INVESTIGATING THE SUITABILITY OF LAND TYPE INFORMATION FOR HYDROLOGICAL MODELLING IN THE MOUNTAIN REGIONS OF HESSEQUA, SOUTH AFRICA

by

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DECLARATION

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1.2 ABSTRACT

The Land Type database of South Africa combines soil associations with various terrain positions within a larger Land Type polygon. The Land Type structure provides the opportunity to unlock the terrain unit information through segmenting the larger Land Type polygon into terrain units. Geographical information systems have the capability to dissect the landscape into terrain morphological units, using remote sensing technology. There is a range of methods and software available that can be used to dissect the landscape, the challenge is to identify a method that would be compatible with Land Type terrain units.

The study area is the catchment of the Korentepoort dam, north of Riversdale in the Hessequa district of the Western Cape. The Hessequa region is regularly struck with drought which leads to an investigation into the water security of the region. The investigation includes the development of a hydrological model for the Korentepoort Dam and bordering catchments. Physically based hydrological models require detailed soil distribution maps with soil physical data. The physical characteristics are used to calculate the amount of surface runoff, drainage and streamflow. Hydrologists use the Land Type information to supply soil character for modelling purposes. The most common soil type from the Land Type memoir is selected to represent the whole Land Type polygon. This representation varies depending on the homogeneity of soils within the landscape, but can be as little as 20%.

The segmentation method is evaluated within the Korentepoort catchment by field observations of the terrain at 190 points in the landscape. This point data is compared to the segmentation map with a different range of acceptable error. The segmentation method is constructed on a 90-meter digital elevation model, which was refined to a 30 meter. The highest acceptable error was selected as 30 meters. At this error, the terrain map was able to predict 77% of the field observation points. Transects were created from the terrain map, which also indicates a good fit with terrain units.

The Land Type information in the catchment was found to be conflicting with field observations and thus updated. The updated Land Type information was used to populate the segmented terrain map. The high resolution of the terrain map was found to be too complex for the hydrological model. A well-used method of soil type aggregation on the basis of hydrology was applied to the updated Land Types. The method divides the soil types into three hydrological response units and was found to be accurate on 10 out of 13 selected profiles. These profiles are selected as modal profiles and represent the soil types of their respective terrain units.

This research made it possible to dissect the landscape into units comparable with those in the Land Type database. This increases the resolution of the Land Type information and could possibly be applied to the whole of South Africa. Methods are suggested in which these terrain maps can be aggregated in a meaningful manner which would enhance its applicability for hydrological modelling.

1.3 OPSOMMING

Die Land Tipe databasis van Suid Afrika groepeer grond tipes in assosiasies op verskillende terrein eenhede binne 'n groter Land Tipe blok. Die Land Tipe inligting bied die geleentheid om hierdie terrein eenheid inligting te ontsluit deur die groter Land Tipe blok op te breek in verskillende terrein eenhede. Geografiese inligting stelsels het die potensiaal om deur middel van afstandswaarnemings tegnologie, 'n landskap te verdeel in terrein morfologiese eenhede. Daar is wel 'n verskeidenheid sagteware en metodes wat gebruik kan word om 'n landskap te segmenteer, die uitdaging is om 'n metode te identifiseer wat die landskap verdeel in eenhede wat ooreenstem met die in die Land Tipes.

Die studie area is die Korentepoort Dam opvangsgebied, noord van Riversdal in die Hessequa distrik van die Weskaap. Die Hessequa distrik word gereeld deur droogtes geraak wat daartoe gelei het dat 'n ondersoek geloots is om die water sekuriteit van die gebied te ondersoek. Die ondersoek sluit in die ontwikkeling van 'n hidrologiese model vir die Korentepoort Dam en nabye opvangsgebiede. Fisies gebaseerde hidrologiese modelle benodig gedetailleerde grond distribusie kaarte waaraan grond fisiese eienskappe gekoppel is. Hierdie fisiese eienskappe word gebruik deur die model om oppervlak afloop, dreinering en stroom vloei te bereken. Hidroloë maak gebruik van die Land Tipe databasis om grond inligting te bekom en dit in die model te gebruik. Die grond tipe wat die messte voorkom in 'n Land Tipe blok word geselekteer om die hele blok te verteenwoordig. Die persentasie voorkoms kan varieer afhangende die homogeniteit van die gronde in die landskap, maar kan so laag as 20% wees.

Die segmentasie metode is geëvalueer binne die Korentepoort opvangsgebied deur terrein observasies te maak en dit te koppel aan punt data. Die punt data is vergelyk met die segmentasie kaart met inagneming van sekere faktore wat variasie kan veroorsaak. Die segmentasie metode is gebaseer op 'n 90 meter digitale terrein model, wat verfyn is tot 'n 30 meter. 'n Aanvaarbare variasie van 30 meter is daarom geselekteer, waar die terrein kaart 77% van die observasie punte verteenwoordig het. Terrein deursneë is vergelyk met die terrein eenhede van die morfologie kaart wat visueel aanvaarbaar pas. Die Land Tipe inligting in die Korentepoort opvangsgebied het afgewyk van die veld waarnemings en is opgedateer. Die opgedateerde Land Tipe inligting is gebruik om die terrein morfologie kaarte te vul met grond inligting. Hierdie hoë resolusie kaart was te besig vir die hidrologiese model wat gelei het na samevoeging van sekere grond tipes. Hierdie samevoegings metode kombineer grond tipes teen opsigte van modale profiele wat die gronde beste voorstel. Die metode het samevoeging van blokke bewerkstellig en nogtans 10 uit 13 profiele in die opvangsgebied korrek verteenwoordig.

Die navorsing maak dit moontlik om die landskap in segmente in te deel wat vergelykbaar is met die Land Tipe terrein eenhede, wat die algehele resolusie van die Land Tipe inligting verbeter. Daarby is metodes voorgestel om hierdie inligting op 'n sinvolle manier te groepeer wat dit ideaal maak vir hidrologiese modulering.

1.4 TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACRU	Agricultural Catchment Research Unit
AWC:	Available Water Capacity (AWC = FC – PWP)
DEM:	Digital Elevation Model
FC:	Field capacity
HRU:	Hydrological Response Unit
kPa:	Kilopascals
LT:	Land Type
MAP:	Mean Annual Precipitation
OM	Organic Matter
PWP:	Permanent Wilting Point
SPAW:	Soil-Plant-Air-Water (Field and Pond Hydrology)
SRTM:	Shutter Radar Topography Mission
SWAT:	Soil Water Assessment Tool
SWC:	Soil Water Characteristics curve
TMU:	Terrain Morphological Unit
WCP	Western Cape Province

CHAPTER 1 GENERAL INTRODUCTION

South Africa is a water scarce country with ever growing population, industry and agriculture sector this natural resource is under immense pressure and is being exploited at a rapid rate. Southern Africa has experienced an increase in inter-annual rainfall variability over the past 40 years, coupled with irregular droughts (Boko *et al*. 2007). The unpredictability of annual weather patterns and a low adaptation capacity to uphold water security can be largely addressed by improving our understanding of hydrology in catchments. This would improve catchment management and ultimately water security in the region (Umvoto-Africa 2010).

Dams and catchment schemes provide the bulk of the water requirement for the Western Cape Province (WCP). Catchment schemes in the Riversdale area divert streams to open channels and to supply farmers. The study falls within the Hessequa municipal district in the WCP. The Hessequa region relies heavily on their sole water source, the Korente-Vette water scheme, which consists of the Korentepoort Dam, Kristalkloof and the Vette River. The water scheme supplies several small towns and a large agriculture sector with water. The region is regularly struck with droughts, which lead to domestic, agricultural and industrial water restrictions that are damaging to the local economy, indicating the need and importance for better water resource management (Umvoto-Africa 2010).

Hydrological modelling is a tool, among several others, that can be used to support water resource management. Hydrological models are continuously improved and the demand for more accurate tools rise with the increased pressure on water security (Refsgaard 2007). Modern software can rather accurately estimate the amount of water that will enter the dam after a rain event. Hydrological models may also be used to predict streamflow in the forecast future climate conditions to inform policy makers in advance. Process-based hydrological models use several data layers to predict streamflow, this includes soils information which is arguably the most variable and costly to acquire via soil survey. The soil information layer is used along with other data inputs to divide a given catchment into Hydrological Response Units (HRU's) – the areas that would react differently to the same environmental stimuli (e.g. rain events)(Govender and Everson 2005). The suitability of a certain soil map for hydrological modelling can be evaluated in terms of the accuracy of soil physical properties and distribution. A sensitivity analyses can be done using a hydrological model, this is however not in the scope of this thesis.

In the 1970's the Department of Agricultural Technical Services initiated a nationwide soils mapping exercise during which the whole area of South Africa was mapped at 1:250 000 scale in terms of Land Types (soil, landscape and climate associations) (Land Type Survey Staff 1972-2002). Since the main interest was focussed on soil use in agriculture, the goal was to identify and quantify agricultural land in terms of soil series, mountainous regions were largely neglected. It is important to determine the accuracy and suitability of Land Type information in mountainous regions because the information is often the only soils information available for hydrologist. With most dams and catchments located in the Western Cape mountain regions and most of these regions increasingly being used for agroforestry, the question around the suitability of the Land Type data for use in hydrological modelling arises. The quality of the information ultimately has an impact on predictions and management of water resources (Gan, Dlamini and Biftu 1997).

Geographical information systems (GIS) software is used to produce the HRU's and integrates information for hydrological modelling (Evans 2012). GIS software has the capacity to delineate terrain units, using digital elevation models (DEM) to calculate slope, curvature, and shape. The software can possibly delineate terrain units based on certain prescribed characteristics. This would enable the precise disaggregation of Land Type terrain units, as prescribed in each Land Type memoir. Hydrologists would, in turn, be able to use the detailed Land Type maps as soil data layer. These segmented maps can be produced for any region of South Africa and increase the resolution of Land Type maps for hydrological use but also for any other field requiring more detailed soils information.

Soil science appears to have entered a renaissance like period where novel approaches are reviving ideas from the past (Hartemink and McBratney 2008). An increased interest in environmental and agricultural sciences has placed soils back on the global research agenda. With the introduction of digital technologies, such as remote soil sensing, computer processing speed, management of spatial data and scientific visualisation methods have provided new opportunities to predict soil properties and processes (Grunwald 2009). Digital soil modelling (DSM) is a field marked by the adoption of new tools and techniques to analyse, integrate and visualise soil and environmental datasets (McBratney, Santos and Minasny 2003).

1.5 PROBLEM STATEMENT

The Land type information is a representation of soil and terrain data, which is widely used as a soil map for hydrological modelling (Vischel *et al*. 2008, Tetsoane 2013). Within a Land Type polygon, soil distribution is supplied in terms of terrain morphological units (TMU's) ranging from crest to valley bottom. A transect sketch indicates where the different terrain units will occur in the Land Type. Detailed soils information is embedded in Land Type polygons based on terrain morphological units. The Land Type survey focused on agricultural suitability, stating various crop production limitations such as mechanical limitations, slope and depth limiting material. It is therefore hypothesised that mountainous regions with low agricultural potential were largely neglected. This hypothesis is further supported by the lack of modal profiles in the Western Cape mountainous regions. The fact that mountainous regions are where the most productive dam catchments of the Western Cape are located, further stresses the need to validate the database in these areas (Schulze and Maharaj 1997).

Physically based hydrological models are used to simulate streamflow in catchments and provide the necessary support for decision makers in terms of flood and drought predictions. Simulation is achieved by identifying units that will respond in different ways during and after precipitation. Hydrological response units (HRU's) are generated from several data layers including; soil properties, land use, climate and digital elevation model (DEM) (Nietsch et al. 2005). The accuracy of the individual data layers is vital to produce accurate streamflow outputs, especially in ungauged basins.

Hydrologists in South Africa commonly use Land Type information as primary soils data for hydrologic modelling, often selecting only one dominant soil form for the catchment, which rarely represents more than half the soils (Vischel *et al*. 2008, Tetsoane 2013). More often than not, the Land Type information is used in these models without any validation of soil characteristics or distribution. For South Africa and any other water scares country, it is of utmost importance to not only validate the soils information, but also increase the resolution of the legacy soil information.

Although the aim of this study is not to evaluate the soil information with a hydrological model, but to review methods which can enhance the use of Land Type information for hydrological modelling.

1.6 OBJECTIVES

- The Overall Aim of the thesis is to identify suitable methods to unlock the detailed soil information aggregated within the Land Type memoirs, and present this information for hydrological response unit generation. A schematic representation of the various steps are illustrate in Figure: 1.1
- Determine the accuracy of the landscape morphology delineation (segmentation) method and compare it with a conventional soil map units.
- Review the Land Type information's accuracy in terms of soil type and soil physical characteristics through measurements of soil hydrologic properties
- Produce a thematic soil map best suited for delineation of hydrological response units (HRU's). This map will focus on soil physical properties and not soil taxonomy. Several profiles will be analysed in terms of their hydrologic response and hydromorphic features, these points will be used to test the thematic map.

1.7 THESIS LAYOUT

Chapter 1: General introduction to the research topic, problem and hypothesis.

Chapter 2: Literature study including previous research on hydrology, digital soil mapping and terrain morphology analytics.

Chapter 3: Description of the study area which includes climate, geology and vegetation.

Chapter 4: Describes various methods used during data collection and soil mapping.

Chapter 5: Investigates the ability of the terrain delineation method to predict the terrain of the catchment.

Chapter 6: Reviews the applicability of the Land Type information within the catchment boundaries, which led to the production of new terrain-soil associations.

Chapter 7: Overall research conclusions and future research recommendations

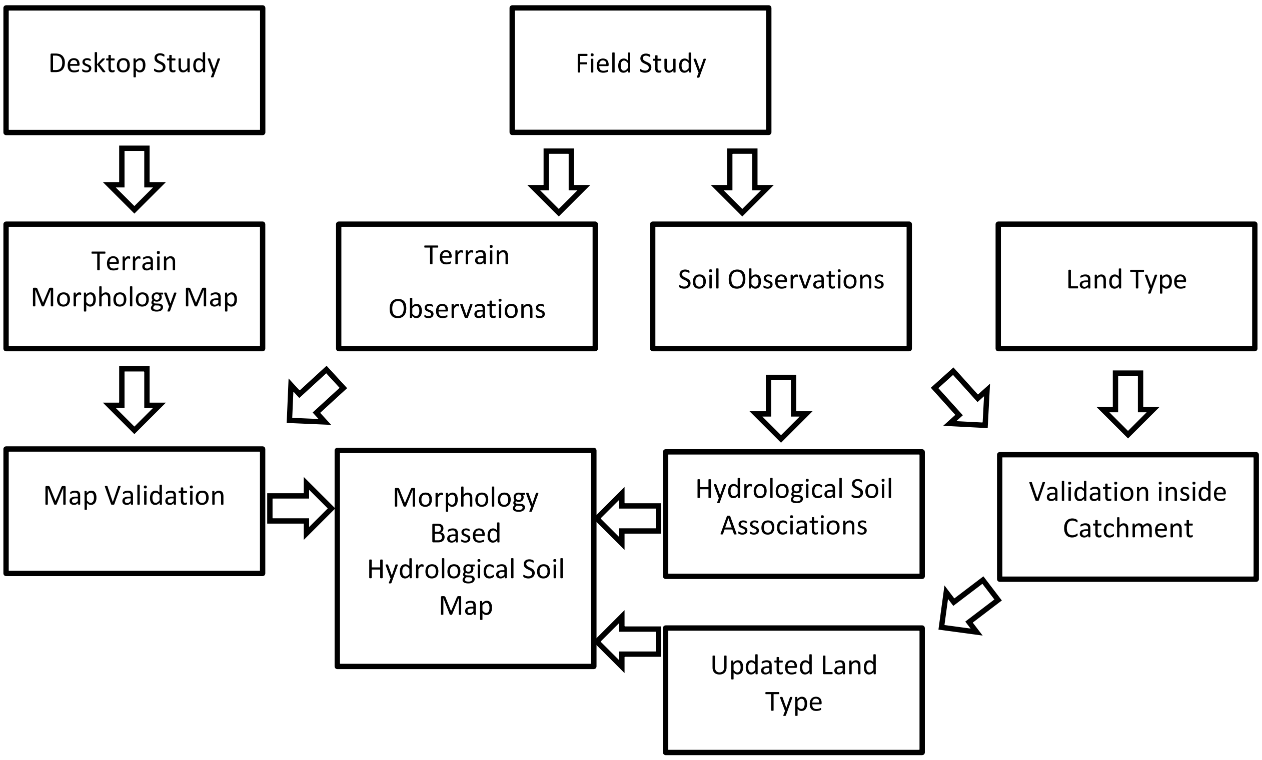

Figure: 1.1 Schematic representation of thesis layout

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

"The fact that the world faces a water crisis has become increasingly clear in recent years. Challenges remain widespread and reflect severe problems in the management of water resources in many parts of the world. These problems will intensify unless effective and concerted actions are taken" (WWAP 2003).

Currently the demand for water grows at more than twice the population rate, whilst new water resources are becoming scarcer (Clothier, Green and Deurer 2008). South African water resources are also under immense pressure due to the growing population, industry and agriculture sectors. Dams and irrigation schemes provide water for domestic, industrial and agricultural industries, thus making it crucial to managing these systems.

Precipitation is the fundamental driving force behind hydrological processes and is the most variable hydrological element (Hamlin 1983). Water cannot be managed in isolation without taking into account other factors that influence supply and demand. The holistic management approach focuses on the entire system rather than separating it into parts, thus the method was soon incorporated into water management as Integrate Water Resources Management (IWRM). "IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems''(GWP 2000). The Water Services Act of South Africa (Act 108 of 1997), which provides the rights to basic water supply and sanitation, recognises that the provision of water and sanitation is an activity different from the overall management of water resources, and needs to conform to IWRM guidelines (Pollard and Du Toit 2008).

Hydrological processes of a catchment area are a reflection of the relationship between different systems and components which all contribute to the complexity of the system. Hydrological modelling explores the different processes and their individual effects on streamflow This plays a major role in IWRM especially in flood forecasting in real-time as early warning systems (Meire 2007). These models should be created with the best quality information in order to calculate and predict with the highest possible precision.

Hydrological modelling software requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the catchment (Neitsch *et al*. 2009). Most of the information needed can easily be obtained from various sources namely: digital elevation models (DEM) for the topography, Normalized Differential Vegetation Index (NDVI) for vegetation cover and legacy soil information for soils input data (Vischel *et al*. 2008, Tetsoane 2013).

In the Liebenbergsvlei catchment, Vischel (2008) increased the soil conductivity by a factor of 60 during calibration. This is equivalent to change the soil texture from sand to sandy clay loam, everything else being equal. Therefore if accurate hydrological modelling is pursued the accuracy of soils and landscape information must become a priority. Tetsoane (2013) found that land management practice and soil parameters had the largest influence on hydrologic possess in the Modder River Basin, Free State Province.

2.2 HYDROLOGY

Hydrology represents an intricate system with interrelating processes that govern water movement in a catchment. The hydrologic cycle is driven by solar energy, which causes water to evaporate, condensate in the atmosphere and precipitates back to earth. Hydrological modelling focuses on the precipitation that falls on the land surface, and the quantities of water that moves through the landscape. In order for the model to make accurate predictions the factors that influence water movement; climate, topography, vegetation and soil information needs to be accurately quantified (Neitsch *et al*. 2009). These predictions will contribute and lead to improved management decisions, especially with regards to climate change and land use (Hughes 2010).

Water quality is heavily impacted by the terrain through which it flows. Mountainous regions in the Southern Cape are known for the occurrence of organic matter enriched streams. These streams, often referred to as black water, contain different soluble organic compounds (e.g. phenols, tannins, humic/fulvic acids and saponins) that are mostly produced by specific plants. This black water is characterised as having a high acidity (pH <5.2)(Midgley and Schafer 1992). The factors influencing the production of organic compounds, mentioned above, are a result of various factors including, vegetation, soil and climate. The treatment process of this water for consumption is costly but crucial because the chlorination process reacts with humic and fulvic acids and produces toxic *dihalocetonitriles* (Oliver 1983). Understanding the pathways of these water transported substances and the vegetation could lead to new management practises. Hydrological models can be used to predict the flow paths and transport of these compounds and others including pesticides, nitrogen, phosphorous and even microbial life, making it an excellent tool to monitor and understand contaminants (Neitsch *et al*. 2009).

The management of dams and catchments are crucial for future water security. Land use within a catchment can have a tremendous impact on catchment dynamics, not only on the amount of water reaching the reservoir but also the amount of silt carried with it (Koch *et al*. 2012). Siltation of dams decreases the amount of water a reservoir can store and, if not addressed, exacerbate the effects of droughts. Hydrologic models are able to predict siltation rates from different land uses and can aid in legislation making and catchment management.

2.2.1 Soil Water Balance

Soil is the first filter of the world's water, the filtering and buffering ultimately influences quality and quantity of underground and surface water (Clothier *et al*. 2008). Solar energy powers the global water cycle; evaporated water condenses due to lower air temperature and precipitates back to earth. The soil water balance is associated with the energy balance which is an expression of the classical law of conservation of energy, which states that energy cannot be created or destroyed only absorbed, released and change of form (Hillel 2013). Predictions of soil moisture must be based on quantitative knowledge of the dynamic balance of water in the soil. The soil water balance is based on the law of conservation of mass, which states that matter cannot be created nor destroyed but only changed from one state or location to another (Hillel 2013). Water content within the soil cannot change significantly without external addition or losses. The water balance is the driving force behind everything that happens in the watershed and is based on this equation (Neitsch *et al*. 2009):

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right)$$

SW_t is the final soil water content, SW_0 is the initial soil water content, t is the time in days, R_{day} is the amount of precipitation on day i , E_a is the amount of evapotranspiration on day i, w_{seep} is the amount of percolation and bypass flow exiting the soil profile bottom on day i and Q_{gw} is the amount of return flow on day i. This equation is summarized in Figure: 2.1, illustrating the various gains and losses. Soil properties have a major effect on water movement in a landscape, governing direction and speed of flow (Figure: 2.1). The soil water balance phase of the hydrologic cycle controls the amount of water, sediment, nutrients and pesticide that will ultimately end up in rivers or reservoirs (Neitsch *et al*. 2009). Quantifying the soil pedon's effect on water movement is crucial step in predicting stream flow within a catchment.

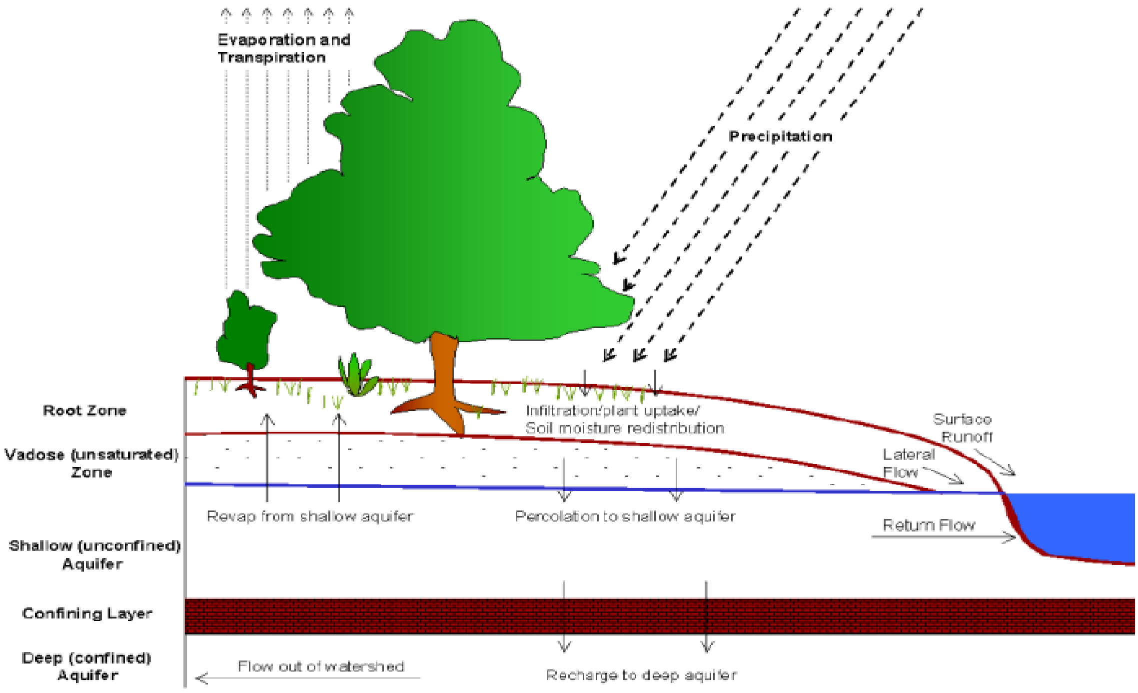

Figure: 2.1 Soil water balance from a hydrological perspective. (Neitsch *et al*. 2009)

2.2.1.2 Topography

The main factor influencing water movement in a catchment area is topography (Wood et al. 1988). The shape of terrain governs the movement of surface water, which transports pollutants and sediment (Jacek 1997). Because the water movement is closely correlated to terrain, and soil genesis is controlled by water regimes, topography has a massive influence on soil distribution. Variability in surface soil moisture is strongly correlated to relative elevation, aspect and clay content (Famiglietti, Rudnicki and Rodell 1998).

2.2.1.3 Soil Profile

The soil profile typically consists of a succession of strata which can be a result of sedimentation, deposition or internal soil forming processes, these layers are referred to as horizons (Hillel 2013). In the field soil horizons are identified by differences in colour, structure and texture (Samadi, Germishuyse and Van der Walt 2005). The soil profile is a matrix where nutrients and water are collected, stored and released, forming suitable habitats for fauna and flora.

The top soil horizon is the zone with the highest biological activity and is often enriched with organic matter. Soil micro-(protozoa and fungi) and macroorganisms (earthworms, arthropods and rodents) influence soil water movement through aggregating soil particles and burrowing which generates preferential flow paths through the profile (Hillel 2013). The South African Soil Classification accommodates an eluvial (A2) horizon referred to as E horizon. This horizon is characterised by the removal of organic material, iron and clay the result being a concentration of quartz and other weathering resistant minerals (Van Der Watt and Van Rooyen 1995). The E horizon is often a layer with higher hydrologic conductivity than above and below soils enabling preferential flow in this horizon which further increases leaching. Underneath the A horizon is the B horizon where illuvial concentrations from the layers above accumulate, this layer is often denser due to the pressure exerted by the soil layers above it. Below the B horizon is the C horizon that consists of fragmented rock. Lithological discontinuity refers to soil layers that did not originate from the parent material, C horizon. Often Lithological discontinuity imposes a hydrological conductivity difference between layers. The hydrologic character of C horizons can vary dramatically depending on the degree of fragmentation, orientation of cracks and type of rock. For example fractured Table Mountain sandstone and shale can conduct water at 10^{-1}-10^{-2} m/d and 10^{-3}-10^{-4} m/d respectively (Xu, Lin and Jia 2009).

2.2.1.4 Vegetation

The effect of vegetation on the soil water balance is determined by the type of vegetation and population density (Bosch and Hewlett 1982). The amount of water that vegetation extracts from the soil is governed by the plant physiology and climatic conditions. This relationship is expressed as the crop factor, the ratio between crop evapotranspiration and surface water evaporation. In most cases, evaporation from surface water is much higher than evapotranspiration of vegetation covered soil (Hillel 2013). Vegetation has the ability to intercept precipitation in the canopy, which decreases infiltration, runoff and increase evaporation. On the other hand, in fog-prone areas, vegetation acts as a condenser and contributes to soil / groundwater recharge (Azevedo and Morgan 1974). Furthermore, plant roots create preferential flow paths along live and dead roots which can increase groundwater recharge and reduce surface runoff (Hendrickx and Flury 2001). Vegetation is also capable of altering the physical characteristics of soil by introducing organic material on the surface and below. Human interventions in natural systems often lead to a disruption in equilibrium; this is often observed in agricultural soils which receive a large amount of disturbance (e.g., irrigation, drainage, tillage, compaction, fertilizer, vegetation change etc.) An example thereof is the human induced dryland salinization of the Berg River, South Africa, where natural deep-rooted vegetation was removed to make way for cultivated lands (Bugan 2014).

