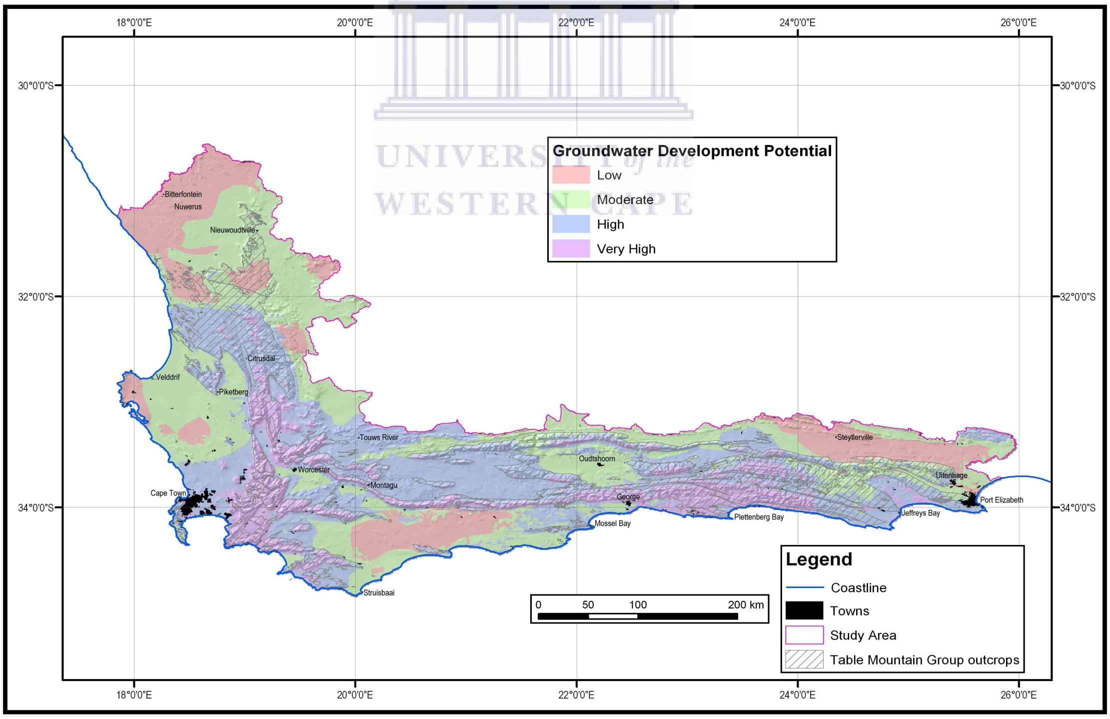

Figure 8.4. Groundwater Development Potential Map – a 'geospatial' intersection of the exploitation and exploration maps (Taken from Fortuin, 2004).

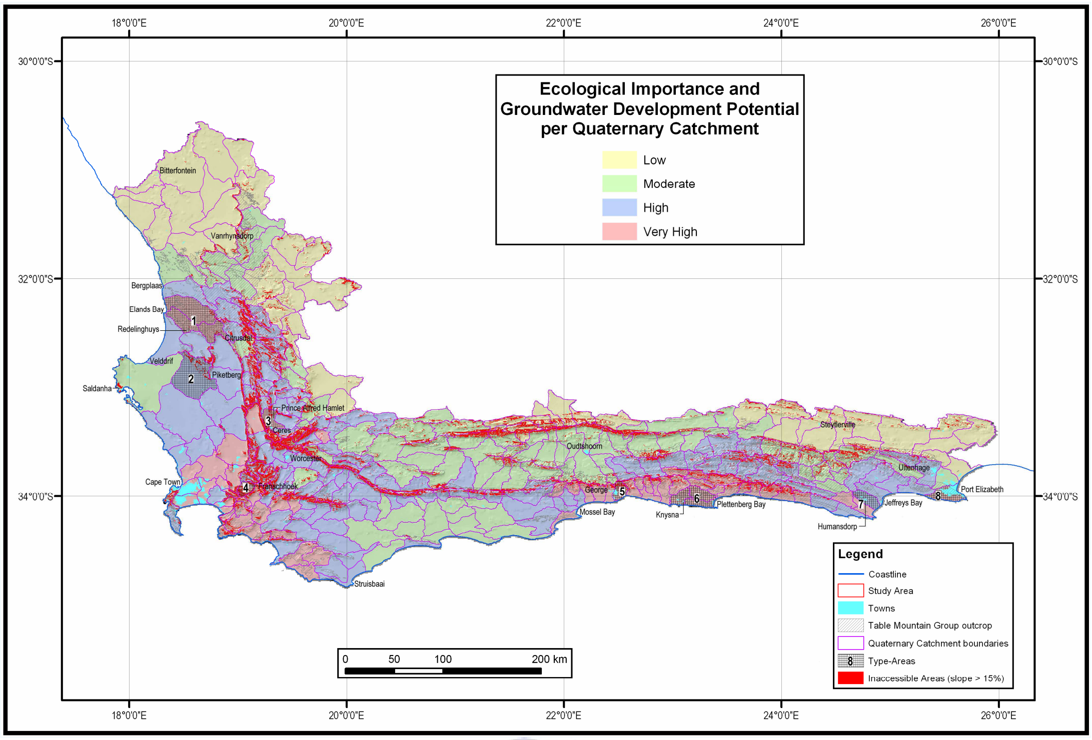

Figure 8.5. Map showing the qualitative rating of Ecological Importance and Groundwater Development Potential for each Quaternary Catchment (Taken from Fortuin, 2004).

Table 8.1 Statistics on the percentage of the Quaternary Catchments containing each 'Sensitivity Priority Group' (Roets *et al.*, 2008).

Sensitivity Priority Grouping	Number of Polygons	Percentage (%) in each group
Critical	138	3.8
Very High	382	10.6
High	1484	41.2
Medium	1440	40
Low	159	4.4
Total	3603	100

Only 3.8% of all the quaternary catchments contain 'Critically Sensitive' aquatic ecosystems associated with the TMG aquifer, with 10.6% having a 'Very High Sensitivity', 41.2% having a 'High Sensitivity', 40% having a 'Medium Sensitivity' and 4.4% having a 'Low Sensitivity'. The 'Sensitivity' of an aquatic ecosystem within each catchment relate to both the importance from a conservation perspective, and the vulnerability of these catchments to groundwater use from the TMG aquifer.

The second step of the GIS modelling as given in Figure 8.3, culminated in the layer shown in Figures 8.7 and 8.8. These geospatial intersections produced the final GIS data layer showing the varying degrees of sensitivity of all the quaternary catchments containing sensitive aquatic ecosystems, including those within the important 10 km buffer area around the TMG aquifer (Xu *et al.,* 2002). This clearly increased the total area of quaternary catchments that may be sensitive to groundwater use from the TMG aquifer.

8.4. Discussion

After several geospatial intersections to fine tune the outcome, the sequence of layers, and the successive intersections, gave an effective ‘Sensitive Aquatic Ecosystem’ layer that successfully linked the TMG aquifer discharge areas to aquatic ecosystems vulnerable to groundwater use. This layer was the first step towards linking the Conceptual Model (Chapter 5) and the GIS model. It also perfectly synchronised with the sensitive aquatic ecosystem layer of C.A.P.E., and the quaternary catchment layer developed by DWAF. This layer included all aquatic ecosystems associated with the TMG aquifer in the “TMG aquifer daylight-domain” and “TMG aquifer surface water interface-domain” as described in Chapter 5 (Roets *et al.,* 2008).

The resultant ‘Sensitive Aquatic Ecosystem’ layer (Figure 8.2 and 8.6) clearly showed where all the sensitive aquatic ecosystems were located within the extent of the TMG aquifer, that had both a high groundwater development potential, and a high conservation value and sensitivity to groundwater use. However, it did not highlight buffer areas around the TMG aquifer where groundwater use from deep circulation in the TMG could impact higher elevation discharges, like springs, seeps and stream discharges in the “TMG aquifer daylight-domain”, or even impact on groundwater discharges at the discharge end of the aquifer in the “TMG aquifer surface water interface-domain”. The need for such a buffer stems from the findings of Xu *et al.* (2002) that suggested a realistic range of influence when abstracting water from the TMG aquifer to be between 3 km and 10 km from the point of abstraction.

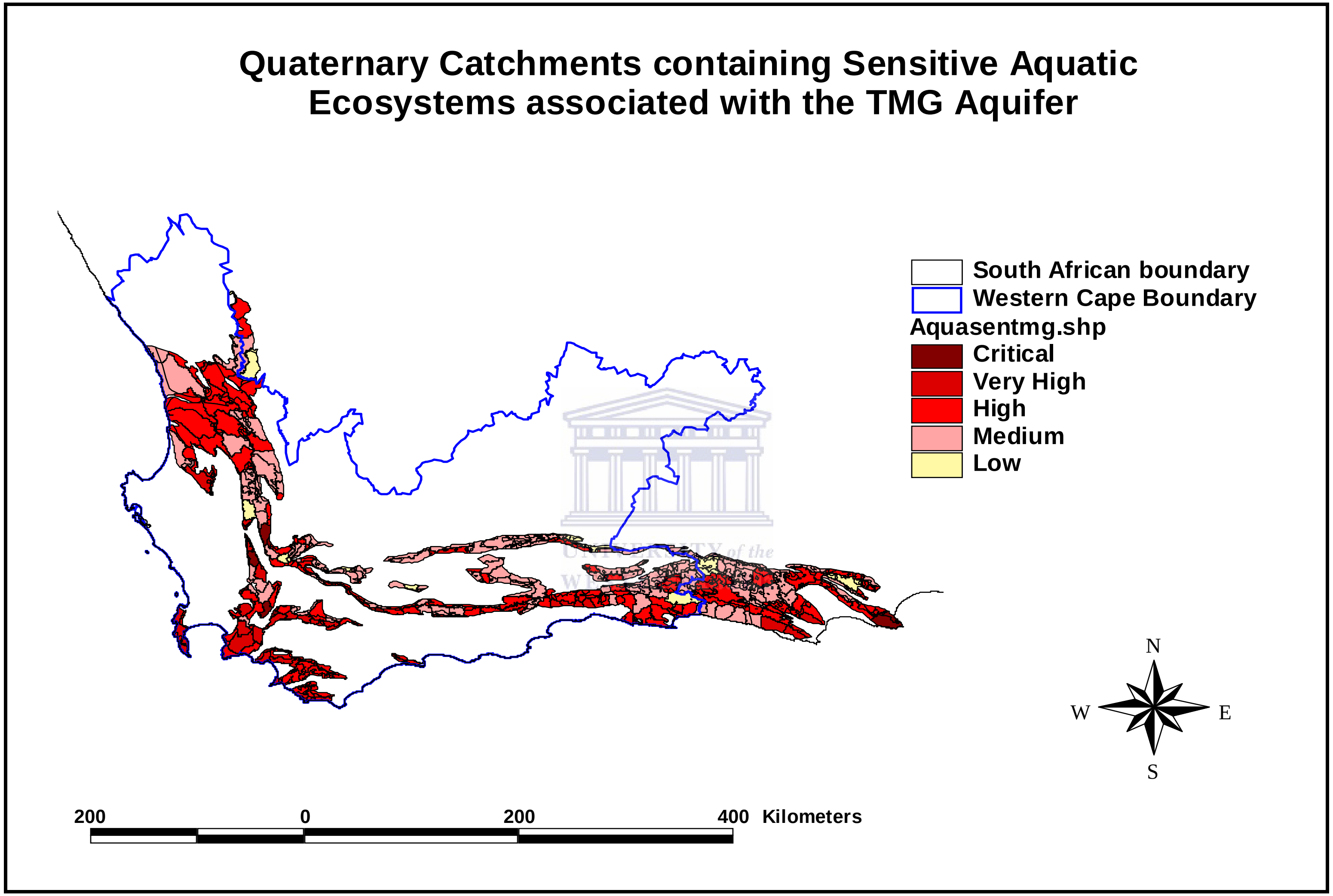

Figure 8.6. Sensitive aquatic ecosystems vulnerable to groundwater use from the TMG (Roets *et al.*, 2008).

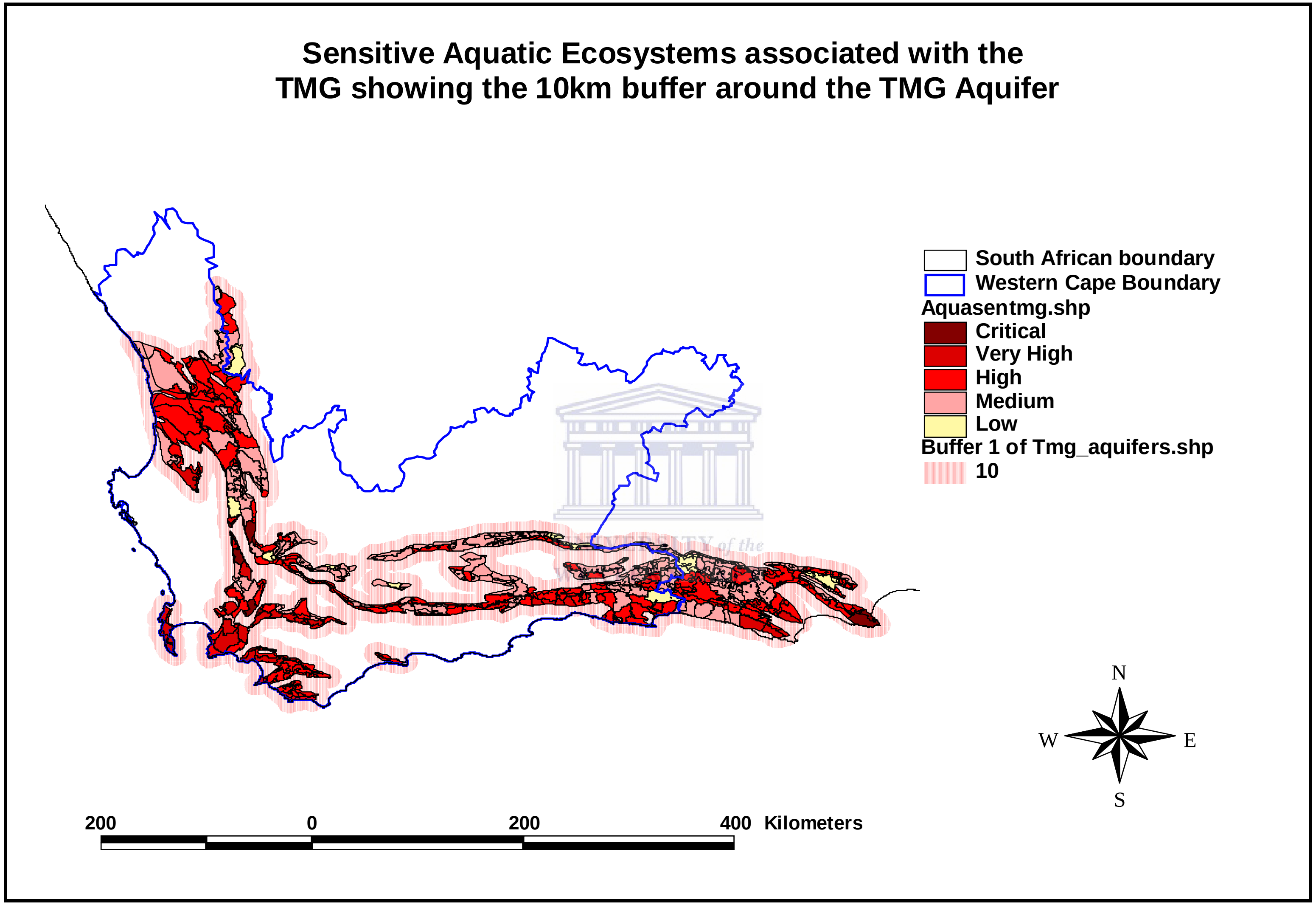

Figure 8.7. Sensitive Aquatic Ecosystems associated with the TMG showing the 10 km buffer area around the TMG aquifer.

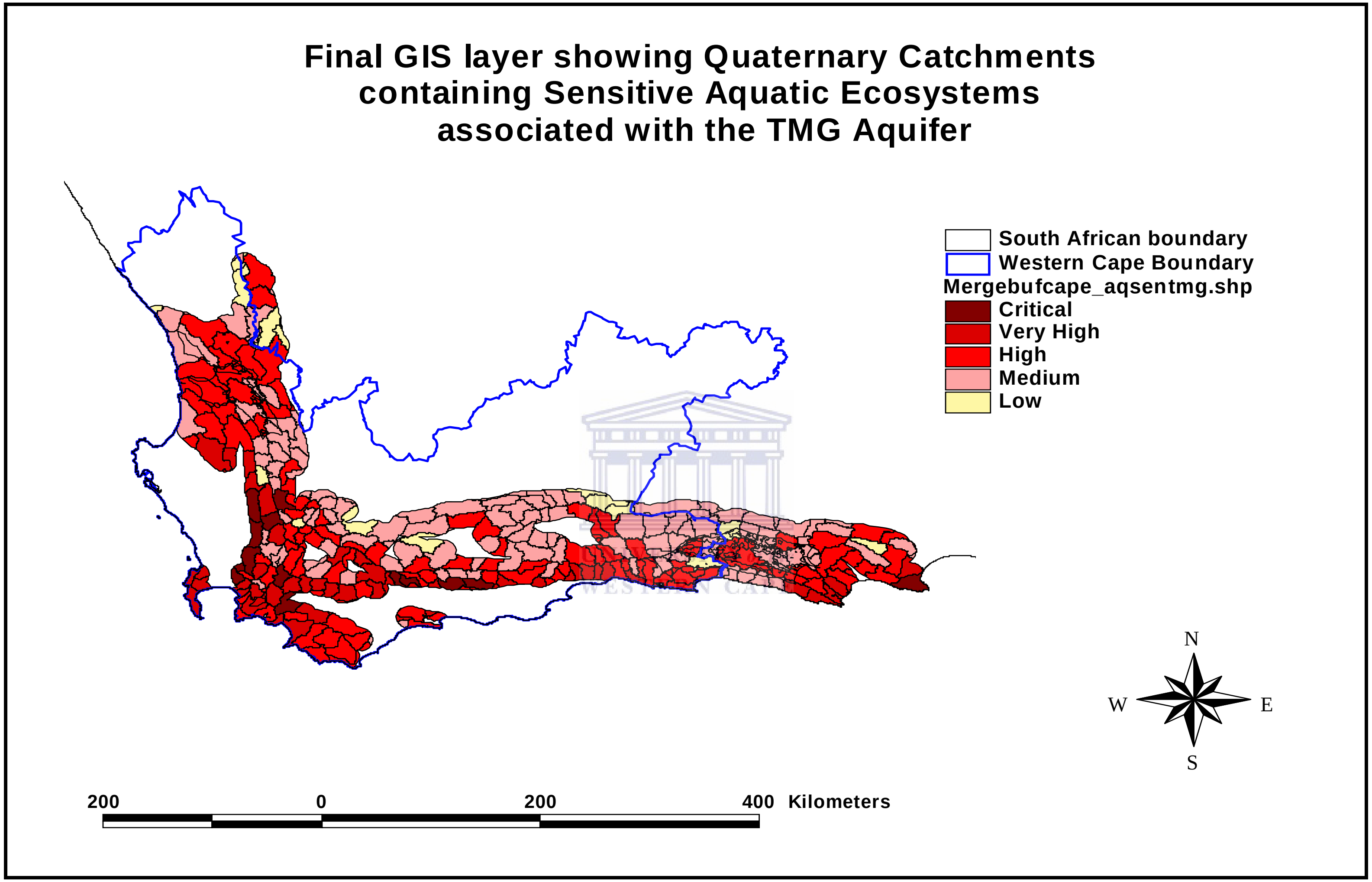

Figure 8.8. Sensitive Aquatic Ecosystems associated with the TMG after intersecting the Quaternary Catchments with the 10 km buffer around the TMG aquifer (Roets *et al.*, 2008).

Target areas for groundwater use could be located in the deep circulating ‘Intermontain domain’ (like the little Karoo) regions where the TMG is at great depths and produces artesian flow when accessed. Similarly, water used from the TMG aquifer will affect the discharge end of the aquifer, which could be located far away from the TMG outcrop areas, in lowland wetlands or marine environments (Figure 8.9). Hence the need for a buffer area to include these scenarios falling outside the spatial extent of the TMG aquifer within which groundwater use could have an impact on the “TMG aquifer daylight domain”, or the “TMG aquifer surface water interface-domain”.

The second step successfully concluded this requirement by producing the 10 km buffer area. This buffer area was also geospatially synchronised with the spatially defined quaternary catchments and the “sensitive aquatic ecosystem” layer (Roets *et al.*, 2008).

Any aquifer is in equilibrium, and when groundwater is used it affects the equilibrium and subsequently reduces discharge and induces recharge of the aquifer (Figure 8.9). Groundwater use will thus affect aquatic ecosystems in the “TMG aquifer daylight domain” through induced recharge in the mountainous areas that will result in reduced discharges at geological contact areas. It will also result in reduced discharges in the “TMG aquifer surface water interface-domain” which is located in intermountain and coastal areas. The following simple diagram explains how the aquifer equilibrium is affected by groundwater use.

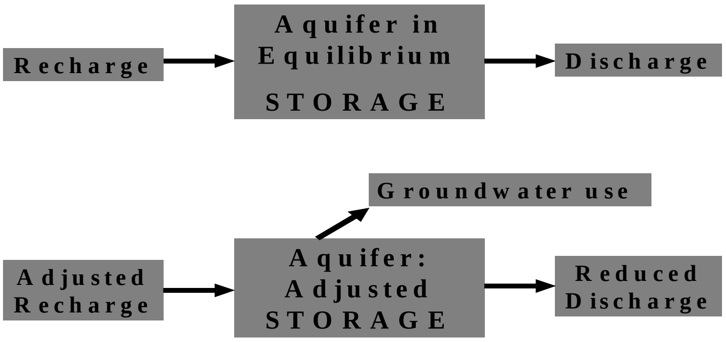

Figure 8.9. Diagram showing an Aquifer in equilibrium (top), and one affected by groundwater use (bottom).

If the storage is affected by groundwater use, the aquifer equilibrium is disrupted and it will result in an increase in the required recharge, and a decrease in discharge from the aquifer (Figure 8.9). This will affect springs, seeps and stream discharges, particularly in the mountain and foothill zones, and may also result in reduced discharge at the discharge end of the aquifer.

8.5. Conclusion

Through current advances in GIS, using existing GIS layers, it was possible to develop a GIS model highlighting all quaternary catchments vulnerable to groundwater use in the TMG. It also succeeded in showing the varying degrees of sensitivity of each catchment. It showed that through careful selection of applicable spatially defined layers, and geospatial intersections, well defined GIS layers can be produced. This is a very inexpensive method of achieving applicable objectives.

The development of this GIS model successfully linked the conceptual model of Chapter 5 to this GIS model. This GIS model makes it possible to show potential “no-go” areas for groundwater development, and or where intensive assessments of the effects of groundwater use may be necessary. This can assist DWAF with the licensing of groundwater use applications and also give developers an idea of where groundwater use may be viable or not.

The quaternary catchments that were highlighted by this model give a good spatial view of the groundwater dependence of aquatic ecosystems that may be affected by groundwater use from the TMG aquifer. All the high elevation aquatic ecosystems were highlighted as being vulnerable to groundwater use from the TMG that relate perfectly to the expected impacts in the “TMG aquifer daylight-domain” (Roets *et al.*, 2008). Similarly the aquatic ecosystems that could be dependent on groundwater discharges from the discharge end of the TMG aquifer in the “TMG aquifer groundwater surface water interface-domain” were also highlighted, most of which fall within the buffer area around the TMG aquifer (Roets *et al.*, 2008).

Reduced aquifer yield as a result of groundwater use, or reduced recharge through lower rainfall, or a change in rainfall intensity and duration, effects predicted to result from climate change, will all have an effect on the aquifer equilibrium, storage and subsequent discharge from the TMG aquifer. This is particularly true for a recharge dependent aquifer system like the TMG with no overburden to buffer the recharge. For this reason it was necessary to highlight all quaternary catchments that contain sensitive aquatic ecosystems that are dependent on groundwater discharges from the TMG aquifer.

All groundwater development applications that fall within any of these highlighted quaternary catchments should be properly investigated and assessed. It is proposed that all groundwater development applications within quaternary catchments highlighted as Critical, Very High, High Medium and Low be assessed in terms of the NEMA regulations (Act 107 of 1998). These applications should follow the most rigorous EIA procedures as required in terms of NEMA. All the other application closer than 50 km’s of these designated areas, targeting the TMG aquifer at depth, should without exception include monitoring of streams, springs and rivers emanating in the quaternary catchments where a link can be anticipated. This monitoring should include at least spring flow (discharge – v-notch monitoring), water level monitoring (water table or piezometric surface near springs, streams and rivers) and basic water quality parameters namely: EC, pH and temperature.

CHAPTER NINE
Conclusions and Recommendations.

9.1. Conclusions

The intensive literature survey of Chapter 2 has proven to be very valuable in linking three different disciplines that resulted in a better conceptual understanding of *how* and *where* groundwater interact with aquatic ecosystems in the TMG. This enabled a better understand of how and to what extent groundwater use may affect the ecologically important groundwater discharges to streams, rivers and wetlands.

This study has successfully proven that there is a definite and intimate link between the TMG aquifer and aquatic ecosystems, especially those located in the mountain and foothill areas of the TMG in the “TMG aquifer daylight-domain”, and those located at the discharge end of the aquifer in the “TMG aquifer surface water interface-domain”. Through the conceptual model developed in Chapter 5 (Roets *et al.,* 2008), it is now possible to say with much more certainty which part of the flow regime of aquatic ecosystems will be vulnerable to groundwater use from the TMG aquifer, and how this may affect the ecological functioning of that ecosystem. From an ecosystems approach, considering process and pattern, it is also important to recognise the ecosystem services supplied by the TMG aquifer through its discharges to surface resources and aquatic ecosystems in general.

Both case studies supported the conceptual model that was developed and highlighted the need for proper assessment of the groundwater resource prior to development. The Kammanassie case study in particular, support the fact that reduced groundwater discharges in the primary groundwater discharge zone of the TMG, the mountain and foothill zones in the “TMG aquifer daylight-domain”, can have devastating effects, not just on the visible flow regime, but also by possible affecting the nutrient concentrations near streams and rivers associated with the TMG (Roets *et al.*, in prep). The modified nutrient concentrations in soils, although not conclusive, could in the long run cause vegetation composition and structure to change. This study also supports the findings by Cleaver (2003) that confirmed how dependent riparian vegetation is on groundwater discharges, a view shared by Le Maitre *et al*. (1999) and Colvin *et al.* (2002). These results has clearly demonstrated that groundwater from the TMG aquifer may affect riparian vegetation directly through water availability (water table and flow) and indirectly by affecting soil nutrient processes.

The second case study added an invaluable dimension to complete the picture and understanding of groundwater surface water interactions, by demonstrating the less obvious and more distant interface. This case study confirmed discharges from the TMG aquifer to distant aquatic ecosystems in the “TMG aquifer surface water interface-domain”, hence the need for buffer areas around the TMG aquifer. Both case studies highlighted the importance to consider the link between the TMG aquifer and surface resources in two primary zones, namely, in the “TMG aquifer daylight-domain” and the “TMG aquifer surface water interface-domain” when investigating groundwater use from the TMG (Roets *et al.,* 2008, Roets *et al.*, 2008b).

Considering the above, it is clear that entire catchments are dependent on groundwater contributions from the TMG aquifer. Initial claims by hydrogeologists that the TMG aquifer is isolated from ecosystems because of its confined to semi-confined nature have been proven not to be true. Catchment managers and water resource planners must take note of this fact and include the groundwater link in their planning and determinations. If surface and groundwater sources are to be planned and managed in isolation the same water could end up being allocated twice.

The GIS model that was developed to highlight the sensitive aquatic ecosystems associated with the TMG, again confirmed how advances in GIS can assist in a very cost effective way to help decision maker with the assessment of applications for groundwater resource development. This GIS model resulted in a tool giving a spatial view of the conceptualised areas of interface between the TMG aquifer and aquatic ecosystems. It also demonstrated how this model can enable, authorities, applicants and hydrogeological assessment practitioners to know the level of assessment needed for a particular development option. In all cases where the groundwater use is targeted in areas highlighted by this model, a thorough hydrogeological assessment should be compulsory (Roets *et al.,* 2008). The GIS model also highlighted the fact that the impacts associated with groundwater use from the TMG can be far reaching in terms of time and scale. The characteristics of the TMG aquifer and the complex interface with surface resources over large spatial scales necessitate thorough hydrogeological assessments before groundwater use should be allowed.

9.2. Recommendations

As is the case with all research, many questions arose that remain unanswered because it fell outside the scope of the current investigations. Many gaps in information and weakness in scientific design emerged that highlight the need for further research before conclusive assumptions can be made. During the course of this study is became clear that further studies would be required to develop: (a) long term monitoring protocol to assess the effect of groundwater use on aquatic ecosystems like for example, soil nutrient cycling in response to groundwater discharges. This would require a much more comprehensive approach including groundwater physics, groundwater quality, soil moisture, soil particle size, soil horizon characteristics, plant ecophysiology and stable isotope assessments; (b) a new water balance model for Groenvlei and the surrounding wetlands, taking into account that the TMG aquifer is linked to some wetlands; (c) a finer scale GIS layer indicating groundwater dependence of aquatic ecosystems on a more localised scale. However, with the many un-known aspects that seem to persist in the understanding of groundwater discharges, particularly from the TMG, this may take some time, and may need a lot more information.

From this study the following recommended actions emerged:

- Generation of better information on the sensitivity of aquatic ecosystems, particularly spatially defined data is required.
- Finer scale geological information that is spatially well defined. This geological data need to consider the different geological formations at different depths beneath the earth’s surface.
- An in-depth assessment should be conducted on the amount of groundwater discharged from the TMG aquifer into the regional primary aquifer of Groenvlei. This will help to develop a completely new water balance model for Groenvlei and may shed light on the water supply challenges for Sedgefield that is ongoing.
- A lot of ground still needs to be covered on the subject of sustainable groundwater use. Determination of the “reserve” for both surface resources and groundwater resources in terms of the National Water Act (Act 36 of 1998) must

consider the contributions of groundwater from the TMG aquifer to surface resources.

As time progress and more information become available, we will have to re-look our approach to groundwater assessments and the use of groundwater. It is also crucially important that government authorities responsible for environmental and water resource management, notable, DWAF and Department of Environmental Affairs and Tourism (DEAT), with their provincial counterparts, become aware of the need to integrate their thinking on water resource management to include groundwater and surface water, and groundwater and terrestrial ecosystem interactions. MacKay (2005) give some perspective on this dire need for good policies and management that take cognisance of the intimate link between groundwater and ecosystems.

Finally, the inevitable effects of global climate change is bound to have a significant, and most probable a severely negative impact on the potential to use groundwater from especially the TMG aquifer. This stems from the fact that the TMG aquifer, as a hard rock aquifer, is entirely recharge dependent because of the exposed nature of the TMG in the recharge areas. There is no overburden as reservoir to buffer the severe effects of climate change. In contrast to the Western Cape situation, 90% of hard rock aquifers across the world have an overburden (reservoir) that recharges the fracture flow aquifers. This aspect will need to inform future planning of groundwater use from the TMG aquifer.

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APPENDIXES

Appendix A: Case study 1 (Kammanassie soil sample analysis by Bemlab)

Spring assessment – October 05

Verslag No.: NR12562/2005

ONTLEDINGS VERSLAG

W. Roets
Cape Nature Conservation
George
Datum ontvang: 18/10/2005
Datum ontleed: 21/10/2005

Verwysing No.	Lab. No.	NH4-N mg/kg	NO3-N mg/kg	P mg/kg
MOL 1	12562	12.700	4.380	6.904
MOL 2	12563	7.850	3.400	8.722
MOL 3	12564	6.680	4.910	23.982
VOR 1	12565	6.950	3.840	16.559
VOR 2	12566	3.280	1.610	10.856
VOR 3	12567	4.390	2.260	6.353
VOL 1	12568	13.080	45.300	58.974
VOL 2	12569	11.590	21.350	19.482
VOL 3	12570	9.960	5.750	15.099
VBL 1	12571	3.010	2.400	6.511
VBL 2	12572	7.440	11.310	28.271
VBL 3	12573	6.050	20.520	16.927
MML 1	12574	4.660	2.800	9.734
MML 2	12575	4.990	1.930	6.727
MML 3	12576	5.340	2.090	24.721
VMR 1	12577	10.030	14.740	29.776
VMR 2	12578	6.520	3.160	13.661
VMR 3	12579	5.200	1.740	11.992
MBR 1	12580	7.110	2.620	12.386
MBR 2	12581	12.020	2.980	13.190
MBR 3	12582	5.830	2.460	2.559
VML 1	12583	5.180	3.000	7.902
VML 2	12584	4.240	3.700	6.639
VML 3	12585	7.400	3.380	12.525
MOR 1	12586	6.050	5.420	10.839
MOR 2	12587	5.350	3.000	6.193
MOR 3	12588	3.590	1.220	10.983
VBR 1	12589	6.910	2.510	11.489
VBR 2	12590	7.290	2.400	13.552
VBR 3	12591	4.820	1.760	7.156
MMR 1	12592	4.040	1.140	2.955
MMR 2	12593	5.860	23.810	7.120
MMR 3	12594	6.320	2.950	15.707
MBL 1	12595	4.910	3.380	3.796
MBL 2	12596	6.610	4.040	7.723
MBL 3	12597	6.500	2.660	42.927

Monster toestand

Monsters in goeie toestand.

Verklaring

Die gerapporteerde resultate is slegs van toepassing op die monster(s) ontvang. Enige advies wat by hierdie verslag ingesluit is, is op die aanname gebaseer dat die monster(s) verteenwoordigend is van die bulk waaruit dit geneem is.

Summer assessment - December 05

Verslag No.: NR15506/2005

ONTLEDINGS VERSLAG

W. Roets
Cape Nature Conservation
George

Datum ontvang: 19/12/2005
Datum ontleed: 29/12/2005

Verwysing No.	Lab. No.	NH4-N mg/kg	NO3-N mg/kg	P Mg/kg
VBR 1	15506	3.940	0.780	75.317
VBR 2	15507	5.310	1.110	168.814
VBR 3	15508	4.960	2.000	122.050
MBL 1	15509	6.490	5.750	81.761
MBL 2	15510	5.250	1.400	44.302
MBL 3	15511	5.180	1.480	37.485
MBR 1	15512	3.930	2.450	41.695
MBR 2	15513	2.930	2.570	49.175
MBR 3	15514	3.390	1.810	107.545
VBL 1	15515	3.410	1.150	126.439
VBL 2	15516	6.300	4.880	242.829
VBL 3	15517	4.960	1.140	131.732
MMR 1	15518	4.970	0.620	46.073
MMR 2	15519	4.300	0.620	98.846
MMR 3	15520	6.220	0.590	76.957
VOL 1	15521	3.470	1.360	116.399
VOL 2	15522	3.600	1.790	129.547
VOL 3	15523	3.750	1.460	109.268
VML 1	15524	4.730	1.060	191.678
VML 2	15525	4.620	0.680	123.365
VML 3	15526	4.560	0.810	116.667
VMR 1	15527	4.100	0.580	117.456
VMR 2	15528	3.700	0.670	147.344
VMR 3	15529	2.440	1.090	116.503
VOR 1	15530	3.180	0.640	161.337
VOR 2	15531	3.880	0.730	126.356
VOR 3	15532	3.560	0.920	135.410
MOR 1	15533	3.440	2.020	126.139
MOR 2	15534	5.510	2.600	112.268
MOR 3	15535	3.170	1.470	71.575
MOL 1	15536	5.070	2.480	90.338
MOL 2	15537	1.960	1.090	33.208
MOL 3	15538	2.120	1.230	52.272
MML 1	15539	2.880	0.650	29.805
MML 2	15540	2.480	0.750	84.243
MML 3	15541	3.700	0.570	79.937

Monster toestand

Monsters in goeie toestand.

Verklaring

Die gerapporteerde resultate is slegs van toepassing op die monster(s) ontvang. Enige advies wat by hierdie verslag ingesluit is, is op die aanname gebaseer dat die monster(s) verteenwoordigend is van die bulk waaruit dit geneem is. Opinies en aanbevelings is nie geakkrediteer nie.

Dr. W.A.G. Kotzé (Direkteur) 29-12-2005
....

Autumn assessment – March 06

Verslag No.: NR2556/2006

ONTLEDINGS VERSLAG

W. Roets
Cape Nature Conservation
George

Datum ontvang: 10/03/2006
Datum ontleed: 05/04/2006

Verwysing No.	Lab. No.	pH mg/kg	EG mS/m	NH4-N mg/kg	NO3-N mg/kg	P mg/kg
MBL 1	2556	5.6	40.600	10.800	14.320	38.031
MBL 2	2557	5.4	22.700	12.120	4.240	34.613
MBL 3	2558	4.9	47.600	14.480	8.800	38.219
MBR 1	2559	4.6	51.900	15.960	2.120	27.830
MBR 2	2560	4.8	31.400	9.200	1.440	14.158
MBR 3	2561	5.4	13.050	9.680	6.200	32.778
MML 1	2562	4.0	16.890	15.760	1.720	65.731
MML 2	2563	4.0	22.500	10.160	1.920	44.120
MML 3	2564	3.9	11.970	8.640	1.840	55.299
MMR 1	2565	4.3	48.800	9.440	1.880	44.089
MMR 2	2566	4.2	10.700	12.160	1.800	42.419
MMR 3	2567	3.9	35.800	11.960	1.880	64.589
MOL 1	2568	5.1	15.040	10.000	5.200	60.845
MOL 2	2569	5.3	8.030	9.280	4.320	28.661
MOL 3	2570	5.6	21.700	11.120	7.240	49.025
MOR 1	2571	5.0	31.800	17.800	12.240	156.343
MOR 2	2572	5.0	6.760	9.640	5.760	73.435
MOR 3	2573	5.3	7.210	13.840	9.520	95.123
VBL 1	2574	5.5	10.900	9.720	2.360	61.816
VBL 2	2575	5.7	26.200	8.240	2.280	36.940
VBL 3	2576	5.2	14.480	14.680	4.000	135.715
VBR 1	2577	6.2	9.630	10.560	4.480	87.843
VBR 2	2578	5.8	11.080	10.720	4.280	126.018
VBR 3	2579	6.1	8.610	9.360	2.720	102.357
VML 1	2580	6.1	24.400	11.000	4.680	122.331
VML 2	2581	5.5	7.150	9.680	2.200	86.466
VML 3	2582	6.5	9.690	7.960	2.920	69.739
VMR 1	2583	4.5	8.540	10.240	2.240	135.930
VMR 2	2584	4.6	13.280	11.280	3.200	89.169
VMR 3	2585	5.7	14.510	10.560	5.200	120.009
VOL 1	2586	5.5	57.900	24.560	25.200	168.982
VOL 2	2587	5.3	67.100	19.160	27.560	118.081
VOL 3	2588	5.1	94.700	24.080	62.720	166.616
VOR 1	2589	5.7	34.500	15.160	15.920	122.850
VOR 2	2590	5.8	42.100	20.520	26.320	160.605
VOR 3	2591	5.3	16.680	9.520	7.360	76.507

Monster toestand

Monsters in goeie toestand.

Verklaring

Die gerapporteerde resultate is slegs van toepassing op die monster(s) ontvang. Enige advies wat by hierdie verslag ingesluit is, is op die aanname gebaseer dat die monster(s) verteenwoordigend is van die bulk waaruit dit geneem is. Opinies en aanbevelings is nie geakkrediteer nie.

Dr. W.A.G. Kotzé (Direkteur)	05-04-2006
....	....
vir BemLab	Datum

Winter assessment – June 06

Verslag No.: NR5841/2006

ONTLEDINGS VERSLAG

W. Roets
Cape Nature Conservation
George

Datum ontvang: 30/06/2006
Datum ontleed: 04/07/2006

Verwysing No.	Lab. No.	pH	EG mS/m	NH4-N mg/kg	NO3-N mg/kg	P mg/kg
MBL 1	5841	5.5	26.200	16.940	1.660	96.318
MBL 2	5842	5.5	7.890	3.240	1.630	31.021
MBL 3	5843	5.3	7.300	1.040	1.510	18.993
MBR 1	5844	5.4	11.910	3.000	2.180	29.817
MBR 2	5845	5.5	12.720	8.640	1.520	32.244
MBR 3	5846	5.7	10.510	3.960	2.430	23.651
MOR 1	5847	4.9	17.890	6.540	2.130	73.472
MOR 2	5848	5.5	17.020	2.600	2.570	47.312
MOR 3	5849	5.6	54.500	6.480	3.390	71.483
MOL 1	5850	5.1	21.700	6.280	2.920	91.113
MOL 2	5851	4.5	45.600	3.800	4.190	98.426
MOL 3	5852	4.8	11.940	3.120	2.410	59.998
MMR 1	5853	4.4	114.100	4.280	1.820	50.829
MMR 2	5854	3.8	54.700	3.160	1.750	55.618
MMR 3	5855	5.3	48.200	2.000	1.810	37.931
MML 1	5856	5.5	10.060	2.440	2.050	109.227
MML 2	5857	5.2	9.680	3.400	1.930	97.500
MML 3	5858	4.0	14.410	5.760	1.920	52.211
VOR 1	5859	5.5	60.300	4.320	15.260	54.923
VOR 2	5860	5.2	16.600	5.520	2.950	88.840
VOR 3	5861	5.3	22.200	40.280	12.040	101.202
VOL 1	5862	5.1	43.900	6.640	4.830	98.915
VOL 2	5863	5.2	47.400	12.800	11.820	136.103
VOL 3	5864	4.9	34.200	7.880	6.820	148.471
VBL 1	5865	5.3	7.330	4.080	2.300	73.043
VBL 2	5866	5.8	23.900	4.960	3.080	127.483
VBL 3	5867	5.7	19.510	3.600	2.960	117.984
VMR 1	5868	5.0	12.900	3.160	2.660	74.505
VMR 2	5869	5.5	9.270	3.240	2.440	66.389
VMR 3	5870	5.5	16.520	4.320	2.660	89.666
VML 1	5871	6.6	10.780	14.160	3.920	69.357
VML 2	5872	6.0	6.930	3.960	2.560	62.162
VML 3	5873	5.7	6.850	2.400	2.420	85.553
VBR 1	5874	6.9	8.890	2.240	2.800	88.789
VBR 2	5875	5.2	16.660	3.040	3.100	122.026
VBR 3	5876	5.7	13.500	5.120	3.100	105.104

Monster toestand

Monsters in goeie toestand.

Verklaring

Die gerapporteerde resultate is slegs van toepassing op die monster(s) ontvang. Enige advies wat by hierdie verslag ingesluit is, is op die aanname gebaseer dat die monster(s) verteenwoordigend is van die bulk waaruit dit geneem is. Opinies en aanbevelings is nie geakkrediteer nie.