2.2.2 Physically Based Hydrological Models

Understanding the theory applied in a certain hydrological model will indicate the most appropriate application. Essentially there exists two different types of hydrological models; Stochastic, which uses empirical historic data, and physical based, which simulates water movement through the soil, bedrock and streams. Finding the appropriate model for a specific application and watershed is quite a challenging task (Borah and Bera 2003). When selecting the most suitable model, the following factors should be taken into account: research problem, watershed size, desired spatial and temporal scales, expected accuracy, user's skills and computer resources .(Borah and Bera 2003). The research problem will have the greatest impact on model selection and should thus be clearly defined. Discussed below are popular hydrologic models in South Africa both physically based and stochastic.

Physical Based Hydrological Models:

1. *ACRU – Agricultural Catchments Research Unit*

ACRU is an Agrohydrological Modelling System developed by the Department of Agricultural Engineering of the University of Natal in Pietermaritzburg, South Africa (Schulze 1995). The model a physical conceptual based model which integrates the various water budgeting and runoff components on the hydrological system (Figure: 2.2). The model uses daily time steps with the option to average monthly values (Schulze 1995). Input data for the model includes rainfall, max-min temperature, A-pan, leaf area index, incoming radiation flux density, relative humidity and wind run. The model divides stormflow into quick flow and delayed flow, resulting in varying response at the catchment outlet. The delayed flow is dependent on the soil properties, catchment size, the density of drainage network and slope (Bugan 2014). ACRU can also be used for crop yield estimations, assessments of wetlands, groundwater modelling and flood estimations (Schulze 1995).

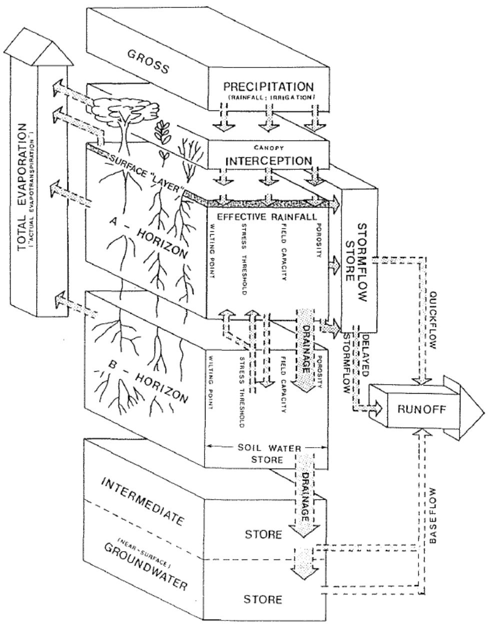

Figure: 2.2 The general structure of the ACRU Agrohydrological modelling program (Tarboton and Schulze 1991).

Soil Input requirements for the ACRU model is divided into several categories depending on the type of simulation (Table: 2.2)

Table: 2.2 Soil inputs used in ACRU

Type of Modelling	Input Requirements
Soil Water Budgeting Routines	Total Porosity Drained Upper Limit Permanent Wilting Point Texture Class Thickness of topsoil Thickness of subsoil
Shallow Groundwater Modelling	Saturated hydraulic conductivity Water table depth Height of capillary fringe
Physically Based Infiltration And Redistribution	Number of soil horizons Soil Water Retention Values Tillage operations Effective porosity Particle size distribution Bulk density Organic matter content

2. *SWAT – Soil Water Assessment Tool*

The Soil Water Assessment Tool (SWAT) is developed and supported by the Unites States Department of Agriculture and the Agricultural research service (USDA / ARS). It is a physically based watershed-scale continuous time-scale model, which operates on daily time steps. The model does not require calibration, but historical data can be used to enhance predictions. SWAT is computationally efficient to operate on large basins and capable of simulating effects of management changes (Arnold *et al*. 1998). The model utilises DEM, soils, land use and climatic data and divides the watershed into small sub-basins and hydrologic response units (HRU's) (Parajuli and Ouyang 2013). The HRU's are zones of similar soil, terrain, land use and climate, thus will react similarly to any given input. SWAT has the ability to simulate contaminant movement, which is of great worth to municipalities managing water resources. The system allows the user to estimate water, sediment and contaminant quantity at any given point and time (Neitsch *et al*. 2009). These traits make the model applicable to ungauged basins and are mostly suited for long term yield and not capable of detailed, single event flood routeing (Arnold *et al*. 1998). SWAT is a capable model for continuous simulations in predominantly agricultural watersheds, falling short in urbanised terrain compared to other models (Borah and Bera 2003)

SWAT has been used locally for different hydrological (Govender and Everson 2005, Tetsoane 2013, Welderufael, Woyessa and Edossa 2013). SWAT can be installed with various GIS programs and can be used without cost in QGIS, increasing suitability for end users such as municipalities.

2.2.2 Modelling Soil Water Balance

Water movement in a soil is correlated with the potential energy of water within the soil. Soil water potential as defined by the International Soil Science Society, " the amount of work that must be done per unit quantity of pure water to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation and atmospheric pressure to the soil water (at the point under consideration) (Aslyng 1963)." The Total Water Potential is the sum of all the separate contributions of these various factors and can be subdivided into Hydraulic Potential which is expressed by the following equation:

$$\Psi_h = \Psi_g + \Psi_p + \Psi_m$$

Where Ψ_h is the hydraulic water potential, Ψ_g is the gravitational potential, Ψ_p is the pressure potential, Ψ_m is the matrix potential (Hillel 2013). Matrix potential is the single largest constituent to water movement in unsaturated soils. When soil pores are saturated with water the matrix potential is practically zero, and does not contribute to water movement within the soil. This in turn increases pressure potential (Ψ_p). The Osmotic potential refers to the presence of solutes that affect the thermodynamic properties of water and lowers its potential energy and is not included in the Hydraulic potential, for it has negligible effect on water movement in soils. Gravitational potential, and pressure potential are the main driving force in soil water movement under saturated conditions. Water will flow from a zone with high water potential towards a point of lower potential. Theoretically soil water potentials are essential for understanding water movement through soil; but seldom used for calculating water flow through a landscape.

Hydrological models assume water will flow from high to low reference levels based on gravitational force. The velocity of water flow through a landscape is determined by the soils ability to conduct water.

Water movement through a soil can either occur under saturated or unsaturated conditions, a soils ability to conduct water under these regimes is referred to as K_{sat} and K_{unsat} (Devices 2006).

Hydrological models centred on the Darcy – Richards equation are often inconsistent with field observations (Clark *et al*. 2009). Darcian models predict flow through a homogeneous porous material but do not predict preferential flow through macropores, variable bedrock topography and fractures (Tromp-van Meerveld and McDonnell 2006, Beven and Clarke 1986). Field measurements that characterise the pore geometry are essential where the preferential flow is the central water movement pathway.

The water content of a soil can range from zero, which does not occur naturally, to saturated (ϕ_{soil}). For plant and soil interactions two intermediary stages are defined; field capacity (FC) and permanent wilting point PWP. PWP is the water content found when plants growing in the soil wilt and do not recover if their leaves are kept in a humid environment overnight (Hillel 2013). FC is the water content found when a thoroughly wetted soil has drained for approximately two days. The two stages are quantified in terms of tensions; Field capacity 33 kilopascals (kPa) and permanent wilting point 1500 kPa for mesotrophic vegetation. The amount of water between these points is referred to as plant available water capacity (PAW). Models use these values in conjunction with crop factors to estimate the volume of water available for plants to use given a certain water content. Models use different input parameters to derive soil properties and water movement.

2.2.3 The main modules of water transport models relying on soil information.

SPAW- Soil Plant Air Water field & pond hydrology

The model is based on earlier work by Saxton *et al*. (1986) describing methods to calculate soil-water characteristics from particle size distribution. The method was updated and included several other input parameters such as gravel content, salinity and compaction (Saxton and Rawls 2006). A detailed illustration of the model routine is summarised in (**Error! Reference source not found.**) and corresponding equations. The input parameters are texture and organic matter (OM) as percentage carbon, although the OM effects are not well observed at low water contents or high clay content. Adjustments can be made to compaction, gravel content and salinity. The SPAW model has been used extensively to predict soil hydraulic properties and reduce monetary costs of hydrological monitoring with adequate accuracy (Tilak *et al*. 2014, Kenjabaev *et al*. 2013). The model does have some minor shortcomings in assuming a particle density of 2650 $kg.m^{-3}$ and the deviation of results when the texture is outside the optimal texture region (Figure: 2.3).

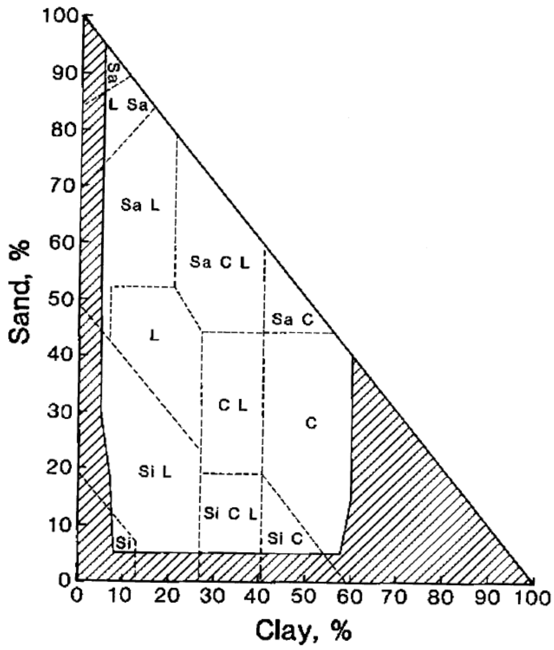

Figure: 2.3 Illustration of the most applicable textural region using SPAW equations (Saxton *et al*. 1986).

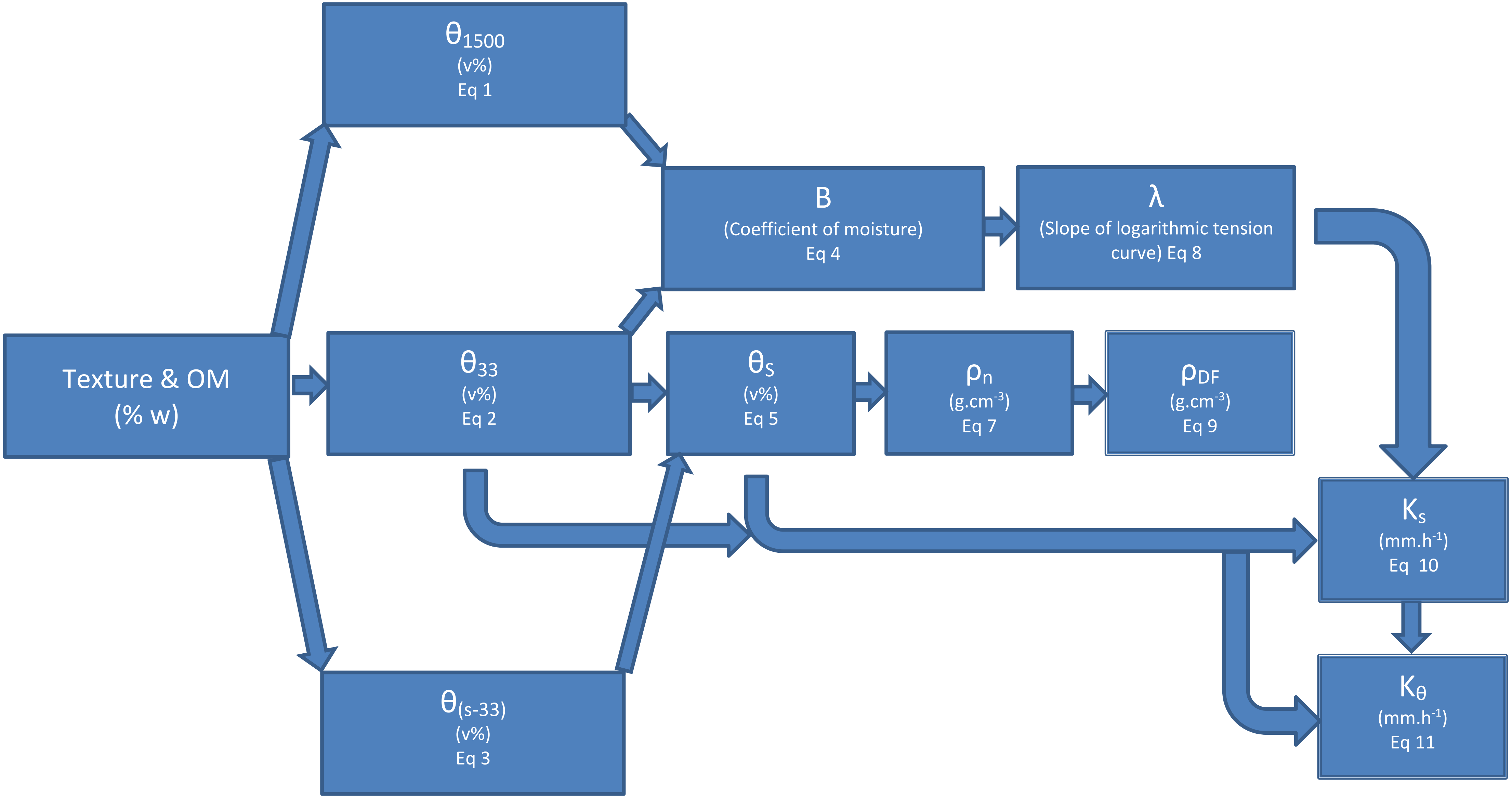

Figure: 2.4 Procedure for calculating Saturated / Unsaturated Hydraulic Conductivity and Bulk density using the SPAW model (Saxton and Rawls 2006).

Equation: 1

$$\theta_{1500t} = -0.024(S) + 0.487(C) + 0.006(OM) + 0.005(S \times OM) - 0.013(C \times OM) + 0.068(S \times C) + 0.031$$

$$\theta_{1500} = \theta_{1500t} + (0.14 \times \theta_{1500t} - 0.02)$$

Equation: 2

$$\theta_{33t} = -0.251(S) + 0.195(C) + 0.011(OM) + 0.006(S \times OM) - 0.027(C \times OM) + 0.452(S \times C) + 0.299$$

$$\theta_{33} = \theta_{33t} + (1.283 \times (\theta_{33t})^2 - 0.374(\theta_{33t}) - 0.015)$$

Equation: 3

$$\theta_{(s-33)t} = 0.278(S) + 0.034(C) + 0.022(OM) - 0.018(S \times OM) - 0.027(C \times OM) - 0.584(S \times C) + 0.078$$

$$\theta_{s-33} = \theta_{(s-33)t} + (0.630 \times \theta_{(s-33)t} - 0.107)$$

Equation: 4 $$B = \frac{[\ln(1500) - \ln(33)]}{[\ln(\theta_{33}) - \ln(\theta_{1500})]}$$

Equation: 5 $$\theta_s = \theta_{33} + \theta_{(S-33)} - 0.097S + 0.043$$

Equation:6 $$\rho_N = (1 - \theta_s) \times 2.65$$

Equation: 7 $$\lambda = \frac{1}{B}$$

Equation: 8 $$\rho_{DF} = \rho_N \times DF$$

Equation: 9 $$K_S = 1930 \times (\theta_s - \theta_{33})^{(3-\lambda)}$$

Equation: 10 $$K_\theta = K_S \times (\frac{\theta}{\theta_s})^{[3+\left(\frac{2}{\lambda}\right)]}$$

Table: 2.1 Equation symbol definitions (Saxton and Rawls 2006).

Symbol	Definition	Symbol	Definition
B	Coefficient of moisture tensions	$\theta_{(s-33)}$	SAT – 33kPa moisture % volume
C	Clay % weight	θ_s	Saturated moisture % volume
OM	Organic matter % weight	ρ_N	Normal bulk density, g.cm^{-3}
S	Sand % weight	ρ_{DF}	Adjusted Bulk density, g.cm^{-3}
SAT	Saturation moisture	DF	Density adjustment factor
θ_{1500t}	1500 kPa moisture, first solution	K_S	Saturated conductivity, mm.h^{-1}
θ_{1500}	1500 kPa moisture % volume	K_θ	Unsaturated conductivity at moisture θ, mm.h^{-1}
θ_{33t}	33 kPa moisture first solution		
θ_{33}	33 kPa moisture % volume	λ	Slope of logarithmic tension-moisture curve
$\theta_{(s-33)t}$	SAT-33kPa moisture first solution		

Infiltration and Overland Flow Equations

When the rate of water application exceeds the infiltration rate, surface depressions fill with water and ultimately overflow causing runoff (Neitsch *et al*. 2009). Soil hydraulic conductivity often decreases down the soil profile together with bulk density. Infiltration rates of soils vary significantly and are affected by subsurface permeability and surface intake rates (Cronshey 1986).

Hydrological models commonly use SCS Curve Number (CN) procedure to estimate surface runoff. CN runoff equation is an empirical model which came into common use in the 1950s (King, Arnold and Bingner 1999). The model specialises in estimating runoff under varying land use and soil types (Rallison and Miller 1982). The most important factors that contribute to determining CN of a specific soil is; hydrologic soil group, cover type, treatment and antecent runoff condition.

Soils hydrological groups divides soils into hydraulic categories ranging from deep sand and gravels with high infiltration (A) to impermeable clay layers with high runoff (D) (Neitsch *et al*. 2009).

Others means of calculating infiltration is the well-known Green and Ampt method (Green and Ampt 1911). Variance between observed infiltration and the Green and Ampt method is illustrated in Figure: 2.5

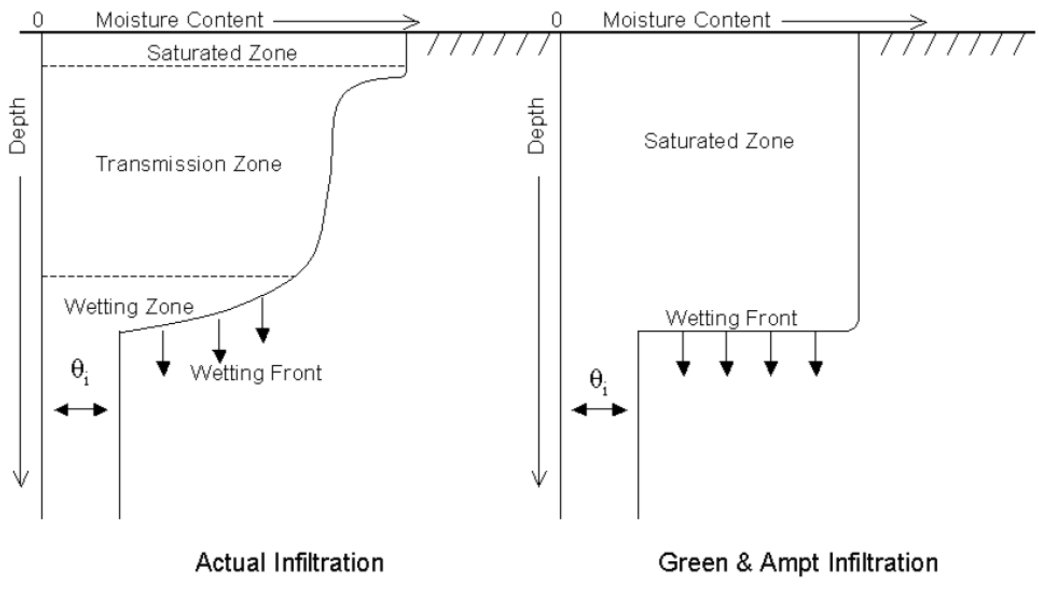

Figure: 2.5 Illustration of Green and Ampt infiltration model compared to observed infiltration (Neitsch *et al*. 2009).

Runoff and Sedimentation Transport

Runoff takes place when the rate of precipitation exceeds the infiltration rate. With rainfall data usually on a daily time step, peak precipitation can exceed infiltration rate, although the average rainfall is below. Peak runoff, which carries most sediment, is calculated using the rational method which is based on the assumption that the whole catchment is contributing (Neitsch *et al*. 2009).

2.2.4.2 Hydrological soil information in South Africa

Soils distribution across South Africa was mapped as a natural resource inventory known as Land Types, which exhibits similar landscape and climate (Fey 2010). Soil series distribution is given as a rough estimate of the percentage of the area of each terrain morphological unit (TMU) (van Zijl, Le Roux and Turner 2013). The Land Type maps are accompanied by a set of memoirs for each area. A transect sketch accompanies the Land Type memoirs and illustrates the positions of TMUs. The Land Types therefore lists a number of soil series that can be found in specific TMUs. Soil types and physical characteristics used in hydrological modelling is listed in the Land Type memoirs (Table: 2.3). Hydrologists commonly use Land Type information as primary soils data for hydrologic modelling, because it is the only soils database for South Africa (Vischel *et al*. 2008, Tetsoane 2013). However this soils database is not compatible with catchment size hydrological modelling as proven by Vischel (2008), where they increased the soil conductivity by a factor of 60 during calibration. This is equivalent to changing the soil texture from sand to sandy clay loam, everything else being equal. Using accurate soils data in models is of utmost importance e.g. Tetsoane (2013) noticed that the most sensitive parameters in his SWAT hydrological simulation of the Modder River basin are dependent on soil parameter, and influence hydrologic processes more than others.

Selected Land Types include modal profiles with a full description of the soil profile, physical and chemical analyses. Modal profiles are included in some Land types containing arable land and slight soil variation to maximise the usage of analyses. Mountainous Land Types are deprived of modal profiles, which implies all data, including texture, was derived from field observations (Table: 2.3) Although the information captured in Land Types meets some model parameter inputs, the accuracy and scale of information are problematic. Land Type information is often incorporated into hydrological models by identifying the dominant soil type and generalising those characteristics to the whole polygon (Tetsoane 2013, Vischel *et al*. 2008).

Table: 2.3 The Land Types indicate the following soils information:

Soil Physical Property	Unit	Description	Hydrology Input parameter
Soil Type	Fraction per TMU	Soils form distribution is given for each TMU. (Binomial System Macvicar *et al* 1977)	Used with knowledge of the classification system, estimations of OM*, mineralogy, and preferential flow can be made.
Depth	Upper and lower limit (mm)	Total soil depth to bedrock or 1.2 meters given per soil type. *e.g. 100-250 mm*	The amount of soil that can possibly store or conduct water.
Clay Content	Upper and lower limit (%)	Percentage clay per horizon per soil type. *e.g. 4-12%*	Primary input: Calculate soil hydraulic properties per horizon.
Texture	Upper and Lower Limit (Type of sand and class)	Classes from the Texture Triangle. Often prefixed with fi (Fine),me (Medium) or co (Coarse). Per soil Type *e.g. coSand- Coarse Sand*	Derive soil hydraulic properties
Depth Limiting material	Type	Abbreviation indicates type of root growth limiting material. Per soil type. *E.g. Rock.*	Used in conjunction with land use, effective rooting depth of specific crops can be deducted.

*OM= Organic Matter

Scale

Land Type polygon size is based on the variation of climate, geology and topography in a certain area (0).From a hydrological perspective, scale compatibility is dependent on catchment size and the amount / distribution of Land Types within the catchment. Large basins with multiple land types would be more compatible with the coarse Land Type information. The problem arises if hydrologists model catchments where dominant soil types do not represent the study area. Simply using a dominant soil form to represent a complex Land Type does not contribute to precision modelling but rather a loss of information. The key to unlocking Land Type information is by disaggregating it, in the same manner in which it was constructed.

Table: 2.4 Summary of South African Land Type information (Land Type Survey Staff 1972-2002).

Total Amount Of Land Types	7075
Average area per LT (ha)	17197
Min Area (ha)	78
Max Area (ha)	2022480
Standard Deviation Area	48219
Land Types with Modal Profiles	37%

2.3 SOIL CLASSIFICATION AND MAPPING

The purpose of soil classification is to provide an objective manner to systematically classify soil (Campbell and Edmonds 1984). In order to represent soil distribution on a map, the soil must be perceived as a spatial entity or pedon. A pedon is defined as the smallest recognisable unit that can be called a soil (Soil Conservation Service 1975). Pedology is a branch of soil science dealing with soils as a natural phenomenon; including their morphological, physical, chemical, mineralogical and biological constitution, genesis, classification and spatial distribution (Van Der Watt and Van Rooyen 1995). The pedological aspects focused on in this study are the geographic distribution of soils and classifying its physical morphological characteristics, and spatial distribution. Pedologists often describe soils as a continuous gradient with no clear divides between border cases. The complex and highly variable nature of soil patterns in landscapes complicate the process of collecting and presenting soil survey data (Wright and Wilson 1979). The classification of soil into taxonomic entities involves grouping soils of specified characteristics together, through this process information is lost or exchanged for ease of communication. The classification and distribution of soils are not only important for the agriculture sector but also environmental studies, engineering and hydrology. Although hydrologists are not concerned with soil form or type and rather the soil physical properties, such as horizon depth, texture and conductivity, soil forms can supply useful information as secondary attributes.

The South African soil taxonomic system is largely based on morphology with little need for laboratory analysis, most classification can be completed in the field (Soil Classification Working Group 1991). The Soil Classification system has two levels known as soil forms and families. The soil form specifies the sequence of diagnostic horizons and materials present and in some cases also the features of the underlying material (Van Huyssteen, Turner and Le Roux 2013). The soil family is defined by a narrow range of variation of soil properties e.g. Luvic or non-luvic.

Soil surveys examine, describe, classify and map soils in an area for a specific purpose (Van Der Watt and Van Rooyen 1995). Although the survey is for a specific purpose, the classification should be done regardless of end use. The soil survey consists of several parts: i) Selection of sites and preparation of soil pits. ii) The description and classification of the soil profile. iii) Sampling of soil for physical and/ or chemical analysis. iv) Mapping of mentioned soil characteristics.

There is always an amount of uncertainty embedded in soil distribution maps, regardless of the methods used to create the map. It is well-accepted that all the properties of a soil cannot be measured at a particular location in space, nor a single property at all points (McBratney and Gruijter 1992). Therefore we sample both and predict variables in the unknown areas.

Conventional prediction methods largely depend on the surveyor's expertise and ability as well as supplementary information (aerial photographs etc.) Digital soil mapping commonly uses remotely sensed data or regular soil surveys and algorithms to predict soil distribution.

If the catena concept is applicable and applied to a study area, the soil properties are directly linked to terrain form (Sommer and Schlichting 1997). The concept explains the regular variation of soils in a landscape as a function of dominant soil forming factors; lithology, climate and topography. The impact of land use and alteration of stream flow paths can have dramatic effects on soil which can complicate predictions (Rubinić *et al*. 2015).

2.3.4 Conventional Soil Mapping

Field observations accompanied by classification and analysed data plays a central role in the conventional mapping process. During mapping soil boundary delineation is done by hand using any information available to increase accuracy. Soil forming factors published by Jenny (1941) supports surveyors to predict soil boundaries and understand soil patterns within a region. The soil forming factors; climate, organisms, relief, parent material and time provide a qualitative means to conceptualise soil distribution. Traditional soil survey methods are the most popular form of soil mapping and inventory and typically involves grid surveying. The method comprises of three steps (Cook *et al*. 1996). Firstly, direct observations of secondary data (geology, vegetation, etc.) and soil profile characteristics are made. Secondly, a conceptual model is developed using the information attained in the first step. The conceptual model is used to infer soil variation. Thirdly, the conceptual model is applied to the survey area to predict soil characteristics in unobserved sites. Generally, less than 0.001% of the survey area are observed and / or sampled (Beckett and Burrough 1971), this is due to the costs associated with field work. The conceptual model does have several shortcomings. This include; variation in soil surveyor's knowledge and expertise which in turn affects the accuracy. Furthermore the end product of a soil survey is a soil map that has unknown assumptions, limitations and accuracy (Beckett and Burrough 1971).

2.3.5 Digital Soil Mapping

Geographic information systems (GIS) software provides a platform to analyse and use vast amounts of information to produce soil maps with a limited amount of field measurements. Digital soil maps (DSM) utilize various technologies to produce quality soil maps while improving the interpretation of soil maps to a wider range of specialist fields (van Zijl *et al*. 2013). DSM depends on the landscape geometry. Digital elevation models (DEM) are GIS based representations of terrain and the backbone of terrain analyses models.

The original introduction of paradigm based science into soil science by Jenny (Hudson 1992, Jenny 1941) conceptualised soil-environment relationships. The concept is expressed by the following equation:

$$S = f(cl, o, r, p, t, \dots),$$

Where soil is considered a function of climate (*cl)*, organisms (*o*), relief (*r*) and parent material (*p*) acting through time (Jenny 1941). The *clorpt* model differs from other models in that the factors are not forces but rather variables that define the state of a soil system (Jenny 1961). The factors do not represent pedogenic processes but rather environmental features, which control processes (Thompson *et al*. 2012). The *clorpt* model is improved with additional concepts, such as the catena approach (Milne 1936) that are able to explain and predict processes at various scales (Thompson *et al*. 2012).

2.3.5.1 Spatial Approaches

Spatial predictions of soil layers, individual soil attributes and soil-landscape processes, are needed at a scale appropriate for environmental management (Moore *et al*. 1993). Moore *et al* (1993) hypothesised that the development of soil toposequences often occurs in response to water movement through and over the landscape. Water movement is controlled by the geometry of the land surface and subsurface materials. The terrain geometry can therefore be used as a first approximation for predicting the soil occurrence. This correlation between soils and environment led to the development of a number of models, which will be discussed in the following sections.

2.3.5.2 SCORPAN Approach

The scorepan approach has been developed to predict soil properties and classes and is based on the known soil forming factors (McBratney *et al*. 2003). The model deviates from Jenny's (1941) soil forming factors equation, in that it was intended for quantitative spatial prediction, rather than explanation (McBratney *et al*. 2003). This deviation is ascribed to the incorporation of soil and space as factors, which can be used to predict other soil attributes (Thompson *et al*. 2012). The conceptual equation can be written as follows (McBratney *et al*. 2003):

$$S = f(s, c, o, r, p, a, n)$$

Expanded to explicitly incorporate space and time (Thompson *et al*. 2012):

$$S[x, y{\sim}t] = f(s[x, y{\sim}t], c[x, y{\sim}t], o[x, y{\sim}t], r[x, y{\sim}t], p[x, y{\sim}t], a[x, y]])$$

S: Soil class or soil attributes.

s: Soils, other attributes of soil at a point

c: Climate Factor

o: Organisms, Vegetation or fauna or human activity

r: Topography and landscape attributes

p: Parent material, lithology

a: Age time factor

n: Space, spatial location

x,y: Spatial location (n)

~t: Time factor

Where a general predictive model will be expressed as:

$$S(x, y, z, t) = f(Q)$$

Where *Q* is the predictor variable(s). The general approach detailed by McBratney (2003) is to collect data of soil (*S*) at a certain time (*t)* at known locations (*x,y*) in the field. Followed by the process of identifying pedological predictor variables and develop a function Q that would fit collected data.

Statistical and geostatistical methods are used to estimate soil properties and classes discussed in section.

The accuracy of modelled predictions is dependant on (McBratney *et al*. 2003):

(i) Adequate predictor variables (e.g. vegetation, terrain) observed at a relatively high data density.

(ii) Having sufficient soil observations points to fit a relationship.

(iii) Functions *f(Q)* able to fit nonlinear relationships.

(iv) A concrete relationship between soils of a region and environment

2.3.5.3 STEP AWBH

Building on the work of Jenny (Jenny 1941) and the SCORPAN factors, the STEP AWBH model utilizes a conceptual modelling framework. This model accounts for natural and anthropogenic factors that determine and alter soil properties (Grunwald, Thompson and Boettinger 2011). The model also builds on the SCORPAN model but separates hydrologic properties (W) from topographic (T) and climatic (A) factors and includes anthropogenic forcings (Thompson *et al*. 2012). The model explains soil properties for a pixel (p_x) of a specific size (x) and location, at a given depth (z) at the current time (t_c) (Thompson *et al*. 2012):

$$SA(z, p_x, t_c) = f\left(\sum_{j}^{n}[S_j(z, p_x, t_c), T_j(p_x, t_c), E_j(p_x, t_c), P_j(p_x, t_c)]\right); \int_{i=0}^{m}\left(\sum_{j}^{n}[A_j(p_x, t_c), W_j(p_x, t_c), B_j(p_x, t_c), H_j(p_x, t_c)]\right)$$

Table: 2.5 Definitions of symbols in STEP-AWBH equation adapted from (Grunwald *et al*. 2016)

Symbol	Definition
SA	Target soil property (e.g., soil organic carbon or soil carbon sequestration rate)
S	Ancillary soil properties (e.g., soil texture, soil spectral data)
T	Topographic properties (e.g., elevation, slope, curvature, compound topographic index)
E	Ecological / geographic properties (e.g., physiographic region, ecoregion)
P	Parent material; geologic properties (e.g., geologic formation)
A	Atmospheric properties (e.g., precipitation, temperature, solar radiation)
W	Water properties (e.g., infiltration rate)
B	Biotic properties (e.g., vegetation/land cover or spectral indices derived from remote sensing
H	Human-induced forcings (e.g., contaminations)
J	Number of properties from j = 1, 2, ….., n
px	Pixel (p) with size x (width = length = x) at a specific location on Earth
tc	Current (c) time (t)
ti	Time to current (tc) with time steps i = 0, 1, 2, …., m
z	Depth

The inclusion of time in the equation accommodates the spatial variation and time-based evolution of STEP-AWBH properties which covary with the target soil property (Thompson *et al*. 2012).

2.3.6 Geostatistical methods

Applying scorepan or STEP-AWBH models to digital soil mapping is similar to conventional mapping, except that the functional relationships between soil attributes and model factors are formulated using mathematical, or statistical models rather than conceptual models (Ryan *et al*. 2000).These models are trained using geo-referenced soil data, expert knowledge or pre-existing soil maps (Thompson *et al*. 2012). There are many geostatistical methods developed to analyse relationships between pedological predictor variables. The most commonly used will be discussed in short:

2.3.6.1 Kriging

Kriging is a form of weighted local averaging that uses a measure of spatial dependence, the variogram, to determine the weights applied to the data when computing the averages (Matheron 1963, Krige 1996). Kriging has been able to support continuous soil properties and classes, give estimates of varying size and estimate uncertainty (Heuvelink and Burrough 2002). Ordinary kriging alone does not adequately incorporate expert knowledge and does not utilise the relationship between environmental variables and soil properties (Scull *et al*. 2003). Several modifications have been made to kriging to better incorporate known soil-landscape associations of which co-kriging are the most noteworthy. Co-kriging takes advantage of correlation that may exist between the variable of interest and other more easily measurable variables (Odeh, McBratney and Chittleborough 1995). Kriging is closely associated with the *scorepan* model in that only the spatial (*n)* factor is used to predict properties at a new location (Thompson *et al*. 2012).

2.3.6.2 General Linear Models

Linear models have been an effective statistical tool for decades and remain one of the most important. Linear models make sizeable assumptions about data structure but possibly inaccurate predictions (Hastie *et al*. 2005). The wider class of linear models, known as generalised linear models (GLM), offers a range of choices, whilst maintaining ease of fit and interpretation (Lane 2002). GLM accommodates non-linearity by transforming variables, thus adapting the model and not the data (McBratney *et al*. 2003).

The basic model workings are that the observed responses, y_i, i=1,2,…,n, are normally distributed with mean and variance given by:

$$E[y_i] = a + bx_i \qquad \text{and} \qquad var[y_i] = s^2$$

x_i is observation i of a single explanatory variable, a and b are intercept and slope factors, and s^2 is the constant variance (Lane 2002). GLM can be adjusted to suit different linear, logarithmic or exponential-normal distributions. Lopatin *et al.* (2016) found GLM to be the most precise in explaining vegetation distribution in Chile.

2.3.6.3 Tree Models

Decision tree analysis is a form of divisive classification. The process of tree modelling involves successively partitioning data into increasingly homogeneous subsets, which, once the partitioning is completed, are called terminal nodes (Lees and Ritman 1991). The rules defining how to partition the data are selected based on statistics that define how well the parting decreases variability within the dataset (Clark *et al*. 1992). Cross-validation illustrates the flexibility of predictions on a certain size tree and involves systematically removing portions of data and running the remaining sample through the tree and observing misclassifications. Several algorithm type decision trees have been developed but it has been found that multivariate decision trees had the highest classification accuracy (Friedl and Brodley 1997).

Odgers *et al.* (2014) introduced a new algorithm to disaggregate soil map units into classes. DSMART ("Disaggregation and Harmonisation of Soil Map Units through Resampled Classification Trees'' successfully disaggregated soil map units and provided a probability of occurrence of soil classes in Western Australia.

2.3.6.4 Expert Knowledge Based Systems

Bui (2004) made the argument that soil maps and their accompanied legends are an extension of structured knowledge obtained by the soil surveyor. Soil surveyors use soil characteristics and soil forming factors to encapsulate the dominant soil – environment relationships (Hudson 1992). A framework to formalise landscape knowledge by structuring terrain objects in a specific order and formalisation of knowledge rules has been developed (Wielemaker *et al*. 2001).

Advantages (Wielemaker *et al*. 2001):

1) Expert knowledge applied during soil surveys and identification of links between terrain and soil is used more efficiently when classification rules are formalised in a GIS using 'is-a' and 'part-of' description
2) Aids knowledge integration and transfer through allowing information on what an object means to be added and altered.
3) Describing the environment in such a comprehensive manner will aid land evaluation and the effects of higher level terrain objects on land qualities

Disadvantages include (Thompson *et al*. 2012):

1) Subjective interpretations, results will differ between individual soil scientists

2) No statistical grounds for inferences

A popular application that uses expert knowledge to formalise the relationship between soil characteristics and environmental covariates is SoLIM (Soil-landscape Inference Model) developed by Zhu and Band (1994). The application has been used in South Africa with Land Type information where soil associations were predicted with adequate results (van Zijl *et al*. 2013).

2.3.7 Sources of information

Modern technologies such as satellite remote sensing are able to provide indirect information for several of the scorepan factors such as surface cover, terrain attributes and soil moisture (McBratney *et al*. 2003). Existing soil maps, on the other hand, can be used to create prediction models and aid in future digital soil mapping.

2.3.7.1 Remote and proximal sensed data

Digital soil mapping often incorporates proximal and remotely sensed data as supplementary or replacement information to produce maps of soil type or classes (Triantafilis, Gibbs and Earl 2013). Ideally, the supplementary information should cover the whole study area on the same scale or smaller as the preferred output scale. Apart from digital elevation models, remote sensed information has played a central part in digital soil mapping (Bui and Moran 2001, Scull *et al*. 2003, Odeh *et al*. 1995). Researchers normally aim to collect data related to all soil forming factors, and at the highest resolution possible, to produce the most accurate digital soil map. Theoretically, if one soil variable is the only unknown factor, predictions of that variable through modelling should provide required accuracy. Table: 2.6 summarizes some of the popular remote sensing types, with the corresponding use in predictive mapping.

Table: 2.6 Summary of various remote sensing techniques.

Sensory Type	Property measured	SCORPAN factor	Disadvantages / Pitfalls
Hyperspectral	Mineralogical Features: Iron oxides (King *et al*. 1995)	s	Results easily affected by soil moisture, vegetation cover atmospheric effects
Gamma radiometrics (GRS)	Geology and textural mineralogy (Thorium, Uranium, Potassium) (Triantafilis *et al*. 2013)	s, p	Surface geology 30-45 cm (Bierwith 1996)
Radar Attenuation (L Band)	Volumetric soil moisture content (Entekhabi *et al*. 2010)	s	Applicable to bare soil because of vegetation interference. Resolved by integration with L-band radiometrics: Soil moisture Active and passive (SMAP)
Radar Attenuation (C & X Band)	Relative terrain surface elevation, used to produce a DEM (Mashimbye, de Clercq and Van Niekerk 2014)	r	Complex terrain features may go unnoticed if the resolution (pixel size) is too big.
Normalised difference vegetation index (NDVI)	Vegetation cover and composition. Soil Moisture, Air temperature (Prasad et al. 2006).	o	Limited soil depth

2.3.4.2 Legacy Data & Expert Knowledge

Field surveys are costly and time-consuming and have subsequently forced researchers to use previously compiled soil inventories as a substitute. Soils inventories are in some cases related to specific terrain attributes, such as Land Systems and Land Types inventories. Increased resolution can be obtained by using terrain analyses and GIS methods (van Zijl *et al*. 2013, Bui and Moran 2001) Legacy data in combination with ancillary data has been used to update soil maps with acceptable accuracy (Kempen *et al*. 2009). Legacy data is interpreted long after it was compiled, which could compromise the accuracy if parameters are not comparable, furthermore the interpretation is often subject to human bias.

2.4 GEOMORPHOLOGY AND LANDFORM MAPPING

''Geomorphology is the science concerned with the form of the land surface and the processes through which it was created (Summerfield 1991).'' Understanding the processes that gave rise to different landforms, is crucial for the development of new delimitation models, but the land surface is central to verification and calibration of these models (Dietrich *et al*. 2003). Digital elevation models (DEMs) represents the land surface but requires processing in order to provide the necessary insight (Jasiewicz and Stepinski 2013). DEMs are particularly valuable in identifying the properties of terrain, e.g., slope, aspect, curvature, flow accumulation, etc. (Saraf *et al*. 2004). Elevation above an arbitrary datum in a landscape is arranged in a raster form, which can be further assessed in GIS. The shaded relief map, or contour map, suggested by Robinson (1946), provide a visual representation of the landscape. Landform data are then usually derived from analysing and inspecting the map. Another method to visualise landscape features is the segmentation approach. The interpretation of topography is built into the procedure and could be decomposed to gain additional information, therefore auto-classification and mapping of landforms have received major interest (Evans 2012, Jasiewicz and Stepinski 2013, MacMillan, Jones and McNabb 2004). Most automated landform segmenting processes are based on differential geometry, either cell-based or object based (Drăguţ and Blaschke 2006). Terrain shape influences a multitude of natural cycles in a landscape and governs water movement, sediment transport and plant and animal habitats (Blaszczynski 1997). The ability to quantify these features is imperative for natural resource, pollution and water management. Natural landform break lines often indicate soil boundaries and can be used to predict soil distribution. The approach proposed by Gessler *et al* (1996) develops statistical relationships between individual soil properties and all relevant terrain derivatives derived from a DEM. This approach can be used to predict continuous soil attributes and soil classifications. (Burrough, van Gaans and Hootsmans 1997). Geostatistics enables sparse observations of the primary attributes to be made and supplemented by secondary attributes that are more densely sampled such as remote sense NDVI scan. Including secondary information can lead to a more consistent description of the property under study (Castrignanò *et al*. 2009). The statistical relationship between attributes developed in one area is often not transferable to other sites (MacMillan *et al*. 2004).

2.4.1 Landform as basic soil units:

In the early pioneer phase of soil science, it was noted that there is a correlation between terrain and soil. Dokuchaev was first to note a variation in soil depth due to topographic redistribution of material in undulating terrain (cited by (Joffe 1949). The catena concept was developed as a framework to explain soil formation on rolling terrain (Milne 1936). The concept was adopted and implemented in many resource inventory studies including the Global Landform Classification and locally, the Land Types Inventories. Historically landforms were delineated manually using field surveys, photometry and emphasised on qualitative interpretation (Bishop *et al*. 2012). The increasing availability of DEMs has encouraged the use of computers and image processing techniques for extrapolating terrain properties (Mashimbye *et al*. 2014). Geomorphological mapping evolved over time and was recently defined by Bishop (2012) as the segmentation of the terrain into abstract spatial units founded upon criteria such as morphology (form), environmental systems associations (land cover, soils, ecology), genetics (process), composition and structure, temporal and spatial topologic relations of surface features (landforms). A good DEM is the backbone of digital surface analysis and stimulated the modern field of geomorphological mapping (Evans, Young and Gill 1979).

2.4.2 Pattern-based terrain classification

Ojaja *et al*. (2002) developed a method of image analyses, which describes patterns of texture, known as Local Binary Patterns (LBD). LBD involves centred cell, surrounded by 8 neighbours, which are classified -1, 0 or 1, and if the neighbour is lower, the same or higher than the centred cell (Stepinski and Jasiewicz 2011). This pattern of analyses (3x3) creates many different variations of landforms, many of which are rare abnormalities. In order to create a geo-morphometry map containing recognisable geomorphons (Figure: 2.6), it was suggested that the other variations (498) be reclassified into the 10 selected land forms (Jasiewicz and Stepinski 2013).

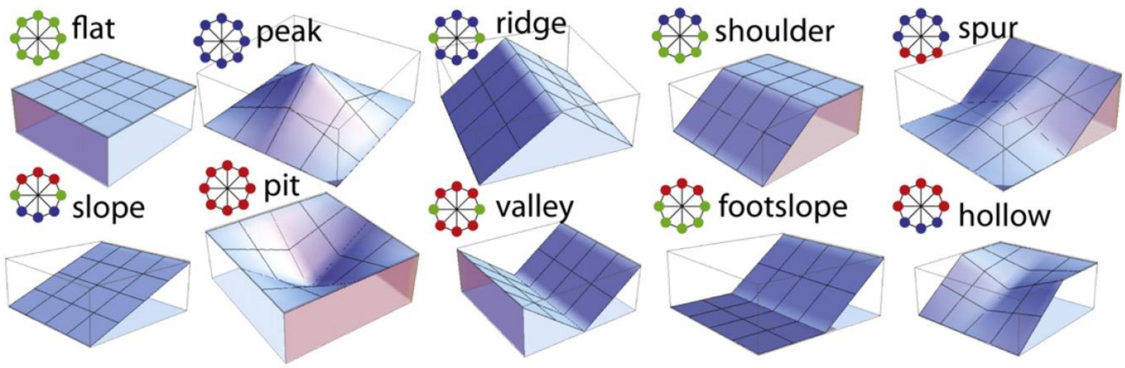

Figure: 2.6 The 10 most common landform elements and ternary patterns illustrated in symbols and 3D (Red – Higher, Blue – Lower, Green – Same value) (Jasiewicz and Stepinski 2013).

The LBD method is flexible in terms of scale of the study area and land form size. The distance between the centre cell and the neighbours (L) can be adjusted down to the original DEM resolution (Jasiewicz and Stepinski 2013). LDB has been successfully employed as a fully automated method, but this means that a certain terrain type in one site may not have the same absolute values of terrain attributes as the exact same terrain type in another site (Stepinski and Jasiewicz 2011). The LBD method is superior to differential geometry when compared to large DEMs, due to lower computational cost (Jasiewicz and Stepinski 2013).

2.4.3 Object-based terrain classification

''Geographic Object-Based Image Analysis (GEOBIA) is a sub-discipline of Geographic Information Science devoted to developing automated methods to partition remote sensing imagery into meaningful image objects, and assessing their characteristics through spatial, spectral and temporal scale, so as to generate new geographic information in GIS-ready format.''(Hay and Castilla 2008) It builds on previous segmentation methods, which includes edge detection, feature extraction and classification that has been used in remote sensing image analysis (Blaschke 2010).

GEOBIA segments an image into objects in the same way humans theoretically classify the landscape to understand it. The methodology is quite flexible and can be modified to suit specific purposes, which include soil mapping (Drăguţ and Blaschke 2006, Wielemaker *et al*. 2001).

The method is often used for terrain segmentation for several reasons (Drăguţ and Blaschke 2006):

1) Criteria of the object classification rules are less dependent on absolute values of terrain. 2) Object-based algorithms can easily be adjusted to perform more accurately even when transferred to a different geographical location. 3) The protocols can be modified to serve a wide range of applications such as land suitability, landscape monitoring, soil mapping (Wielemaker *et al*. 2001).

2.5 CONCLUSION

Catchment hydrology refers to a complex system with many parameters influencing the system. Climate is the main hydrological driver, while the soil can be viewed as a sponge, collecting and releasing water at a certain rate, in all directions. Soils being the most difficult hydrological parameter to accurately account for, creating useable soil maps with as little field observations as possible will be of great value to hydrologist.

South African environmental researchers are in the fortunate position to have a complete digital soils inventory of the whole country. The Land Type soils information includes the necessary soil physical data needed for hydrological calculations. Although the soils information is aggregated based on terrain, the information can be successfully disaggregated if the correct terrain model can be created. One pitfall in particular with the Land Type's information, no clear definitions of terrain units used are provided and instead, each Land Type map includes a transect sketch, where the terrain units are roughly indicated. This can be troublesome when terrain classification is automated. GIS and terrain analyses software have advanced rapidly in recent years, providing a variety of different tools and protocols to identify terrain attributes. The challenge is to produce an accurate terrain classifier that is able to disaggregate a Land Type into precise terrain units.

CHAPTER 3 SITE DESCRIPTION

3.1 INTRODUCTION

The area under study is the Korentepoort Dam catchment (122 km^2) north of Riversdale in the Hessequa district. The study area was selected on the basis of climate and climate change susceptibility. The region is located in a climatic transition zone, between winter and year-round rainfall areas. As such the area receives both winter and summer rainfall. The Hessequa region is also prone to harsh droughts, which has led to interventions by local government to implement water restrictions.

3.1.1 Study Area in Hessequa

The town of Riversdale is situated between Heidelberg and Albertinia in the Hessequa region, Western Cape Province, South Africa (Figure: 3.1). The area has experienced severe droughts in the past, which called for drastic domestic and industrial water use restrictions being imposed. Precautionary water restrictions are still implemented even if there is no shortage in water supply. The study area is the Korentepoort catchment, north of Heidelberg and Riversdale on the southern slopes of the Langeberg Mountain range (Figure: 3.1).

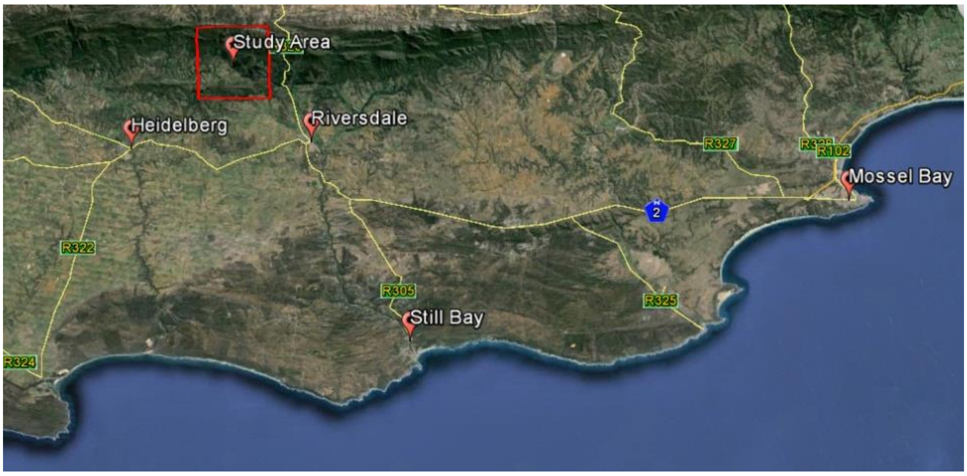

Figure: 3.1 Location of the Study area Korentepoort Catchment area, north between Heidelberg and Riversdale in the Hessequa region of South Africa (Google Earth 2016).

The main industry in the area is agriculture, consisting of grain and fruit production as well as livestock farming with cattle, sheep and ostriches. The Korentepoort Dam, together with several other streams supply local farmers with irrigation water, but only the dam delivers water to the Riversdale municipal treatment plant for domestic use. Several small towns south of Riversdale are also dependent on the dam for domestic water. The study area covers about 100 km^2 which includes arable land, pastures, undisturbed fynbos and forest plantations.

3.2 LITERATURE OF THE STUDY AREA

3.2.1 Geology

The study area lies in the foothills of the Langeberg Mountains, which are part of the Cape Fold Belt and consists predominantly of Sandstone. The catchment soils have different geological origins that includes quartzitic sandstone from the Table Mountain Group, shale and siltstone from the Bokkeveld Group and conglomerate and sandstone from the Uitenhage Group (Rogers 1984, Rogers 1988).

3.2.1.1 Bedrock Topography

Between Mossel Bay and Cape Agulhas, Palaeozoic deposits comprise of faulted and folded sediments of the Cape Supergroup, which consists of the Table Mountain, Bokkeveld and Witteberg Groups. Table Mountain Group sandstones re-occur in the anticline of the Langeberg to the north of Riversdale. Sediments of the Enon Formation fill an east-west downfault in the Palaeozoic sediments, which occurs at around 26 km from the coast on the Riversdale Plain.(Rogers 1984, Rogers 1988, Deacon, Jury and Ellis 1992)

Echograms indicated that the Bokkeveld shale is easily plained to a relatively even surface, in contrast to the Table Mountain Group sandstones that can produce highly irregular topography and major bedrock depressions(Rogers 1984, Rogers 1988)

3.2.1.2 Physical Geography And Geomorphology

The Southern Cape region includes three distinct geomorphological features: the Coastal Foreland, Cape Folded Belt Mountains and the Great Karoo basin, which are situated between the Folded Belt and the South African Plateau (Henshilwood 1995). The Korentepoort catchment is bordered by the Langeberg Mountains, a part of the Cape Fold Mountain range. The Hessequa region has a unique soil - geomorphological relationship, with both regional and local river terraces. It was proposed by Ellis (1973) that the occurrence is brought about by land surface change as well as sea-level fluctuation. Remnants of the Old African Surface are found as cappings on hilltops and outcroppings along valley sides. Silcrete is often found capping deep preweathered pallid zones (Figure: 3.2).

The pallid zone usually overlie the Bokkeveld Series shales, which is weathered to a white clay, often to a depth of several meters (Summerfield 1981). In the Riversdale and Heidelberg area, Silcrete caps and corresponding pallet zone overlie Enon gravels, with the occasional addition of ferritic cappings (Figure: 3.2) (Schloms, Ellis and Lambrechts 1983). The degree of weathering beneath these cappings are somewhat lower. These preweathered clays are associated with soil forms exhibiting strong structure such as Sterkspruit and Estcourt. This white clay largely consists of kaolinite with a set of unique physical characteristics, which includes swell and shrink, highly dispersive and high water retention capacity.

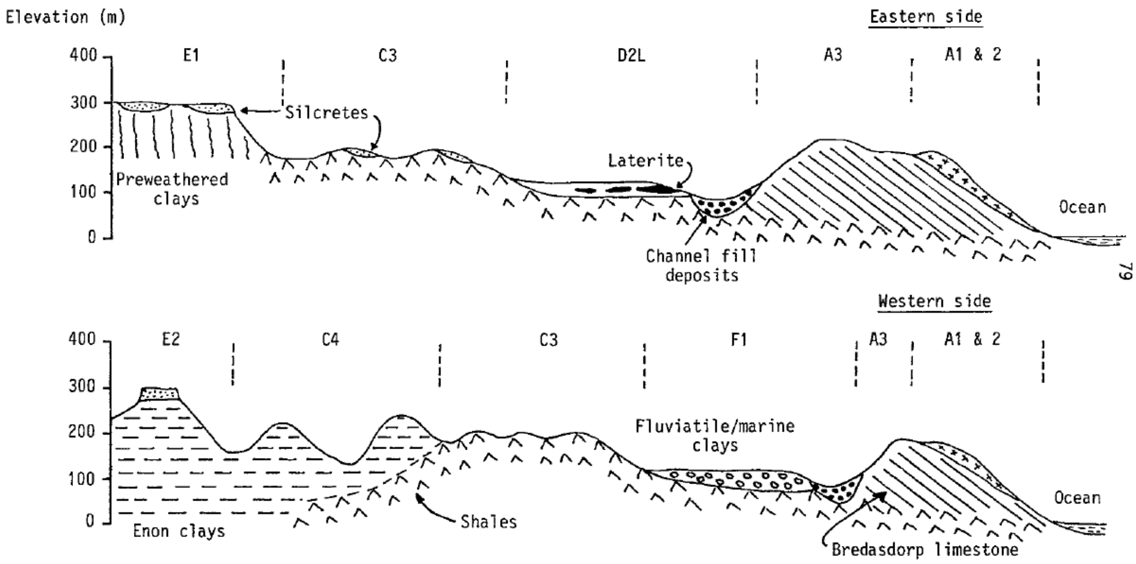

Figure: 3.2 A north-south cross section through the coastal platform just east of Riversdale, in the Duivenhoks River catchment, Heidelberg (Schloms et al. 1983).