Dr. W.A.G. Kotzé (Direkteur)	07-07-2006
....	....
vir BemLab	Datum

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 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    1
                    PhD - Promotor Prof Lincoln Raitt :
                                           09:09 Thursday, August 30, 2007

           T
           r
           a    S                   S
      R    n    e              R    a  N   N
      i    s    a            x   B  m  H   O    P
 O    v    e R  s    R    T    T   a  p  4   3    h
 b    e    c x  o    x    x    x   n  l  _   _    o
 s    r    t T  n    S    S    S   k  e  N   N    s

  1 Marnevicks B MxB Herfs  MxHerfs  BxHerfs  MxBxH Left  1 10.80 14.32  38.031
  2 Marnevicks B MxB Herfs  MxHerfs  BxHerfs  MxBxH Left  2 12.12  4.24  34.613
  3 Marnevicks B MxB Herfs  MxHerfs  BxHerfs  MxBxH Left  3 14.48  8.80  38.219
  4 Marnevicks B MxB Herfs  MxHerfs  BxHerfs  MxBxH Right 1 15.96  2.12  27.830
  5 Marnevicks B MxB Herfs  MxHerfs  BxHerfs  MxBxH Right 2  9.20  1.44  14.158
  6 Marnevicks B MxB Herfs  MxHerfs  BxHerfs  MxBxH Right 3  9.68  6.20  32.778
  7 Marnevicks B MxB Lente  MxLente  BxLente  MxBxL Left  1  4.91  3.38   3.796
  8 Marnevicks B MxB Lente  MxLente  BxLente  MxBxL Left  2  6.61  4.04   7.723
  9 Marnevicks B MxB Lente  MxLente  BxLente  MxBxL Left  3  6.50  2.66  42.927
 10 Marnevicks B MxB Lente  MxLente  BxLente  MxBxL Right 1  7.11  2.62  12.386
 11 Marnevicks B MxB Lente  MxLente  BxLente  MxBxL Right 2 12.02  2.98  13.190
 12 Marnevicks B MxB Lente  MxLente  BxLente  MxBxL Right 3  5.83  2.46   2.559
 13 Marnevicks B MxB Somer  MxSomer  BxSomer  MxBxS Left  1  3.93  2.45  41.695
 14 Marnevicks B MxB Somer  MxSomer  BxSomer  MxBxS Left  2  2.93  2.57  49.175
 15 Marnevicks B MxB Somer  MxSomer  BxSomer  MxBxS Left  3  3.39  1.81 107.545
 16 Marnevicks B MxB Somer  MxSomer  BxSomer  MxBxS Right 1  6.49  5.75  81.761
 17 Marnevicks B MxB Somer  MxSomer  BxSomer  MxBxS Right 2  5.25  1.40  44.302
 18 Marnevicks B MxB Somer  MxSomer  BxSomer  MxBxS Right 3  5.18  1.48  37.485
 19 Marnevicks B MxB Winter MxWinter BxWinter MxBxW Left  1   .    1.66  96.318
 20 Marnevicks B MxB Winter MxWinter BxWinter MxBxW Left  2  3.24  1.63  31.021
 21 Marnevicks B MxB Winter MxWinter BxWinter MxBxW Left  3  1.04  1.51  18.993
 22 Marnevicks B MxB Winter MxWinter BxWinter MxBxW Right 1  3.00  2.18  29.817
 23 Marnevicks B MxB Winter MxWinter BxWinter MxBxW Right 2  8.64  1.52  32.244
 24 Marnevicks B MxB Winter MxWinter BxWinter MxBxW Right 3  3.96  2.43  23.651
 25 Marnevicks M MxM Herfs  MxHerfs  MxHerfs  MxMxH Left  1 15.76  1.72  65.731
 26 Marnevicks M MxM Herfs  MxHerfs  MxHerfs  MxMxH Left  2 10.16  1.92  44.120
 27 Marnevicks M MxM Herfs  MxHerfs  MxHerfs  MxMxH Left  3  8.64  1.84  55.299
 28 Marnevicks M MxM Herfs  MxHerfs  MxHerfs  MxMxH Right 1  9.44  1.88  44.089
 29 Marnevicks M MxM Herfs  MxHerfs  MxHerfs  MxMxH Right 2 12.16  1.80  42.419
 30 Marnevicks M MxM Herfs  MxHerfs  MxHerfs  MxMxH Right 3 11.96  1.88  64.589
 31 Marnevicks M MxM Lente  MxLente  MxLente  MxMxL Left  1  4.66  2.80   9.734
 32 Marnevicks M MxM Lente  MxLente  MxLente  MxMxL Left  2  4.99  1.93   6.727
 33 Marnevicks M MxM Lente  MxLente  MxLente  MxMxL Left  3  5.34  2.09  24.721
 34 Marnevicks M MxM Lente  MxLente  MxLente  MxMxL Right 1  4.04  1.14   2.955
 35 Marnevicks M MxM Lente  MxLente  MxLente  MxMxL Right 2  5.86   .     7.120
 36 Marnevicks M MxM Lente  MxLente  MxLente  MxMxL Right 3  6.32  2.95  15.707
 37 Marnevicks M MxM Somer  MxSomer  MxSomer  MxMxS Left  1  4.97  0.62  46.073
 38 Marnevicks M MxM Somer  MxSomer  MxSomer  MxMxS Left  2  4.30  0.62  98.846
 39 Marnevicks M MxM Somer  MxSomer  MxSomer  MxMxS Left  3  6.22  0.59  76.957
 40 Marnevicks M MxM Somer  MxSomer  MxSomer  MxMxS Right 1  2.88  0.65  29.805
 41 Marnevicks M MxM Somer  MxSomer  MxSomer  MxMxS Right 2  2.48  0.75  84.243
 42 Marnevicks M MxM Somer  MxSomer  MxSomer  MxMxS Right 3  3.70  0.57  79.937
 43 Marnevicks M MxM Winter MxWinter MxWinter MxMxW Left  1  2.44  2.05 109.227
 44 Marnevicks M MxM Winter MxWinter MxWinter MxMxW Left  2  3.40  1.93  97.500
 45 Marnevicks M MxM Winter MxWinter MxWinter MxMxW Left  3  5.76  1.92  52.211
 46 Marnevicks M MxM Winter MxWinter MxWinter MxMxW Right 1  4.28  1.82  50.829
 47 Marnevicks M MxM Winter MxWinter MxWinter MxMxW Right 2  3.16  1.75  55.618
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 48 Marnevicks M MxM Winter MxWinter MxWinter MxMxW Right 3  2.00  1.81  37.931
 49 Marnevicks O MxO Herfs  MxHerfs  OxHerfs  MxOxH Left  1 10.00  5.20  60.845
 50 Marnevicks O MxO Herfs  MxHerfs  OxHerfs  MxOxH Left  2  9.28  4.32  28.661
 51 Marnevicks O MxO Herfs  MxHerfs  OxHerfs  MxOxH Left  3 11.12  7.24  49.025
 52 Marnevicks O MxO Herfs  MxHerfs  OxHerfs  MxOxH Right 1 17.80 12.24 156.343
 53 Marnevicks O MxO Herfs  MxHerfs  OxHerfs  MxOxH Right 2  9.64  5.76  73.435
 54 Marnevicks O MxO Herfs  MxHerfs  OxHerfs  MxOxH Right 3 13.84  9.52  95.123
 55 Marnevicks O MxO Lente  MxLente  OxLente  MxOxL Left  1 12.70  4.38   6.904
 56 Marnevicks O MxO Lente  MxLente  OxLente  MxOxL Left  2  7.85  3.40   8.722
 57 Marnevicks O MxO Lente  MxLente  OxLente  MxOxL Left  3  6.68  4.91  23.982
 58 Marnevicks O MxO Lente  MxLente  OxLente  MxOxL Right 1  6.05  5.42  10.839
 59 Marnevicks O MxO Lente  MxLente  OxLente  MxOxL Right 2  5.35  3.00   6.193
 60 Marnevicks O MxO Lente  MxLente  OxLente  MxOxL Right 3  3.59  1.22  10.983
 61 Marnevicks O MxO Somer  MxSomer  OxSomer  MxOxS Left  1  3.44  2.02 126.139
 62 Marnevicks O MxO Somer  MxSomer  OxSomer  MxOxS Left  2  5.51  2.60 112.268
 63 Marnevicks O MxO Somer  MxSomer  OxSomer  MxOxS Left  3  3.17  1.47  71.575
 64 Marnevicks O MxO Somer  MxSomer  OxSomer  MxOxS Right 1  5.07  2.48  90.338
 65 Marnevicks O MxO Somer  MxSomer  OxSomer  MxOxS Right 2  1.96  1.09  33.208
 66 Marnevicks O MxO Somer  MxSomer  OxSomer  MxOxS Right 3  2.12  1.23  52.272
 67 Marnevicks O MxO Winter MxWinter OxWinter MxOxW Left  1  6.28  2.92  91.113
 68 Marnevicks O MxO Winter MxWinter OxWinter MxOxW Left  2  3.80  4.19  98.426
 69 Marnevicks O MxO Winter MxWinter OxWinter MxOxW Left  3  3.12  2.41  59.998
 70 Marnevicks O MxO Winter MxWinter OxWinter MxOxW Right 1  6.54  2.13  73.472
 71 Marnevicks O MxO Winter MxWinter OxWinter MxOxW Right 2  2.60  2.57  47.312
 72 Marnevicks O MxO Winter MxWinter OxWinter MxOxW Right 3  6.48  3.39  71.483
 73 Vermaaks   B VxB Herfs  VxHerfs  BxHerfs  VxBxH Left  1  9.72  2.36  61.816
 74 Vermaaks   B VxB Herfs  VxHerfs  BxHerfs  VxBxH Left  2  8.24  2.28  36.940
 75 Vermaaks   B VxB Herfs  VxHerfs  BxHerfs  VxBxH Left  3 14.68  4.00 135.715
 76 Vermaaks   B VxB Herfs  VxHerfs  BxHerfs  VxBxH Right 1 10.56  4.48  87.843
 77 Vermaaks   B VxB Herfs  VxHerfs  BxHerfs  VxBxH Right 2 10.72  4.28 126.018
 78 Vermaaks   B VxB Herfs  VxHerfs  BxHerfs  VxBxH Right 3  9.36  2.72 102.357
 79 Vermaaks   B VxB Lente  VxLente  BxLente  VxBxL Left  1  3.01  2.40   6.511
 80 Vermaaks   B VxB Lente  VxLente  BxLente  VxBxL Left  2  7.44 11.31  28.271
 81 Vermaaks   B VxB Lente  VxLente  BxLente  VxBxL Left  3  6.05   .    16.927
 82 Vermaaks   B VxB Lente  VxLente  BxLente  VxBxL Right 1  6.91  2.51  11.489
 83 Vermaaks   B VxB Lente  VxLente  BxLente  VxBxL Right 2  7.29  2.40  13.552
 84 Vermaaks   B VxB Lente  VxLente  BxLente  VxBxL Right 3  4.82  1.76   7.156
 85 Vermaaks   B VxB Somer  VxSomer  BxSomer  VxBxS Left  1  3.94  0.78  75.317
 86 Vermaaks   B VxB Somer  VxSomer  BxSomer  VxBxS Left  2  5.31  1.11 168.814
 87 Vermaaks   B VxB Somer  VxSomer  BxSomer  VxBxS Left  3  4.96  2.00 122.050
 88 Vermaaks   B VxB Somer  VxSomer  BxSomer  VxBxS Right 1  3.41  1.15 126.439
 89 Vermaaks   B VxB Somer  VxSomer  BxSomer  VxBxS Right 2  6.30  4.88 242.829
 90 Vermaaks   B VxB Somer  VxSomer  BxSomer  VxBxS Right 3  4.96  1.14 131.732
 91 Vermaaks   B VxB Winter VxWinter BxWinter VxBxW Left  1  4.08  2.30  73.043
 92 Vermaaks   B VxB Winter VxWinter BxWinter VxBxW Left  2  4.96  3.08 127.483
 93 Vermaaks   B VxB Winter VxWinter BxWinter VxBxW Left  3  3.60  2.96 117.984
 94 Vermaaks   B VxB Winter VxWinter BxWinter VxBxW Right 1  2.24  2.80  88.789
 95 Vermaaks   B VxB Winter VxWinter BxWinter VxBxW Right 2  3.04  3.10 122.026
 96 Vermaaks   B VxB Winter VxWinter BxWinter VxBxW Right 3  5.12  3.10 105.104
 97 Vermaaks   M VxM Herfs  VxHerfs  MxHerfs  VxMxH Left  1 11.00  4.68 122.331
 98 Vermaaks   M VxM Herfs  VxHerfs  MxHerfs  VxMxH Left  2  9.68  2.20  86.466
 99 Vermaaks   M VxM Herfs  VxHerfs  MxHerfs  VxMxH Left  3  7.96  2.92  69.739
100 Vermaaks   M VxM Herfs  VxHerfs  MxHerfs  VxMxH Right 1 10.24  2.24 135.930
101 Vermaaks   M VxM Herfs  VxHerfs  MxHerfs  VxMxH Right 2 11.28  3.20  89.169
102 Vermaaks   M VxM Herfs  VxHerfs  MxHerfs  VxMxH Right 3 10.56  5.20 120.009
103 Vermaaks   M VxM Lente  VxLente  MxLente  VxMxL Left  1  5.18  3.00   7.902
104 Vermaaks   M VxM Lente  VxLente  MxLente  VxMxL Left  2  4.24  3.70   6.639
105 Vermaaks   M VxM Lente  VxLente  MxLente  VxMxL Left  3  7.40  3.38  12.525
106 Vermaaks   M VxM Lente  VxLente  MxLente  VxMxL Right 1 10.03 14.74  29.776
107 Vermaaks   M VxM Lente  VxLente  MxLente  VxMxL Right 2  6.52  3.16  13.661
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  108 Vermaaks   M VxM Lente  VxLente  MxLente  VxMxL Right 3  5.20  1.74  11.992
  109 Vermaaks   M VxM Somer  VxSomer  MxSomer  VxMxS Left  1  4.10  0.58 117.456
  110 Vermaaks   M VxM Somer  VxSomer  MxSomer  VxMxS Left  2  3.70  0.67 147.344
  111 Vermaaks   M VxM Somer  VxSomer  MxSomer  VxMxS Left  3  2.44  1.09 116.503
  112 Vermaaks   M VxM Somer  VxSomer  MxSomer  VxMxS Right 1  4.73  1.06 191.678
  113 Vermaaks   M VxM Somer  VxSomer  MxSomer  VxMxS Right 2  4.62  0.68 123.365
  114 Vermaaks   M VxM Somer  VxSomer  MxSomer  VxMxS Right 3  4.56  0.81 116.667
  115 Vermaaks   M VxM Winter VxWinter MxWinter VxMxW Left  1 14.16  3.92  69.357
  116 Vermaaks   M VxM Winter VxWinter MxWinter VxMxW Left  2  3.96  2.56  62.162
  117 Vermaaks   M VxM Winter VxWinter MxWinter VxMxW Left  3  2.40  2.42  85.553
  118 Vermaaks   M VxM Winter VxWinter MxWinter VxMxW Right 1  3.16  2.66  74.505
  119 Vermaaks   M VxM Winter VxWinter MxWinter VxMxW Right 2  3.24  2.44  66.389
  120 Vermaaks   M VxM Winter VxWinter MxWinter VxMxW Right 3  4.32  2.66  89.666
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    2
                      PhD - Promotor Prof Lincoln Raitt :
                                             09:09 Thursday, August 30, 2007

                              The GLM Procedure

                            Class Level Information

Class       Levels  Values

River          2  Marnevicks Vermaaks

Transect         3  B M O

RxT            5  MxB MxM MxO VxB VxM

Season          4  Herfs Lente Somer Winter

RxS            8  MxHerfs MxLente MxSomer MxWinter VxHerfs VxLente VxSomer VxWinter

TxS           12  BxHerfs BxLente BxSomer BxWinter MxHerfs MxLente MxSomer MxWinter
               OxHerfs OxLente OxSomer OxWinter

RxTxS          20  MxBxH MxBxL MxBxS MxBxW MxMxH MxMxL MxMxS MxMxW MxOxH
MxOxL MxOxS
               MxOxW VxBxH VxBxL VxBxS VxBxW VxMxH VxMxL VxMxS VxMxW

Bank           2  Left Right

Sample          3  1 2 3

                         Data for Analysis of NH4_N

                      Number of Observations Read        120
                      Number of Observations Used        119


                         Data for Analysis of NO3_N

                      Number of Observations Read        120
                      Number of Observations Used        118


                          Data for Analysis of Phos

                      Number of Observations Read        120
                      Number of Observations Used        120
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NOTE: Variables in each group are consistent with respect to the presence or absence
      of missing values.
  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    3
                      PhD - Promotor Prof Lincoln Raitt :
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                             The GLM Procedure

Dependent Variable: NH4_N

                                    Sum of
 Source                    DF        Squares      Mean Square    F Value    Pr > F
 River                     1      2.14753447       2.14753447      0.45    0.5076
 Transect                   2      5.58136460       2.79068230      0.59    0.5634
 RxT                       1      8.29098021       8.29098021      1.74    0.1986
 RxT(Bank*Sample)              25      118.8300364       4.7532015       1.00    0.4789
 Season                     3     967.1840830     322.3946943      67.80    <.0001
 RxS                        3      16.6802890       5.5600963       1.17    0.3273
 TxS                       6      15.1963170       2.5327195       0.53    0.7818
 RxTxS                      3       7.2460030       2.4153343       0.51    0.6780
 Error                    74      351.869075       4.754987
 Corrected Total             118      1493.025682


         R-Square     Coeff Var      Root MSE    NH4_N Mean
         0.764325      33.41454      2.180593      6.525882


  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    4
                      PhD - Promotor Prof Lincoln Raitt :
                                          09:09 Thursday, August 30, 2007

                             The GLM Procedure

         Level of             ------------NH4_N------------
         River          N            Mean          Std Dev

         Marnevicks     71       6.63633803       3.82575865
         Vermaaks       48       6.36250000       3.14990071


          Level of           ------------NH4_N------------
          Transect      N            Mean          Std Dev

          B            47       6.65936170       3.48898104
          M             48       6.24166667       3.41606551
          O             24       6.83291667       4.05196837


          Level of           ------------NH4_N------------
          RxT            N            Mean          Std Dev

          MxB          23       7.05521739       3.95105034
          MxM           24       6.03833333       3.55052068
          MxO           24       6.83291667       4.05196837
          VxB          24       6.28000000       3.01778640
          VxM          24       6.44500000       3.33974485


          Level of           ------------NH4_N------------
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Season        N          Mean         Std Dev

Herfs       30     11.2013333      2.44334386
Winter       29      4.2765517      2.49597430
Lente        30      6.3500000      2.16270584
Somer         30      4.2006667      1.23416853


Level of           ------------NH4_N------------
RxS           N          Mean         Std Dev

MxHerfs      18      11.7800000      2.72028545
MxWinter     17       4.1023529      1.98340468
MxLente      18       6.4672222      2.39613857
MxSomer       18       4.0550000      1.37968560
VxHerfs      12      10.3333333      1.71252781
VxWinter     12       4.5233333      3.16583849
VxLente      12       6.1741667      1.84435482
VxSomer       12       4.4191667      0.99348293


Level of           ------------NH4_N------------
TxS           N          Mean         Std Dev

BxHerfs      12      11.2933333      2.48113366
BxWinter     11       3.9018182      1.95258710
BxLente      12       6.5416667      2.14670078
BxSomer       12       4.6708333      1.14723746
MxHerfs      12      10.7366667      2.01438163
MxWinter     12       4.3566667      3.25187312
MxLente      12       5.8150000      1.64276651
MxSomer       12       4.0583333      1.10114679
OxHerfs       6      11.9466667      3.30910663
OxWinter      6       4.8033333      1.82771624
OxLente       6       7.0366667      3.11640605
OxSomer        6       3.5450000      1.47521863


Level of          ------------NH4_N------------
RxTxS        N          Mean         Std Dev

MxBxH        6      12.0400000      2.70182161
MxBxL       6       7.1633333      2.49766024
MxBxS       6       4.5283333      1.34179606
MxBxW        5       3.9760000      2.82256621
MxMxH        6      11.3533333      2.56454804
MxMxL       6       5.2016667      0.82351482
MxMxS       6       4.0916667      1.38301723
MxMxW        6       3.5066667      1.35756645
MxOxH       6      11.9466667      3.30910663
MxOxL       6       7.0366667      3.11640605
MxOxS       6       3.5450000      1.47521863
MxOxW        6       4.8033333      1.82771624
VxBxH       6      10.5466667      2.21481075
VxBxL       6       5.9200000      1.72408816
VxBxS       6       4.8133333      1.02293043
VxBxW       6       3.8400000      1.11427106
VxMxH       6      10.1200000      1.19893286
VxMxL       6       6.4283333      2.08712641
VxMxS       6       4.0250000      0.86726582
```

```
                VxMxW        6        5.2066667       4.43703805
     Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    5
                    PhD - Promotor Prof Lincoln Raitt :
                                          09:09 Thursday, August 30, 2007

                           The GLM Procedure

                         t Tests (LSD) for NH4_N

        NOTE: This test controls the Type I comparisonwise error rate, not the
                         experimentwise error rate.


                    Alpha                         0.05
                    Error Degrees of Freedom           25
                    Error Mean Square            4.753201
                    Critical Value of t          2.05954
                    Least Significant Difference    0.839
                    Harmonic Mean of Cell Sizes  57.27731

                      NOTE: Cell sizes are not equal.


            Means with the same letter are not significantly different.


             t Grouping          Mean      N    River

                    A        6.6363     71    Marnevicks
                    A
                    A        6.3625     48    Vermaaks
     Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    6
                    PhD - Promotor Prof Lincoln Raitt :
                                          09:09 Thursday, August 30, 2007

                           The GLM Procedure

                         t Tests (LSD) for NH4_N

        NOTE: This test controls the Type I comparisonwise error rate, not the
                         experimentwise error rate.


                    Alpha                         0.05
                    Error Degrees of Freedom           25
                    Error Mean Square            4.753201
                    Critical Value of t          2.05954
                    Least Significant Difference   1.0612
                    Harmonic Mean of Cell Sizes  35.80952

                      NOTE: Cell sizes are not equal.


            Means with the same letter are not significantly different.


              t Grouping          Mean      N    Transect

                     A        6.8329     24    O
                     A
```

```
                 A       6.6594     47    B
                 A
                 A       6.2417     48    M
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    7
                 PhD - Promotor Prof Lincoln Raitt :
                                    09:09 Thursday, August 30, 2007

                        The GLM Procedure

                      t Tests (LSD) for NH4_N

    NOTE: This test controls the Type I comparisonwise error rate, not the
                    experimentwise error rate.


                 Alpha                          0.05
                 Error Degrees of Freedom          25
                 Error Mean Square           4.753201
                 Critical Value of t         2.05954
                 Least Significant Difference   1.3018
                 Harmonic Mean of Cell Sizes   23.7931

                   NOTE: Cell sizes are not equal.


         Means with the same letter are not significantly different.


             t Grouping         Mean      N    RxT

                   A       7.0552     23    MxB
                   A
                   A       6.8329     24    MxO
                   A
                   A       6.4450     24    VxM
                   A
                   A       6.2800     24    VxB
                   A
                   A       6.0383     24    MxM
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    8
                 PhD - Promotor Prof Lincoln Raitt :
                                    09:09 Thursday, August 30, 2007

                        The GLM Procedure

                      t Tests (LSD) for NH4_N

    NOTE: This test controls the Type I comparisonwise error rate, not the
                    experimentwise error rate.


                 Alpha                          0.05
                 Error Degrees of Freedom          74
                 Error Mean Square           4.754987
                 Critical Value of t         1.99254
                 Least Significant Difference   1.1267
                 Harmonic Mean of Cell Sizes  29.74359

                   NOTE: Cell sizes are not equal.
```

```
             Means with the same letter are not significantly different.


                t Grouping          Mean      N    Season

                       A       11.2013     30    Herfs

                       B        6.3500     30    Lente

                       C        4.2766     29    Winter
                       C
                       C        4.2007     30    Somer
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter    9
                    PhD - Promotor Prof Lincoln Raitt :
                                     09:09 Thursday, August 30, 2007

                               The GLM Procedure

                              t Tests (LSD) for NH4_N

         NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.