3.2.2 Vegetation Composition and Distribution

The Riversdale Plain is defined as the area between the Duivenhoks River to the west, the Gouritz River to the east and the Langeberg Mountains to the north. Three Major vegetation groups occur on the Riversdale Plain, namely two non-fynbos groups (Forest and Thicket, and Karroid and Renoster Shrubland) and one Fynbos Group (Grassy, Asteraceous, Restioid and Proteoid) (Rebelo *et al*. 1991).

Studies conducted in the Mountainous regions of Riversdale and Albertinia by McDonald *et al* (1996) found that in the Eastern Langeberg region (Figure: 3.3) the plant communities where 72% immature vegetation, which includes the following floristic communities:

- *Restio inconspicuus – (Chondropetalum mucronatum, Selago serrata, Erica melanthera)* Shrubland
- *Tertatia bromoides – (Protea coronata, Hypodiscus striatus, Berzelia galpinii)* Shrublands
- *Ischyrolepis hystrix - (Phylica rubra, Phylica pinea)* Shrublands

Soil moisture and nutrient status are largely responsible for Fynbos community distribution (Campbell 1986, McDonald *et al*. 1996).

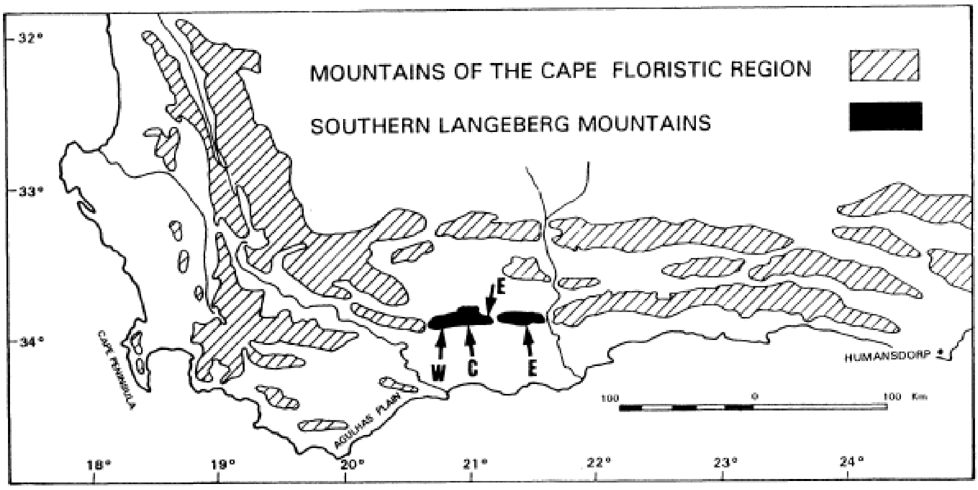

Figure: 3.3 The position of the Southern Langeberg in relation to the other mountains of the Cape Floristic Region. E –Easter zone- Riversdale and Albertinia area of vegetation studies by McDonald et al. (1996).

3.2.3 Climate of Hessequa

The Hessequa region is classified as Climatic Region A (Schulze 1965). The region experiences a bimodal rainfall pattern with peaks in spring and autumn. The orographic effect of the mountains results in higher precipitation in the mountains and lower rainfall in the coastal area. Langeberg Mountain creates a large rainfall gradient with annual rainfall ranging from 1200-1400 $mm.yr^{-1}$ mean annual precipitation (MAP) on mountain peaks and 500-800 $mm.yr^{-1}$ on southern slopes (Figure: 3.4). The rain shadow effect is substantial, imposing arid conditions to the North of the mountain, with rainfall between 250-450 $mm.yr^{-1}$ (Figure: 3.4).The average annual precipitation in the Riversdale Plain is 420 mm, and 790 mm in the upper Korentepoort catchment, which also exhibits a slightly higher rainfall in winter (Figure: 3.5).

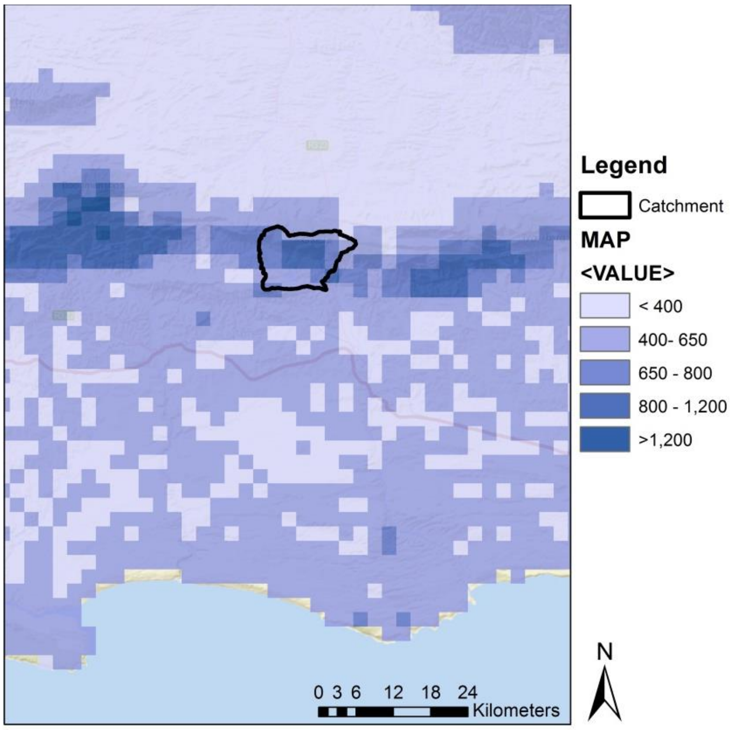

Figure: 3.4 Mean Annual Precipitation (MAP) in mm yr^{-1}. The orographic rainfall from the coast reaching high precipitation in the Korentepoort catchment (Dent, Lynch and Schulze 1987).

Annual evaporation measured at the Korentepoort Dam is 1321 mm (from 1989-2011). West and south-west winds predominate in the winter and spring with an average daily maximum strength of 54 km h^{-1}. During the summer months, predominant winds are from the east and south-west with an average maximum strength of 65 km h^{-1} but are less frequent than the winds of the winter months (Carter and Brownlie 1990).

Average daily maximum temperatures in January and July are 22°C and 16°C respectively. The average daily minimum temperatures in January are about 15°C and 7°C and in July. In winter and spring snow occasionally falls on the Langeberg Mountains (Carter and Brownlie 1990).

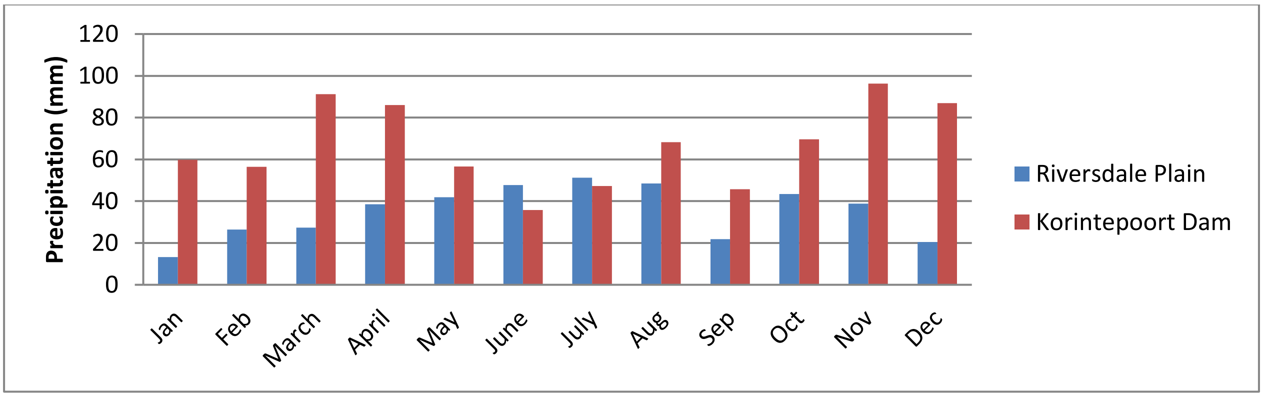

Figure: 3.5 The long term average monthly rainfall of the Riversdale plain (blue) and Korintepoort dam (red).

3.2.4 Land Use

The Korentepoort Dam is surrounded by high fynbos and forestry plantations, which consist predominantly of pine (*Pinus pinaster*) and isolated Blue-gum (*Eucalyptus globulus*) sites. Some indigenous broad-leaved yellowwood (*podocarpus latifolius*) trees can be found in the inaccessible mountain ravines. In the West of the catchment some dryland cultivation is encountered together with low fynbos (Figure: 3.6). Agricultural activity within the catchment includes cultivated pasture, wheat and canola and dairy farming. A substantial area of these agricultural land is reserved as natural veld for grazing, and wildlife reservation.

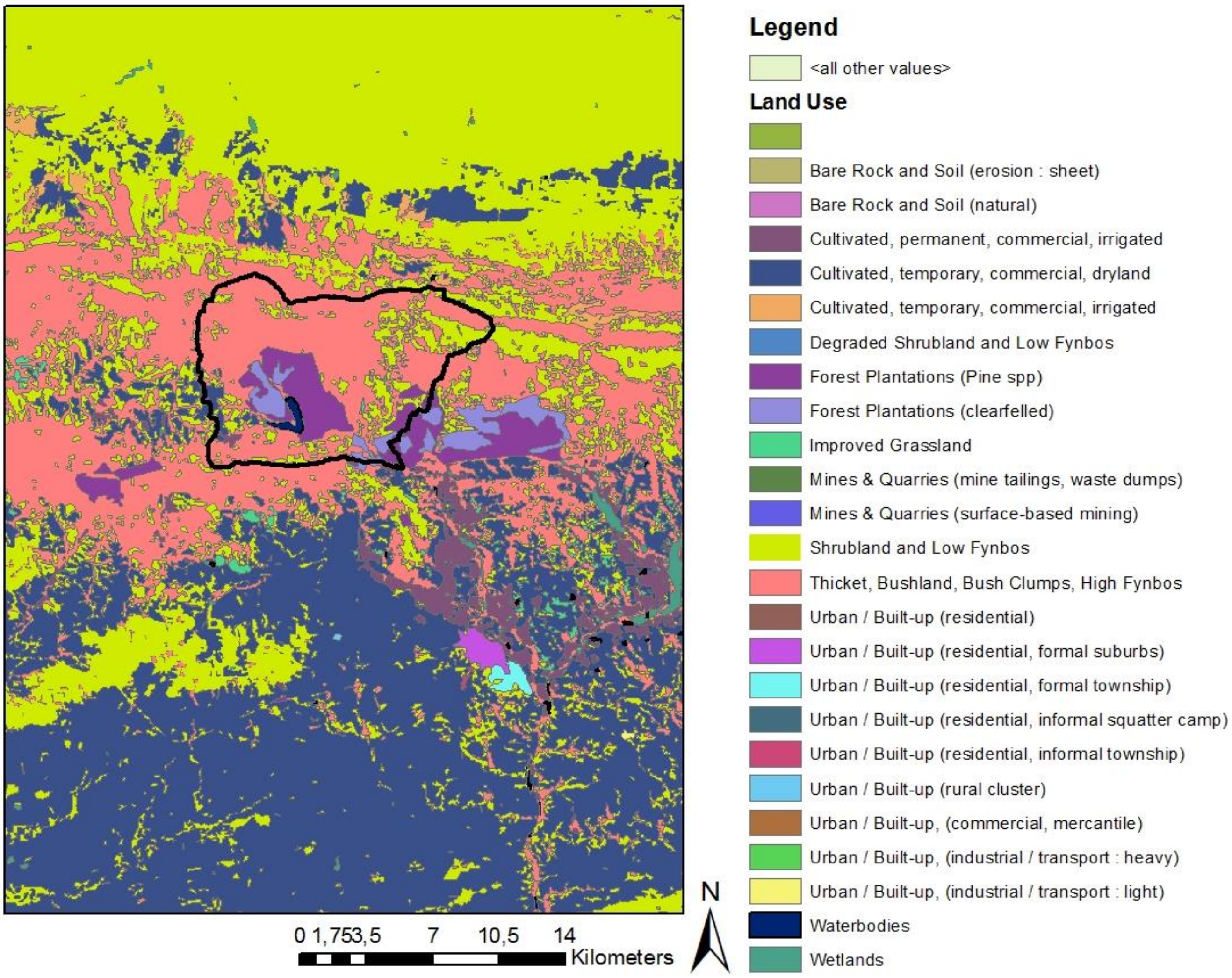

Figure: 3.6 Land Use in the Korentepoort catchment and surrounding areas.

3.2.5 Soils of the Region

Soils of the region as prescribed by the Land Types contrast greatly from the coast to the mountain (Figure: 3.7). Soils occurring along the coast consist mostly of deep grey sandy soils and shallow sandy soils with lime throughout most of the landscape. The Riversdale plain, which is primarily used for agriculture, are dominated by duplex and shallow soils with or without lime. The study area is a mixture of duplex, shallow soils with little to no lime. The mountainous Land Types in the northern part is entirely composed of rock outcrops.

Preweathered clays are located between 200-300 m.a.s.l. in the region. These clays and other relict materials regularly display features that are not in sync with current climatic conditions and therefore complicates soil classification. Common classification pitfalls encountered in this region are the identification of relict mottles as current signs of wetness.

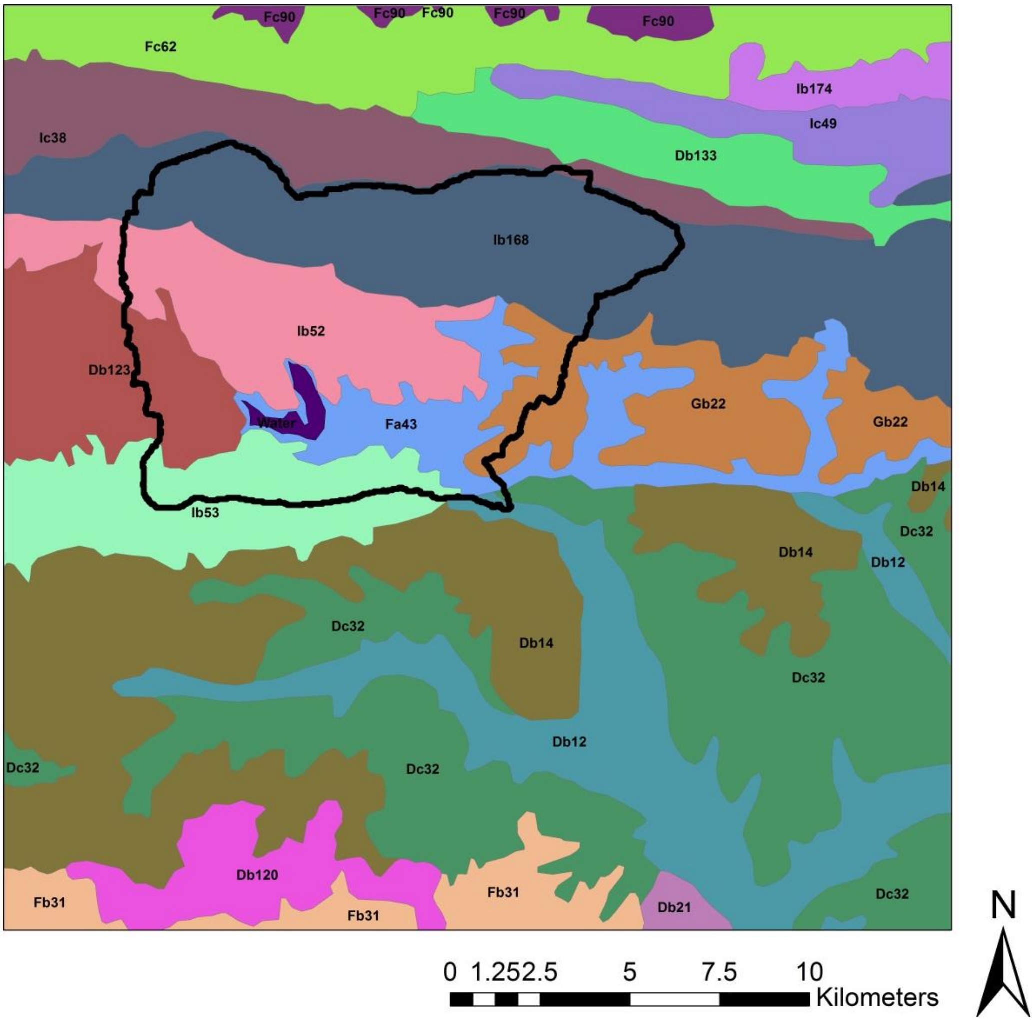

Figure: 3.7 Soil distribution of the Hessequa region as defined by the Land Types information. (Land Type Survey Staff 1972-2002) (Land Type memoirs included in Appendix B)

Table: 2.7 Land Type soil code descriptions (Land Type Survey Staff 1972-2002):

Soil Pattern code	Description	Soil Pattern code	Description
Ae	Freely drained, red, eutrophic, apedal soils comprise >40% of the land type (yellow soils comprise <10%)	**Fb**	Shallow soils (Mispah & Glenrosa forms) predominate; usually lime in some of the bottomlands in landscape
Af	Freely drained, red, eutrophic, apedal soils comprise >40% of the land type (yellow soils comprise <10%); with dunes	**Fc**	Shallow soils (Mispah & Glenrosa forms) predominate; usually lime throughout much of landscape
Ag	Freely drained, shallow (<300 mm deep), red, eutrophic, apedal soils comprise >40% of the land type (yellow soils comprise <10%)	**Gb**	Podzols occur (comprise >10% of land type); dominantly shallow
Ca	Land type qualifies as Ba-Bd, but >10% occupied by upland duplex/margalitic soils	**Ha**	Deep grey sands dominant (comprise >80% of land type)
Db	Duplex soils (sandier topsoil abruptly overlying more clayey subsoil) comprise >50% of land type; <50% of duplex soils have non-red B horizons	**Hb**	Deep grey sands sub dominant (comprise >20% of land type)
Dc	Either red or non-red duplex soils (sandier topsoil abruptly overlying more clayey subsoil) comprise >50% of land type; plus >10% occupied by black or red clays	**Ib**	Rock outcrops comprise >60% of land type
Fa	Shallow soils (Mispah & Glenrosa forms) predominate; little or no lime in landscape	**Ic**	Rock outcrops comprise >80% of land type

3.3 CONCLUSION:

The natural environment is key to understanding the soils of the study area but also the hydrology. The orographic effect caused by the Langeberg mountains influences vegetation and soil formation and weathering. The Korentepoort catchment and surrounding areas are home to a spectrum of plant colonies, land uses and geology. Above ground differences in vegetation can be related to a change in subsurface soil characteristics. This is, however, more difficult to identify within the forestry area, especially after harvest.

Building on previous research of vegetation, geology and soil types conducted in the area enables our research to focus on a specific environmental attribute, soil distribution pattern. Investigating the medium through which water moves in the landscape enriches our understanding of the terrestrial hydrology, which will improve decision making and adaptation capacity to environmental change.

CHAPTER 4 MATERIALS AND METHODS

4.1 INTRODUCTION

All the observations and sampling was done during 2015 and 2016, only excavated sites were sampled and physical properties measured. The Geographical Positioning System device used to capture the location of any observations and sample sites was the Trimble Juno 3B. Soil physical and chemical analyses were done on samples taken from 38 profile pits. Soil and terrain descriptions are based on the Long Profile description method (Turner 1991), with some deviation. Methodology of the relative chapters are included under the relevant chapters.

Methodology can be divided into four stages:

- Desk-top Study
- Field work
- Laboratory Analyses
- Data aggregation on GIS

4.2 DESK-TOP STUDY

After examining the literature on terrain-soil interactions with water movement the field and laboratory work was defined. Terrain attributes that were to be investigated included; terrain morphological unit, slope and aspect, in order to compare with the segmentation map. Hydrological parameters that were to be identified included soil form and family, stone content, hydraulic conductivity, texture and bulk density.

Terrain analysis was done using elevation models. A segmentation map indicating terrain classes was prepared. The segmentation process divided the landscape into four terrain units, and subdividing terrain units 3 & 5 into convex (31 & 51) and concave (32 & 52). The map was firstly populated with Land Type data. A Comparison between Land Type soils and the soils database developed for this project is done in Chapter 6.

4.3 FIELD WORK

Soil distribution maps were collected from individual land owners of the Korentepoort catchment area, who also found the land type information insufficient for their individual needs. The forestry plantation, owned by Cape Pine, is the single biggest contributor.

The soils of the catchment were investigated at road cuttings and profile pits, sampled and classified. Soil physical properties were determined. The soil occurrence was compared with land type information and local agroforestry soil maps.

4.3.1 Soils Characterization

Representative soil samples were taken from profile pits for the different horizons using a core sampler which was used for bulk density and gravimetric water content calculations. Infiltration of selected horizons was determined using the minidisk infiltrometer from Decagon Devices. Soil structure was determined and recorded in the field. Soil samples were dried and sieved to acquire physical properties (Table: 2.8) of each horizon at different sampling sites.

4.3.1.1 Soil Classification

Soils were classified at all observation sites according to the South African Soil Taxonomic system up to family level (Soil Classification Working Group 1991). It is important to take into account the different soil classification systems used during the Land Type surveys and the current system used in this thesis. This might exacerbate the soil form differences between the Land Type surveys and observations made in the field; therefore a focus is redirected in terms of soil physical properties. Soil classification was accompanied profile descriptions formulated from the Long Profile description method (Turner 1991) which included the following:

Table: 2.8 Soil properties recorded at profile positions

Soil Horizon properties	Description
Depth of lower boundary	Total horizon depth (mm)
Moisture status	Dry, moist, wet.
Colour	Wet and dry matrix colour of undisturbed sample.
Mottles	Occurrence, size, colour and cause (e.g. Redox, lime, gypsum etc.)
Structure	Grade, size and type (e.g. Strong, Coarse, Prismatic)
Micropores and Cracks	Occurrence with size.
Cementation of Horizon structure	Structure, Grade, Extent and agent (e.g. Nodular, slight, continuous, iron oxides)
Cutans	Occurrence and type (e.g. many, organic)
Coarse fragments	Occurrence, size, shape (e.g. few, gravel rock fragments, rounded)

4.3.1.2 Soil Physical Properties

Bulk density and soil moisture content

Soil bulk density was determined for all horizons using the clod and core method where permitted. Samples were weighed in the field and after oven drying at 105 °C for 48 hours for bulk density and gravimetric soil water content (Blake 1965).

Particle size

The hydrometer method was used to determine the silt and clay fraction, while sieving was used to determine the sand fractions, coarse, medium and fine (Gee, Bauder and Klute 1986) (Table: 4.2). The texture triangle was used to determine the soil texture class.

Table: 4.2 Soil Particle size classes. note fine sand includes the very fine sand class (Klute 1986).

Class	Particle Diameter (mm)	Method of separation
Gravel	>20	Sieve
Coarse sand	20-0.5	Sieve
Medium sand	0.5-0.25	Sieve
Fine sand	0.25-0.05	Sieve
Silt	0.05-0.002	Sedimentation
Clay	<0.002	Sedimentation

Unsaturated hydraulic conductivity

Selected profiles were analysed using a mini disk infiltrometer. A sand layer was used to facilitate suction and water movement between the porous plate and the soil (Figure: 4.1). Suctions were adjusted to 2cm head on all readings, this restricted infiltration to the meso pores. Duplicate measurements were taken from the centre of each horizon. Results were entered into the Decagon infiltrometer spreadsheet (Devices 2016), which uses the texture of the soil layer together with the van Genuchten tables to calculate the unsaturated hydraulic conductivity (Figure: 4.1.).

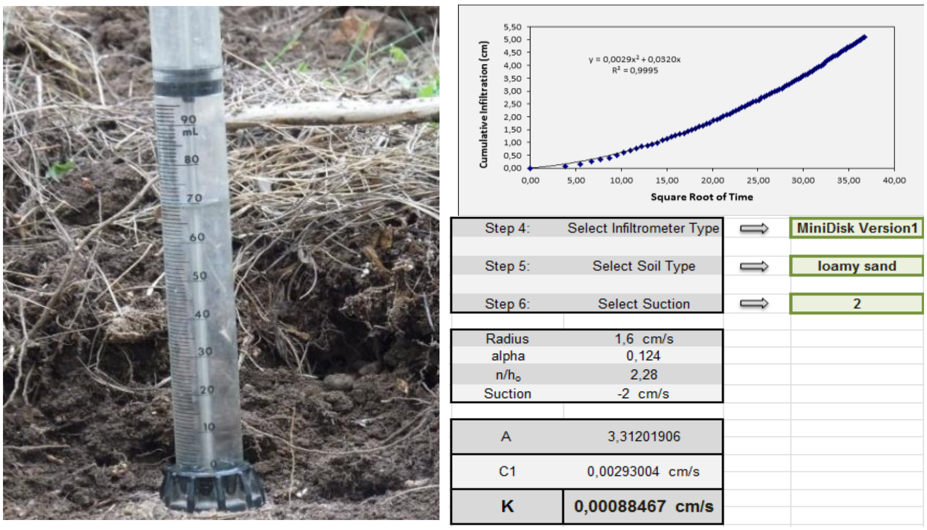

Figure: 4.1 Measuring (left) and calculating (right) unsaturated hydraulic conductivity using the Decagon Infiltrometer macro (Devices 2016). Profile illustrated is no. 3 in the Appendix

Soil water retention curve

A selection of soil profiles (15 profiles, 35 horizons) were analysed using the pressure plate method to determine the soil water tension at different water contents (Richards 1949). The tension intervals were as follows: saturated (0), 10, 50, 100, 250 and 500 kPa. Required tensions outside the measurement range were extrapolated.

4.3.2 Terrain and Hydropedological Support

Terrain attributes were characterised as indicated in Table: 4.3. Quantifying the terrain properties is essential to developing a Hydropedological relation. In-field investigation of soil - landscape series will be compared to the Land Type series. Collecting information regarding the soil forming factors will facilitate delineation of soil boundaries and conceptualise soil pattern distribution and related secondary attributes.

Table: 4.3 Site Properties recorded at profile positions.

Site Record	Description
Water table	Depth to water table (mm)
Terrain Unit	Terrain position comparable with land type terrain units (e.g. 1,2,3,4,5)
Slope	Slope Percentage, Aspect, Slope Type (Concave, convex or straight)
Microrelief features	Mounds, ridges basins within a 20m radius of profile observation
Surface rock cover	Areal percentage of hard rock and boulders (>250mm) within 10m radius of profile observation.
Surface stone	Areal percentage of concretions and gravel (<250mm)
Parent Material	The nature of the origin of the solum (e.g. Single origin, binary origin)
Lithology of underlying material	Defining the underlying material as Sedimentary, Metamorphic or Igneous rock. Specifying further if possible. Degree of weathering included

4.3.3 Land Use and Land Cover

Land use of surrounding agriculture lands was recorded using geo-tagged photographs. Forestry maps indicated areas under plantation and the species used. Missing data was supplemented with satellite imagery.

4.4 MAPS

4.4.1 Conventional Soil Map

A Conventional Soil distribution map was constructed from various sources of information which include existing soil maps, satellite imagery, contour lines, and observations at road cuttings and at soil profile pits. Satellite imagery of vegetation together with contour lines was used as an indicator of change in soil patterns, this was especially useful in the inaccessible parts of the catchment. Preference was given to the profiles classified and sampled, although only 39 points were classified and sampled in the 100 km^2 area, the road cuttings observations and existing soil maps enabled delineation of soil types between profile points. The map was constructed using ARC map 10.1 GIS software which enabled accurate spatial analyses when later compared to the DSM.