                      Alpha                        0.05
                      Error Degrees of Freedom           74
                      Error Mean Square            4.754987
                      Critical Value of t          1.99254
                      Least Significant Difference    2.054
                      Harmonic Mean of Cell Sizes  8.949153

                         NOTE: Cell sizes are not equal.


             Means with the same letter are not significantly different.


                 t Grouping           Mean      N    TxS

                      A            11.947      6    OxHerfs
                      A
                      A            11.293     12    BxHerfs
                      A
                      A            10.737     12    MxHerfs

                      B             7.037      6    OxLente
                      B
                 C    B             6.542     12    BxLente
                 C    B
                 C    B    D        5.815     12    MxLente
                 C         D
                 C    E    D        4.803      6    OxWinter
                 C    E    D
                 C    E    D        4.671     12    BxSomer
                      E    D
                      E    D        4.357     12    MxWinter
                      E    D
                      E    D        4.058     12    MxSomer
                      E    D
```

```
                E    D         3.902     11    BxWinter
                E
                E            3.545      6    OxSomer
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   10
                PhD - Promotor Prof Lincoln Raitt :
                                    09:09 Thursday, August 30, 2007

                     The GLM Procedure

                   t Tests (LSD) for NH4_N

     NOTE: This test controls the Type I comparisonwise error rate, not the
                 experimentwise error rate.


               Alpha                        0.05
               Error Degrees of Freedom           74
               Error Mean Square            4.754987
               Critical Value of t          1.99254
               Least Significant Difference    1.624
               Harmonic Mean of Cell Sizes  14.31579

                  NOTE: Cell sizes are not equal.


         Means with the same letter are not significantly different.


            t Grouping          Mean       N    RxS

                A       11.7800     18    MxHerfs
                A
                A       10.3333     12    VxHerfs

                B        6.4672     18    MxLente
                B
                B        6.1742     12    VxLente

                C        4.5233     12    VxWinter
                C
                C        4.4192     12    VxSomer
                C
                C        4.1024     17    MxWinter
                C
                C        4.0550     18    MxSomer
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   11
                PhD - Promotor Prof Lincoln Raitt :
                                    09:09 Thursday, August 30, 2007

                     The GLM Procedure

                   t Tests (LSD) for NH4_N

     NOTE: This test controls the Type I comparisonwise error rate, not the
                 experimentwise error rate.


               Alpha                        0.05
               Error Degrees of Freedom           74
               Error Mean Square            4.754987
```

```
               Critical Value of t          1.99254
               Least Significant Difference   2.5211
               Harmonic Mean of Cell Sizes  5.940594

                 NOTE: Cell sizes are not equal.


        Means with the same letter are not significantly different.


             t Grouping          Mean      N    RxTxS

                  A          12.040     6    MxBxH
                  A
                  A          11.947     6    MxOxH
                  A
                  A          11.353     6    MxMxH
                  A
                  A          10.547     6    VxBxH
                  A
                  A          10.120     6    VxMxH

                  B           7.163     6    MxBxL
                  B
            C      B          7.037     6    MxOxL
            C      B
            C      B   D       6.428     6    VxMxL
            C      B   D
            C   E   B   D       5.920     6    VxBxL
            C   E   B   D
            C   E   B   D       5.207     6    VxMxW
            C   E   B   D
            C   E   B   D       5.202     6    MxMxL
            C   E   B   D
            C   E   B   D       4.813     6    VxBxS
            C   E   B   D
            C   E   B   D       4.803     6    MxOxW
            C   E      D
            C   E      D       4.528     6    MxBxS
               E      D
               E      D       4.092     6    MxMxS
               E      D
               E      D       4.025     6    VxMxS
               E      D
               E      D       3.976     5    MxBxW
               E
               E             3.840     6    VxBxW
               E
               E             3.545     6    MxOxS
               E
               E             3.507     6    MxMxW
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   12
               PhD - Promotor Prof Lincoln Raitt :
                                 09:09 Thursday, August 30, 2007

                     The GLM Procedure

Dependent Variable: NO3_N

                         Sum of
```

```
Source                   DF        Squares     Mean Square    F Value    Pr > F
River                   1      0.01067038      0.01067038      0.00    0.9556
Transect                  2     51.86639294      25.93319647      7.68    0.0025
RxT                     1     18.69692803      18.69692803      5.54    0.0268
RxT(Bank*Sample)           25      84.4270194       3.3770808       0.77    0.7669
Season                    3     143.8481053      47.9493684      10.91    <.0001
RxS                     3      43.9651438      14.6550479       3.33    0.0240
TxS                     6      41.7343470       6.9557245       1.58    0.1645
RxTxS                     3      17.1157053       5.7052351       1.30    0.2817
Error                  73     320.9253319       4.3962374
Corrected Total           117     722.5896441


           R-Square     Coeff Var      Root MSE    NO3_N Mean
            0.555868      69.81180      2.096721      3.003390

 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   13
                PhD - Promotor Prof Lincoln Raitt :
                                 09:09 Thursday, August 30, 2007

                    The GLM Procedure

          Level of            ------------NO3_N------------
          River          N           Mean          Std Dev

          Marnevicks     71       3.01112676       2.52111061
          Vermaaks       47       2.99170213       2.45684078


           Level of           ------------NO3_N------------
           Transect      N            Mean          Std Dev

           B           47       3.20319149       2.54475685
           M            47       2.31361702       2.14902144
           O            24       3.96291667       2.68593030


           Level of           ------------NO3_N------------
           RxT           N            Mean          Std Dev

           MxB          24       3.40208333       2.93466979
           MxM           23       1.61000000       0.68581736
           MxO          24       3.96291667       2.68593030
           VxB          23       2.99565217       2.10910973
           VxM          24       2.98791667       2.79591935


           Level of           ------------NO3_N------------
           Season        N            Mean          Std Dev

           Herfs        30       4.43333333       3.20592698
           Lente        28       3.62428571       2.87200334
           Somer         30       1.53666667       1.21808310
           Winter        30       2.46066667       0.67676682


           Level of           ------------NO3_N------------
           RxS           N            Mean          Std Dev

           MxHerfs      18       5.13555556       3.93208554
```

```
MxWinter     18       2.21222222       0.70121370
MxLente      17       3.02235294       1.17212163
MxSomer      18       1.67500000       1.25732325
VxHerfs      12       3.38000000       1.08831814
VxWinter     12       2.83333333       0.44167724
VxLente      11       4.55454545       4.30170051
VxSomer      12       1.32916667       1.17907096


Level of            ------------NO3_N------------
TxS           N            Mean          Std Dev

BxHerfs      12       4.77000000       3.63078254
BxLente      11       3.50181818       2.65634643
BxSomer      12       2.21000000       1.55984265
BxWinter     12       2.35583333       0.65079613
MxHerfs      12       2.62333333       1.18025678
MxLente      11       3.69363636       3.74510153
MxSomer      12       0.72416667       0.17819593
MxWinter     12       2.32833333       0.60994535
OxHerfs       6       7.38000000       2.99863969
OxLente       6       3.72166667       1.52397397
OxSomer       6       1.81500000       0.64611918
OxWinter      6       2.93500000       0.75354496


Level of            ------------NO3_N------------
RxTxS         N            Mean          Std Dev

MxBxH         6       6.18666667       4.81329271
MxBxL         6       3.02333333       0.59577401
MxBxS         6       2.57666667       1.62856583
MxBxW         6       1.82166667       0.38716491
MxMxH         6       1.84000000       0.07155418
MxMxL         5       2.18200000       0.72963690
MxMxS         6       0.63333333       0.06345602
MxMxW         6       1.88000000       0.10807405
MxOxH         6       7.38000000       2.99863969
MxOxL         6       3.72166667       1.52397397
MxOxS         6       1.81500000       0.64611918
MxOxW         6       2.93500000       0.75354496
VxBxH         6       3.35333333       1.00857655
VxBxL         5       4.07600000       4.05477866
VxBxS         6       1.84333333       1.54205923
VxBxW         6       2.89000000       0.31157664
VxMxH         6       3.40666667       1.25969308
VxMxL         6       4.95333333       4.84111833
VxMxS         6       0.81500000       0.21454603
VxMxW         6       2.77666667       0.56954953
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   14
              PhD - Promotor Prof Lincoln Raitt :
                                  09:09 Thursday, August 30, 2007

                      The GLM Procedure

                   t Tests (LSD) for NO3_N

  NOTE: This test controls the Type I comparisonwise error rate, not the
                 experimentwise error rate.
```

```
                 Alpha                        0.05
                 Error Degrees of Freedom           25
                 Error Mean Square           3.377081
                 Critical Value of t          2.05954
                 Least Significant Difference   0.7117
                 Harmonic Mean of Cell Sizes  56.55932

                   NOTE: Cell sizes are not equal.


          Means with the same letter are not significantly different.


            t Grouping          Mean      N    River

                 A        3.0111     71    Marnevicks
                 A
                 A        2.9917     47    Vermaaks
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   15
                  PhD - Promotor Prof Lincoln Raitt :
                                  09:09 Thursday, August 30, 2007

                        The GLM Procedure

                      t Tests (LSD) for NO3_N

     NOTE: This test controls the Type I comparisonwise error rate, not the
                     experimentwise error rate.


                 Alpha                        0.05
                 Error Degrees of Freedom           25
                 Error Mean Square           3.377081
                 Critical Value of t          2.05954
                 Least Significant Difference   0.8968
                 Harmonic Mean of Cell Sizes  35.62105

                   NOTE: Cell sizes are not equal.


          Means with the same letter are not significantly different.


               t Grouping          Mean      N    Transect

                    A        3.9629     24    O
                    A
                 B    A        3.2032     47    B
                 B
                 B           2.3136     47    M
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   16
                  PhD - Promotor Prof Lincoln Raitt :
                                  09:09 Thursday, August 30, 2007

                        The GLM Procedure

                      t Tests (LSD) for NO3_N

     NOTE: This test controls the Type I comparisonwise error rate, not the
```

```
                    experimentwise error rate.


                 Alpha                        0.05
                 Error Degrees of Freedom           25
                 Error Mean Square            3.377081
                 Critical Value of t          2.05954
                 Least Significant Difference    1.102
                 Harmonic Mean of Cell Sizes  23.58974

                   NOTE: Cell sizes are not equal.


         Means with the same letter are not significantly different.


              t Grouping          Mean      N    RxT

                   A        3.9629     24    MxO
                   A
                   A        3.4021     24    MxB
                   A
                   A        2.9957     23    VxB
                   A
                   A        2.9879     24    VxM

                   B        1.6100     23    MxM
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   17
                 PhD - Promotor Prof Lincoln Raitt :
                                 09:09 Thursday, August 30, 2007

                        The GLM Procedure

                      t Tests (LSD) for NO3_N

      NOTE: This test controls the Type I comparisonwise error rate, not the
                    experimentwise error rate.


                 Alpha                        0.05
                 Error Degrees of Freedom           73
                 Error Mean Square            4.396237
                 Critical Value of t          1.99300
                 Least Significant Difference   1.0885
                 Harmonic Mean of Cell Sizes  29.47368

                   NOTE: Cell sizes are not equal.


         Means with the same letter are not significantly different.


             t Grouping          Mean      N    Season

                  A        4.4333     30    Herfs
                  A
                  A        3.6243     28    Lente

                  B        2.4607     30    Winter
                  B
```

```
                B       1.5367     30    Somer
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   18
                PhD - Promotor Prof Lincoln Raitt :
                                 09:09 Thursday, August 30, 2007

                       The GLM Procedure

                     t Tests (LSD) for NO3_N

    NOTE: This test controls the Type I comparisonwise error rate, not the
                    experimentwise error rate.


                Alpha                       0.05
                Error Degrees of Freedom          73
                Error Mean Square           4.396237
                Critical Value of t          1.99300
                Least Significant Difference    1.981
                Harmonic Mean of Cell Sizes  8.898876

                  NOTE: Cell sizes are not equal.


         Means with the same letter are not significantly different.


              t Grouping         Mean      N    TxS

                   A        7.3800      6    OxHerfs

                   B        4.7700     12    BxHerfs
                   B
              C    B         3.7217      6    OxLente
              C    B
              C    B         3.6936     11    MxLente
              C    B
              C    B         3.5018     11    BxLente
              C    B
              C    B         2.9350      6    OxWinter
              C
              C    D         2.6233     12    MxHerfs
              C    D
              C    D         2.3558     12    BxWinter
              C    D
              C    D         2.3283     12    MxWinter
              C    D
              C    D         2.2100     12    BxSomer
              C    D
              C    D         1.8150      6    OxSomer
                   D
                   D        0.7242     12    MxSomer
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   19
                PhD - Promotor Prof Lincoln Raitt :
                                 09:09 Thursday, August 30, 2007

                       The GLM Procedure

                     t Tests (LSD) for NO3_N
    NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.
```

```
                   Alpha                        0.05
                   Error Degrees of Freedom           73
                   Error Mean Square             4.396237
                   Critical Value of t          1.99300
                   Least Significant Difference   1.5725
                   Harmonic Mean of Cell Sizes  14.12431

                     NOTE: Cell sizes are not equal.


           Means with the same letter are not significantly different.


               t Grouping           Mean      N    RxS

                    A           5.1356     18    MxHerfs
                    A
               B    A            4.5545     11    VxLente
               B
               B    C            3.3800     12    VxHerfs
               B    C
               B    C    D        3.0224     17    MxLente
                    C    D
               E    C    D        2.8333     12    VxWinter
               E    C    D
               E    C    D        2.2122     18    MxWinter
               E         D
               E         D       1.6750     18    MxSomer
               E
               E                1.3292     12    VxSomer
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   20
                  PhD - Promotor Prof Lincoln Raitt :
                                        09:09 Thursday, August 30, 2007

                         The GLM Procedure

                        t Tests (LSD) for NO3_N

      NOTE: This test controls the Type I comparisonwise error rate, not the
                        experimentwise error rate.


                   Alpha                        0.05
                   Error Degrees of Freedom           73
                   Error Mean Square             4.396237
                   Critical Value of t          1.99300
                   Least Significant Difference   2.4366
                   Harmonic Mean of Cell Sizes  5.882353

                     NOTE: Cell sizes are not equal.


           Means with the same letter are not significantly different.


                t Grouping           Mean      N    RxTxS

                     A            7.380      6    MxOxH
```

```
       A
   B    A          6.187     6    MxBxH
   B    A
   B    A    C      4.953     6    VxMxL
   B         C
   B    D    C      4.076     5    VxBxL
        D    C
        D    C     3.722     6    MxOxL
        D    C
        D    C     3.407     6    VxMxH
        D    C
        D    C     3.353     6    VxBxH
        D    C
   E    D    C      3.023     6    MxBxL
   E    D    C
   E    D    C      2.935     6    MxOxW
   E    D    C
   E    D    C      2.890     6    VxBxW
   E    D    C
   E    D    C      2.777     6    VxMxW
   E    D    C
   E    D    C      2.577     6    MxBxS
   E    D
   E    D          2.182     5    MxMxL
   E    D
   E    D          1.880     6    MxMxW
   E    D
   E    D          1.843     6    VxBxS
   E    D
   E    D          1.840     6    MxMxH
   E    D
   E    D          1.822     6    MxBxW
   E    D
   E    D          1.815     6    MxOxS
   E
   E              0.815     6    VxMxS
   E
   E              0.633     6    MxMxS
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   30
               PhD - Promotor Prof Lincoln Raitt :
                                 09:09 Thursday, August 30, 2007

                       The UNIVARIATE Procedure
                          Variable:  rNH4_N

                              Moments

    N                      119    Sum Weights              119
    Mean                     0    Sum Observations           0
    Std Deviation   1.72682984    Variance          2.98194131
    Skewness        0.53598467    Kurtosis           1.7101155
    Uncorrected SS    351.869075    Corrected SS      351.869075
    Coeff Variation            .    Std Error Mean    0.15829823


                       Basic Statistical Measures

        Location                  Variability

      Mean      0.00000     Std Deviation            1.72683
```

```
    Median   -0.04083     Variance              2.98194
    Mode       .          Range                11.54711
                          Interquartile Range   1.85500


                  Tests for Location: Mu0=0

       Test          -Statistic-    -----p Value------

       Student's t    t         0    Pr > |t|    1.0000
       Sign           M      -1.5    Pr >= |M|   0.8546
       Signed Rank    S    -178.5    Pr >= |S|   0.6379


                   Tests for Normality

   Test                  --Statistic---    -----p Value------

   Shapiro-Wilk          W     0.975104    Pr < W      0.0262
   Kolmogorov-Smirnov    D     0.080432    Pr > D      0.0580
   Cramer-von Mises      W-Sq  0.121137    Pr > W-Sq   0.0599
   Anderson-Darling      A-Sq  0.739408    Pr > A-Sq   0.0532


                  Quantiles (Definition 5)

                  Quantile       Estimate

                  100% Max      6.7883333
                  99%           4.3912500
                  95%           3.0180000
                  90%           2.2187500
                  75% Q3        0.8200000
                  50% Median   -0.0408333
                  25% Q1       -1.0350000
                  10%          -1.9858333
                  5%           -3.0187500
                  1%           -3.4133333
                  0% Min       -4.7587778


                   Extreme Observations

         ------Lowest-----        -----Highest-----

            Value     Obs            Value     Obs

         -4.75878       5          3.09083      75
         -3.41333     103          3.48750      25
         -3.21875      49          3.82125      52
         -3.16500      27          4.39125      55
         -3.12125      60          6.78833     115


                     Missing Values

                          -----Percent Of-----
         Missing                     Missing
          Value      Count    All Obs        Obs
```

```
          .          1       0.83      100.00


    Stem Leaf                     #             Boxplot
       6 8                        1                *
       6
       5
       5
       4
       4 4                        1                0
       3 58                       2                0
       3 001                      3                |
       2 699                      3                |
       2 0224                     4                |
       1 55778                    5                |
       1 0022333                  7                |
       0 55566677778888999       17             +-----+
       0 111112222333444         15             |  +  |
      -0 44333333222200          14             *-----*
      -0 999999998866655         15             |     |
      -1 4443332111000           13             +-----+
      -1 987555                   6                |
      -2 42100                    5                |
      -2 65                       2                |
      -3 42210                    5                |
      -3
      -4
      -4 8                        1                0
         ----+----+----+----+
```

```
                     Normal Probability Plot
 6.75+                                       *
      |
      |
      |
      |
      |                                  * ++
      |                                *+++
      |                              ****+
      |                            **++
      |                           **+
      |                         ++**
      |                      ++***
      |                    +*****
      |                  *****
      |                ****
      |             *****
      |          *****+
      |         ***++
      |        ***+
      |      +**
      |   * ****
      |  +++
      |++
-4.75+*
       +----+----+----+----+----+----+----+----+----+----+
           -2        -1         0        +1        +2
```

```
Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   31
              PhD - Promotor Prof Lincoln Raitt :
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                  The UNIVARIATE Procedure
                     Variable:  rNO3_N

                          Moments

        N                   118    Sum Weights             118
        Mean                  0    Sum Observations          0
        Std Deviation    1.65618585    Variance          2.74295156
        Skewness         1.32643693    Kurtosis          5.3926104
        Uncorrected SS     320.925332    Corrected SS       320.925332
        Coeff Variation           .    Std Error Mean      0.15246427


                  Basic Statistical Measures

           Location                  Variability

          Mean     0.000000     Std Deviation           1.65619
          Median   0.040319     Variance               2.74295
          Mode      .          Range                11.43167
                         Interquartile Range      1.12775


                  Tests for Location: Mu0=0

           Test          -Statistic-    -----p Value------

           Student's t    t         0    Pr > |t|    1.0000
           Sign           M         5    Pr >= |M|   0.4075
           Signed Rank    S       -77    Pr >= |S|   0.8372


                    Tests for Normality

         Test                 --Statistic---    -----p Value------

         Shapiro-Wilk         W     0.875985    Pr < W     <0.0001
         Kolmogorov-Smirnov    D      0.17168    Pr > D     <0.0100
         Cramer-von Mises      W-Sq  0.753001    Pr > W-Sq  <0.0050
         Anderson-Darling      A-Sq  4.013137    Pr > A-Sq  <0.0050


                  Quantiles (Definition 5)

                  Quantile       Estimate

                  100% Max       7.5995833
                  99%           6.0829167
                  95%           2.4268889
                  90%           1.4468889
                  75% Q3         0.4887500
                  50% Median     0.0403194
                  25% Q1        -0.6390000
                  10%           -2.1770833
                  5%           -2.4631111
                  1%           -3.3537500
```

```
                 0% Min        -3.8320833


                  Extreme Observations

         ------Lowest-----        -----Highest-----

            Value      Obs           Value      Obs

         -3.83208        4         3.25542       52
         -3.35375      100          3.40792       16
         -3.17958        5         5.78600       80
         -2.82792      108          6.08292        1
         -2.72458       50         7.59958      106


                    Missing Values

                          -----Percent Of-----
         Missing                         Missing
          Value       Count     All Obs         Obs

            .           2         1.67      100.00


   Stem Leaf                           #            Boxplot
      7 6                              1             *
      7
      6
      6 1                              1             *
      5 8                              1             *
      5
      4
      4
      3
      3 34                             2             0
      2
      2 2334                           4             0
      1 56                             2             |
      1 011112334                      9             |
      0 555555666689                  12          +-----+
      0 00000011111111122222333333334444    32    *--+--*
     -0 4443332222222111100           19          |     |
     -0 98887666555                   11          +-----+
     -1 32210                          5             |
     -1 98775                          5             |
     -2 44332210                       8             0
     -2 875                            3             0
     -3 42                             2             0
     -3 8                              1             0
        ----+----+----+----+----+----+--


                     Normal Probability Plot
       7.75+                                    *
           |
           |
           |                                 *
           |                                *
           |
```

```
     |
     |                                   +
     |                                +++
     |                             **++
     |                            +++
     |                          ++***
     |                        +++**
     |                      +++****
     |                    +++****
     |                ********* 
     |             *****
     |           ***++
     |          ***+
     |        ***
     |     ******
     |   **++
     | *+*+
-3.75+*+++
     +----+----+----+----+----+----+----+----+----+----+
        -2      -1       0      +1      +2
```

```
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   33
                 PhD - Promotor Prof Lincoln Raitt :
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                       The CORR Procedure

               3  Variables:    NH4_N    NO3_N    Phos


                       Simple Statistics

Variable         N        Mean      Std Dev         Sum      Minimum      Maximum

NH4_N          119     6.52588      3.55707    776.58000      1.04000     17.80000
NO3_N          118     3.00339      2.48515    354.40000      0.57000     14.74000
Phos           120    63.55211     46.67597         7626      2.55900    242.82900


                   Pearson Correlation Coefficients
                     Prob > |r| under H0: Rho=0
                       Number of Observations

                       NH4_N         NO3_N          Phos

              NH4_N       1.00000       0.50985       0.00179
                                        <.0001        0.9846
                            119           117           119

              NO3_N       0.50985       1.00000      -0.04208
                          <.0001                      0.6510
                            117           118           118

              Phos        0.00179      -0.04208       1.00000
                          0.9846        0.6510
                            119           118           120
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   34
```

```
                    PhD - Promotor Prof Lincoln Raitt :
                                      09:09 Thursday, August 30, 2007

                Plot of NH4_N*NO3_N$RxTxS.  Symbol used is '*'.

  20 ˆ
     ,
     ,
     ,                                      * MxOxH
     ,
     ,
     ,    MxMxH * * MxBxH
  15 ˆ               * VxBxH
     ,              * VxMxW            * MxBxH
     ,                               * MxOxH
NH4_N ,       MxMxH MxBxL   * MxOxL
     ,       *    *     * MxBxH
     ,       VxMxH *   VxBxH         * MxOxH
     ,      MxMxHVxMxHVxMx*** * VxMxH                          * MxBxH
  10 ˆ      MxMxH*** VxBxMxOxH *    * MxBxH                        * VxMxL
     ,  MxBxH * *   * VxBxH*      * MxOxH
     ,   MxBxW ** * VxMxH MxOxH
     ,      MxMxHVxBx* * MxOxL
     ,  MxMxS MxOxW**xB*LVxMxLMxOxL                        * VxBxL
     ,     *  MxMx*x****xO*WMx*xL * MxBxS
     , MxMxSxMxMx*x**xMxOxW VxBx* MxOxL
   5 ˆ  VxM*S*****V*B***xMxBxL
     ,VxBxM***Vx*x***MxBx* VxMxL
     , MxMx*x*x***M*B*xVxBx* MxOxW
     , VxMx*xVx**L*** *xVxBxW
     , VxMx* **M**x*M*OxW
     , MxMxSMxOxSxVxMVxBxW
     ,        * MxBxW
   0 ˆ

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
     0       2       4       6       8      10      12      14      16

                                NO3_N

NOTE: 3 obs had missing values.  25 obs hidden.  126 label characters hidden.


                Plot of NH4_N*Phos$RxTxS.  Symbol used is '*'.

     20 ˆ
        ,
        ,
        ,                              * MxOxH
        ,
        ,
        ,       * MxBxH   * MxMxH
     15 ˆ                            * VxBxH
        ,         * MxBxH * VxMxW
        ,  MxOxL                  * MxOxH
   NH4_N ,    *      MxMxH
        ,    *     * *     * MxMxH
        ,   MxBxL MxBxH * MxOxH   * VxMxH VxMxH
        ,      VxMxL *   MxOxH    * VxBxH *** VxBxH
     10 ˆ     MxOxH** * MxM*HVxBx* VxMxH      * VxMxH
```

```
    ,MxBxH *  *MxB*HMxMxH * MxOxH * VxBxH
    ,    MxBxW * *   * MxMxH
    , VxM*LMxOxL VxBxH   * VxMxH
    ,MxBxL**Mx*xLxBxL MxOxWMxMxS
    ,MxVx*x* *xMxL* MxBxL ***  * MxOxW                        VxBxS *
    ,MxO****MxMxLMxBx* MxMxWMxOxVxBx* VxBxS      VxBxS
  5 ˆxMx***Vx*xL * * VxMxWVxBx*MxM*SVxM***VxBxW    *     * VxMxS
    ,MxB**VxM*LMxB*S*Vx*xW**  *Vx*xS ***VxMxS
    ,VxMxM*LMxO*LMxBMxMx*MxO*VxM**M*Mx* * VxB*SVxMxS
    ,    *xBxW * Mx*** *  *VxMxWMxBVSBx*MxOxS
    ,VxBxL MxMxS**MxO*W VxMxW**MxMx* * VxBxW
    ,         MxOxS MxOxS VxBxW MxMxWVxMxS
    ,       * MxBxW
  0 ˆ
    Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
      0          50          100         150         200         250

                                Phos

NOTE: 1 obs had missing values.  14 obs hidden.  82 label characters hidden.
  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   35
                     PhD - Promotor Prof Lincoln Raitt :
                                 09:09 Thursday, August 30, 2007

             Plot of NO3_N*NH4_N$RxTxS.  Symbol used is '*'.



NO3_N ,
     ,
  15 ˆ                            * VxMxL
     ,                            * MxBxH
     ,
     ,
     ,                                          * MxOxH
     ,                     * VxBxL
     ,
  10 ˆ
     ,                                   * MxOxH
     ,                                     * MxBxH
     ,
     ,                             * MxOxH
     ,                          * MxBxH
     ,              MxOxL ** MxBxS     * MxOxH
   5 ˆ            MxOxW VxBxS ** MxOxL VxMx* * * MxBxH
     ,            VxM*LMxBxLMxO*W MxOxL *MxOx**VxMx* * MxOxL* VxBxH
     ,      MxOxWMxBxW*Vx*xWMx*xL **VxMxL VxBxH VxMxH     * VxMxW
     ,    VxBxW **V*M**x***** V*B**  *MxMx*VxBxH * * MxBxL
     ,   MxMxMx*x*V**x**Mx**W*Vx*x*xBx**Vx**H* MxMx** MxMxH      * MxBxH
     ,MxBxWV*Mx*** ***V*B***xMxMxS VxBx* * VxMxH MxMxH           * MxMxH
     ,    MxOxS **Mx******xBx* MxMxS MxBxW
   0 ˆ       MxMxSxVxMxMVxMxMxS
     ,

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
    0.0      2.5      5.0      7.5     10.0     12.5     15.0     17.5     20.0

                                NH4_N

NOTE: 3 obs had missing values.  28 obs hidden.  152 label characters hidden.
```

```
           Plot of NO3_N*Phos$RxTxS.  Symbol used is '*'.



    NO3_N ,
          ,
       15 ˆ         * VxMxL
          ,         * MxBxH
          ,
          ,
          ,                              * MxOxH
          ,       * VxBxL
          ,
       10 ˆ
          ,                    * MxOxH
          ,         * MxBxH
          ,
          ,           * MxOxH
          ,  MxOxL   * MxBxH
          ,    * MxOxL   MxOxH * * MxBxS  VxMxH
        5 ˆMxOMxBxL*MxOxH    *    VxBxH     **VxBxH               VxBxS *
          ,MxOx*VxMx* * MxBxHMxVxMxW*  * MxOxW* * VxBxH
          ,MxO***VxMxMxOMxBxSVx**HVxMxHxWMxOxSVxBxW
          ,MxBx***MxBMxM***Mx*x**MxO**Mx*x* ***VxBxW
          ,VxB**V*B*** **V**x**V*Bx**V*Bx*VxM**V*BVxMxH
          ,VxB*****Mx***M*B*SV*M*VxMxH*MxBx*Mx**SVxBxS   * VxBxS
          ,MxMxVxMxBx*MxB*SMxMxHx***MxB*W  ***VxBxS* VxMxS     * VxMxS
        0 ˆ     MxMxS MxMxS   MxMxS MxMxS VxMxS
          ,
          Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
            0          50          100         150         200        250

                                        Phos

NOTE: 2 obs had missing values.  26 obs hidden.  141 label characters hidden.


 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   36
                    PhD - Promotor Prof Lincoln Raitt :
                                        09:09 Thursday, August 30, 2007

           Plot of Phos*NH4_N$RxTxS.  Symbol used is '*'.

 Phos ,
      ,
  250 ˆ
      ,                   * VxBxS
      ,
      ,
      ,
  200 ˆ
      ,              * VxMxS
      ,
      ,               * VxBxS
      ,                                          * MxOxH
  150 ˆ             * VxMxS
      ,          MxOxS VxBxW            * VxMxH        * VxBxH
      ,       VxMxS * VxMx* VxBxS            * VxBxH
      ,      VxBx* * * **** VxBxS       VxMxH * * VxMxH
```

```
    ,     MxMxW *Vx*xWMxM*S* MxOxS
 100 ˆ       VxMxWMx*x** VxBxW MxOxW      * VxBxH         * MxOxH
    ,    VxBxW **MxOxW * *MxMx*     VxMxH *  *  * VxMxH
    ,     MxMxS *MxO**VxMxWxS** MxBxS   MxOxH
    ,       VxMxW **Vx*xVxBxW **    *MxMxH*MxOxH    VxMxW *     * MxMxH
    ,       MxOxW *Vx*xWMxMxSMxOxWVxMx*   **VxBxH * MxMxH
  50 ˆ    MxOxS ** *VxM*W *  *MxBxLVxBxH MxMxH  * MxOxH
    ,   MxMxW *MxBxW *MxMx*   * VxBxL*MxB*W * *    * MxMxH * MxBxH
    ,   MxOxS *  ***MxMxBxSMxOMxMx*   * * ** MxBxH * MxBxH      * MxBxH
    ,MxBxW * MxMxSVxM*LVxM*L ***VxBMxOxMxOxVxMxL MxBxL
    ,       VxBxL * * *x*** ********    * MxBxH   *  * MxOxL
   0 ˆ           MxOxL *Mx*xL*xMxBxVxMxL
    ,            MxMxLMxBxLMxBxL

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
       0.0      2.5      5.0      7.5     10.0     12.5     15.0     17.5     20.0

                                NH4_N

NOTE: 1 obs had missing values.  9 obs hidden.  63 label characters hidden.


               Plot of Phos*NO3_N$RxTxS.  Symbol used is '*'.

 Phos ,
    ,
 250 ˆ
    ,                     * VxBxS
    ,
    ,
    ,
 200 ˆ
    ,      * VxMxS
    ,
    ,      * VxBxS
    ,                                          * MxOxH
 150 ˆ     * VxMxS
    ,     VxMxH * VxBxW * VxBxH
    , VxBxS *VxB*SMxO*S   * VxBxH
    , VxMx***MxM*WMx**SVxBxW* * VxMxH
    ,  VxMxSMxB**Vx*x* VxBxWVxMxH
 100 ˆ     *MxB*S*Mx*VxMxH * MxOxW                 * MxOxH
    , MxMxS VxMxM*****VxBxW* VxBxH
    ,VxBxS**MxOxSVxMxHMxOxW      * MxBxS
    ,     VxB** **** *  * VxMxW * MxOxH
    ,     MxMx*xW**MxOxW     * MxOxH
  50 ˆ  MxO*Mx*x**Vx*xMxBxS              * MxOxH
    , MxMxS  ******* MxBxLMxBxH              * MxBxH               * MxBxH
    ,   Mx*x* *Mx*xMxBxH  * MxOxL  * MxBxH               * VxBxL        * VxMxL
    ,   MxBxW *V*B*L*VxMxLxMx*xL
    , MxOxL ** ** *****V**x*   * MxOxL
   0 ˆ    MxB*HVxMx*xLM*OxL
    ,     MxMxL MxBxL MxBxL

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
        0        2        4        6        8       10       12       14       16

                                NO3_N

NOTE: 2 obs had missing values.  23 obs hidden.  101 label characters hidden.
```

```
  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   37
                     PhD - Promotor Prof Lincoln Raitt :
                                          09:09 Thursday, August 30, 2007

--------------------------------- River=Marnevicks ----------------------------------

                            The CORR Procedure

                  3  Variables:    NH4_N    NO3_N    Phos


                            Simple Statistics

Variable          N        Mean      Std Dev         Sum      Minimum      Maximum

NH4_N            71     6.63634      3.82576    471.18000      1.04000     17.80000
NO3_N            71     3.01113      2.52111    213.79000      0.57000     14.32000
Phos            72    48.93422     34.26971         3523      2.55900    156.34300


                      Pearson Correlation Coefficients
                        Prob > |r| under H0: Rho=0
                          Number of Observations

                            NH4_N         NO3_N          Phos

                NH4_N       1.00000       0.56691       0.02977
                                  <.0001        0.8053
                               71            70            71

                NO3_N       0.56691       1.00000       0.12647
                           <.0001                      0.2933
                               70            71            71

                Phos        0.02977       0.12647       1.00000
                           0.8053        0.2933
                               71            71            72
  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   38
                     PhD - Promotor Prof Lincoln Raitt :
                                          09:09 Thursday, August 30, 2007

---------------------------------- River=Vermaaks ----------------------------------

                            The CORR Procedure

                  3  Variables:    NH4_N    NO3_N    Phos


                            Simple Statistics

Variable          N        Mean      Std Dev         Sum      Minimum      Maximum

NH4_N            48     6.36250      3.14990    305.40000      2.24000     14.68000
NO3_N            47     2.99170      2.45684    140.61000      0.58000     14.74000
Phos            48    85.47894     54.07102         4103      6.51100    242.82900


                      Pearson Correlation Coefficients
                        Prob > |r| under H0: Rho=0
                          Number of Observations
```

```
                  NH4_N        NO3_N         Phos

          NH4_N       1.00000      0.40755      0.00694
                                    0.0045       0.9627
                          48           47           48

          NO3_N       0.40755      1.00000     -0.21611
                       0.0045                    0.1446
                          47           47           47

          Phos        0.00694     -0.21611      1.00000
                       0.9627       0.1446
                          48           47           48
 Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   39
              PhD - Promotor Prof Lincoln Raitt :
                                       09:09 Thursday, August 30, 2007

-------------------------------- River=Marnevicks ---------------------------------

          Plot of NH4_N*NO3_N$RxTxS.  Symbol used is '*'.

NH4_N ,
     ,
  20 ˆ
     ,
     ,
     ,                                  * MxOxH
     ,
     ,   MxMxH * * MxBxH
  15 ˆ
     ,                         MxBxH *  * MxOxH
     ,                 MxOxL
     ,          * MxMxH    **MxBxH
     ,   MxMxH *    * MxBxL
     ,                     MxOxH    * MxOxH                        * MxBxH
  10 ˆ            * MxMxH MxOxH *  * * MxBxH
     ,  MxBxH * * MxMxH    * MxOxH
     ,   MxBxW ** MxMxHMxOxL
     ,       MxOxL *Mx*xL  MxOxL
     , MxMxS MxMxW* **M*Bx*   *   * MxBxS
     , MxMx* MxMx* ** MxOxMxBxL * MxOxL
   5 ˆ MxMx*Mx**W* * *** MxBxL
     , MxMx* *  *Mx*xMxBxS * MxOxW
     , MxOx* * ****** MxBxS
     ,  MxO*S *Mx*xW* MxOxW
     , MxMxS *  *MxMxW
     ,   MxOxS * MxBxW
   0 ˆ
     ,

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
    0        2        4        6        8       10       12       14       16

                              NO3_N

NOTE: 2 obs had missing values.  7 obs hidden.  43 label characters hidden.


          Plot of NH4_N*Phos$RxTxS.  Symbol used is '*'.
```

```
NH4_N ,
   ,
 20 ˆ
   ,
   ,
   ,                                        * MxOxH
   ,
   ,         * MxBxH         * MxMxH
 15 ˆ
   ,            * MxBxH               * MxOxH
   ,          MxBxH
   ,  * MxOxL     *   * MxMxH
   ,     * MxBxL       MxOxH   * MxMxH
   ,         MxBxH *    *  MxOxH
 10 ˆ        MxBxH *    * MxMxH *    * MxOxH
   ,MxBxH *MxOxH *     * MxMxH
   ,  MxOxL       * MxBxW   * MxMxH
   ,MxBx** MxMxL               MxOxW MxBxS
   ,MxM*LMx*xL * MxOxL * MxBxL     **   *   * MxOxW
   ,M*B*L*   MxMxL   MxMxS * MxMxW    * MxMxS        * MxOxS
  5 ˆ  ***MxOxL * MxB*S ** MxMxW             * MxOxS
   , * MxMxL  * MxBxW *   * MxOxW MxOxS  MxOxW * MxMxS
   ,    * MxBxW ** MxBxW * * *    *   * MxMxS *   * MxBxS  * MxOxS
   ,   MxOxL     * MxMxS * *MxMxW        * MxMxS    * MxMxW
   ,        MxOxS * * MxOxW
   ,       * MxBxW MxMxW
  0 ˆ
   ,

Šˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆ
    0        25        50        75       100       125       150       175

                                 Phos

NOTE: 1 obs had missing values.  2 obs hidden.  15 label characters hidden.
  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   40
                  PhD - Promotor Prof Lincoln Raitt :
                                         09:09 Thursday, August 30, 2007

--------------------------------- River=Marnevicks ----------------------------------

              Plot of NO3_N*NH4_N$RxTxS.  Symbol used is '*'.


NO3_N ,
   ,
 15 ˆ
   ,                        * MxBxH
   ,
   ,
   ,                                       * MxOxH
   ,
   ,
 10 ˆ
   ,                              * MxOxH
   ,                               * MxBxH
   ,
   ,                         * MxOxH
   ,                      * MxBxH
```

```
     ,                MxOxL ** MxBxS     * MxOxH
   5 ˆ                     MxBx* MxOxL     * MxOxH MxBxH
     ,         MxOxW * MxBxLMxO*W MxOxL * MxOxH    * * MxOxL
     ,        MxBxW MxMxL*MxMx*MxBx*
     ,     MxMxWx* *MxBxS* **  * M*BxL MxMxH MxMxH * MxBxL
     ,      MxO*S* ** **  ** * M*MxW   *  *  *     ** MxMxH      * MxBxH
     ,MxBxW *  **Mx***M*MxM*SMxBxS     * * MxBxH MxMxH           * MxMxH
     ,     MxOxS **Mx*x*  *    * MxMxS MxBxW
   0 ˆ        MxMxS MxMxS MxMxS
     ,

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
       0.0      2.5      5.0      7.5     10.0     12.5     15.0     17.5     20.0

                                   NH4_N


NOTE: 2 obs had missing values.  10 obs hidden.  48 label characters hidden.



                Plot of NO3_N*Phos$RxTxS.  Symbol used is '*'.


NO3_N ,
     ,
  15 ˆ
     ,               * MxBxH
     ,
     ,
     ,                                         * MxOxH
     ,
     ,
  10 ˆ
     ,                             * MxOxH
     ,               * MxBxH
     ,
     ,                  * MxOxH
     ,   MxOxL      * MxBxH
     ,    *   MxOxL            MxOxH *   * MxBxS
   5 ˆ MxOxL     * MxOxH         * MxOxH
     ,MxO*LMxBxL   * * MxBxH       MxOxW         * MxOxW
     ,Mx*x*MxBxL     MxBxL MxBxS     *      MxOxW    MxOxS
     ,MxB***** MxBxH MxMx* **MxOMxMxH MxOxW   *MxMxWMxM*W
     , * * MxMxL****MxB***  *** * *MxM*HMxOxS *  *   **MxBxS  * MxOxS
     ,M*BxH** * MxBx***  *MxM**MxOx* * MxMxS    * MxBxW
     ,MxMxOxLMxBxW *MxOMxB*SMxMxW MxOxS ** *     * MxMxS
   0 ˆ           MxMxS  MxMxS       MxMxS MxMxS
     ,

Šˆƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒˆ
     0        25        50        75       100       125       150       175

                                   Phos


NOTE: 1 obs had missing values.  4 obs hidden.  39 label characters hidden.

  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   41
                    PhD - Promotor Prof Lincoln Raitt :
```

```
                                        09:09 Thursday, August 30, 2007

-------------------------------- River=Marnevicks ----------------------------------

                 Plot of Phos*NH4_N$RxTxS.  Symbol used is '*'.

 Phos ,
      ,
  200 ˆ
      ,
      ,
      ,
      ,
      ,                                               * MxOxH
  150 ˆ
      ,
      ,
      ,             * MxOxS
      ,           MxBxS
      ,    MxMxW *  * MxOxW * MxOxS
  100 ˆ        MxMxW * ** MxMxS
      ,           MxMxS  *    * MxOxW                   * MxOxH
      ,    MxMxS *   *  MxOxS  * MxBxS
      ,           * MxOxS    *** MxOxW    * MxOxH
      ,          MxMxW      MxOxW   MxMxH MxOxH    * MxMxH       * MxMxH
      ,      MxOxW * MxMxW  MxMxW      *    * MxOxH
   50 ˆ    MxOxS ** *   *  *Mx*xS      MxMxHMxMxH*
      ,   MxMxW * MxBxS*MxMx*   * MxBxL    *  * *    * MxMxH * MxBxH
      ,   MxOxS *  ***MxBxS *  MxOxL    *   * MxBxH  * MxBxH
      ,         MxMxS *    *MxMx*  MxBxW * MxOxH               * MxBxH
      ,MxBxW *     MxBxW MxMxOxL* MxBxL   * MxBxH   * MxBxL
      ,        MxOxL *   *** ** * * * MxOxL         * MxOxL
    0 ˆ           MxMxL *  *  * MxBxL
      ,                MxBxL

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
   0.0      2.5      5.0      7.5     10.0     12.5     15.0     17.5     20.0

                                   NH4_N

NOTE: 1 obs had missing values.  1 obs hidden.  13 label characters hidden.


                 Plot of Phos*NO3_N$RxTxS.  Symbol used is '*'.

 Phos ,
      ,
  200 ˆ
      ,
      ,
      ,
      ,
      ,                                        * MxOxH
  150 ˆ
      ,
      ,
      ,          * MxOxS
      ,        MxMxW
      ,   MxMxS  **  * MxOxS
  100 ˆ     *MxB*S* MxMxW   * MxOxW
```

```
     , MxMxS MxBxW * * MxOxW                   * MxOxH
     ,     * MxOxS MxOxS          * MxBxS
     ,     *   *  *    * MxOxW    * MxOxH
     , MxMxSMxMx* MxOxW
     , MxMxSMxMx*xW*MxOxW      * MxOxH
  50 ˆ  MxO*S * **Mx*xMxBxS             * MxOxH
     ,  MxMxMx* ** ** MxBxL                  * MxBxH                * MxBxH
     , MxOx* * *Mx*xMxBxW  * MxBxH  * MxBxH
     , MxMxSMxBxS***MxBxH  * M*OxH
     ,  MxBxH ** MxBx* MxBxL MxOxL
     , MxOxL * Mx*xL****  * *   * MxOxL
   0 ˆ MxMxL *MxMxL*MxO*L MxOxL
     ,          MxBxL MxBxL

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
       0        2        4        6        8       10       12       14       16

                                  NO3_N

NOTE: 1 obs had missing values.  9 obs hidden.  31 label characters hidden.
  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   42
                       PhD - Promotor Prof Lincoln Raitt :
                                              09:09 Thursday, August 30, 2007

---------------------------------- River=Vermaaks -----------------------------------

                  Plot of NH4_N*NO3_N$RxTxS.  Symbol used is '*'.