4.4.2 Digital Terrain Map

Terrain analysis was done using SRTM 90 m digital elevation model (DEM), which was refined to a 30 m raster DEM. Terrain segmentation processes were developed with the ability to separate a landscape into morphological units, using the DEM and several terrain analyses tools in ARC map

10.1. The segmentation process divided the landscape into four terrain morphological units (TMU), which can be compared with Land Type units: 1, Crest; 3, Midslope ; 4, Footlope; 5, Valley bottom. Terrain unit 2; scarp was not included in the segmentation because the 90 m DEM would not be able to delineate the steep slopes (>100% slope) and these slopes have limited soil development if any.

The morphon mapping process entailed the following steps (Figure: 4.2);

- Redefining the 90 m DEM by converting it to 2 m contour lines, thereafter the 2 m contour lines were converted to an interpolated hydrology raster surface of 30 m pixel size.
- Calculate curvature and classify (Dikau 1988)
- Calculate streamlines and flow direction. (Gruber and Peckham 2009)
- Separate terrain morphological classes (Crest, concave and convex mid-slopes, foot slope, valley bottom, and drainage lines) (Iwahashi and Pike 2007)
- Classed Wetness index (Böhner and Selige 2006): multipath smoothed
- Ridgeline definition (Rodriguez *et al*. 2002)
- Combine effects in a terrain classification for the land types separately.

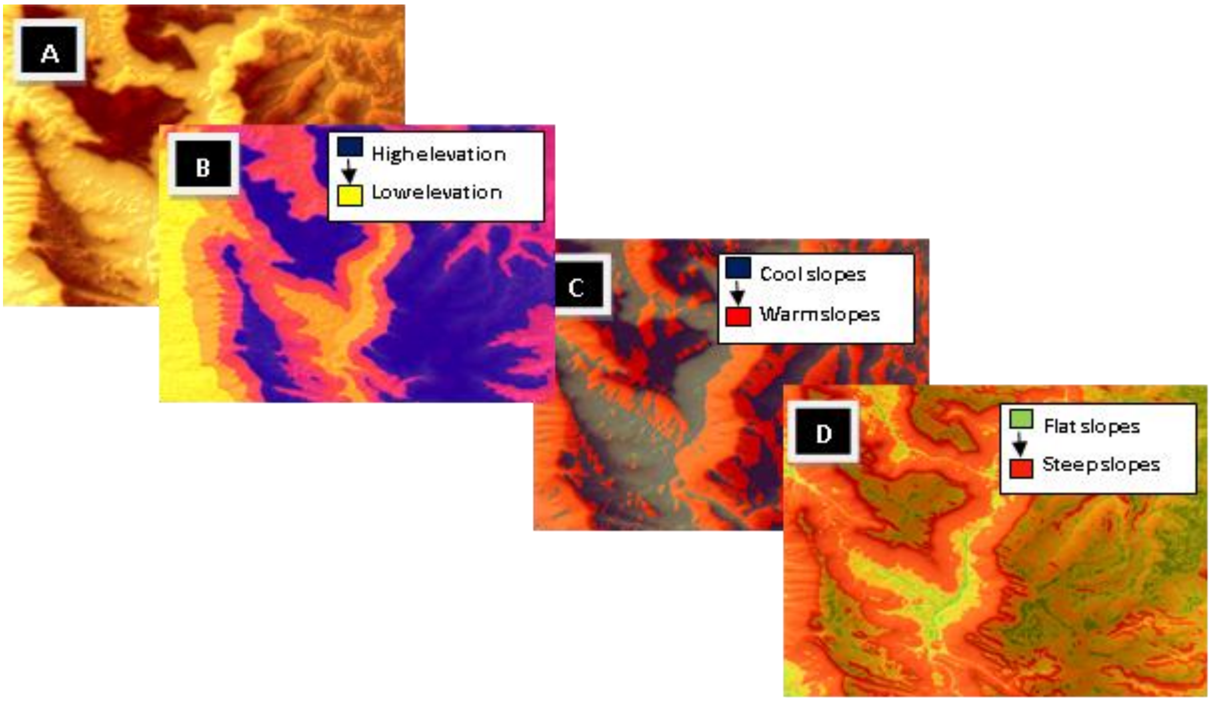

Figure: 4.2 Different Spatial layers which were generated separately. A: Interpolated DEM, B Altitude Draped over DEM, C: Aspect draped over DEM, D: Slope Draped over DEM (De Clercq and van der Merwe 2015).

At first, the Land Type information would have been used to populate the TMU's with soils information. Unfortunately soil observations within the study area alluded to some inconsistencies in the LT information. Therefore the Land Type information's applicability was further investigated in CHAPTER 6.

4.5 CONCLUSION

Characterising the covariates that accompany these soil types (e.g. terrain, vegetation) may help us to understand soil–landscape relationships better and expand the application of these results. The Land Type information provides useful information for agricultural and environmental sciences, however the need to verify the accuracy of the information remains.

In-field measurements of unsaturated hydraulic conductivity is used as a relative infiltration rate measurement because the reading is greatly affected by the soil water content at the time of measurement. By investigating the medium through which the water moves in the landscape, a better understanding of the terrestrial hydrology is achieved, which will enhance decision making and adaptive capacity resulting from environmental change.

CHAPTER 5 INCREASED RESOLUTION OF LAND TYPE INFORMATION THROUGH MORPHON SEGMENTATION FOR THE KORENTEPOORT MOUNTAIN CATCHMENT[1]

5.1 INTRODUCTION

Sourcing reliable soil information is expensive and a time consuming endeavour. It is common for soil scientist and surveyors to use legacy soil data, to minimize field surveying. The Land Type information is the only nation wide soil inventory for South Africa, and therefore the most popular for environmental studies including hydrological modelling. More often than not the Land Type information is used in these models without any validation of soil characteristics or distribution. South Africa being a water scarce country, the need arises to not only validate the soils information but also improve the resolution of the Land Type information.

Digital soil mapping (DSM) in South Africa is a growing research field (Hensley *et al*. 2007, Van den Bergh, Weepener and Metz 2009, van Zijl *et al*. 2013), with the potential to enhance the Land Type map resolution if the landscape can be segmented accurately into terrain units (Mashimbye *et al*. 2014). Topographical breaklines often indicate boundaries between adjacent geomorphological units, which could, in turn, be used to indicate soil boundaries (MacMillan *et al*. 2004). Digital elevation models (DEM) are a subset of digital terrain models (DTM) and the most important constituent thereof, it is also the basis of digital terrain modelling. The term DEM is often used when referring to DTM, and digital surface models (DSM), the terms described by Li (1990) explains the slight differences:

Ground: ‘‘the solid surface of the earth’’.

Height: ‘‘measurement from the base to the top’’, ‘‘elevation above the ground or recognition level’’, ‘‘distance upwards’’.

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[1] Malan, G.J., De Clercq, W.P., Rozanov, AB. Clarke C, Helness, H., Damman, S., Elema, (2016). Refined methods to assess climate change impacts: Increased resolution of soils information through morphon segmentation of the Korentepoort mountain catchment. *Submitted to the South African Journal of Plant and Soil.*
The candidate was fully responsible for preparing this paper, with guidance form the mentioned co-authurs.

Elevation: ‘’height above a given level, especially that of sea or horizon’’.

Terrain: ‘’tract of country considered with referred to its natural features, etc.’’

This differentiation is important when considering the technology available during the Land Type survey. Contour lines were used to sketch transects and delineate the Land Types; these contours were developed with photogrammetric methods, which cannot distinguish between terrain (objects on top of the ground) and ground level. Mashimbye (2014) indicated high-resolution DEM is advantageous for landscape segmentation with end use being soil predictions in South Africa. Soil types and physical information is specified in the Land Type survey memoirs according to terrain morphological units. These units represent soil series that can be expected within a terrain unit accompanied with soil depth and percentage clay. Increasing the Land Type information scale / resolution for a certain area, the basis of segmentation should be terrain morphological unit.

The disaggregation of Land Types was published both locally and similar soil maps internationally as a method to increase resolution and accuracy from existing data (Bui and Moran 2001, Fels and Matson 1996, Gallant and Dowling 2003, van Zijl *et al*. 2013). Terrain units can be segmented using several different methods with varying accuracy and repeatability. The use of detailed soil surveys and expert knowledge has been applied in some parts of South Africa with adequate accuracy (van Zijl *et al*. 2013) but the method repeatability is low for it relies on individual knowledge. Automated image analyses have proven to be reproducible and advantageous in respect to providing information for geomorphological and terrain studies (Drăguţ and Blaschke 2006).

The correlation between soil physical properties and TMU’s can be used with DSM to produce soil maps with higher resolution and accuracy compared to conventional soil maps. This would be especially advantageous for hydrologist who is only interested in soil characteristics and not nomenclature. Soil mapping, even DSM, is often subject to human bias, therefore the DSM techniques used in the study were automated as much as possible. The DSM created was compared to a conventional soil map to illustrate the advantage of DSM. This chapter accepts the Land Type data to be representative of the area, therefore the terrain prediction accuracy was compared to terrain units observed in the field.

5.2 METHODS

5.2.1 Site Description

Riversdale is situated 94 km East of Mossel Bay in the Hessequa region along the foothills of the Langeberg Mountain, Western Cape province. The study site is the Korentepoort Dam catchment north-west of the Riversdale town and covers 112 km^2, which includes arable land, undisturbed fynbos veld and plantations. The catchment contains nine Land Types, while this chapter focuses on the four main Land Types surrounding the dam, contributing to 95% of the catchment area (Land Type Survey Staff 1972-2002). The Korentepoort catchment boundary delineation was done using the SWAT tool in ArcMap. The catchment includes a weir below the dam (important for hydrological modelling), and the region will henceforth be referred to as the catchment or Korentepoort catchment.

5.2.2 Field Observations

The terrain and soils of the catchment were investigated at road cuttings and profile pits, samples were collected at profile pits and classified according to South African Soil Taxonomy (Group 1991). The soil classification data was used to produce a conventional soil distribution map, whilst the terrain classification was used to validate the segmentation map.

5.2.3 Terrain Analysis

The segmentation process described in CHAPTER 4 divides the landscape into four terrain units, which can be compared with Land Type units: 1, Crest; 3, Midslope; 4, Footslope; 5, Valley bottom.

The morphology map was compared to all the terrain classification sites (196 points) with four different distances of error, referred to as buffer zones. The distances 0, 4, 15, 30 m were selected (Figure: 5.1). The GPS device logged an average standard error of 3.8 m, which prompted the 4 m buffer zone. The 15 and 30 m buffer zones were selected based on the resolution of the improved 90 m SRTM (30 m), which governs the resolution of the segmentation map. If the observed terrain unit was within the buffer zone it was accepted as an accurate prediction.

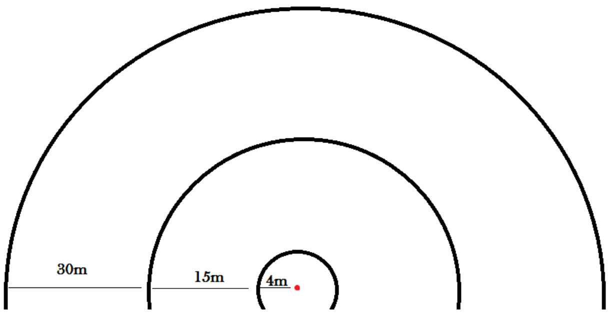

Figure: 5.1 Sizes of buffer zones compared

Transects were created from the 30 m DEM and populated with terrain units generated by the segmentation process and compared with the Land Type memoirs' terrain sketch. The Land Type transect lines are not displayed on the map, with only the height above sea level as a reference. There is no unit of measurement on the sketch to illustrate scale. Therefore the DEM transects were created on the basis of height above sea level and a visual similarity to the memoir sketch.

5.2.4 Conventional/Traditional Soil Map

Traditional soil mapping techniques include the gathering of all information be it soil observations, terrain morphology, vegetation and additional soil maps. The mapping was done after all field observations were completed. The terrain morphology was evaluated in-field and with 2 m contour lines, which was derived from the DEM. Vegetation and 3rd party soil maps were used as an indicator of soil boundaries, not as soil form indicators, in areas that were not investigated. The map was drawn by hand using GIS software and compared with the morphology map.

5.2.5 Integration of Information

Third party soil maps were used to improve our understanding of soils distribution throughout the region. The Southern Cape soils maps were updated with enhanced toposequences descriptions but do not include the catchment area (Schloms *et al*. 1983). Integration of the information was done in ArcMap. The morphon map was used to cluster the soil observation points and the clustering was used to determine whether the morphon mapping could segment the landscape and soil information into sensible groupings. The resultant soils groupings were then used to reflect on the adequacy of morphon mapping as a process of soil inventory development.

5.3 RESULTS AND DISCUSSION

5.3.1 Land Type Distribution

Analyses of the composition of Land Types within the catchment illustrate the complexity and different scales of information within the catchment. The catchment boundaries were delineated using a digital elevation model within SWAT (Figure: 5.3). The total area represented by all the Land Types present in the catchment is one order of magnitude larger than the catchment size, which can account for some error. Less than 11% of the total areas of the nine Land Types are within the catchment area (Table: 2.9). Because there are no modal profiles, thus no indication where observations were made during LT survey, the catchment could fall within an extrapolated area, which was ignored. Considering the size of the catchment alone, it could make out a single Land Type polygon, if the geology and soil–terrain associations allowed. Large parts of the catchment are inaccessible, with forestry roads being the only roads through the surrounding hillsides.

Table: 2.9 Land Type composition of the Korentepoort catchment (Land Type Survey Staff 1972-2002).

Land Type	Area of LT in catchment (ha)	Total area of LT (ha)	Contribution to Catchment (%)
Db12	25	7269	0.3
Db123	879	7855	11.2
Dc32	7	24444	0.03
Fa43	1357	2326	58.3
Gb22	501	3253	15.4
Ib168	4213	27873	15.1
Ib52	2948	10810	27.3
Ib53	1083	6610	16.4
Ic38	21	13475	0.2
Dam	172		
Total	11206	103915	10.78%

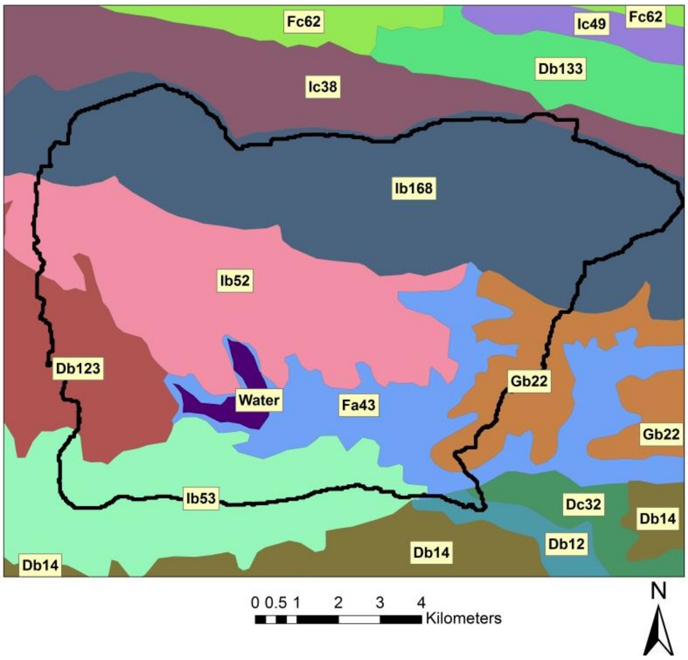

Figure: 5.1 Distribution of Land Types in the Korentepoort catchment (Land Type Survey Staff 1972-2002).

5.3.2 Landscape Morphology

The terrain within the study area is highly variable, ranging from steep, evenly sloped mountain foothills to highly dissected rolling hills. This challenging landscape provides good testing grounds for the segmentation method (Figure: 5.3).

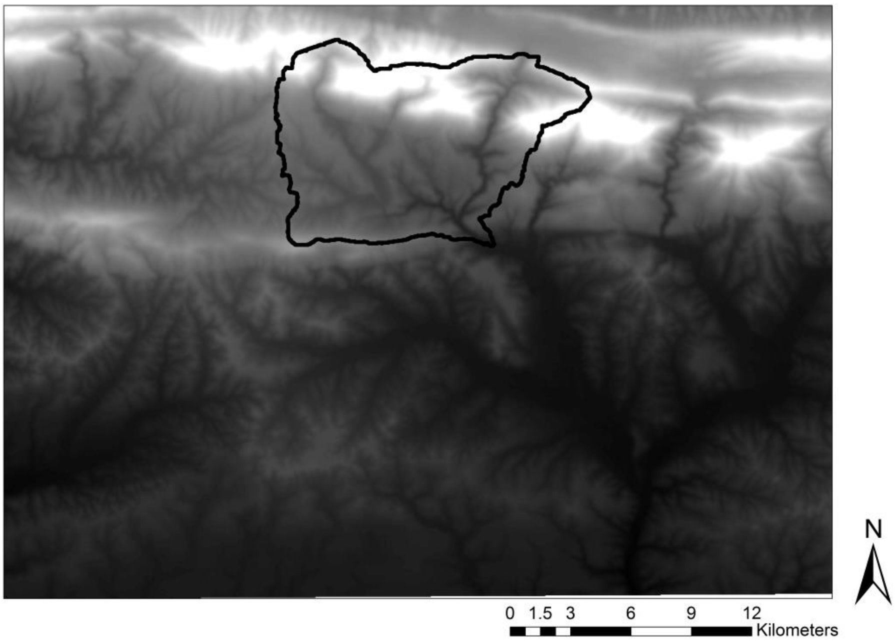

Figure: 5.3 Shaded Digital Elevation Model of the region, note the highly dissected landscape. The catchment boundary as delineated by SWAT is outlined.

5.3.2.1 Landscape analyses through transects

The DEM derived catena was compared to the Land Types (LT) published catenas for the region (Figure: 5.5) the methods used to create these transects are referred to in 5.2.3. The comparisons between two transects provide insight into the terrain type variability in a hillslope. It is clear that more detail could be captured using the segmentation process, but TMU's produced might not have the same characteristics as LT TMU's. More detailed terrain segmentation does, however, offer the opportunity to develop finer terrain – soil associations

The segmentation process dissected LT Ib168 and Fa43 into more or less the same units as the Land Type transects. The differences between the two sets of results may also have been influenced by the different methods of construction: SRTM (Shutter Radar Topography Mission) being a DTM (Digital Terrain map) and the map used in the Land Type surveys are based on stereo-photogrammetric methods, which produce a DSM (Digital Surface Map) (Figure: 5.4). This, in turn, could compromise the applicability of the Land Type information when associated with these terrain units, for the soil associations was constructed on larger, less refined terrain units.

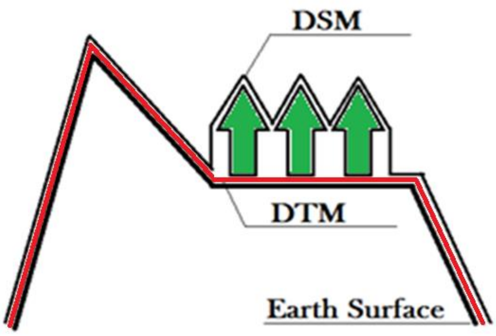

Figure: 5.4 Illustration of Digital Terrain Models (DTM) and Digital Surface Models (DSM, which includes surface objects).

In all transects, except Ib168, the valley bottom (TMU 5) is frequently designated on flat terrain above the actual valley. This phenomenon is attributed to the morphology identification process, which struggles to differentiate between a plateau and valley bottom. The segmentation process is able to identify small features in the landscape, which are not indicated on the original LT memoirs. These features are however comparable with field observations.

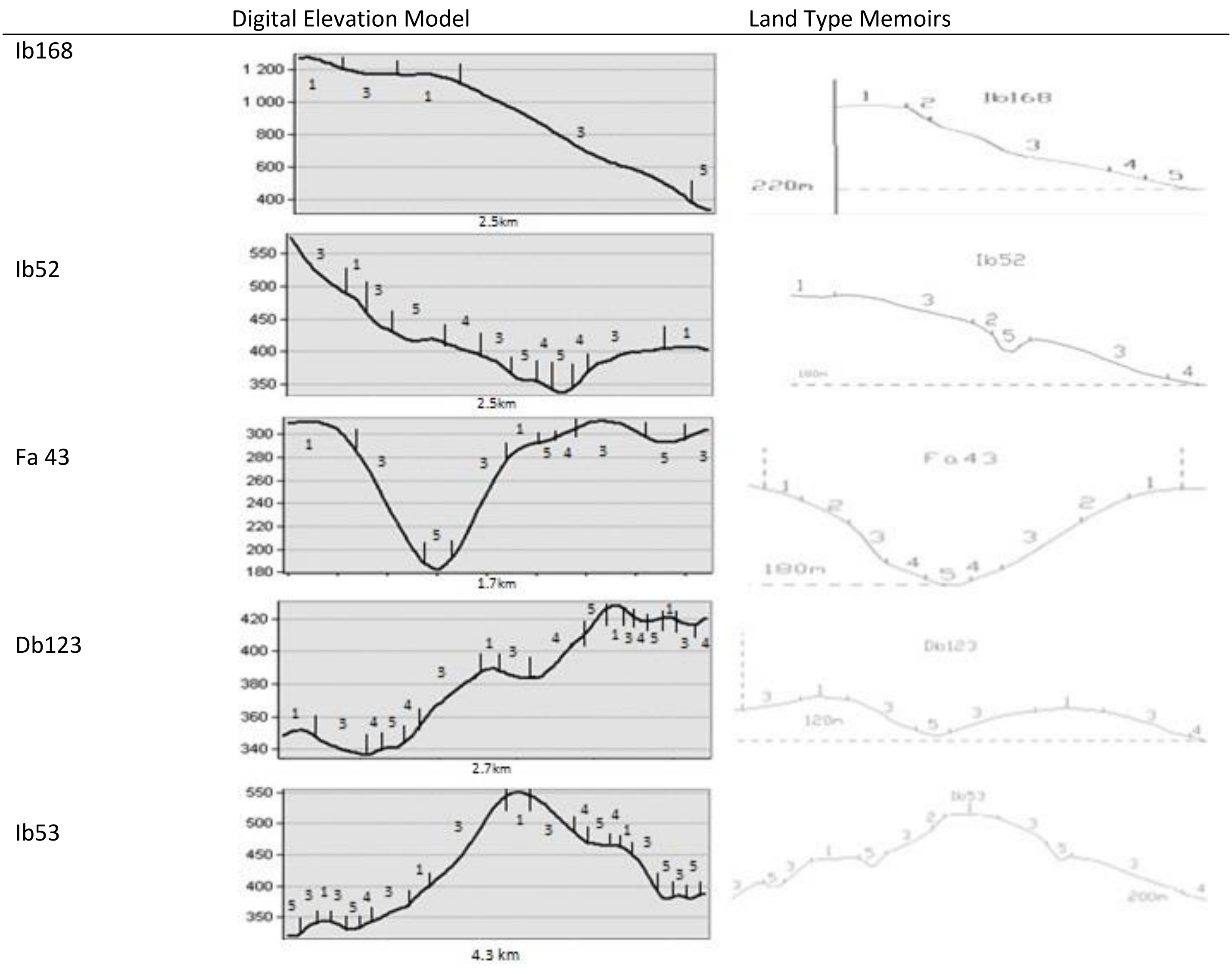

Figure: 5.5 Comparing transects from the Land Type with DEM generated. Terrain units assigned from the segmentation process.

5.3.2.2 Landscape Analyses through Terrain Segmentation

The segmentation method proved to be able to dissect the landscape into different terrain units with adequate accuracy. Various sources of error could affect the prediction accuracy including; GPS and DEM (micro morphology (relief) <30 m).

The morphological segmentation method accurately predicted 57% of terrain units at all the point observations, with no buffer zone. If the average GPS standard deviation is considered, the prediction accuracy increased to 62%. Since the morphology map was constructed from a 30 m DEM, 15 and 30 m buffer zones were also analysed. On profile observations 75%, accuracy was obtained on both 15 and 30 m buffers. The scout observations achieved 74% and 77% accuracy respectively (Table: 5.2).

Table: 5.2 Segmentation map prediction accuracy with various buffer distances.

Type of observation	Number of Observations	Point %	4 m Buffer %	15 m Buffer %	30 m Buffer %
Scout	154	57	61	74	77
Profile	36	58	64	75	75
Total	190	57	62	74	77

There is a noticeable difference in terrain unit area allocation according to the different datasets (Table: 5.3). The main difference in allocation can be attributed to the method used. The transect method used for the Land Types, only measured a mere slice in the landscape (one dimensional), whilst the segmentation method actually divided the whole area (two-dimensional).

Table: 5.3 Comparing area's allocated for the terrain morphological units from different data sources:

	Percentage Area		
Terrain Unit	Land Type Memoirs	DEM Transect*	Morphology Segmentation
Db123			
1	20	20	13
3	50	40	47
4	10	26	18
5	20	14	22
Fa43			
1	10	17	18
3	45	56	49
4	15	5	10
5	10	22	23
Ib52			
1	35	16	10
3	52	45	50
4	5	16	22
5	6	23	19
Ib53			
1	20	17	15
3	55	53	61
4	12	8	12
5	10	22	12
Ib168			
1	5	21	22
3	80	67	62
4	5	7	6
5	5	5	10

*Calculated from measurements made of Figure: 5.5 on GIS.

The area allocated for each TMU should be as accurate as possible, because each TMU's will be populated with the corresponding soil type from the LT data. The SWAT model ultimately, uses this information for streamflow calculations. Terrain unit 3, mid slope, is dominant in all the datasets; this is consistent with the undulated landscape and field observations.

5.3.2.1 Conventional Soil Map

Conventional soil maps are classically used for natural resource planning and are rarely used for hydrological modelling in South Africa, it is, however, the standard for precision agriculture and environmental impact assessments. As expected the conventional soils map produced much larger map units than the segmentation method, but was able to capture a wide variety of soil types (Figure: 5.7).

The variation in soil and landscape combined with the large scale is difficult to account for using conventional soil mapping techniques. Large areas within the catchment are inaccessible, increasing the need for remotely sensed data. On the other hand, the map inherited detailed soil information inside the agroforestry zone from 3rd party soil maps.

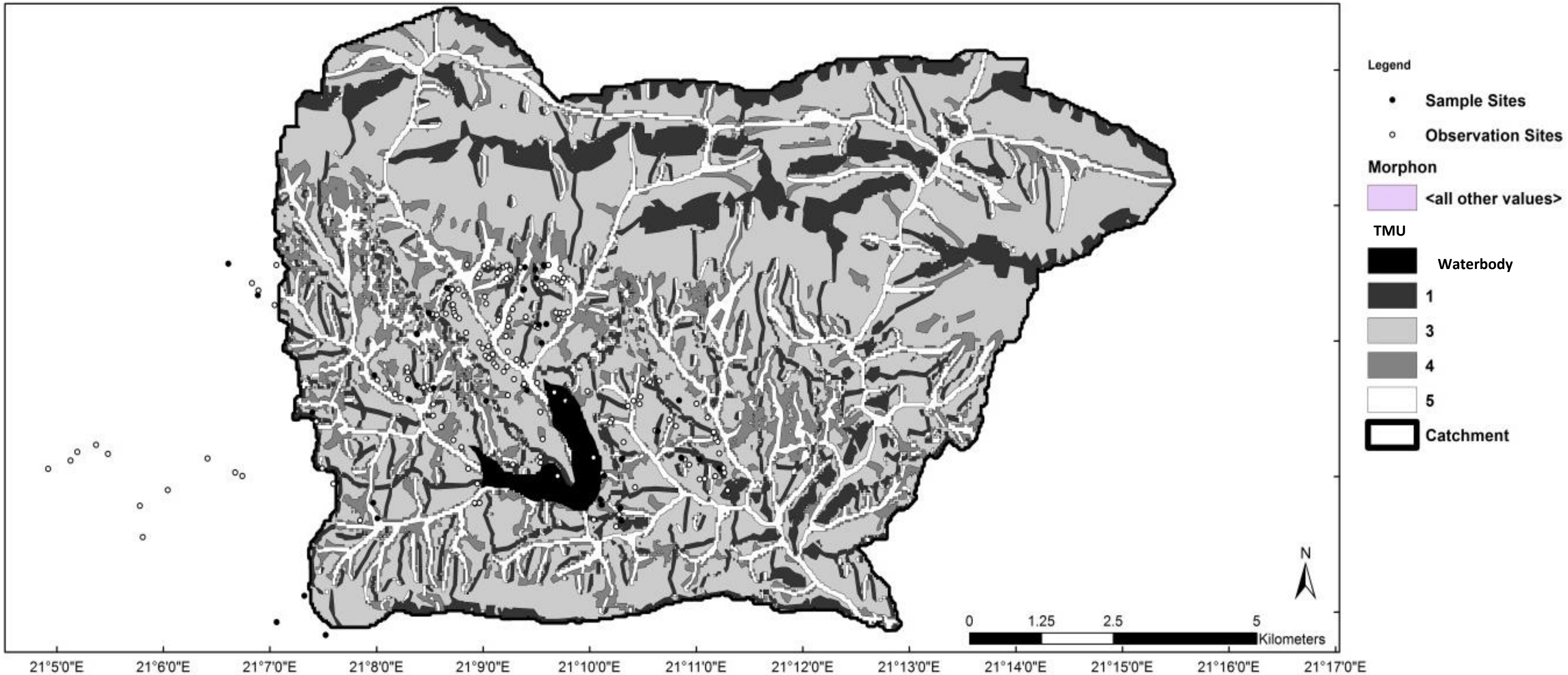

Figure: 5.6 Terrain morphology map with observation sites. Terrain morphological units (TMU) are clustered not indicating different curvature.

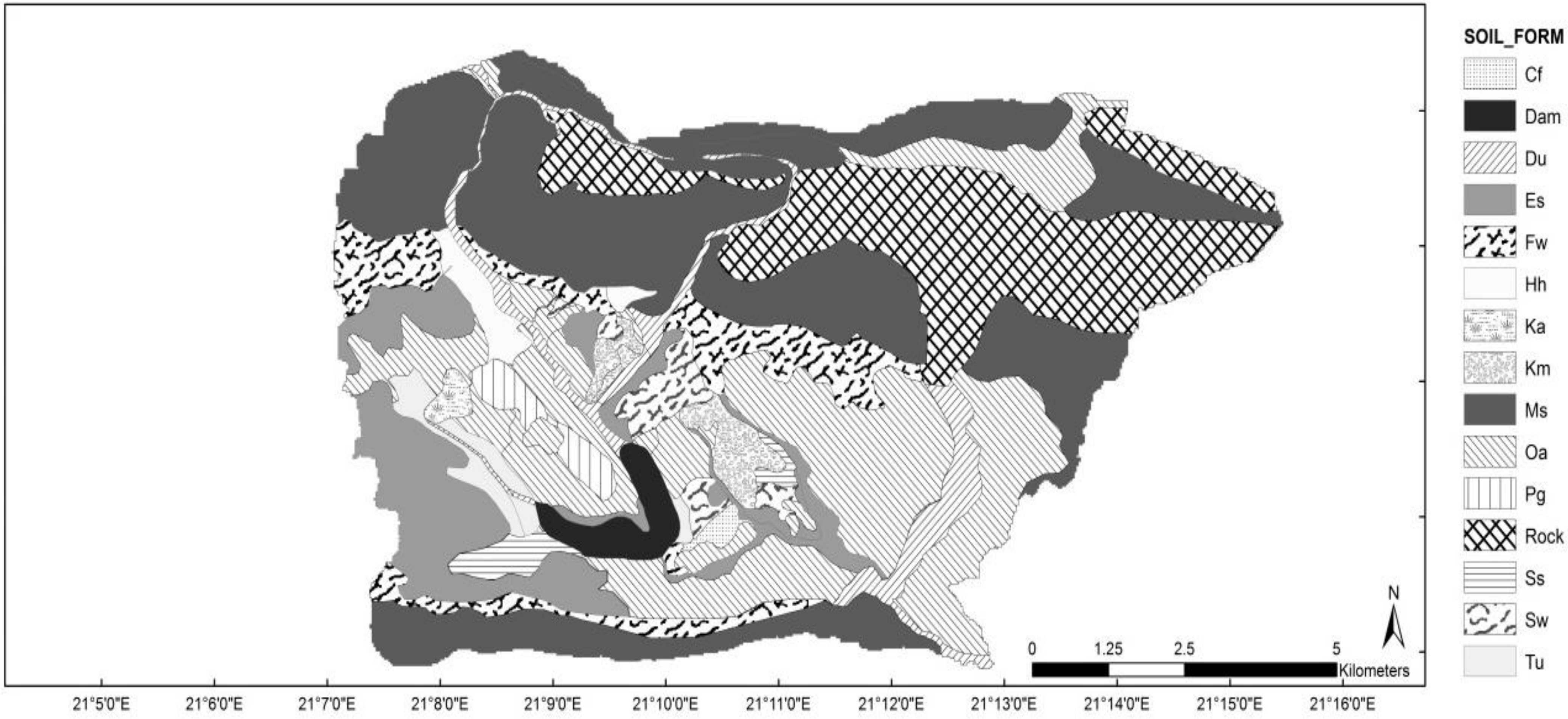

Figure: 5.7 Convention Soil map of the catchment.

A pixel-polygon comparison was done between the segmentation and conventional maps. A portion of Land Type Ib52 was selected due to the high observation point density (Figure: 5.8). The block or polygon size represented by an observation point was compared. Soil Type polygon area differed substantially between conventional and morphology segmentation mapping techniques. The morphology map units were smaller than conventional map units. Comprising 5–60% of conventional mapping units, this supports results found from the transect sketches.

Conventional soil mapping techniques are time-consuming and therefore very expensive, especially on a catchment scale. Although 3rd party soil maps were ascertained to aid map development, the mountainous valleys which make up about one-third were never investigated. This is however not of large concern, the steep mountain slopes do not permit extensive soil development.

Table: 5.4 Scale analyses of a section within Land Type Ib52, as illustrated by Figure: 5.8.

Survey indicated soils at sampling sites	Area allocated (%) (Land Type Memoirs)	Conventional soil map unit (ha)	Percentage morphon area within conventional map unit
Estcourt	19	38.21	5.25
Fernwood	8.7	64.34	15.54
Swartland	1.9	13.62	7.34
Dundee	1.6	18.95	10.55
Houwhoek	1.4	99.20	9.07
Houwhoek	1.4	19.99	60.04
Pinegrove	1.4	133.31	5.25
Klapmuts	0.6	44	25

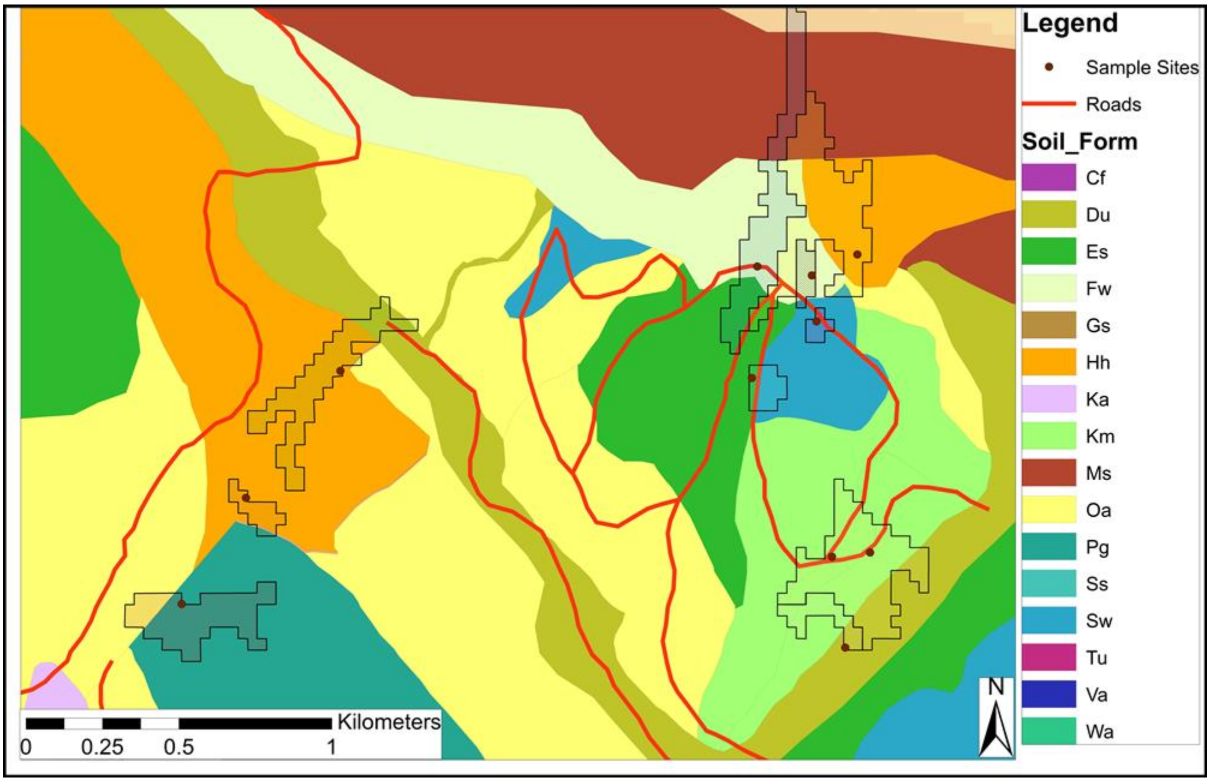

Figure: 5.8 Conventional soils map (background map)with observation points and representative segmentation map units (overlayd grey polygons).

5.4 CONCLUSION

This chapter deals with the segmentation process ability to dissect the landscape therefore the soil information are not evaluated, but is dealt with in the next chapter. The segmentation method developed was able to segment the landscape into terrain unit blocks comparable with Land Type terrain units. Good accuracy of 77% was achieved using the original DEM resolution (30 m SRTM). Terrain units derived from segmentation are smaller compared to those in the Land Type memoirs. This finer delineation of terrain units can have a positive effect on soil distribution prediction.

The area allocated to terrain units differs to a small degree from the Land Types, this is probably due to the scale of the Land Types and the variation in terrain within the catchment and surrounding areas.

A comparison of map unit size was done between the morphology map and a conventional soil map. Digital terrain modelling is able to produce high-resolution terrain maps, which if accompanied with a soil-landscape association, could yield higher resolution maps than conventional soil maps. Perhaps the most convincing argument for morphological mapping is the prospect of applying a well-defined soil – landscape association without visiting the area under study and accurately predicting soil characteristics. This method would also be extremely beneficial when inaccessible areas are to be classified. Given that the whole of South Africa is surveyed on the basis of soil – landscape associations, this method can theoretically be used to increase the resolution of Land Type information from 1:250 000 up to 1: 50 000. The accuracy of soil information used to populate the TMU's are of course dependent on the correctness of the soil- landscape association and should preferably be validated.

Modern technology can be used to enhance our understanding of soil-landscape interactions, and has the ability to revitalise databases of the past, through enhanced terrain surveying and digital terrain modelling. Although the morphology segmentation method was successful in this terrain, transferability to other regions should be confirmed.

CHAPTER 6 INTEGRATION OF LAND TYPE SOIL INFORMATION WITH MORPHON MAPPING FOR HYDROLOGICAL MODELLING.

6.1 INTRODUCTION

The Land Type survey focused on agricultural suitability, neglecting some regions of low agricultural potential. The Land Types covering the Korentepoort catchment and surrounding mountains does not have any modal profiles, suggesting the physical data accompanied with the Land Types are derived from field observation and not laboratory analyses. It is therefore suspected that the area under study is not sufficiently represented by the existing Land Type maps. The Hessequa region is extremely dependent on the Korentepoort catchment and regularly struck with droughts further, stresses the need to validate this database.

The segmentation process was developed to unlock the detailed soils information within the Land Type data and create high-resolution soil maps with limited to no field visits. One major drawback of using the segmentation method is the dependence on the accuracy of the Land Type information's soil – terrain associations. The detail will not increase accuracy if the soils information used to populate the segmentation map is irreconcilable with occurring soils. Necessitating verification of the LT information of the catchment area, with observed soils information. Since the terrain segmentation process yielded satisfactory accuracy, the results will be used during conceptualising new soil-landscape relationships and develop the updated LT's.

In this chapter, field observations were compared with Land Type information of the Korentepoort catchment. The majority of soils observed in the catchment were transitional or disturbed soils, which are difficult to classify into a single soil form. Therefore modal profiles were identified and characterised in order to compare to the larger ''grey zone''. The Land Type soil physical information was also compared with field observations, because hydrological models solely uses soil physical properties for predictions and not nomenclature.

Soils information for South Africa is readily available and identifying and interpreting soil properties and their relative distribution can aid in predictions of hydrological processes (Van Tol *et al*. 2010). The segmentation map was used in the SWAT hydrological model, but the program was unable to produce workable hydrological response units (HRU's) with the highly pixelated map. Modellers need to consider the benefits before selecting a specific soils data resolution, depending on watershed size and level of accuracy required because more effort is required to prepare and calibrate the model when a fine resolution soil data is used (Geza and McCray 2008). Although the LT polygons scale are coarse compared to most catchments in the Western Cape, the disaggregation based on TMUs might increase resolution and accuracy. It is well documented that an increase in soils data resolution increases model output accuracy (Geza and McCray 2008). As a rule of thumb, the soil layer should be more or less the same resolution as that of land use, for a minimum amount of HRU's. When the soil layer is too cluttered, the program is unable to use the soils information layer, therefore only utilise the land use and the terrain model when delineating HRU's. Therefore an acceptable method is pursued to produce a more condensed soil map while conserving as much detail as possible. Two methods were identified to aggregate the soils map into computable polygons. Aggregation based on 1) terrain units and 2) soil associations. Different terrain units can be clustered together in an effort to simplify the map (e.g. TMU 4 and 5). This method posed some problems, due to the fact that the soil occurring in these terrain units often differs substantially in their water regimes and conductance. Creating soil associations based on hydrological character is a method already used with success in South Africa (Van Tol *et al*. 2010). This method associates soil types into discrete units on the basis of their hydrological response. The hydrological response can be deduced from soil hydromorphic character or measured in-field.

6.2 METHODS

6.2.1 Comparing and Updating Land Type Information

Soils of the catchment were classified according to the South African Soil Classification System (Soil Classification Working Group 1991) and analysed as mentioned in CHAPTER 4. In order to assess the segmentation product through hydrological modelling, the process of updating the LTs should be the same as the original LT production process. Updating the Land Type information is vital to enable comparisons of results to areas in the country where the Land Type information represents the soils. The Land Type information is an extension of the surveyors understanding of the soil-landscape relationship in a certain climatic area. Conceptual models were developed for each land type segment within the catchment using field observations and transect sketches from orographic maps.

Modern SRTM terrain model was used to create transects which were assigned terrain units from the terrain segmentation process. These transects were used to calculate the terrain unit allocation for each Land Type. Soil-terrain associations were developed using all soil observations in the catchment and third party soil maps.

A comparison was done between the updated Land Types and the original; this was done on the basis of soil type and area. The updated Land Type is considered to be correct and the original Land Types were compared with it. An example calculation is given below (Table: 2.10).

Table: 2.10 Example calculation for LT evaluation

Original LT Soil Forms	Updated LT	Updated Occurrence	Match	Original LT soil type and spatial representation
Estcourt	Estcourt	35%	Match	50% soil type
Oakleaf	Cartref	15%	No Match	35% spatial

6.2.2 Hydropedological Associations

The undulated landscape caused the segmentation product to be of very high resolution, or pixelated. This large amount of variation would not be comparable to the land use blocks of the area, thus would create too many HRUs. Building on Hydropedological work done in South Africa, the soil forms in each updated Land Type were re-classified / associated into hydrological soil types (Van Tol *et al*. 2010).

Hydropedological classes proposed by van Tol *et al* (2013) was considered, it groups soil types into six different classes, but would do little to aggregate the map units. Therefore his previously proposed hydrological soil types were chosen, with only three classes (Van Tol *et al*. 2010). These soil hydrological groups are illustrated in Figure: 6.1.

Recharge: Vertical drainage: Net water loss from the profile will be into the underlying material/ geology/ aquifer.

Interflow: Lateral flow: Net water loss from the profile will be into the adjacent profile in the same soil layer. Water infiltrates the permeable top soil layers and reaches the impermeable subsoil layer. Possible drainage or resurfacing of water lower down the hillside.

Responsive: Surface runoff: Net water loss from the profile occurs on the surface. This can occur on low infiltration top soil or due to shallow soils, with low permeability in the subsoil layer. The latter will produce surface runoff through the build-up of a water table top of the impermeable layer, causing water to rise up to the soil surface. Further additions of water will not be able to infiltrate, but would move laterally on top of the soil surface.

Responsive (Mispah)	Interflow (Estcourt)	Recharge (Oakleaf)

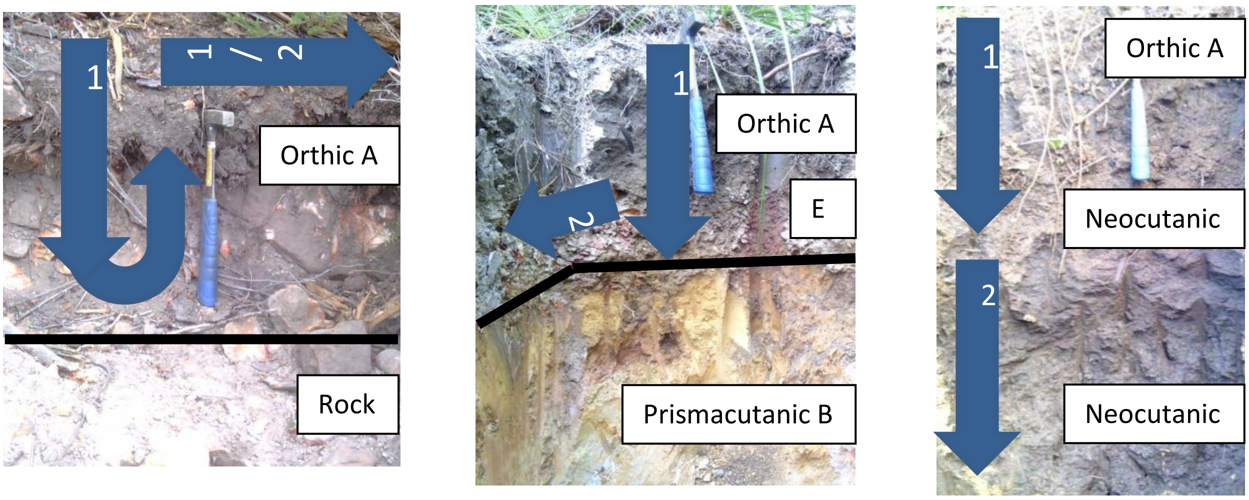

Figure: 6.1 Hydrological Soil types and common soil forms associated with them. Arrows indicate water movement and black lines are impermeable or very low permeability layers.

The classification was done based on the results of two different methods: 1) Infiltrometer, which measures unsaturated hydraulic conductivity in the field. 2) Soil water retention or characteristic curve (SWC). Parameter selection is based on hydromorphic characteristics detected in the field; it was found that soil layers with infiltration rates below 20 $mm.hr^{-1}$ exhibited slight sighs of gleying and mottling. Although this infiltration rate seems high, water contents ranged from 0.17-0.33 m^3m^{-3} and averaging 0.26 m^3m^{-3} which is high . Unsaturated hydraulic conductivity methods are described in 4.3.1.1. This value was used to identify the neutral profile, and classify the soil forms into hydrological associations. The neutral profile is thought to have more or less equal amounts of runoff, sub-surface flow, and deep drainage, without any signs of gleying or mottling.

SWC method compares each horizon to the selected neutral profile. Moisture retention curves of the modal profiles were compared to the SWC equation of the neutral profile, by calculating the area between the curves. Soil horizons that are able to hold more water than the neutral soil throughout the tension range are considered to impede water movement. Furthermore, the hydropedological classes are assigned from the topsoil downwards.

The re-classification of soil groups enables aggregation of soil types into larger groups, which are compatible with HRU development, whilst focusing on hydrological traits of the soils.

Definitions were created for the three hydrological soil types, with special reference to the soils found in the Korentepoort catchment (0). Although the South African soil taxonomic system often relies on water regimes and drainage characteristics to distinguish between soil forms, one soil form is not exclusively associated with a certain hydrological regime.

Table: 2.11 Soil characteristics commonly associated with hydrological soil types.

Hydrological Soil Type	Characteristics	Horizons	K_{unsat}
Recharge	No signs of wetness throughout the profile No abrupt change in clay content No signs of surface crusting E-Horizons (Podzolization)	Neocutanic Podzol Lithocutanic E Horizons Pedocutanic	A: >20 mm/h E/B: >20 mm/h B2: >20 mm/h
Interflow	Sharp increase in clay content with depth E-Horizons (Reduction)	Pedocutanic Prismacutanic Saprolite Bedrock E Horizons	A: >20 mm/h E: >20 mm/h B1/2: <20 mm/h
Responsive	Shallow top soils High clay content subsoil Redox mottles in subsoil - Signs of wetness Shallow soils on bedrock or Crusting	Surface Rock G-horizon Bedrock	A: <20 mm/h

6.2.3 Hydrological Response Unit Delineation

Soil physical information was associated with certain hydrological soil types within a GIS environment. The Soil Water Assessment Tool (SWAT) was used together with land use information to develop HRU's for the Korentepoort catchment. Three slope classes were developed from the DEM, which constituted the terrain part of the response units.

6.3 RESULTS AND DISCUSSION

6.3.1 Updated Land Type information

Within the catchment, several of the Land Types do not represent the spatial distribution of soils sufficiently. The most striking of these mismatches is the surface rock cover, which is easily observed from a distance. Further investigation of soil physical properties is compared with the Land Type memoirs. The four Land Types making up 94% of the catchment, was updated with new landscape-soil-associations. A condensed comparison in 0 is given between the Updated Land Type and the original. The complete updated Land Types with physical properties are supplied in the Appendix A.
The DEM derived transects (Figure: 5.5) were used in conjunction with the segmentation map (Figure: 5.6) to allocate Terrain Morphological Units (TMU's) in each LT. Theoretically, the Updated Land Types would, therefore, be compatible with the disaggregation methods, and provide an example of good segmentation - Land Type match. Several profiles were selected to represent the soil forms and their physical characteristics, these profiles are considered modal profiles and are attached in Appendix.

6.3.1.1 Land Type Information Comparison

The Land Type information was found to be a good source to acquaint oneself with the soils of the region, but the main problem related to the actual distribution of soil types in this undulating landscape within the catchment boundaries. In most LT polygons more than half the soil forms listed were observed in the field but often observed soils was not recorded in the LTs. As mentioned in the LTs, the soils of the area are highly variable and difficult to quantify, with various indications of soil movement down the hills. With little to no topsoil / microrelief indicators, filled channels could misrepresent an area if sampled or classified (Figure: 6.2).

Figure: 6.2 Road cutting indicative of a filled channel with well-rounded boulders and soil mixture.

6.3.1.2 Soil Classification Comparison

Land Type (LT) Ib53 represented the observed soils the best, identifying 63% of the different soil types, which make up 72% of the area. Land Type Fa43 followed and represented 58% of the soil forms observed. Land Types Fa43, Db123 and Ib52 represented 53%, 30% and 16% observed soils respectively.

The greatest inconsistency between observed soil types and Land Type memoirs was found in LT Ib52 (0). Soil types dominating the Land Types were not observed within the catchment boundaries, whilst those observed was seldom recorded in the Land Types. The Ib Land Types are characterised by shallow soils in mountainous regions, which can be found north of the catchment. Although this LT soil information is contrasting from field observation, the area under question is only 27% of the Land type, with the remaining area outside the catchment. It is thus not unexpected that LT Ib52 does not accurately predict soils in the marginal foothills.

Table: 6.2 Comparing the top five most common soil forms according to the Updated and Land Type information, highlighted forms occur in both datasets.

	Updated Land Type		Land Type Memoirs	
Land Type	Soil Forms	Distribution	Soil Forms	Distribution
Db123	Estcourt	18%	Sterkspruit	27%
Db123	Oakleaf	13%	Glenrosa	24%
Db123	Mispah	10%	Swartland	22%
Db123	Glenrosa	9%	Hutton	9%
Db123	Fernwood	9%	Mispah	6%
Ib53	Mispah	49%	Clovelly	16%
Ib53	Fernwood	14%	Mispah	7%
Ib53	Dundee	13%	Hutton	7%
Ib53	Oakleaf	8%	Kroonstad	7%
Ib53	Estcourt	7%	Wasbank	7%
Ib53	Rock	7%	Longlands	7%
Fa43	Oakleaf	34%	Rock	47%
Fa43	Estcourt	14%	Cartref	12%
Fa43	Swartland	10%	Mispah	10%
Fa43	Dundee	7%	Glenrosa	6%
Fa43	Cartref	6%	Houwhoek	4%
Ib52	Oakleaf	24%	Rock	64%
Ib52	Estcourt	13%	Mispah	7%
Ib52	Sterkspruit	11%	Cartref	13%
Ib52	Dundee	8%	Houwhoek	8%
Ib52	Fernwood	8%		

6.3.1.3 Soil Physical Properties:

The soil physical properties accompanied by the Land Type memoirs are essential parameters required for hydrological modelling. Although the memoirs only give a range of depth and clay content (percentage), this is still valuable information to the hydrologist. Field measurements of soil depth together with laboratory analyses of texture permitted accurate updates to the Land Types. The depth weighted average were calculated for the Land Types and Updated Land Types. The soils occurrence (%) were multiplied with the physical property (depth or clay %), the values are then summed. Bulk densities ranged from 1.12 - 1.93 g.cm^{-3}, lower bulk density was recorded in top soil horizons.

The main soil physical parameters were averaged as per surface area allocated. In all but one LT, the topsoil clay content was underestimated, particularly in the Ib Land Types. Average soil depth was grossly underestimated and would not represent the water storing capacity of the soils or the catchment. LT Db123 is most comparable to the updated version.

Table: 6.3 Depth weighted average of soil physical properties as indicated in the Land Types and Updated Land Types.

Land Type ID	Land Type		Updated Land Type	
	Topsoil clay (%)	Soil depth (mm)	Topsoil clay (%)	Soil depth (mm)
Db123	14.44	362	7.8	563.72
Fa43	2.79	146.59	8.6	725
Ib52	0.843	69.5	8.03	739
Ib53	1.9	106.65	5.03	413

6.3.2 Soil Associations – Field and Laboratory Observations

Soils were divided into 3 hydrological soil types according to their relative hydrological behaviour. This method was found to be accurate in predicting hydrological response and matched hydro-morphological observations and infiltration tests done in the field.

6.3.2.1 Responsive

Responsive soils conduct the majority of precipitation along the surface, as runoff. These soils are characterised by low infiltration rates (K_{unsat} < 20 mm/hr) in the topsoil and shallow soils on top of an impeding layer or a combination of both. Soils with high water holding capacity are prone to low hydraulic conductivity and infiltration. Highly dispersive clays are common throughout the study area, which could cause blockage of pores in the top soil layers. In some cases the topsoil comprises exclusively of these dispersive clays, displaying very strong structure and forming massive prism-like structures (Figure: 6.3). These prism ped surfaces are often coated with the organic material and riddled with plant roots, which show signs of pressure from swelling and shrinking (Figure: 6.3).

Figure: 6.3 Highly structured top soil (left) and subsoil (right).

These prismatic structures are associated with cyclic wetting and drying, causing the high clay content soil to swell and shrink. Preferential flow paths are often created between these structures, which assists initial water infiltration and lateral movement until the swelling process fill the cracks (Figure: 6.4.).