NH4_N ,
     ,
15.0 ˆ
     ,            VxMxW * VxBxH
     ,
     ,
12.5 ˆ
     ,
     ,        VxMxH *      * VxMxH
     ,             VxBxH **  * VxMxH
10.0 ˆ      VxMxH ** VxBxH VxBxH                                    * VxMxL
     ,     VxMxH * * VxBxH
     ,
     ,     VxBxH *  * VxMxH
 7.5 ˆ       VxBxL *   * VxMxL                          * VxBxL
     ,           * VxBxL
     ,              * VxMxL * VxBxS
     ,   VxMxS VxBxL VxMxL
 5.0 ˆ VxBxS *  **    * VxBxW
     , VxMx** VxMx* *    * VxMxL
     , VxMx** VxBxS ** VxBxW
     , VxBxS *  VxB** *xMxW
 2.5 ˆ VxMxS * VxMx* * VxBxW
     ,          VxMxW
     ,
     ,
 0.0 ˆ
     ,

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
       0        2        4        6        8       10       12       14       16
```

```
                                NO3_N

NOTE: 1 obs had missing values.  8 obs hidden.  16 label characters hidden.


              Plot of NH4_N*Phos$RxTxS.  Symbol used is '*'.

   NH4_N ,
         ,
    15.0 ˆ
         ,               * VxMxW          * VxBxH
         ,
         ,
    12.5 ˆ
         ,
         ,                   * VxMxH  * VxMxH
         ,                   * VxBxH * * VxBxH
    10.0 ˆ          * VxMxL * VxBxH      VxMxH * VxMxH
         ,              VxMxH *    * VxBxH
         ,
         ,   VxMxL    * VxBxH * VxMxH
     7.5 ˆVxBxL**  * VxBxL
         ,     * VxBxL
         ,VxMxL * VxBxL                                  VxBxS *
         ,   VxMxL                VxBxW VxBxS      VxBxS
     5.0 ˆ    **VxBxL            VxMxW *    ***VxBxW    *     * VxMxS
         ,    * VxMxL    VxBxW *   *  VxMx***VxMxS
         ,           VxMxW *   * VxBxSVxMx* VxBxW* VxMxS
         ,    * VxBxL  VxMxW * *      VxBxW ** VxBxS
     2.5 ˆ                VxMxW **      * VxMxS
         ,                  VxBxW
         ,
         ,
     0.0 ˆ
         ,
         Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
           0          50         100         150         200         250

                                 Phos

NOTE: 2 obs hidden.  2 label characters hidden.
  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   43
                   PhD - Promotor Prof Lincoln Raitt :
                                          09:09 Thursday, August 30, 2007

--------------------------------- River=Vermaaks ----------------------------------

              Plot of NO3_N*NH4_N$RxTxS.  Symbol used is '*'.


NO3_N ,
      ,
   15 ˆ                                * VxMxL
      ,
      ,
      ,
      ,
      ,                        * VxBxL
      ,
   10 ˆ
```

```
    ,
    ,
    ,
    ,
    ,
    ,                             VxMxH
  5 ˆ               * VxBxS             *  * VxMxH
    ,       VxMxL          VxMxL      VxBxH ** VxBxH          * VxBxH
    ,VxBxWVxBVxMx*  VxBxW   VxMxL  * VxMxH                         * VxMxW
    , *VxMx*  * *V*Bx** VxMxL * *     *      * VxBxH    * VxMxH
    ,  *VxM**VxB*LVxM*VxMxL VxBxL *    * VxBxH *  * VxMxH
    ,  *VxMxW* VxBxW * * VxBxS              VxMxH
    ,VxMxS    * ** **VxMxS
  0 ˆ       VxMxS VxMxS
    ,

Šˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆ
     2       4       6       8      10      12      14      16

                         NH4_N


NOTE: 1 obs had missing values.  6 obs hidden.  17 label characters hidden.


            Plot of NO3_N*Phos$RxTxS.  Symbol used is '*'.


  NO3_N ,
        ,
     15 ˆ      * VxMxL
        ,
        ,
        ,
        ,
        ,    * VxBxL
        ,
     10 ˆ
        ,
        ,
        ,
        ,
        ,
        ,                     VxMxH
      5 ˆ                   VxMxH **VxBxH               VxBxS *
        ,   VxMxL        VxMxW  * VxBxH   * * VxBxH
        , VxB**       VxMxW *VxBVxMxVxBxH VxBxW
        ,VxBx*** VxMxL  VxM*W**VxM*H  *VxB*** VxBxW
        ,VxMx* *     * VxBx** *  * VxMxHVxB*W * VxMxH
        ,    **VxBxL   VxBxH VxMxW VxMxS *  **VxBxS    * VxBxS
        ,   VxMxL            * VxBxS   ***VxBxS* VxMxS     * VxMxS
      0 ˆ                      VxMxS
        ,
        Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
          0        50       100       150       200       250

                          Phos
```

```
NOTE: 1 obs had missing values.  4 obs hidden.  17 label characters hidden.

  Wietche Roets - SoilPhDKam2006finalLAST-VxO.SAS Sonder VxO vir Autum en Winter   44
                     PhD - Promotor Prof Lincoln Raitt :
                                            09:09 Thursday, August 30, 2007

--------------------------------- River=Vermaaks ----------------------------------

               Plot of Phos*NH4_N$RxTxS.  Symbol used is '*'.

Phos ,
 250 ˆ
    ,                    * VxBxS
    ,
    ,
    ,
 200 ˆ
    ,             * VxMxS
    ,
    ,               * VxBxS
    ,
 150 ˆ        * VxMxS
    ,            VxBxW                         * VxMxH                 * VxBxH
    ,  VxBxW * VxBxS * VxBxS                           * VxBxH
    ,  *   *  *  * * * VxBxS                 VxMxH *  * VxMxH
    ,VxMxS VxBxW VxMxS* VxBxW
 100 ˆVxMxW                                * VxBxH
    , **VxBxW     * VxMxW                VxMxH *    *   * VxMxH
    ,     VxMxW * VxBxS                        VxBxH
    ,VxMxW **   * VxBxW                * VxMxH                        * VxMxW
    ,          * VxMxW                  * VxBxH
  50 ˆ
    ,                          * VxBxH
    ,                  VxBxL     * VxBxL      * VxMxL
    ,          VxMxL VxMxL *  VxBxL
    ,VxBxL *     *   ***      * * ** VxMxL
   0 ˆ              VxBxL  VxMxL
    ,

Šˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆ
ƒ
     2         4         6         8        10        12        14        16

                                    NH4_N

NOTE: 2 obs hidden.


               Plot of Phos*NO3_N$RxTxS.  Symbol used is '*'.

 Phos ,
  250 ˆ
     ,                    * VxBxS
     ,
     ,
     ,
  200 ˆ
     ,      * VxMxS
     ,
     ,      * VxBxS
```

```
     ,
 150 ˆ     * VxMxS
     ,     VxMxH * VxBxW * VxBxH
     , VxMxS * VxBxS  *    * VxBxH
     ,    ***   *   **VxBxW * * VxMxH
     ,    VxMxS  VxBx* VxBxWVxMxH
 100 ˆ        VxMxH * VxBxH
     ,     VxMxW*****VxBxW* VxBxH
     ,VxBxS *  VxMxWVxMxW
     ,     VxBxW ****    * VxMxW
     ,      VxBxH ** VxMxW
  50 ˆ
     ,          * VxBxH
     ,                                        * VxBxL        * VxMxL
     ,       VxMxL  VxMxL
     ,    VxBxL *  *  ** * VxMxL
   0 ˆ          VxBxL
     ,

Šƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒ
       0       2       4       6       8      10      12      14      16

                              NO3_N

NOTE: 1 obs had missing values.  6 obs hidden.  3 label characters hidden.
```

Statistical analysis of ph and electrical conductivity of Kammanassie soil samples using SPSS:

Univariate Analysis of Variance for EC

Between-Subjects Factors

		N
RIVER	Marnevicks	36
	Vermaaks	36

Descriptive Statistics

Dependent Variable: EG

RIVER	Mean	Std. Deviation	N
Marnevicks	26.133	21.7141	36
Vermaaks	23.586	20.4038	36
Total	24.859	20.9595	72

Levene's Test of Equality of Error Variances[a]

Dependent Variable: EG

F	df1	df2	Sig.
.094	1	70	.761

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+RIVER

Tests of Between-Subjects Effects

Dependent Variable: EG

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	116.765[a]	1	116.765	.263	.610
Intercept	44494.925	1	44494.925	100.235	.000
RIVER	116.765	1	116.765	.263	.610
Error	31073.521	70	443.907		
Total	75685.211	72			
Corrected Total	31190.286	71			

[a] R Squared = .004 (Adjusted R Squared = -.010)

Contrast Coefficients (L' Matrix)

Intercept

Parameter	Contrast L1
Intercept	1.000
[RIVER=Marnevicks]	.500
[RIVER=Vermaaks]	.500

The default display of this matrix is the transpose of the corresponding L matrix.
Based on Type III Sums of Squares.

RIVER

Parameter	Contrast L2
Intercept	0
[RIVER=Marnevicks]	1
[RIVER=Vermaaks]	-1

The default display of this matrix is the transpose of the corresponding L matrix.
Based on Type III Sums of Squares.

Univariate Analysis of Variance for pH

Between-Subjects Factors

		N
RIVER	Marnevicks	36
	Vermaaks	36

Descriptive Statistics

Dependent Variable: PH

RIVER	Mean	Std. Deviation	N
Marnevicks	4.939	.5963	36
Vermaaks	5.561	.5145	36
Total	5.250	.6356	72

Levene's Test of Equality of Error Variances[a]

Dependent Variable: PH

F	df1	df2	Sig.
2.339	1	70	.131

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

[a] Design: Intercept+RIVER

Tests of Between-Subjects Effects

Dependent Variable: PH

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.969[a]	1	6.969	22.469	.000
Intercept	1984.500	1	1984.500	6398.337	.000
RIVER	6.969	1	6.969	22.469	.000
Error	21.711	70	.310		
Total	2013.180	72			
Corrected Total	28.680	71			

[a] R Squared = .243 (Adjusted R Squared = .232)

Contrast Coefficients (L' Matrix)

Intercept

	Contrast
Parameter	L1
Intercept	1.000
[RIVER=Marnevicks]	.500
[RIVER=Vermaaks]	.500

The default display of this matrix is the transpose of the corresponding L matrix.
Based on Type III Sums of Squares.

RIVER

	Contrast
Parameter	L2
Intercept	0
[RIVER=Marnevicks]	1
[RIVER=Vermaaks]	-1

The default display of this matrix is the transpose of the corresponding L matrix.
Based on Type III Sums of Squares.

EC-Values	RV-.5m	RV-1m	S/W	GVW-.5m	GVW-1m	GVWSW	GVWa11m	GVWaS/W	GVNW6m	LPG1	LPG2	LPG3-6.5m	LPST1	LPST2	LPST3	GVBH-2m	GVBH-11m	S/W
Kobe 19/7	5066	5488		9391	8722				487	748	735	780	1097	1689	963	5730	4550	
Jaco 30/7							4040			680			930	3180		5250	5040	
Jaco Blab							4640				720		1010	3620		6050	5860	
Wiets 29/9	4538	6660	4730	7310	7702	3720	4501	4272		796	511	845	978	409	850	5455	5277	4235
Wiets12/10	5870	8706	4748	5846	9007	3734	4707	4378	4020	814	538	878	1032	455	890	6255	6160	4220
Wiets 27/10	5724	8862	4767	4336	9077	3910	4764	4259	3987	878	551	878	1023	1016	897	4627	6357	4231
	21198	29716		26883	34508		22652		8494	3916	3055	3381	6070	10369	3600	33367	33244	
Average	5299.5	7429		6720.75	8627		4530.4		2831.333	783.2	611	845.25	1011.667	1728.167	900	5561.167	5540.667	
Water level in piezos																		
Wiets 29/9	-0.2	-0.2	w/Level	-0.1	-0.2	w/level	w/level	w/level	Not taken	-4.14	-4.14	-4.14	-0.2	-0.2	-0.83	-0.49	-0.63	w/level
Wiets12/10	-0.2	-0.3	w/Level	0.2	-0.2	w/level	w/level	w/level	-1.8	-4.11	-4.11	-4.11	-0.2	-0.2	-0.83	-0.3	-0.2	w/level
Wiets 27/10	-0.2	-0.3	w/Level	-0.1	w/level	w/level	w/level	w/level	Not taken	-4.05	-4.05	-4.05	-0.2	-0.2	-0.83	-0.56	-0.68	w/level
Temp																		
Wiets 29/9	15.5	14.1	13.7	15.2	15.2	15.1	18.2	20.9	Not taken	16.2	16.1	15.9	16	14.9	15.6	18.2	19.5	not taken
Wiets12/10	15.9	14.5	20	15	16	16.5	18.1	20.9	15.1	16.5	16.4	16.1	16	15	15.5	15.1	19.6	20.1
Wiets 27/10	16.2	15.9	20.4	17.4	14	22	18.1	24.1	Not taken	16.5	16.5	16.5	16.5	15.6	15.7	18.7	19.6	24.2
EC-Values	GVN-.5m	GVN-1m	S/W	GVE-11m	GVE-7m	GVE-5m	VKA-8.2m	VKA-.5m	VKA-1m	S/W	VKB-11m	VKB-5m	VKB-.5m	VKB-1m	S/W			
Kobe 19/7	896	1097		495	3462	1160					338	224	866	700				
Jaco 30/7				390	1140	670	190	780	310		180		240	130				
Jaco Blab				720	480	1210		720	330		160	210	200					
Wiets 29/9	857	1034	609	555	356	290	158	242	80	109	288	137	744	551	99			
Wiets12/10	887	997	703	572	338	324	166	370	107	120	341	169	1026	695	117			
Wiets 27/10	865	1023	612	549	354	336	169	306	132	122	379	162	1084	813	146			
	3505	4151		3281	6130	3990	683	2418	959		1686	902	4160	2889				
Average	876.25	1037.75		546.8333	1021.667	665	227.6667	483.6	191.8		281	180.4	693.3333	577.8				
Water level in piezos																		
Wiets 29/9	w/level	w/level	w/level	-3.27	-3.27	-3.27	-2.3	-0.2	-0.3	w/level	-3.2	-3.2	-0.2	-0.3	w/level			
Wiets12/10	w/level	w/level	w/level	-3.12	-3.12	-3.12	-2.5	-0.2	-0.5	w/level	-2.8	-3	-0.2	-0.4	w/level			
Wiets 27/10	w/level	w/level	w/level	-3.5	-3.2	-3.2	-2.16	-0.2	-0.3	w/level	-3.35	-3	-0.2	-0.6	w/level			
Temp																		
Wiets 29/9	15.6	15.2	17.7	18	16.5	16.6	13.2	12.4	11.6	12.3	14.5	13.5	14.6	13.6	12.4			
Wiets12/10	15.4	15.5	16.7	18	17.4	16.5	13.5	12.7	12.5	15.1	14.5	13.4	15.1	14.1	15.5			
Wiets 27/10	16.7	16.9	17.9	18	17.1	16.9	13.4	13.7	13.1	15.4	14.5	13.6	16	14.9	20.4			

Appendix B – Case study 2: Groenvlei and Van Kervelsvlei

Data files not covered in text:

Verslag No.: GR17770/2006

ONTLEDINGS VERSLAG

Jaco Nel
Universiteit van Weskaapland
University of the Wester Cape
Ground Water Group
Datum ontvang: 01/08/2006
Datum ontleed: 07/08/2006

Boord	Lab.	Diepte	Grond	pH	Weerst.	H$^+$	Klip	P Bray II	K	Uitruilbare katione (cmol(+)/kg)				Cu	Zn	Mn	B	C
	No.	(cm)		(KCl)	(Ohm)	(cmol/kg)	(Vol %)	mg/kg		Na	K	Ca	Mg	mg/kg				%
1 Groenvlei East	17770	20	Sand	5.4	8340	0.35	1	66	33	0.06	0.08	1.03	0.20	0.07	0.2	0.5	0.04	0.12
2 Groenvlei East	17771	100	Sand	4.7	9180	0.45	1	35	23	0.05	0.06	0.45	0.07	0.13	0.1	0.1	0.02	0.05
3 Groenvlei East	17772	175	Sand	4.7	9030	0.35	1	32	21	0.05	0.05	0.36	0.06	0.06	0.2	0.1	0.02	0.05
4 Groenvlei East	17773	230	Sand	4.5	8580	0.45	1	42	23	0.05	0.06	0.33	0.05	0.08	0.1	0.0	0.05	0.05
5 Groenvlei East	17774	300	Sand	4.1	8260	0.50	1	12	23	0.04	0.06	0.11	0.02	0.13	0.2	0.2	0.04	0.03
6 Peilvond Groenv Ea	17775	370	Sand	5.4	1	0.45	1	24	88	0.12	0.23	1.33	0.66	0.13	1.0	1.8	0.09	0.10
4 WP Main injecation	17776		Sand	6.4	1780		1	21	158	0.31	0.40	4.20	1.48	0.11	1.5	6.7	0.23	1.05
WP Meaw Pool	17777		Sand	6.6	5490		1	52	71	0.06	0.18	3.79	0.59	0.20	1.5	5.5	0.11	0.41
WP Jan Vest Part Sta	17778		Sand	7.6	1		1	26	187	0.23	0.48	29.78	3.55	0.05	0.0	0.3	1.02	7.66
Duin panne	17779		Sand	8.0	3430		1	4	45	0.05	0.12	12.80	0.40	0.02	0.0	0.2	0.22	0.49
Metodes#			N/A	S05	S04	S09	N/A	S12	S15	S15	S15	S15	S15	S16	S16	S16	S10	S08

Waardes in swartdruk is kleiner as die laagste kwantifiseerbare konsentrasie.
Indien pH > 7.0 is word die Olsen metode(S13) vir die bepaling van P gebruik.
Indien pH > 6.5 is word die Walkley Black metode(S08) vir die bepaling van Koolstof gebruik.
#Verwys na BemLab werkinstruksies

Report No.: WT2078/2006

ANALYSES REPORT

Jaco Nel
Universiteit van Weskaapland
University of the Wester Cape
Ground Water Group
Date received: 01/08/2006
Date tested: 02/08/2006

Origin	Lab. No.	pH	EC	Na	K	Ca	Mg	Fe	Cl	CO_3	HCO_3	SO_4	B	Mn	Cu	Zn	P	NH_4-N	NO_3-N
			mS/m	mg/l															
Lake Pleasant Gate 2	2078	7.4	72	72.6	1.2	56.9	13.7	0.15	170.1	30.1	119.4	12	0.07	0.03	0.00	0.01	0.28	1.11	1.18
Lake Pleas LP Stat 2	2079	7.3	362	530.4	7.7	150.7	21.5	0.07	906.7		568.0	54	0.41	0.01	0.01	0.00	0.43	0.00	0.17
Lake Pleasant Sta 1	2080	7.4	101	123.8	6.9	63.8	22.1	0.02	172.7		321.5	48	0.15	0.04	0.00	0.00	0.29	0.00	0.05
Groenvlei Noord Wes	2081	7.8	464	699.7	21.4	44.1	85.0	0.06	1237.2	93.4	485.4	141	0.59	0.01	0.00	0.00	0.12	0.03	0.06
LP NE 11 m	2082	7.5	72	71.6	2.0	68.0	10.5	0.00	127.8	57.2	189.9	21	0.07	0.01	0.00	0.00	0.02	0.17	1.67
Boothuis 11 m	2083	7.3	586	542.6	20.6	34.0	213.9	0.33	1106.8		2201.7	47	2.20	0.02	0.00	0.00	3.34	57.40	0.22
Boothuis 2 m	2084	7.1	605	818.9	20.3	133.0	92.2	0.60	1569.4		1041.1	29	0.61	0.08	0.01	0.00	0.44	0.54	0.03
Oppervlak Boothuis	2085	8.1	474	727.0	20.0	44.7	92.5	0.00	1299.7	105.4	338.4	137	0.61	0.00	0.01	0.00	0.04	0.36	0.90
LP NE 5 m	2086	7.0	121	173.2	11.6	34.6	26.1	0.66	299.6		214.4	41	0.19	0.06	0.00	0.00	0.11	2.40	0.70
VK Site A 0.5	2087	6.3	72	41.0	10.7	77.7	17.8	22.68	75.8		437.9	2	0.04	1.67	0.00	0.01	0.09	2.30	0.90
VK Site B 0.5	2088	6.0	20	19.1	7.4	11.2	8.2	9.49	34.4		108.7	3	0.05	0.06	0.01	0.03	0.15	1.90	0.30
LP NE 7 m	2089	6.5	48	60.3	14.0	29.5	11.6	3.92	115.4		186.8	20	0.09	0.12	0.01	0.01	2.58	1.70	0.30
VK A Site A	2090	6.6	33	23.4	9.3	38.4	8.7	10.28	42.3		180.7	2	0.03	0.09	0.01	0.02	0.20	0.10	0.10
VK B Site A	2091	5.3	21	34.0	4.2	6.3	4.9	6.96	59.0		107.2	7	0.03	0.11	0.00	0.01	0.22	1.40	0.10
VK Site B 11 m	2092	5.7	16	31.9	233.0	43.9	107.2	382.23	132.2		246.5	13	0.80	1.20	0.00	0.56	5.87	1.18	0.30
Methods[#]		W05	W04	W01	W01	W01	W01	W01	W07	W06	W06	W01	W01	W01	W01	W01	W01	W02	W03

Values in bold is smaller than the lowest quantifiable concentration.
[#]Refer to BemLab work instructions

Dr. W.A.G. Kotzé (Director) .... for BemLab

04-08-2006 .... Date

Basis Versadiging

Boord No.	Lab. No.	Na %	K %	Ca %	Mg %	T-Waarde cmol/kg
1 Groenvlei East	17770	3.56	4.87	59.62	11.66	1.73
2 Groenvlei East	17771	4.56	5.36	41.94	6.63	1.08
3 Groenvlei East	17772	5.36	6.13	41.19	6.82	0.86
4 Groenvlei East	17773	4.97	6.30	35.32	5.70	0.94
5 Groenvlei East	17774	5.61	8.14	14.62	3.35	0.73
6 Peilvond Groenv Ea	17775	4.46	8.11	47.72	23.56	2.79
4 WP Main injecation	17776	4.85	6.32	65.71	23.12	6.39
WP Meaw Pool	17777	1.20	3.93	82.03	12.84	4.62
WP Jan Vest Part Sta	17778	0.67	1.41	87.49	10.43	34.03
Duin panne	17779	0.39	0.86	95.77	2.98	13.36

Meganiese ontleding

Boord No.	Lab. No.	Klei %	Slik %	Sand %	Klassifikasie
1 Groenvlei East	17770	1.4	4.8	93.8	Sa
2 Groenvlei East	17771	0.6	3.8	95.6	Sa
3 Groenvlei East	17772	0.2	4.8	95.0	Sa
4 Groenvlei East	17773	0.7	5.0	94.3	Sa
5 Groenvlei East	17774	1.3	0.8	97.9	Sa
6 Peilvond Groenv Ea	17775	3.0	3.7	93.3	Sa
4 WP Main injecation	17776	0.3	1.7	98.0	Sa
WP Meaw Pool	17777	0.2	2.0	97.8	Sa
WP Jan Vest Part Sta	17778	0.0	3.2	96.8	Sa
Duin panne	17779	0.0	0.8	99.2	Sa

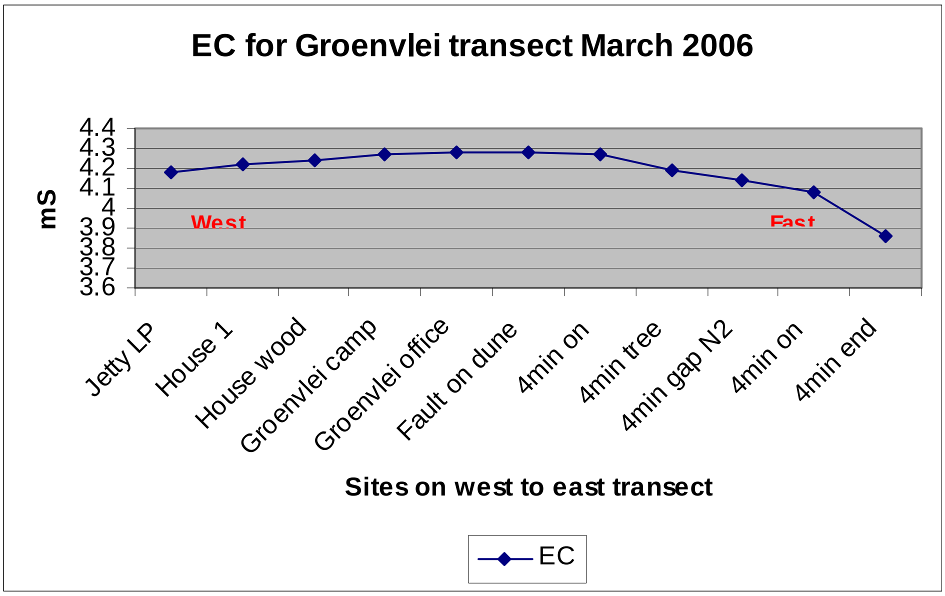
Dr. W.A.G. Kotzé (Direkteur)	10-08-2006
....	....
vir BemLab	Datum

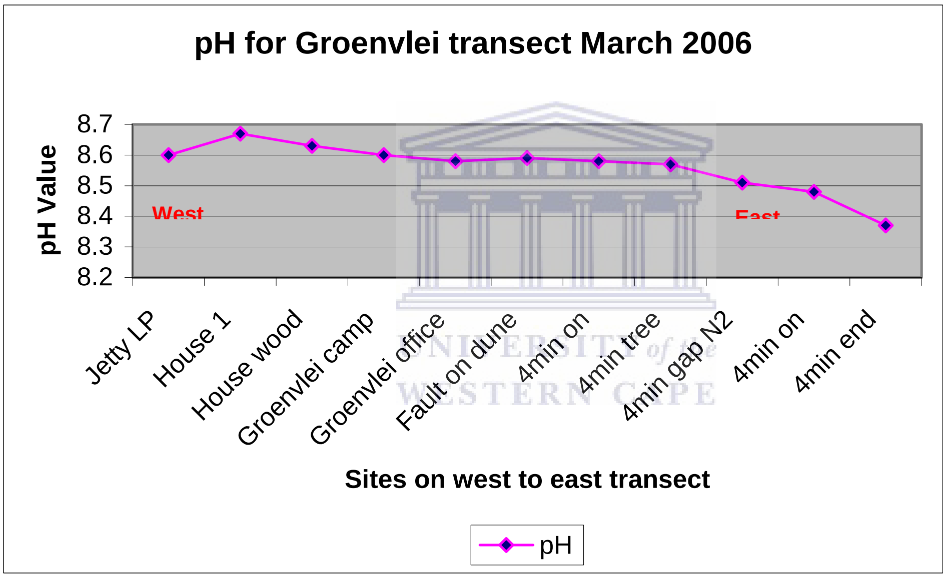
EC values (μS/cm), with averages in red, after discarding of the first three measurements that was taken when piezometers had not stabilised yet.

	RV-.5m	RV-1m	S/W	GVW-.5m	GVW-1m	GVWa11m	S/W	GVNW6m	
29-Sep	4538	6660	4730	7310	7702	4501	4272		
12-Oct	5870	8706	4748	5846	9007	4707	4378	4020	
27-Oct	5724	8862	4767	4336	9077	4764	4259	3987	
Total	16132	24228	14245	17492	25786	13972	12909	8007	
Average	5377.333	8076	4748.333	5830.667	8595.333	4657.333	4303	2669	
	LPG1	LPG2	LPG3	LPST1	LPST2	LPST3	GVBH-2	GVBH-11	S/W
29-Sep	796	511	845	978	409	850	5455	5277	4235
12-O	814	538	878	1032	455	890	6255	6160	4220
27-Oct	878	551	878	1023	1016	897	4627	6357	4231
Total	2488	1600	2601	3033	1880	2637	16337	17794	12686
Average	829.3333	533.3333	867	1011	626.6667	879	5445.667	5931.333	4228.667
	GVN-.5m	GVN-1m	S/W	GVE-11m	GVE-7m	GVE-5m			
29-Sep	857	1034	609	555	356	290			
12-Oct	887	997	703	572	338	324			
27-Oct	865	1023	612	549	354	336			
Total	2609	3054	1924	1676	1048	950			
Average	869.6667	1018	641.3333	558.6667	349.3333	316.6667			
	VKA-8.2m	VKA-.5m	VKA-1m	S/W	VKB-11m	VKB-5m	VKB-.5m	VKB-1m	S/W
29-Sep	158	242	80	109	288	137	744	551	99
12-Oct	166	370	107	120	341	169	1026	695	117
27-Oct	169	306	132	122	379	162	1084	813	146
Total	493	918	319	351	1008	468	2854	2059	362
Average	164.3333	306	106.3333	117	336	156	951.3333	686.3333	120.6667

Groenvlei Conductivity and pH Transect 28/3/06.

Sites West to east (landmark descriptions)	pH	ECm/S/m
Jetty LP	8.6	4.178
House 1	8.67	4.222
House wood	8.63	4.24
Groenvlei camp	8.6	4.267
Groenvlei office	8.58	4.284
Fault on dune	8.59	4.275
4min on	8.58	4.268
4min tree	8.57	4.189
4min gap N2	8.51	4.136
4min on	8.48	4.078
4min end	8.37	3.86





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          Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS            1
                PhD - Promotor Prof Lincoln Raitt :
  Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                   12:59 Monday, July 9, 2007

                                               Log
 Obs   Location   Depth    LocxDep     Block      ECValue   ECValue

  1     GVW       0.5m    GVW0.5m    Kobe19/7       9391    9.14751
  2     GVW       0.5m    GVW0.5m    Jaco30/7          .          .
  3     GVW       0.5m    GVW0.5m    JacoBlab          .          .
  4     GVW       0.5m    GVW0.5m    Wiets29/9      7310    8.89700
  5     GVW       0.5m    GVW0.5m    Wiets12/10     5846    8.67351
  6     GVW       0.5m    GVW0.5m    Wiets27/10     4336    8.37471
  7     GVW       1m      GVW1m      Kobe19/7       8722    9.07360
  8     GVW       1m      GVW1m      Jaco30/7          .          .
```