These prism and columnar structures are found throughout the catchment, predominantly in the subsoil, but when exposed to the surface, these offer little infiltration ability. During rainfall events, water will follow the preferential cracks alongside the prisms, reaching the saprolite or underlying bedrock, causing water to build up within the cracks where the B horizon fades into the saprolite parent material. If the topsoil is shallow water will eventually saturate the profile, leading to surface runoff. Under moist conditions, the preferential flow paths will be reduced, further decreasing infiltration into the underlying material.

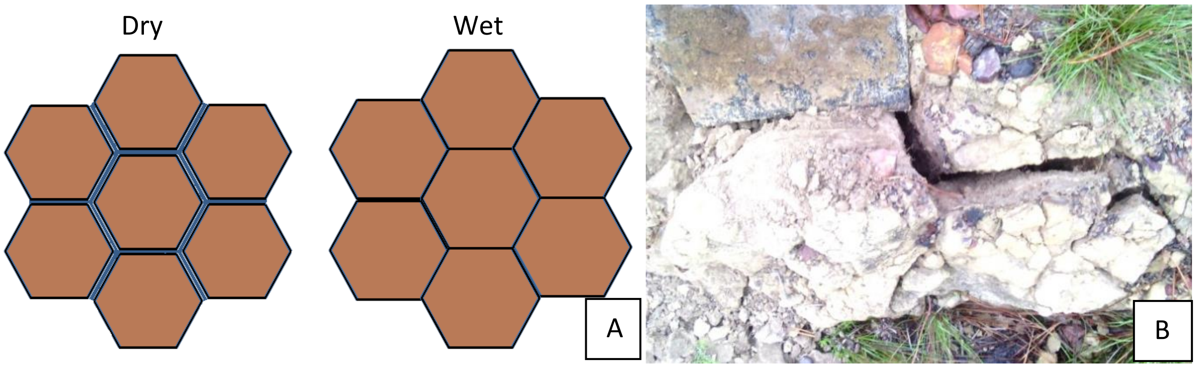

Figure: 6.4 **A**: Illustration of observed swell and shrink patterns of prismatic soil structures. **B**: Exposed preferential flow paths of Prismacutanic B horizons as seen from above.

Figure: 6.5 Shallow topsoil above prismatic structure on top of saprolite.

Soil moisture retention analyses revealed that these topsoils store more water than the neutral soil in the surface horizons. The water storing capacity is considerably more at saturation, where hydrologic conductivity will be at its highest (Figure: 6.6).

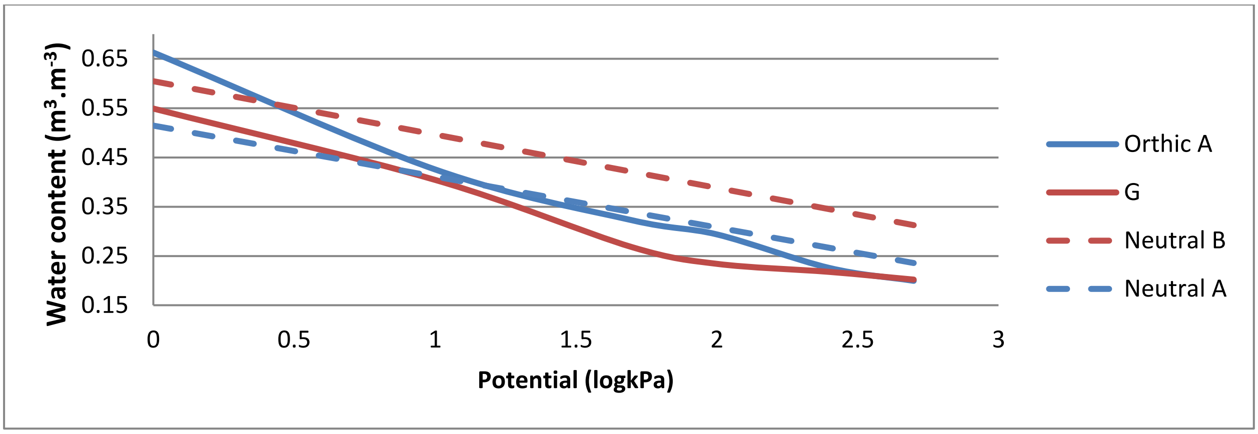

Figure: 6.6 Soil water retention curve analyses of Responsive soils

6.3.2.1 Interflow

Interflow soils are characterised with neutral to loose top soil and subsoil with low permeability, often with an E horizon in between. E horizons often able to conduct water faster than adjacent layers. These profiles are recognised in the catchment with varying degree of ease, some cases the hydromorphic features are obvious and others quite subtle (Figure: 6.7).

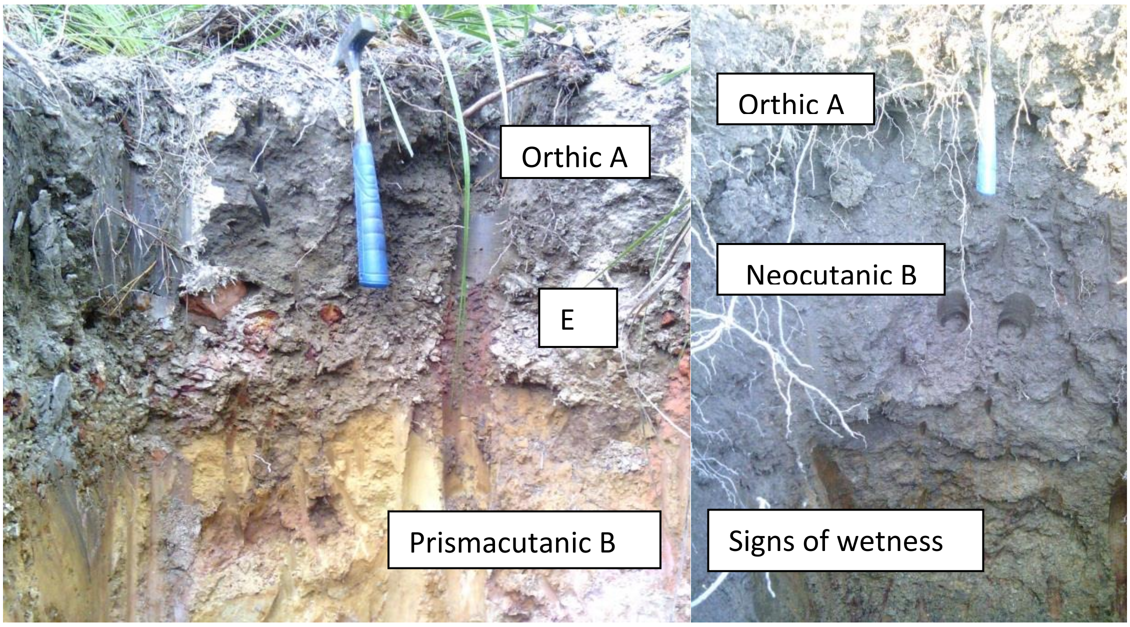

Figure: 6.7 Profiles exhibiting hydro-morphological character indicating subsoil water accumulation and movement.

Interflow soils SWC exhibited substantial differences compared the neutral profiles. The subsoil horizons B2 illustrated more water holding capacity across the tension range (Figure: 6.8), indicating a higher retention ability. The E horizon, which was thought to accelerate subsurface flow did not indicate significant variation from neutral profile's A horizon, although it did indicate a lower retention capacity than the neutral B. It is understood that water would build up on top of the B2 horizon, which will cause faster, saturated flow, within the E horizon.

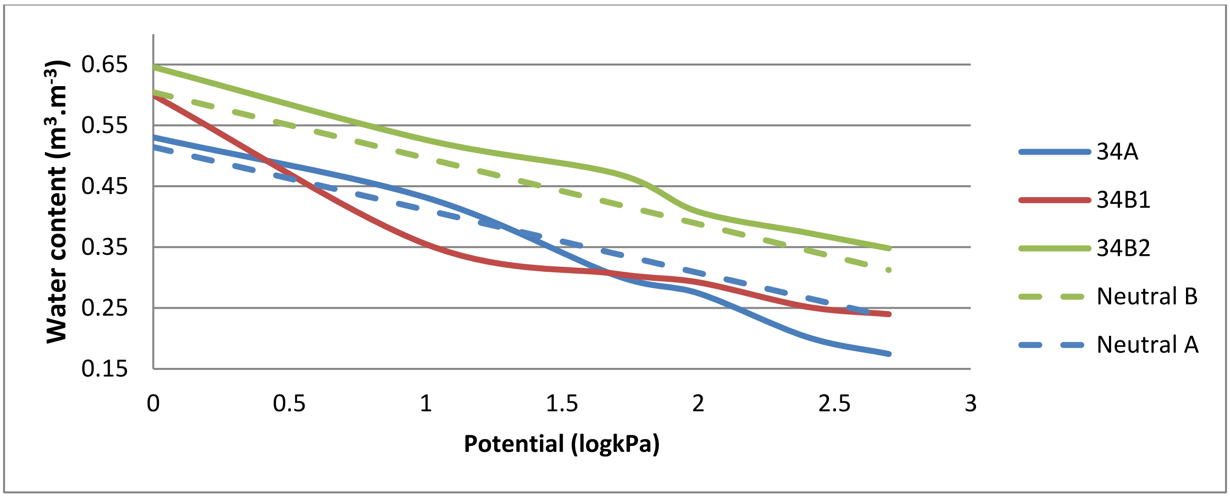

Figure: 6.8 Soil water characteristic curve analyses of Interflow soils

6.3.2.2 Recharge

In this landscape where sandstone and shale are found intermittently, the bedrock and its character affect and even dominates the hydrologic character of the profile. Certain aspects such as the degree of weathering, orientation and preferential flow paths were documented and included in profile descriptions. In the study area, sandstone bedrock was associated with well-drained soil profiles, while the shale's orientation defined whether it conducted or restricted recharge.

Recharge soils are characterised by fast infiltration (K_{unsat} >20 mm hr^{-1}), both in the topsoil and the subsoil layers. Compared to the neutral profile these horizons lose water more easily and conduct it through the profile or underlying bedrock (Figure: 6.10). Profiles exhibited a lack of structure and low clay content in both the top and subsoil layers.

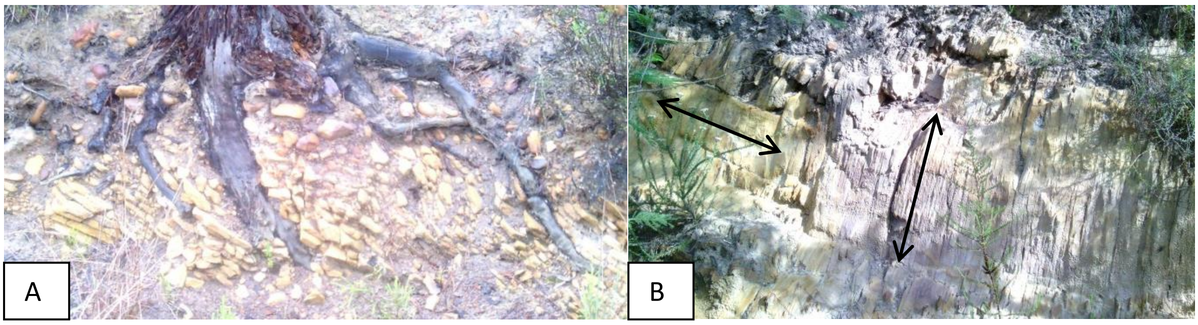

Figure: 6.9 **A**: This highly fractured sandstone is not restricting normal root development or vertical water movement. **B:** Different shale orientation, influencing preferential flow paths.

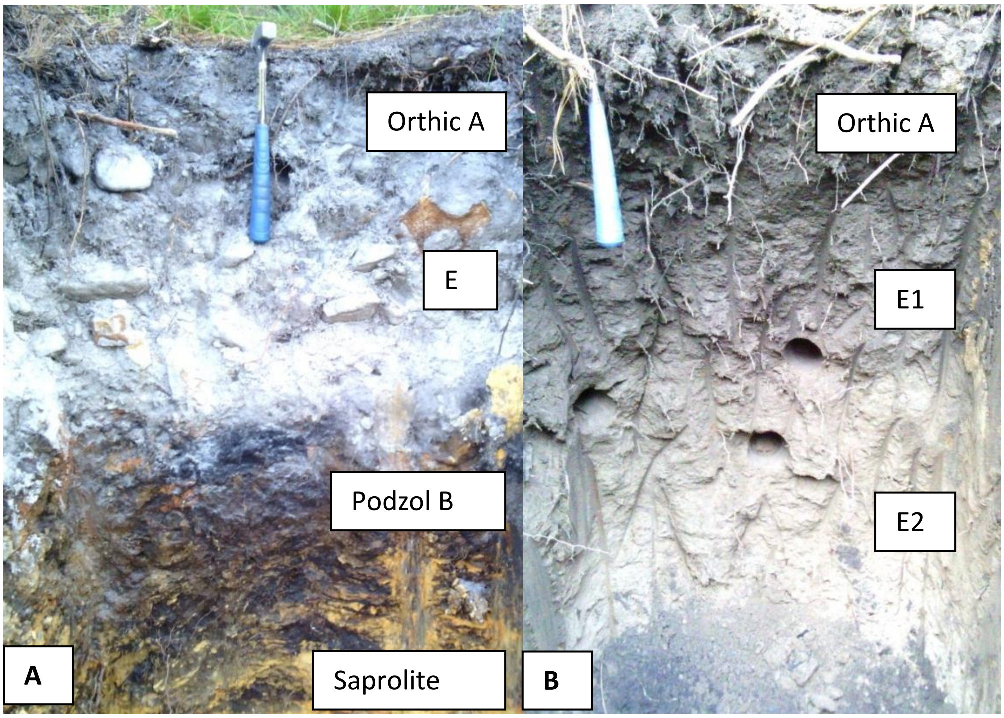

Figure: 6.10 **A**: Recharge soils with high water conducting abilities shallow overlying fractured organic enriched sandstone (Houwhoek Soil form). **B**: Deep sand (Fernwood Soil form).

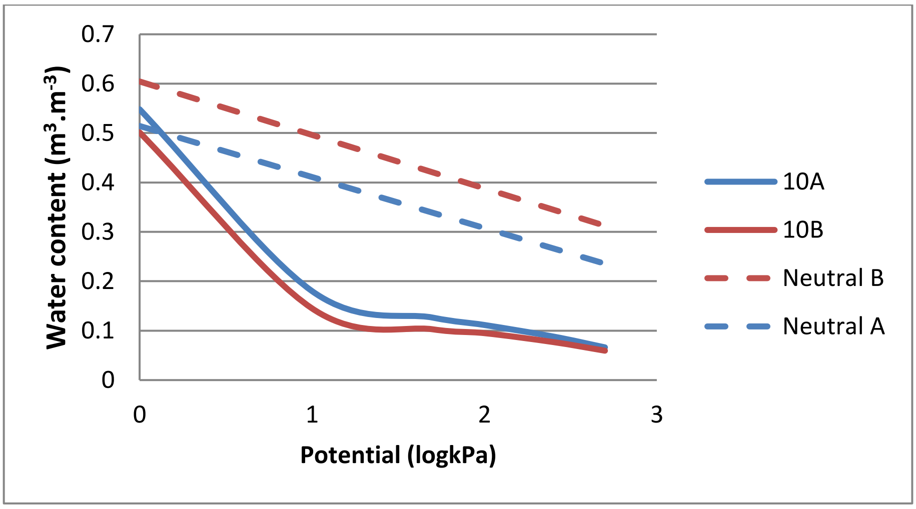

Figure: 6.11 Soil water characteristics curve analyses of Recharge soil

6.3.3 Hydropedological Mapping

The Updated Land Type soil types were re-classified as mentioned in section 6.3.2, after which the hydrological soil type with the highest representation were selected to represent the TMU. The total representation fraction is used to estimate the percentage that would be represented by the new class (Table: 6.4). Some soil types can have different hydrological soil type classification, based on their depth and location in the landscape. For instance it was observed that the water table was high in the Dundee forms in LT Ib53 causing subsurface flow, were in LT52 the water table was below survey depth. The average occurrence is 67% (Calculated from Figure: 6.4) which would, in other words, represent the whole catchment.

Table: 6.4 Hydrological Soil types distribution per updated LT and TMU.

Updated Land Type	Terrain Unit	Dominant Soil Type	Occurrence (%)	Hydrological Soil Type	Occurrence (%)
Db123	1	Mispah	40	Recharge	90
	3	Oakleaf	25	Recharge	50
	4	Tukulu	25	Interflow	40
	5	Estcourt (shallow)	50	Response	60
Fa43	1	Oakleaf	40	Recharge	75
	3	Oakleaf	30	Recharge	65
	4	Tukulu	35	Interflow	55
	5	Oakleaf	45	Recharge	82
Ib52	1	Oakleaf	20	Recharge	77
	3	Estcourt	23	Interflow	50
	4	Oakleaf	25	Recharge	50
	5	Dundee	35	Recharge	74
Ib53	1	Mispah (shallow)	50	Response	75
	3	Mispah	73	Interflow	75
	4	Fernwood	25	Recharge	55
	5	Dundee	60	Interflow	75
Ib168	1	Rock	70	Response	70
	3	Houwhoek	30	Recharge	80
	4	Rock	40	Response	65
	5	Rock	50	Response	70

Two major geoprocessing tools are applied to the map to decrease resolution and generalise the map (Figure: 6.12). 1) Resample, this data management tool is used to alter the raster cell size, the majority option was selected which determines the new value of the cell based on the most popular value within the filter window. Raster pixel size was changed to 100 meters. 2) Boundary clean, this spatial analyst tool smoothens the boundary between zones by expanding and shrinking, and reclassifying pixels by giving priority to larger zones to expand into zones with smaller areas.

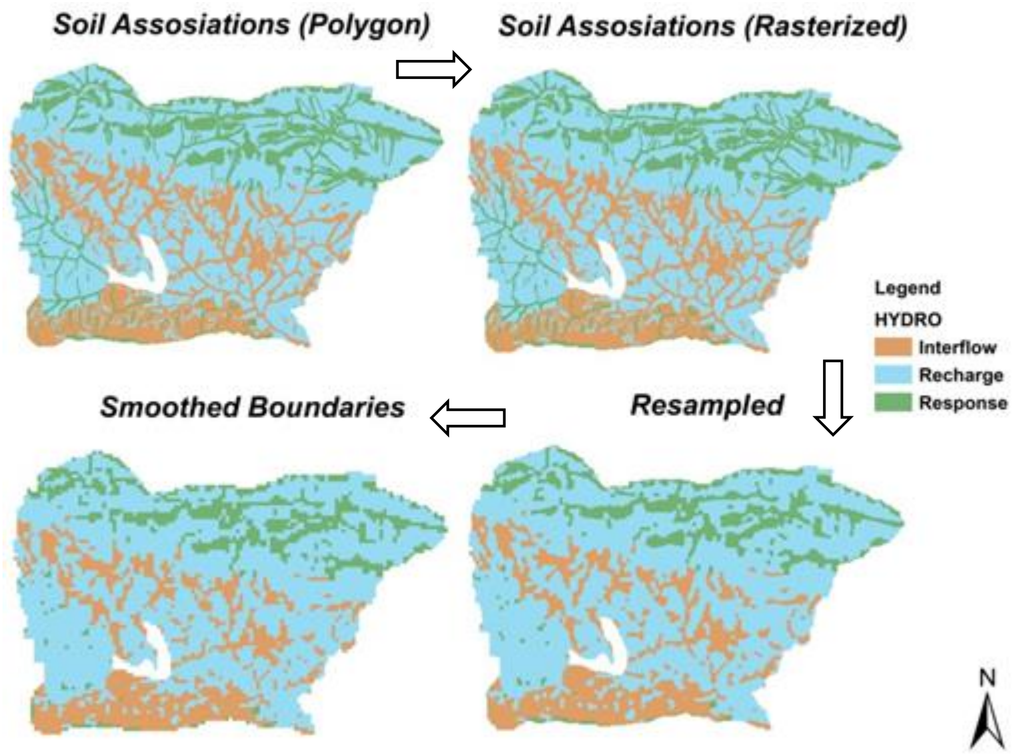

Figure: 6.12 Hydropedology map with three geoprocessing tools applied to de-clutter the map.

6.3.3.1 Map validation

The modal profiles were used to verify whether the Hydropedological map represents the hydrologically classified soils observed in the field. Profile positions and corresponding hydrological soil type according to Figure: 6.12 were compared to field and laboratory hydrological analyses (Table: 6.5).

The hydropedology map was able to predict ten of the thirteen modal profiles according to their hydrological response. This proves the hydrological response map is able to retain accuracy of a selected soil trait while at the same time decreasing resolution. A comparison was done between the terrain morphological map, and the two sets of land type information, in their broad polygon configuration when reclassified into hydrological soil types (Figure: 6.13). This figure ultimately illustrates the amount of information that is lost when the Land Type polygons are not disaggregated, (B vs. C) and the different outcomes when the Land Type information is updated with field observations and measurements (A vs. B)

Laboratory and field analyses results differed in two profiles: no.8 and 12. One crucial difference between the laboratory analyses and field testing is the coarse fraction, which was removed for laboratory analyses, and field bulk density / particle arrangement. According to the Saxton & Rawls (2006) an increase in coarse fragments leads to a lowering of hydraulic conductivity. Therefore it's expected for the laboratory results to overestimate the conduction ability of stone lined or compacted horizons.

The Hydropedological map was successfully integrated with land use and slope classes in SWAT to form a HRU map of the catchment (Figure: 6.14). Each hydrological response unit is a unique combination of soil, land use and slope within a single subbasin. A total of 434 different HRU's were created for the catchment with 25 subbasins. A complete list thereof is attached in Appendix C.

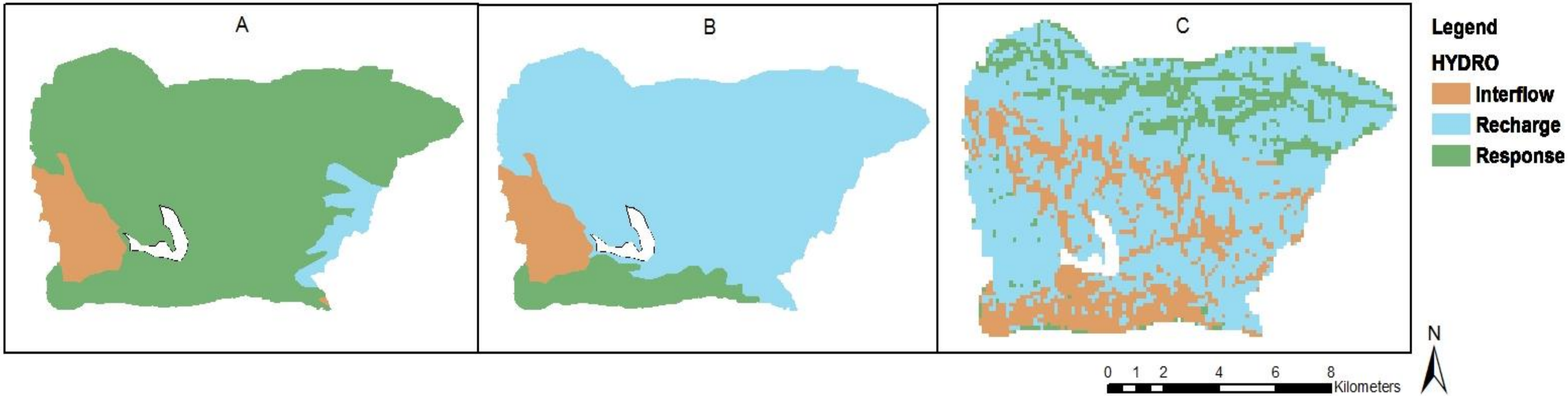

Figure: 6.13 Different data sources reclassified according to hydrological soil associations. **A**: Land Type **B**: Updated Land Type. **C**: Terrain morphological map

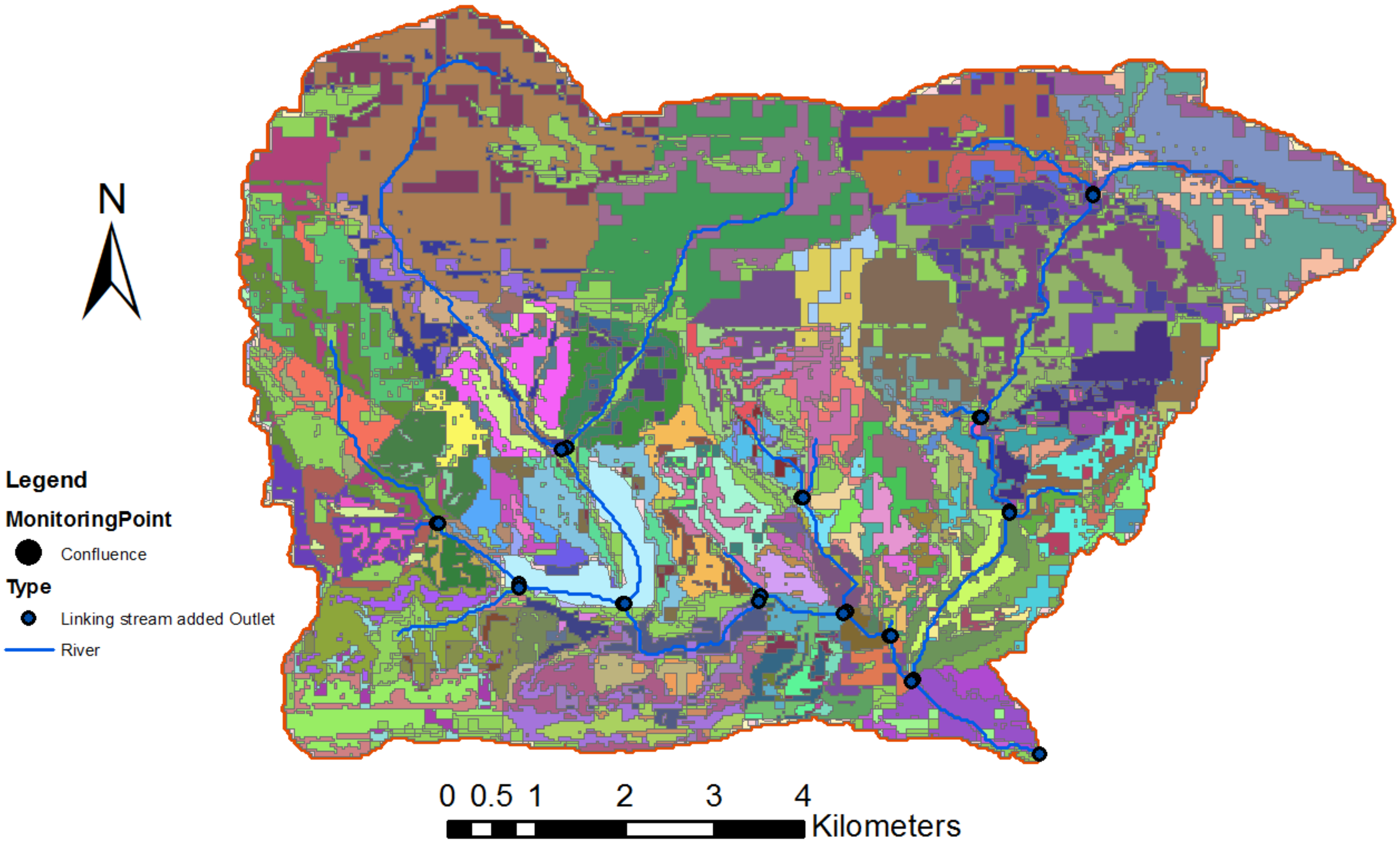

Figure: 6.14 Hydrological Response Units (HRU) map generated with the hydropedology map, land use maps and slope classes using SWAT modell. Complete deffinitions of unique HRU's in Appendix C.

Table: 6.5 Comparison between field, laboratory and map hydrological soil group allocation.