9	GVW	1m	GVW1m	JacoBlab	.	.
10	GVW	1m	GVW1m	Wiets29/9	7702	8.94924
11	GVW	1m	GVW1m	Wiets12/10	9007	9.10576
12	GVW	1m	GVW1m	Wiets27/10	9077	9.11350
13	GVWa	11m	GVWa11m	Kobe19/7	.	.
14	GVWa	11m	GVWa11m	Jaco30/7	4040	8.30400
15	GVWa	11m	GVWa11m	JacoBlab	4640	8.44247
16	GVWa	11m	GVWa11m	Wiets29/9	4501	8.41205
17	GVWa	11m	GVWa11m	Wiets12/10	4707	8.45681
18	GVWa	11m	GVWa11m	Wiets27/10	4764	8.46884
19	GVNW	6m	GVNW6m	Kobe19/7	487	6.18826
20	GVNW	6m	GVNW6m	Jaco30/7	.	.
21	GVNW	6m	GVNW6m	JacoBlab	.	.
22	GVNW	6m	GVNW6m	Wiets29/9	.	.
23	GVNW	6m	GVNW6m	Wiets12/10	4020	8.29904
24	GVNW	6m	GVNW6m	Wiets27/10	3987	8.29079
25	LPG	1m	LPG1m	Kobe19/7	748	6.61740
26	LPG	1m	LPG1m	Jaco30/7	680	6.52209
27	LPG	1m	LPG1m	JacoBlab	.	.
28	LPG	1m	LPG1m	Wiets29/9	796	6.67960
29	LPG	1m	LPG1m	Wiets12/10	814	6.70196
30	LPG	1m	LPG1m	Wiets27/10	878	6.77765
31	LPG	2m	LPG2m	Kobe19/7	735	6.59987
32	LPG	2m	LPG2m	Jaco30/7	.	.
33	LPG	2m	LPG2m	JacoBlab	720	6.57925
34	LPG	2m	LPG2m	Wiets29/9	511	6.23637
35	LPG	2m	LPG2m	Wiets12/10	538	6.28786
36	LPG	2m	LPG2m	Wiets27/10	551	6.31173
37	LPG	3_6.5m	LPG3_6.5	Kobe19/7	780	6.65929
38	LPG	3_6.5m	LPG3_6.5	Jaco30/7	.	.
39	LPG	3_6.5m	LPG3_6.5	JacoBlab	.	.
40	LPG	3_6.5m	LPG3_6.5	Wiets29/9	845	6.73934
41	LPG	3_6.5m	LPG3_6.5	Wiets12/10	878	6.77765
42	LPG	3_6.5m	LPG3_6.5	Wiets27/10	878	6.77765
43	LPST	1m	LPST1m	Kobe19/7	1097	7.00033
44	LPST	1m	LPST1m	Jaco30/7	930	6.83518
45	LPST	1m	LPST1m	JacoBlab	1010	6.91771
46	LPST	1m	LPST1m	Wiets29/9	978	6.88551
47	LPST	1m	LPST1m	Wiets12/10	1032	6.93925
48	LPST	1m	LPST1m	Wiets27/10	1023	6.93049
49	LPST	2m	LPST2m	Kobe19/7	1689	7.43189
50	LPST	2m	LPST2m	Jaco30/7	3180	8.06464
51	LPST	2m	LPST2m	JacoBlab	3620	8.19423
52	LPST	2m	LPST2m	Wiets29/9	409	6.01372
53	LPST	2m	LPST2m	Wiets12/10	455	6.12030
54	LPST	2m	LPST2m	Wiets27/10	1016	6.92363
55	LPST	3m	LPST3m	Kobe19/7	963	6.87005
56	LPST	3m	LPST3m	Jaco30/7	.	.
57	LPST	3m	LPST3m	JacoBlab	.	.
58	LPST	3m	LPST3m	Wiets29/9	850	6.74524

59	LPST	3m	LPST3m	Wiets12/10	890	6.79122
60	LPST	3m	LPST3m	Wiets27/10	897	6.79906
61	GVBH	2m	GVBH2m	Kobe19/7	5730	8.65347
62	GVBH	2m	GVBH2m	Jaco30/7	5250	8.56598
63	GVBH	2m	GVBH2m	JacoBlab	6050	8.70781
64	GVBH	2m	GVBH2m	Wiets29/9	5455	8.60429
65	GVBH	2m	GVBH2m	Wiets12/10	6255	8.74114
66	GVBH	2m	GVBH2m	Wiets27/10	4627	8.43966
67	GVBH	11m	GVBH11m	Kobe19/7	4550	8.42288
68	GVBH	11m	GVBH11m	Jaco30/7	5040	8.52516
69	GVBH	11m	GVBH11m	JacoBlab	5860	8.67590
70	GVBH	11m	GVBH11m	Wiets29/9	5277	8.57111
71	GVBH	11m	GVBH11m	Wiets12/10	6160	8.72583
72	GVBH	11m	GVBH11m	Wiets27/10	6357	8.75731
73	GVN	0.5m	GVN0.5m	Kobe19/7	896	6.79794
74	GVN	0.5m	GVN0.5m	Jaco30/7	.	.
75	GVN	0.5m	GVN0.5m	JacoBlab	.	.
76	GVN	0.5m	GVN0.5m	Wiets29/9	857	6.75344
77	GVN	0.5m	GVN0.5m	Wiets12/10	887	6.78784
78	GVN	0.5m	GVN0.5m	Wiets27/10	865	6.76273
79	GVN	1m	GVN1m	Kobe19/7	1097	7.00033
80	GVN	1m	GVN1m	Jaco30/7	.	.
81	GVN	1m	GVN1m	JacoBlab	.	.
82	GVN	1m	GVN1m	Wiets29/9	1034	6.94119
83	GVN	1m	GVN1m	Wiets12/10	997	6.90475
84	GVN	1m	GVN1m	Wiets27/10	1023	6.93049
85	GVE	11m	GVE11m	Kobe19/7	495	6.20456
86	GVE	11m	GVE11m	Jaco30/7	390	5.96615
87	GVE	11m	GVE11m	JacoBlab	720	6.57925
88	GVE	11m	GVE11m	Wiets29/9	555	6.31897
89	GVE	11m	GVE11m	Wiets12/10	572	6.34914
90	GVE	11m	GVE11m	Wiets27/10	549	6.30810
91	GVE	7m	GVE7m	Kobe19/7	3462	8.14960
92	GVE	7m	GVE7m	Jaco30/7	1140	7.03878
93	GVE	7m	GVE7m	JacoBlab	480	6.17379
94	GVE	7m	GVE7m	Wiets29/9	356	5.87493
95	GVE	7m	GVE7m	Wiets12/10	338	5.82305
96	GVE	7m	GVE7m	Wiets27/10	354	5.86930
97	GVE	5m	GVE5m	Kobe19/7	1160	7.05618
98	GVE	5m	GVE5m	Jaco30/7	670	6.50728
99	GVE	5m	GVE5m	JacoBlab	1210	7.09838
100	GVE	5m	GVE5m	Wiets29/9	290	5.66988
101	GVE	5m	GVE5m	Wiets12/10	324	5.78074
102	GVE	5m	GVE5m	Wiets27/10	336	5.81711
103	VKA	8.2m	VKA8.2m	Kobe19/7	.	.
104	VKA	8.2m	VKA8.2m	Jaco30/7	190	5.24702
105	VKA	8.2m	VKA8.2m	JacoBlab	.	.
106	VKA	8.2m	VKA8.2m	Wiets29/9	158	5.06260
107	VKA	8.2m	VKA8.2m	Wiets12/10	166	5.11199
108	VKA	8.2m	VKA8.2m	Wiets27/10	169	5.12990

```
     109    VKA     0.5m     VKA0.5m    Kobe19/7         .      .
     110    VKA     0.5m     VKA0.5m    Jaco30/7       780    6.65929
     111    VKA     0.5m     VKA0.5m    JacoBlab       720    6.57925
     112    VKA     0.5m     VKA0.5m    Wiets29/9      242    5.48894
     113    VKA     0.5m     VKA0.5m    Wiets12/10     370    5.91350
     114    VKA     0.5m     VKA0.5m    Wiets27/10     306    5.72359
     115    VKA     1m       VKA1m      Kobe19/7         .      .
     116    VKA     1m       VKA1m      Jaco30/7       310    5.73657
     117    VKA     1m       VKA1m      JacoBlab       330    5.79909
     118    VKA     1m       VKA1m      Wiets29/9       80    4.38203
     119    VKA     1m       VKA1m      Wiets12/10     107    4.67283
     120    VKA     1m       VKA1m      Wiets27/10     132    4.88280
     121    VKB     11m      VKB11m     Kobe19/7       338    5.82305
     122    VKB     11m      VKB11m     Jaco30/7       180    5.19296
     123    VKB     11m      VKB11m     JacoBlab       160    5.07517
     124    VKB     11m      VKB11m     Wiets29/9      288    5.66296
     125    VKB     11m      VKB11m     Wiets12/10     341    5.83188
     126    VKB     11m      VKB11m     Wiets27/10     379    5.93754
     127    VKB     5m       VKB5m      Kobe19/7       224    5.41165
     128    VKB     5m       VKB5m      Jaco30/7         .      .
     129    VKB     5m       VKB5m      JacoBlab       210    5.34711
     130    VKB     5m       VKB5m      Wiets29/9      137    4.91998
     131    VKB     5m       VKB5m      Wiets12/10     169    5.12990
     132    VKB     5m       VKB5m      Wiets27/10     162    5.08760
     133    VKB     0.5m     VKB0.5m    Kobe19/7       866    6.76388
     134    VKB     0.5m     VKB0.5m    Jaco30/7       240    5.48064
     135    VKB     0.5m     VKB0.5m    JacoBlab       200    5.29832
     136    VKB     0.5m     VKB0.5m    Wiets29/9      744    6.61204
     137    VKB     0.5m     VKB0.5m    Wiets12/10    1026    6.93342
     138    VKB     0.5m     VKB0.5m    Wiets27/10    1084    6.98841
     139    VKB     1m       VKB1m      Kobe19/7       700    6.55108
     140    VKB     1m       VKB1m      Jaco30/7       130    4.86753
     141    VKB     1m       VKB1m      JacoBlab         .      .
     142    VKB     1m       VKB1m      Wiets29/9      551    6.31173
     143    VKB     1m       VKB1m      Wiets12/10     695    6.54391
     144    VKB     1m       VKB1m      Wiets27/10     813    6.70073
           Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS             2
                 PhD - Promotor Prof Lincoln Raitt :
   Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                  12:59 Monday, July 9, 2007

                       The GLM Procedure

                    Class Level Information

Class      Levels  Values

Block           6  Jaco30/7 JacoBlab Kobe19/7 Wiets12/10 Wiets27/10 Wiets29/9

Location       10  GVBH GVE GVN GVNW GVW GVWa LPG LPST VKA VKB
```

```
Depth          10  0.5m 11m 1m 2m 3_6.5m 3m 5m 6m 7m 8.2m

LocxDep         24  GVBH11m GVBH2m GVE11m GVE5m GVE7m GVN0.5m
GVN1m GVNW6m GVW0.5m
                GVW1m GVWa11m LPG1m LPG2m LPG3_6.5 LPST1m LPST2m
LPST3m VKA0.5m
                VKA1m VKA8.2m VKB0.5m VKB11m VKB1m VKB5m


                  Number of Observations Read        144
                  Number of Observations Used        120
             Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                3
                    PhD - Promotor Prof Lincoln Raitt :
   Incomplete Randomized Blocks design - Treatments design incomplete factorial
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                            The GLM Procedure

Dependent Variable: ECValue

                                Sum of
 Source                  DF          Squares     Mean Square    F Value    Pr > F

 Model                    28     617295897.3      22046282.0      43.95    <.0001

 Error                   91      45648420.3        501631.0

 Corrected Total           119     662944317.6


             R-Square     Coeff Var      Root MSE    ECValue Mean

             0.931143      37.89289      708.2591        1869.108


 Source                  DF       Type I SS     Mean Square    F Value    Pr > F

 Block                    5       4409799.9        881960.0       1.76    0.1294
 Location                  9     601229249.4      66803249.9     133.17    <.0001
 Depth                    8       2904492.9        363061.6       0.72    0.6701
 LocxDep                    6       8752355.1       1458725.8       2.91    0.0122
             Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                4
                    PhD - Promotor Prof Lincoln Raitt :
   Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                     12:59 Monday, July 9, 2007

                            The GLM Procedure

Dependent Variable: LogECValue
```

```
                          Sum of
Source              DF       Squares     Mean Square    F Value    Pr > F

Model               28     150.4506669       5.3732381      22.19    <.0001

Error             91      22.0310988      0.2421000

Corrected Total          119     172.4817657


          R-Square     Coeff Var      Root MSE    LogECValue Mean

          0.872270      7.221296      0.492037          6.813688


Source              DF       Type I SS     Mean Square    F Value    Pr > F

Block               5       3.0781728       0.6156346       2.54    0.0335
Location             9     138.7171752      15.4130195      63.66    <.0001
Depth               8       5.1645466       0.6455683       2.67    0.0112
LocxDep              6       3.4907724       0.5817954       2.40    0.0335
          Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                  5
                PhD - Promotor Prof Lincoln Raitt :
   Incomplete Randomized Blocks design - Treatments design incomplete factorial
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                       The GLM Procedure

Level of         -----------ECValue-----------     ----------LogECValue---------
Block         N          Mean         Std Dev          Mean          Std Dev

Jaco30/7       15       1543.33333       1846.72168       6.63421914       1.25585974
JacoBlab       14       1852.14286       2184.53367       6.81912355       1.26427962
Kobe19/7       20       2206.50000       2756.25783       7.12114212       1.04693118
Wiets12/10     24       1941.41667       2538.40907       6.80847001       1.25499662
Wiets27/10     24       1856.79167       2359.71371       6.83763835       1.19845034
Wiets29/9      23       1735.91304       2413.38941       6.64052785       1.28732732


Level of         -----------ECValue-----------     ----------LogECValue---------
Location      N          Mean         Std Dev          Mean          Std Dev

GVBH        12       5550.91667       616.76922       8.61588014       0.11378111
GVE        18       744.50000       740.32594       6.36584280       0.63486048
GVN         8       957.00000       91.47209       6.85984036       0.09496788
GVNW         3       2831.33333       2030.31927       7.59269855       1.21628288
GVW         8       7673.87500       1789.20568       8.91685270       0.26904740
GVWa         5       4530.40000       291.17229       8.41683469       0.06654742
LPG        14       739.42857       127.52660       6.59055074       0.18659838
```

```
LPST       16      1252.43750      886.24722      6.96640306      0.55987471
VKA        14       290.00000      214.10889      5.45638564      0.66254134
VKB        22       438.04545      312.04662      5.83961347      0.71330407


Level of          -----------ECValue-----------     ----------LogECValue---------
Depth        N            Mean          Std Dev           Mean          Std Dev

0.5m        19      1945.57895      2695.67869      6.87557728      1.14529924
11m         23      2646.21739      2439.44610      7.17443896      1.36399654
1m          29      1810.10345      2800.81380      6.73359881      1.20921529
2m          17      2752.41176      2343.73972      7.43975527      1.08665300
3_6.5m       4       845.25000        46.19794      6.73848093      0.05579490
3m           4       900.00000        46.82592      6.80139177      0.05156466
5m          11       444.72727       394.05789      5.80234489      0.76605810
6m           3      2831.33333      2030.31927      7.59269855      1.21628288
7m           6      1021.66667      1234.41673      6.48824082      0.93421885
8.2m         4       170.75000        13.64734      5.13787640      0.07813314


Level of          -----------ECValue-----------     ----------LogECValue---------
LocxDep      N            Mean          Std Dev           Mean          Std Dev

GVBH11m      6      5540.66667       700.50772      8.61303428      0.12894092
GVBH2m       6      5561.16667       588.15488      8.61872600      0.10879481
GVE11m       6       546.83333       107.67993      6.28769354      0.20023975
GVE5m        6       665.00000       425.96291      6.32159404      0.65562641
GVE7m        6      1021.66667      1234.41673      6.48824082      0.93421885
GVN0.5m      4       876.25000        18.28251      6.77548821      0.02086297
GVN1m        4      1037.75000        42.43721      6.94419251      0.04043189
GVNW6m       3      2831.33333      2030.31927      7.59269855      1.21628288
GVW0.5m      4      6720.75000      2154.81405      8.77318153      0.32871751
GVW1m        4      8627.00000       635.49194      9.06052388      0.07617668
GVWa11m      5      4530.40000       291.17229      8.41683469      0.06654742
LPG1m        5       783.20000        74.14310      6.65974038      0.09594020
LPG2m        5       611.00000       107.45464      6.40301693      0.17260871
LPG3_6.5     4       845.25000        46.19794      6.73848093      0.05579490
LPST1m       6      1011.66667        55.90945      6.91808051      0.05531885
LPST2m       6      1728.16667      1382.51386      7.12473315      0.93864604
LPST3m       4       900.00000        46.82592      6.80139177      0.05156466
VKA0.5m      5       483.60000       248.27163      6.07291419      0.52170145
VKA1m        5       191.80000       118.67687      5.09466447      0.64010711
VKA8.2m      4       170.75000        13.64734      5.13787640      0.07813314
VKB0.5m      6       693.33333       385.89049      6.34611974      0.75493771
VKB11m       6       281.00000        90.93294      5.58725929      0.36374891
VKB1m        5       577.80000       267.03502      6.19499851      0.75499809
VKB5m        5       180.40000        35.80922      5.17924591      0.20015024
           Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                    6
                  PhD - Promotor Prof Lincoln Raitt :
     Incomplete Randomized Blocks design - Treatments design incomplete factorial
```

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                                 12:59 Monday, July 9, 2007

                       The GLM Procedure

                    t Tests (LSD) for ECValue

  NOTE: This test controls the Type I comparisonwise error rate, not the
                 experimentwise error rate.


              Alpha                         0.05
              Error Degrees of Freedom           91
              Error Mean Square             501631
              Critical Value of t          1.98638
              Least Significant Difference   455.81
              Harmonic Mean of Cell Sizes  19.05325

                NOTE: Cell sizes are not equal.


        Means with the same letter are not significantly different.


           t Grouping          Mean      N    Block

                A        2206.5     20    Kobe19/7
                A
             B    A        1941.4     24    Wiets12/10
             B    A
             B    A        1856.8     24    Wiets27/10
             B    A
             B    A        1852.1     14    JacoBlab
             B
             B           1735.9     23    Wiets29/9
             B
             B           1543.3     15    Jaco30/7
         Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                  7
                PhD - Promotor Prof Lincoln Raitt :
  Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                 12:59 Monday, July 9, 2007

                       The GLM Procedure

                   t Tests (LSD) for LogECValue

  NOTE: This test controls the Type I comparisonwise error rate, not the
                 experimentwise error rate.


              Alpha                         0.05
```

```
                 Error Degrees of Freedom          91
                 Error Mean Square             0.2421
                 Critical Value of t          1.98638
                 Least Significant Difference   0.3167
                 Harmonic Mean of Cell Sizes  19.05325

                  NOTE: Cell sizes are not equal.


            Means with the same letter are not significantly different.


        t Grouping          Mean      N    Block

                  A        7.1211     20    Kobe19/7
                  A
               B    A        6.8376     24    Wiets27/10
               B    A
               B    A        6.8191     14    JacoBlab
               B    A
               B    A        6.8085     24    Wiets12/10
               B
               B           6.6405     23    Wiets29/9
               B
               B           6.6342     15    Jaco30/7
      Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                  8
            PhD - Promotor Prof Lincoln Raitt :
Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                  12:59 Monday, July 9, 2007

                       The GLM Procedure

                     t Tests (LSD) for ECValue

    NOTE: This test controls the Type I comparisonwise error rate, not the
                    experimentwise error rate.


                 Alpha                          0.05
                 Error Degrees of Freedom          91
                 Error Mean Square             501631
                 Critical Value of t          1.98638
                 Least Significant Difference   681.43
                 Harmonic Mean of Cell Sizes  8.524903

                  NOTE: Cell sizes are not equal.


            Means with the same letter are not significantly different.
```

```
          t Grouping         Mean      N    Location

                A       7673.9      8    GVW

                B       5550.9     12    GVBH

                C       4530.4      5    GVWa

                D       2831.3      3    GVNW

                E       1252.4     16    LPST
                E
             F  E        957.0      8    GVN
             F  E
             F  E        744.5     18    GVE
             F  E
             F  E        739.4     14    LPG
             F
             F          438.0     22    VKB
             F
             F          290.0     14    VKA
         Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                  9
               PhD - Promotor Prof Lincoln Raitt :
  Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                    12:59 Monday, July 9, 2007

                     The GLM Procedure

                   t Tests (LSD) for LogECValue

    NOTE: This test controls the Type I comparisonwise error rate, not the
                    experimentwise error rate.


               Alpha                        0.05
               Error Degrees of Freedom          91
               Error Mean Square             0.2421
               Critical Value of t          1.98638
               Least Significant Difference   0.4734
               Harmonic Mean of Cell Sizes  8.524903

                NOTE: Cell sizes are not equal.


        Means with the same letter are not significantly different.


          t Grouping         Mean      N    Location
```

```
           A       8.9169      8    GVW
           A
        B    A       8.6159     12    GVBH
        B
        B          8.4168      5    GVWa

           C       7.5927      3    GVNW

           D       6.9664     16    LPST
           D
           D       6.8598      8    GVN
           D
        E    D       6.5906     14    LPG
        E
        E          6.3658     18    GVE

           F       5.8396     22    VKB
           F
           F       5.4564     14    VKA
      Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                10
              PhD - Promotor Prof Lincoln Raitt :
 Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                          12:59 Monday, July 9, 2007

                          The GLM Procedure

                        t Tests (LSD) for ECValue

   NOTE: This test controls the Type I comparisonwise error rate, not the
                        experimentwise error rate.


                 Alpha                          0.05
                 Error Degrees of Freedom         91
                 Error Mean Square            501631
                 Critical Value of t         1.98638
                 Least Significant Difference   778.32
                 Harmonic Mean of Cell Sizes  6.534559

                   NOTE: Cell sizes are not equal.


         Means with the same letter are not significantly different.


            t Grouping         Mean      N    Depth

                 A        2831.3      3    6m
                 A
                 A        2752.4     17    2m
```

```
        A
     B   A       2646.2     23    11m
     B
     B   C       1945.6     19    0.5m
         C
         C      1810.1     29    1m

         D      1021.7      6    7m
         D
     E   D        900.0      4    3m
     E   D
     E   D        845.3      4    3_6.5m
     E   D
     E   D        444.7     11    5m
     E
     E          170.8      4   8.2m
        Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                11
                PhD - Promotor Prof Lincoln Raitt :
 Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                      12:59 Monday, July 9, 2007

                         The GLM Procedure

                      t Tests (LSD) for LogECValue

   NOTE: This test controls the Type I comparisonwise error rate, not the
                     experimentwise error rate.


                     Alpha                        0.05
                     Error Degrees of Freedom           91
                     Error Mean Square             0.2421
                     Critical Value of t          1.98638
                     Least Significant Difference   0.5407
                     Harmonic Mean of Cell Sizes  6.534559

                       NOTE: Cell sizes are not equal.


          Means with the same letter are not significantly different.


           t Grouping         Mean      N    Depth

                A       7.5927      3    6m
                A
                A       7.4398     17    2m
                A
             B   A       7.1744     23    11m
             B
```

```
          B    C       6.8756     19    0.5m
          B    C
          B    C       6.8014      4    3m
          B    C
          B    C       6.7385      4    3_6.5m
          B    C
          B    C       6.7336     29    1m
               C
               C       6.4882      6    7m

               D       5.8023     11    5m

               E       5.1379      4    8.2m
       Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                 12
              PhD - Promotor Prof Lincoln Raitt :
 Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                       12:59 Monday, July 9, 2007

                     The GLM Procedure

                  t Tests (LSD) for ECValue

  NOTE: This test controls the Type I comparisonwise error rate, not the
                  experimentwise error rate.


          Alpha                         0.05
          Error Degrees of Freedom        91
          Error Mean Square           501631
          Critical Value of t        1.98638
          Least Significant Difference   906.62
          Harmonic Mean of Cell Sizes  4.816054

            NOTE: Cell sizes are not equal.


     Means with the same letter are not significantly different.


       t Grouping         Mean      N    LocxDep

              A         8627.0      4    GVW1m

              B         6720.8      4    GVW0.5m

              C         5561.2      6    GVBH2m
              C
              C         5540.7      6    GVBH11m

              D         4530.4      5    GVWa11m
```

```
          E        2831.3      3    GVNW6m

          F        1728.2      6    LPST2m
          F
      G   F         1037.8      4    GVN1m
      G   F
      G   F         1021.7      6    GVE7m
      G   F
      G   F         1011.7      6    LPST1m
      G   F
      G   F          900.0      4    LPST3m
      G   F
      G   F          876.3      4    GVN0.5m
      G   F
      G   F          845.3      4    LPG3_6.5
      G
      G             783.2      5    LPG1m
      G
      G             693.3      6    VKB0.5m
      G
      G             665.0      6    GVE5m
      G
      G             611.0      5    LPG2m
      G
      G             577.8      5    VKB1m
      G
      G             546.8      6    GVE11m
      G
      G             483.6      5    VKA0.5m
      G
      G             281.0      6    VKB11m
      G
      G             191.8      5    VKA1m
      G
      G             180.4      5    VKB5m
      G
      G             170.8      4    VKA8.2m
   Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                13
         PhD - Promotor Prof Lincoln Raitt :
Incomplete Randomized Blocks design - Treatments design incomplete factorial
                                   12:59 Monday, July 9, 2007

                  The GLM Procedure

              t Tests (LSD) for LogECValue

   NOTE: This test controls the Type I comparisonwise error rate, not the
               experimentwise error rate.
```

```
   Alpha                          0.05
   Error Degrees of Freedom           91
   Error Mean Square              0.2421
   Critical Value of t         1.98638
   Least Significant Difference   0.6298
   Harmonic Mean of Cell Sizes  4.816054

     NOTE: Cell sizes are not equal.


Means with the same letter are not significantly different.


  t Grouping            Mean      N    LocxDep

          A           9.0605      4    GVW1m
          A
   B       A           8.7732      4    GVW0.5m
   B       A
   B       A           8.6187      6    GVBH2m
   B       A
   B       A           8.6130      6    GVBH11m
   B
   B                  8.4168      5    GVWa11m

          C           7.5927      3    GVNW6m
          C
   D       C           7.1247      6    LPST2m
   D
   D       E           6.9442      4    GVN1m
   D       E
   D       E           6.9181      6    LPST1m
   D       E
   D       E    F       6.8014      4    LPST3m
   D       E    F
   D       E    F       6.7755      4    GVN0.5m
   D       E    F
   D       E    F       6.7385      4    LPG3_6.5
   D       E    F
   D    G    E    F       6.6597      5    LPG1m
       G    E    F
       G    E    F       6.4882      6    GVE7m
       G    E    F
       G    E    F       6.4030      5    LPG2m
       G    E    F
       G    E    F       6.3461      6    VKB0.5m
       G    E    F
       G    E    F       6.3216      6    GVE5m
       G        F
```

```
          G       F       6.2877     6    GVE11m
          G       F
          G    H    F       6.1950     5    VKB1m
          G    H
          G    H          6.0729     5    VKA0.5m
             H
       I        H          5.5873     6    VKB11m
       I
       I                  5.1792     5    VKB5m
       I
       I                  5.1379     4    VKA8.2m
       I
       I                  5.0947     5    VKA1m
      Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                14
            PhD - Promotor Prof Lincoln Raitt :
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                               12:59 Monday, July 9, 2007

                The UNIVARIATE Procedure
                  Variable:  rECValue

                      Moments

   N                     120    Sum Weights            120
   Mean                    0    Sum Observations         0
   Std Deviation      619.35464    Variance           383600.17
   Skewness          0.19842796    Kurtosis          6.62684913
   Uncorrected SS     45648420.3    Corrected SS      45648420.3
   Coeff Variation             .    Std Error Mean      56.5390846


               Basic Statistical Measures

      Location                 Variability

    Mean     0.000000     Std Deviation          619.35464
    Median   7.300663     Variance                  383600
    Mode      .           Range                     4967
                        Interquartile Range    290.08517


               Tests for Location: Mu0=0

      Test          -Statistic-    -----p Value------

      Student's t    t         0    Pr > |t|    1.0000
      Sign           M         3    Pr >= |M|   0.6483
      Signed Rank    S        15    Pr >= |S|   0.9689
```

```
                 Tests for Normality

Test                  --Statistic---    -----p Value------

Shapiro-Wilk          W       0.8167    Pr < W      <0.0001
Kolmogorov-Smirnov    D      0.20259    Pr > D      <0.0100
Cramer-von Mises      W-Sq  1.502939    Pr > W-Sq   <0.0050
Anderson-Darling      A-Sq  7.717354    Pr > A-Sq   <0.0050


                Quantiles (Definition 5)

                Quantile          Estimate

                100% Max        2493.09868
                99%             2298.76908
                95%             1061.30205
                90%              420.35182
                75% Q3           145.67784
                50% Median         7.30066
                25% Q1          -144.40733
                10%             -594.79215
                5%              -869.43985
                1%             -2325.21255
                0% Min         -2473.91751


                 Extreme Observations

        ------Lowest-----        -----Highest-----

           Value      Obs           Value      Obs

        -2473.92       19         1262.77       24
        -2325.21        6         1511.06       50
        -1262.67       53         1690.26       51
        -1140.88       52         2298.77       91
        -1132.23       67         2493.10        1


                     Missing Values

                         -----Percent Of-----
        Missing                        Missing
         Value       Count     All Obs        Obs

           .           24       16.67      100.00


   Stem Leaf                                 #           Boxplot
```

```
 24 9                                      1               *
 22 0                                      1               *
 20
 18
 16 9                                      1               *
 14 1                                      1               *
 12 16                                     2               *
 10
  8 1                                      1               0
  6 303                                    3               0
  4 91                                     2               |
  2 399034455                              9               |
  0 0111113334445556677899999011222444555568999    42    +--+--+
 -0 98663221100999988888766544321111               31    +-----+
 -2 932543200                              9               |
 -4 79643                                  5               |
 -6 84972                                  5               0
 -8 04                                     2               0
-10 43                                     2               *
-12 6                                      1               *
-14
-16
-18
-20
-22 3                                      1               *
-24 7                                      1               *
    ----+----+----+----+----+----+----+----+--
Multiply Stem.Leaf by 10**+2


                      Normal Probability Plot
      2500+                                      *
          |                                  *
          |
          |
          |                                 *
      1500+                                    *   +++
          |                             ** +++
          |                             +++
          |                           +++*
          |                         +++ **
       500+                          +++   **
          |                      +++  *****
          |                   ***********
          |               ********
          |             **** +++
      -500+              *** +++
          |           ***+++
          |         **+++
          |       **+
```

```
   |  ++*
-1500++++
   |
   |
   |
   |  *
-2500+*
    +----+----+----+----+----+----+----+----+----+----+
        -2       -1        0       +1       +2


       Wietsche Roets - GroenvleiECData2Sonder SWenRV.SAS                15
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                                        12:59 Monday, July 9, 2007

                    The UNIVARIATE Procedure
                     Variable:  rLogECValue

                            Moments

N                       120    Sum Weights              120
Mean                      0    Sum Observations           0
Std Deviation     0.4302735    Variance          0.18513528
Skewness         -0.3267036    Kurtosis          2.68165015
Uncorrected SS   22.0310988    Corrected SS      22.0310988
Coeff Variation           .    Std Error Mean    0.03927842


                 Basic Statistical Measures

       Location                    Variability

   Mean     0.000000     Std Deviation            0.43027
   Median   0.030722     Variance                 0.18514
   Mode      .           Range                    3.03837
                         Interquartile Range      0.30980


                 Tests for Location: Mu0=0

      Test           -Statistic-    -----p Value------

      Student's t    t         0    Pr > |t|    1.0000
      Sign           M         5    Pr >= |M|   0.4114
      Signed Rank    S       194    Pr >= |S|   0.6135


                     Tests for Normality
```

```
Test                --Statistic---    -----p Value------

Shapiro-Wilk          W     0.939576    Pr < W     <0.0001
Kolmogorov-Smirnov    D     0.127436    Pr > D     <0.0100
Cramer-von Mises      W-Sq  0.520434    Pr > W-Sq  <0.0050
Anderson-Darling      A-Sq  2.677898    Pr > A-Sq  <0.0050


            Quantiles (Definition 5)

            Quantile       Estimate

            100% Max       1.5196712
            99%            0.9785087
            95%            0.6547937
            90%            0.5638334
            75% Q3         0.1660832
            50% Median     0.0307225
            25% Q1        -0.1437206
            10%           -0.4799136
            5%            -0.7382662
            1%            -1.3163730
            0% Min        -1.5186961


             Extreme Observations

     ------Lowest------      ------Highest-----

        Value      Obs          Value      Obs

     -1.518696      19       0.740642       24
     -1.316373     140       0.778054       23
     -1.185374     135       0.931925       51
     -0.960149      53       0.978509       50
     -0.929768      52       1.519671       91


               Missing Values

                     -----Percent Of-----
      Missing                    Missing
       Value      Count    All Obs        Obs

         .          24      16.67      100.00


   Stem Leaf                          #            Boxplot
     14 2                           1              *
     12
```

```
  10
   8 38                                2          0
   6 0345648                             7          0
   4 59499                              5          |
   2 11267889477                           11          |
   0 012333444445566666789001134555566677779    39         +--+--+
  -0 96544443110087777666555422211              29         +-----+
  -2 66385321                             8          |
  -4 609753311                             9          |
  -6 520                                 3          0
  -8 633                                 3          0
 -10 9                                  1          *
 -12 2                                  1          *
 -14 2                                  1          *
     ----+----+----+----+----+----+----+----
 Multiply Stem.Leaf by 10**-1
```

```
                    Normal Probability Plot
   1.5+                                    *
      |
      |                                  ++
   0.9+                                +*+*+
      |                            +*****
      |                          ++***
   0.3+                         +++****
      |                    **********
      |                ********
  -0.3+                 ***+++
      |            ****+
      |         ++**+
  -0.9+  ++++***
      |++   *
      |  *
  -1.5+*
       +----+----+----+----+----+----+----+----+----+----+
          -2       -1        0       +1       +2
```

SEDGEFIELD LAKE AREAS

CO- ORDINATE SYSTEM : WGS 84 / Lo 23

	Y	X	H	
VANK1	9271.760	3764621.080	148.630	
VANK2	8959.600	3765281.880	148.890	
RUIG2	15221.720	3764874.300	2.510	
GR/OOS	10046.680	3767111.630	6.360	WHITE STINK WOOD
GR/NO	11023.880	3766885.720	2.150	
GR/W/BH	13683.660	3767490.210	2.170	CHALETS
P2M	13681.470	3767491.240	2.280	CHALETS
P11M	13679.970	3767492.150	2.170	CHALETS
GR/W/UA	15334.800	3766446.950	2.4	
GR/W/WL	15290.080	3766341.090	2.16	
GR/NW	15459.080	3766220.840	6.540	
POOL	15622.160	3766432.200	7.490	
LP/GATE	15696.120	3766364.340	6.590	
LP/STA1	15886.050	3766468.560	1.760	
LP/STA2	15887.010	3766473.450	1.680	
LP/STA3	15872.220	3766469.380	3.190	
LP/STA4	15868.840	3766470.380	3.850	
MEAN SL			0	

Appendix C

Roets W, Xu Y, Raitt L, and Brendonck L. (2008). *Groundwater discharges to aquatic ecosystems associated with the Table Mountain Group (TMG) Aquifer: A CONCEPTUAL MODEL*. WaterSA,Vol 34 No 1. pp 77-87.

Appendix D

Submitted to *Hydrobiologia*. **Roets W, Xu Y, Calitz FJ, El-Kahloun M, Meire P and Brendonck L. in prep.** *Soil nutrient concentrations in response to groundwater use in the Table Mountain Group (TMG) Aquifer - A comparative study in the Kammanassie Mountain Complex*.

Appendix E

1. **Roets W, Xu Y, Raitt L, El-Kahloun M, Meire P, Calitz F, Batelaan O, Anibas C, Paridaens K, Vandenbroucke T, Verhoest NEC and Brendonck L. 2008.** *Determining Discharges from the Table Mountain Group (TMG) Aquifer to Wetlands in the Southern Cape - South Africa*. Hydrobiologia, 607. pp175-186.