Profile Number	Soil Type	Horizon	K_{unsat} (mm/hr)	Infiltrometer Class	SWRC[a] Horizon Class	Profile SWRC Class	Final Class	Map Class
1	Oakleaf	Orthic A	29.96	Recharge	Conduct	Recharge	Recharge	Recharge
2	Tukulu	Orthic A	27.30	Interflow	Conduct		Interflow	Interflow
		Neocutanic	26.11		Conduct			
		S.O.W			Obstruct	Interflow		
3	Mispah	Orthic A	18.70	Responsive	Conduct	Recharge	Responsive	Responsive
4	Tukulu	Orthic A	23.49	Interflow	Conduct		Interflow	Interflow
		Neocutanic	34.68		Conduct			
		SOW[b]			Obstruct	Interflow		
5	Pinegrove	Orthic A	31.54	Recharge	Conduct	Recharge	Recharge	Interflow
6	Dundee	Orthic A	33.84	Recharge	Conduct	Recharge	Recharge	Recharge
7	Houwhoek	Orthic A	53.39	Recharge	Conduct	Recharge	Recharge	Recharge
8	Estcourt	Orthic A	74.25	Interflow	Conduct		Interflow	Interflow
		E	128.54		Conduct			
		Prismacutanic	0.73		Obstruct	Interflow		
9	Mispah	Orthic A	38.35	Recharge	Conduct	Recharge	Recharge	Recharge
10	Estcourt	Orthic A	57.01	Interflow	Conduct		Interflow	Interflow
		E	65.28		Conduct			
		Prismacutanic	4.68		Obstruct	Interflow		
11	Fernwood	Orthic A	61.2	Recharge	Conduct		Recharge	Recharge
		E	43.2		Conduct	Conduct		
12	Kroonstad	Orthic A	19.16	Responsive	Conduct		Responsive	Recharge
		E	28.8		Conduct			
		G	1.09		Obstruct	Interflow		
13	Swartland	Orthic A	18	Responsive	Obstruct	Responsive	Responsive	Interflow

a: Soil Water Characteristics Curve; b: Signs of wetness;

6.4 CONCLUSION

The Land Type information is a good source to equate oneself with the greater region, but it failed to represent the soils within the catchment. Updating the Land Type information for the study area is undoubtedly necessary, especially when comparing the soil physical properties. These properties are the only soil input for hydrological modelling and overshadow the importance of soil nomenclature. The updated Land Types offer detailed soil-landscape relationships within the study area and allow the morphology map to be populated with Land Type like data and illustrate possible results when accurate soil-terrain relationship is encountered.

The re-classification of soil types into hydrological associations based on physical characteristics proved to be a valuable method to reduce the number of map units. This method reduces the amount of effort when setting up the hydrological model whilst not compromising the amount of hydrological relevant information. The hydropedology map was successfully integrated into HRU's. It is important to understand that the hydrological model uses the soil physical properties together with rainfall intensity, terrain and antecedent moisture content to ultimately determine the amount of surface runoff and drainage. The boundaries between different hydrological soil groups are solely derived from soil morphology, although the soil's ability to conduct and hold water was measured. These relative measurements enabled the separation of soil types into discrete units. Investigating the three parameters, all factors influencing water movement in the soil are taken into account. Unsaturated hydraulic conductivity measurements in the field are influenced by texture, pore size distribution and water content. Although there are some drawbacks to the method, it supports soil hydromorphic features observed in the field. Water characteristics curve is a representation of the texture and organic matter content, the method can be used with ease to distinguish between soils with variable water holding capacities. The soil morphology can be considered the result of all the factors influencing water movement, including slope, preferential flow paths and surface / subsurface runoff from neighbouring soils. Studying redox signs is a proven method to determine water regimes in a given profile, unfortunately the method is dependent on surveyor expertise and knowledge. Furthermore the skills needed to identify soil hydromorphic features is limited to pedologists. Field and laboratory measurements together with the segmentation map, can be used by environmental scientists and hydrologists to determine soil physical properties and ultimately enhance parameter model accuracy, especially in ungauged basins.

CHAPTER 7 CONCLUSION AND RECOMMENDATION

7.1 RESEARCH CONCLUSION

Land form mapping as evolved tremendously over the past decades due to the incorporation of new technologies and remote sensing into geographical information systems. Soil scientists realised the potential of terrain delineation and was quick to adopt it in digital soil mapping techniques. Technological progress has brought the Land Types information back into focus, with the possibility to enhance and revitalise the database. The need for high resolution soil maps are growing from various disciplines including, precision agriculture, hydrology, ecology and natural resource planning. This study focuses on the application of Land Type information in hydrological modelling

Terrain features were successfully identified and delineated, solely relying on remotely sensed information and appropriate segmentation techniques. The Land Type format, 1-5 Terrain Morphological Units, was found to be compatible / comparable with the digital terrain segmentation processes. Good prediction capability was reached of 77% within a 30 m range of error. However, a few terrain features, such as a plateau, are not included in the Land Type TMU's and thus creates some error in the terrain map. This could be mitigated by adjusting the method used to identify the TMU's.

The Land Type information seems to represent the larger mountainous area outside the catchment, however, within the catchment, observed soil types and their distribution deviate substantially from the memoirs Soils development in these two landscapes differs dramatically, the mountainous region is characterised with scarps, steep slopes and convex midslopes. This landscape is unstable and considered zones of soil removal and thus limits extensive soils development. The lower foothills and alluvial fans, however, are characterised by concave footslope's and flat valley's which are considered zones of soil accumulation and development. Overall, clay content and soil depth was underestimated by the Land Type memoirs.

The terrain morphology map was used to create a soil association map, based on hydropedologic character which can easily be used to identify HRU's without sacrificing accuracy. Aggregation of soil types was based on relative hydrological response and not soil taxonomy. Soils with similar soil physical properties were grouped together using three different techniques, this proved to aggregate the map units in a meaningful manner, representing 10 out of 13 profiles. Two of above mentioned methods can be used without extensive knowledge of soil morphology or Pedology and will enable other environmental sciences to evaluate soil hydrology. Moving away from expert knowledge based methods and developing techniques that would yield the same results when applied by different users is essential for hydrological studies.

Modelling the hydrological cycle plays an important part in understanding the water security of a region and the various factors that influence it. HRU development plays a central role in physically based hydrological models, producing accurate soils information on a meaningful scale is vital. Models are interactive and can aid decision making in regards to climate change, land use change and contaminant transport to name a few. This study will hopefully encourage hydrologists and soil scientists to further research the interactions between terrain, soil and water in South Africa.

7.2 RECOMMENDATIONS FOR FUTURE RESEARCH

To improve our ability to accurately predict soil information from Land Type information, research recommendations include the following:

- Refine the segmentation method to increase the accuracy of terrain identification and verify the segmentation accuracy in other landscapes.
- Programming the segmentation process into a single GIS tool, with automatic linkage to the Land Type database.
- Evaluate the hillslope hydrology within the catchment, through runoff and subsoil water measurements. This can be modelled with Hydrus 2D, and incorporated within the catchment model.
- Determine the effects of Land Use change on runoff and siltation in the Korentepoort catchment.
- A sensitivity analysis in terms of various HRU derived maps must be done through hydrological modelling.

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APPENDIX A

Soil Properties & Modal Profiles

Table 1: Summarised Soil types and physical properties per Land Type. Standard error recorded in brackets

Land type	Soil Form	Hydrological Soil Type	ΔZ (mm)			Texture (%)								
						A Horizon			B1 (or E) Horizon			B2 Horizon		
			A	B1	B2	Sand	Clay	Silt	Sand	Clay	Silt	Sand	Clay	Silt
Db123	Mispah	Recharge	350			94.0	2	4.0						
	Oakleaf	Recharge	300	600	600	86.0	8	6.0	84	8	8			
	Kroonstad	Interflow	350	100	800	76.0	8	16.0	78	10	12			
	Estcourt	Interflow	255 (49)	230 (46)	870 (175)	77 (5.7)	9 (2.2)	14 (3.7)	75 (3.4)	10 (1.6)	15 (1.9)	35 (12.8)	26 (9.4)	39 (14.6)
	Tukulu	Interflow	300	650	300	86.0	4	10.0	76	10	14			
Fa43	Oakleaf	Recharge	200 (38)	640 (165)	675 (110)	81 (2.5)	8 (0.6)	10.4 (1.9)	80 (4.6)	9 (1.9)	11 (2.8)			
	Tukulu	Interflow	200 (0)	400 (50)	700 (100)	81 (7)	7 (3)	12 (4)	81 (7)	7 (3)	12 (4)			
	Swartland	Interflow	225 (25)	380 (40)	850 (50)	64 (4)	16 (2)	20 (2)	56 (4)	24 (4)	20 (8)	32	14	54
	Mispah	Recharge	350			84	8.0	8.0						
	Fernwood	Recharge	350	1200		86	6.0	8.0	80	6	14			
	Klapmuts	Interflow	100	230	340	56	18.0	26.0	68	10	22	48	16	36
Ib52	Pinegrove	Recharge	350	400	200	88	4.0	8.0						
	Oakleaf	Recharge	262 (37)	562 (114)	600	82(2.5)	8 (2)	2 (1.8)	86 (4.5)	6 (2.7)	8 (2.3)			
	Klapmuts	Interflow	233 (72)	283 (159)	600 (173)	74 (3.5)	11 (1.7)	14 (2)	74 (12.2)	13 (4)	13 (8.4)			
	Fernwood	Recharge	300	300 (100)		93 (1)	3 (1)	4 (0)						
	Dundee	Recharge	300	1200		80	8	12	78	10	12			
	Houwhoek	Recharge	300 (0)	215 (65)	450	87 (7)	4 (2)	9 (5)	56	28	16			
	Estcourt	Interflow	350	200	1000	76	10	14	88	4	8	12	38	50
	Swartland	Interflow	80	900	1400	60	20	20	32	32	36	10	34	56
Ib53	Mispah	Recharge	225 (75)			90 (2)	2 (0)	8 (2)						
	Fernwood	Recharge	100	200	300	88	2	10						

	M1: Oakleaf 2120
Coordinates	33°59'27.3"S 21°09'48.3"E
Terrain unit	Midslope (3)
Slope	17%
Slope type	Straight
Aspect	S
Altitude (m.a.s.l)	333
Surface stone content	Few <5%
Land use	Natural Vegetation
Age	Shrubs
Underlying Material	Colluvium

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk Density (g.cm-3)	Kunsat (mm.h-1)
	Orthic A	350	10	Coarse Sand	Sandy Loam	0	1.18	35.82
	Neocutanic B	800	16	Fine Sand	Sandy Loam	0	1.5	29.96
	Unconsolidated Material Without Signs of wetness	350	16	Fine Sand	Sandy Loam	0	1.5	

M2: Tukulu 2120

Coordinates	34°00'10.2"S 21°10'06.0"E
Terrain unit	Footslope (4)
Slope	22%
Slope type	Straight
Aspect	W
Altitude (m.a.s.l)	335
Surface stone content	Few <5%
Land use	Natural Veg
Age	Brush
Underlying Material	Hardened sediment

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
	Orthic A	200	4	Coarse Sand	Sand	5	1.38	27.31
	Neocutanic B	350	10	Medium Sand	Sandy Loam	8	1.56	26.12
	Unconsolidated Material With Signs of wetness	800						

M3: Mispah 2100

Coordinates	34°00'12.6"S 21°10'06.6"E
Terrain unit	Midslope (3)
Slope	26%
Slope type	Convex
Aspect	W
Altitude (m.a.s.l)	347
Surface stone content	Medium 30%
Land use	Natural Veg
Age	Brush
Underlying Material	Sandstone

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orthic A	300	8	Medium Sand	Loamy Sand	64	-	18.7
R	Hard Rock	-	-	-	-	-	-	-

M4: Tukulu 2110

Coordinates	33°59'59.7"S 21°10'08.3"E
Terrain unit	Foot Slope (4)
Slope	23%
Slope type	Convex
Aspect	W
Altitude (m.a.s.l)	334
Surface stone content	Few <5%
Land use	Forestry
Age	Young Trees
Underlying Material	Colluvium

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orthic A	200	10	Coarse Sand	Sandy Loam	8	1.31	23.5
B1	Neocutanic B	450	9	Coarse Sand	Sandy Loam	12	1.33	34.68
B2	Unconsolidated Material With Signs of Wetness	600	12	Coarse Sand	Sandy Loam	9	1.58	-

M5: Pinegrove 1000

Coordinates	33°58'57.1"S 21°08'22.8"E
Terrain unit	Midslope (3)
Slope	3%
Slope type	Straight
Aspect	East
Altitude (m.a.s.l)	438
Surface stone content	15-25%
Land use	Forestry
Age	Mature Trees
Underlying Material	Boulders >250mm

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orthic A	350	4	Fine Sand	Sand	26	-	31.54
B1	Podzol B	400	4	Fine Sand	Sand	37	-	-
B2	Unconsolidated without wetness	200	-	-	-	>50	-	-

M6: Dundee 2110

Coordinates	33°59'00.9"S 21°09'32.9"E
Terrain unit	Valley Bottom (5)
Slope	5%
Slope type	Straight / Flat
Aspect	East
Altitude (m.a.s.l)	362
Surface stone content	5%
Land use	Forestry
Age	Recently Harvested
Underlying Material	Alluvial Sand

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orthic A	300	8	Coarse Sand	Loamy Sand	0	1.04	33.84
B1	Stratified Alluvium	1500	10	Coarse Sand	Sandy Loam	0	1.07	-

M7: Houwhoek 2100

Coordinates	33°58'26.4"S 21°09'34.2"E
Terrain unit	Crest (1)
Slope	13%
Slope type	Convex
Aspect	Southeast
Altitude (m.a.s.l)	446
Surface stone content	10-25%
Land use	Forestry
Age	Young Trees
Underlying Material	Highly fractured sandstone

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orthic A	300	2	Coarse Sand	Sand	45	-	53.39
E1	E	200	2	Coarse Sand	Sand	67	-	48.3
B1	Podzol B	450	-	-	-	-	-	-
B2	Saprolite	500	-	-	-	-	-	-

M8: Estcourt 1100

Coordinates	33°58'37.2"S 21°09'23.1"E
Terrain unit	Upper Midslope (3)
Slope	11%
Slope type	Straight
Aspect	Southwest
Altitude (m.a.s.l)	427
Surface stone content	2-10%
Land use	Forestry
Age	Mature Trees
Underlying Material	Highly weathered shale

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orthic A	300	10	Coarse Sand	Sandy Loam	11	1.27	74.25
E1	E	150	4	Coarse Sand	Sand	63	-	128.25
B1	Prismacutanic B	450	38	Fine Sand	Silty Clay Loam	<5	1.61	0.73
B2	Saprolite	250	-	-	-	-	-	-

M9: Mispah 2100

Coordinates	33°58'25.8"S 21°06'36.5"E
Terrain unit	Crest (1)
Slope	2%
Slope type	Straight
Aspect	South
Altitude (m.a.s.l)	479
Surface stone content	2-10%
Land use	Natural Vegetation
Age	-
Underlying Material	Slightly fractured Sandstone

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A1	Orthic A	300	2	Coarse Sand	Sand	68	-	38.35
R	Hard Rock	-	-	-	-	-	-	-

M10: Estcourt 1100

Coordinates	33°58'39.7"S 21°06'53.2"E
Terrain unit	Midslope (3)
Slope	9%
Slope type	Convex
Aspect	South
Altitude (m.a.s.l)	460
Surface stone content	2-10%
Land use	Natural vegetation
Age	
Underlying Material	Shale

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A1	Orthic A	300	2	Coarse Sand	Sand	<5	1.34	57
E1	E	320	2	Coarse Sand	Loamy Sand	35	-	65.3
B1	Prismacutanic B	500	4	Fine Silt	Silt	<5	1.5	4.7

M11: Estcourt 1100

Coordinates	34°00'11.7"S 21°07'58.2"E
Terrain unit	Foot Slope (4)
Slope	22%
Slope type	Convex
Aspect	Southeast
Altitude (m.a.s.l)	387
Surface stone content	<2%
Land use	Forestry
Age	Recent harvested
Underlying Material	Shale

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orthic A	120	10	Fine Sand	Sandy Loam	<5	1.44	30.58
E	E	150	14	Fine Sand	Sandy Loam	54	-	-
B	Prismacutanic B	800	26	Fine Sand	Sandy Clay Loam	<5	1.8	7.6

M12: Kroonstad 1000

Coordinates	33°59'15.2"S 21°07'58.8"E
Terrain unit	Foot Slope (4)
Slope	11%
Slope type	Straight
Aspect	South
Altitude (m.a.s.l)	369
Surface stone content	2-10%
Land use	Forestry
Age	Mature Trees
Underlying Material	Colluvium

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orhtic A	350	8	Fine Sand	Sandy Loam	5	1.26	19.16
E	E	100	10	Fine Sand	Sandy Loam	46	-	28.8
B	Pedocutanic B	600	12	Fine Sand	Sandy Loam	8	1.5	-

M13: Swartland 2111

Coordinates	33°59'20.9"S 21°08'32.1"E
Terrain unit	Foot Slope (4)
Slope	33%
Slope type	Convex
Aspect	Southwest
Altitude (m.a.s.l)	376
Surface stone content	<2%
Land use	Forestry
Age	Mature trees
Underlying Material	Shale

Horizon	Diagnostic horizons	Depth	Clay %	Sand Grade	Texture Class	Coarse Fraction %	Bulk density (g.cm-3)	Kunsat (mm.h-1)
A	Orthic A	120	20	Fine Sand	Sandy Clay Loam	<5	1.1	18
B1	Pedocutanic B	650	32	Fine Sand	Clay Loam	<5	1.18	-
B2	Saprolite	400	34	Fine Sand	Silty Clay Loam	6	1.48	-

APPENDIX B

Land Type Memoirs:

Land Type Survey Staff (1972-2002) Land types of South Africa on 1:250 000 scale. *ARC-Institute for Soil, Climate and Water, Pretoria.*

LAND TYPE / *LANDTIP* .... : **Db123**

CLIMATE ZONE *KLIMAATSONE* ...... : 790H

Area / *Oppervlakte* .... : 7855 ha

Estimated area unavailable for agriculture

Beraamde oppervlakte onbeskikbaar vir landbou : 400 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte* :

3320 Ladismith (7193 ha) 3420 Riversdale (662 ha)

Inventory by *Inventaris deur* :

BHA Schloms & B Stehr

Modal Profiles *Modale profiele* :

None / Geen

Terrain uni *Terreineenhei* .... :	1	3	4	5
% of land type *% van landtipe* .... :	20	50	10	20
Area *Oppervlakte (ha)* .... :	1571	3928	786	1571
Slope / *Helling (%)* .... :	1 - 3	15 - 30	2 - 7	0 - 3
Slope length *Hellingslengte (m)* .... :	300 - 500	500 - 1000	200 - 300	90 - 100
Slope shape *Hellingsvorm* .... :	Y-Z	Y	X	X
MB0, MB1 (ha) .... :	1178	3731	746	1382
MB2 - MB4 (ha) .... :	393	196	39	189

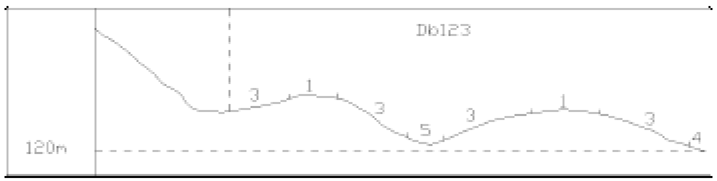
Soil series or land classes *Grondseries of landklasse*	**Depth** *Diepte* (mm)	MB :	ha	%	ha	%	ha	%	ha	%	**Total** *Totaal* ha	%	**Clay content %** *Klei-inhoud %* A	E	B21	Hor	**Texture** *Tekstuur* Class / *Klas*	**Depth limiting material** *Diepte-beperkende materiaal*
Stanford Ss23, Sterkspruit Ss26	200-300	1 :	157	10	1178	30	314	40	471	30	2121	27.0	15-20		>40	A	fiSaLm-Lm	pr
Kanonkop Gs13, Williamson Gs16	250-400	1 :	707	45	982	25	157	20			1846	23.5	10-20		15-25	A	fiSaLm-Lm	so,R
Swartland Sw31, Hogsback Sw32	200-300	1 :	314	20	982	25	196	25	236	15	1728	22.0	15-20		35-55+	B	ClLm-Cl	vp
Lichtenburg Hu23, Msinga Hu26	500-700	0 :			589	15	79	10			668	8.5	10-15		10-20	B	fiSaLm-Lm	R
Mispah Ms10	200-300	3 :	236	15	196	5	39	5			471	6.0	10-15			A	LmfiSa	R
Kosi We20, Witsand We21	200-300	0 :							361	23	361	4.6	6-10		6-15	B	LmmeSa-SaLm	sp
Dundee Du10	>1200	0 :							314	20	314	4.0	2-6			A	fi/meSa	
Coarse deposits/Growwe afsettings		2 :	157	10							157	2.0						
Stream beds/Stroombeddings		4 :							189	12	189	2.4						

For an explanation of this table consult LAND TYPE INVENTORY (table of contents)

Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Terrain type *Terreintipe* : C4

Terrain form sketch/*Terreinvormskets*



Geology: Shale of the Bokkeveld Group.

Geologie Skalie van die Bokkeveld Groep.

LAND TYPE / *LANDTIP* .... : **Ib53**
CLIMATE ZONE ***KLIMAATSONE*** ...... : 1674H
Area / *Oppervlakte* .... : 6610 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 30 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte* :
3320 Ladismith (577 ha) 3420 Riversdale (6033 ha)

Inventory by *Inventaris deur* :
BHA Schloms, F Ellis & B Stehr

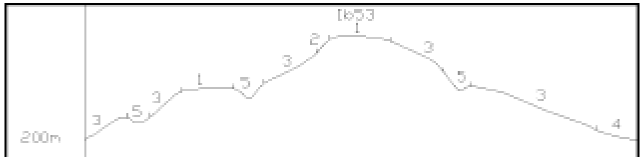
Modal Profiles *Modale profiele* :
None / Geen

Terrain uni ***Terreineenhei*** .... :	1	2	3	4	5
% of land type *% van landtipe* .... :	20	3	55	12	10
Area *Oppervlakte (ha)* .... :	1322	198	3636	793	661
Slope / *Helling (%)* .... :	2 - 6	>100	15 - 45	2 - 7	0 - 4
Slope length *Hellingslengte (m)* .... :	100 - 200	40 - 60	500 - 2000	50 - 100	90 - 100
Slope shape *Hellingsvorm* .... :	Y	Y-Z	Y-X	X-Z	X
MB0, MB1 (ha) .... :	0	0	909	793	0
MB2 - MB4 (ha) .... :	1322	198	2727	0	661

Soil series or land classes *Grondseries of landklasse*	**Depth** *Diepte* (mm)	MB :	ha	%	ha	%	ha	%	ha	%	ha	%	**Total** *Totaal* ha	%	**Clay content %** *Klei-inhoud %* A	E	B21	Hor	**Texture** *Tekstuur* Class / *Klas*	**Depth limiting material** *Diepte-beperkende materiaal*
Soil-rock complex		:																		
Grond-rotskompleks:		:																		
Rock/Rots		4 :	1190	90	198	100	2363	65			264	40	4016	60.8						
Mispah Ms10	<150	3 :	132	10			364	10					496	7.5	0-6			A	me/coSa	R
Waterridge Cf20, Grovedale Cf30, Albertinia Hh20, Houwhoek Hh30	200-400	1 :					909	25					909	13.8	0-6	0-6	6-10	E	me/coSa	R,rh
Sonnenblom Cv21, Clansthal Hu24	400-800	1 :							396	50			397	6.0	6-15		6-15	B	meSa-SaLm	R
Rosehill Sw30, Swartland Sw31, Hartbees Ss24, Elim Es31, Uitvlugt Es34	200-400	1 :							396	50			397	6.0	6-15	0-6	15-35	B	meSaLm-SaClLm	vp,pr
Coarse deposits/Growwe afsettings		2 :									397	60	397	6.0						

For an explanation of this table consult LAND TYPE INVENTORY (table of contents)
Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Terrain type ***Terreintipe*** : C5
Terrain form sketch *Terreinvormskets*



Geology: Quartzitic sandstone and subordinate shale of the Table Mountain Group.

Geologie Kwartsitiese sandsteen en ondergeskikte skalie van die Tafelberg Groep.

Remark(s): Soils are very variable and difficult to quantify.
Opmerking(s): Gronde is hoogs varieerend en moeilik om te kwantifiseer.

LAND TYPE / ***LANDTIP*** .... : **Fa43**
CLIMATE ZONE *KLIMAATSONE* ...... : 789H
Area / *Oppervlakte* .... : 2326 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 100 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte* :
3320 Ladismith (853 ha) 3420 Riversdale (1473 ha)

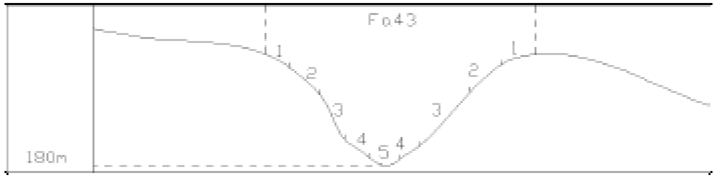
Inventory by *Inventaris deur* :
F Ellis & B Stehr

Modal Profiles *Modale profiele* :
None / Geen

Terrain uni ***Terreineenhei***	1	2	3	4	5
% of land type *% van landtipe*	10	20	45	15	10
Area *Oppervlakte (ha)*	233	465	1047	349	233
Slope / *Helling (%)*	0 - 3	>100	25 - 70	4 - 6	0 - 3
Slope length *Hellingslengte (m)*	100 - 200	80 - 100	250 - 300	100 - 150	70 - 75
Slope shape *Hellingsvorm*	Y	Y	Y	Y	X
MB0, MB1 (ha)	93	0	188	105	186
MB2 - MB4 (ha)	140	465	858	244	47

Soil series or land classes ***Grondseries of landklasse***	**Depth** ***Diepte*** (mm)	MB	ha	%	ha	%	ha	%	ha	%	ha	%	**Total** ***Totaal*** ha	%	**Clay content %** ***Klei-inhoud %*** A	E	B21	Hor	**Texture** ***Tekstuur*** Class / *Klas*	**Depth limiting material** ***Diepte-beperkende materiaal***
Rock / Rots		4			465	100	524	50	105	30			1093	47.0						
Grovedale Cf30	100-350	3	93	40			126	12	70	20			288	12.4	0-6	0-6	2-8	E	coSa	so,R
Mispah Ms10	100-250	3	47	20			157	15	35	10			238	10.3	0-6			A	fi/meSa	R
Kosi We20, Dundee Du10	300-800	1									186	80	186	8.0	4-10		2-12	B	fi/meSa	sp,U
Kanonkop Gs13	200-400	1	47	20			52	5	35	10			134	5.8	6-15		10-20	A	fiSa-SaLm	so,R
Albertinia Hh20, Garcia Hh21	200-450	1	47	20			52	5					99	4.3	2-8	2-8	2-10	E	meSa-LmSa	rh,so
Dohne Es13	300-450	1					31	3	35	10			66	2.9	6-10	6-15	>45	E	fiSa-SaLm	pr
Swartland Sw31	300-500	1					31	3	17	5			49	2.1	10-20		35-55	B	ClLm-Cl	vp
Stanford Ss23	300-400	1					21	2	17	5			38	1.7	6-15		>45	A	fiSa-SaLm	pr
Coarse deposits/Growwe afsettings		2					52	5	35	10			87	3.8						
Stream beds/Stroombeddings		4									47	20	47	2.0						

Terrain type ***Terreintipe*** : C4
Terrain form sketch *Terreinvormskets*



For an explanation of this table consult LAND TYPE INVENTORY (table of contents)
Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Mainly quartzitic sandstone of the Table Mountain Group.

Geologie Hoofsaaklik kwartsitiese sandsteen van die Tafelberg Groep.

LAND TYPE / *LANDTIP* .... : **Ib52**
CLIMATE ZONE *KLIMAATSONE* ...... : 786W
Area / *Oppervlakte* .... : 10810 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 10 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte* :
3320 Ladismith (10011 ha) 3420 Riversdale (799 ha)

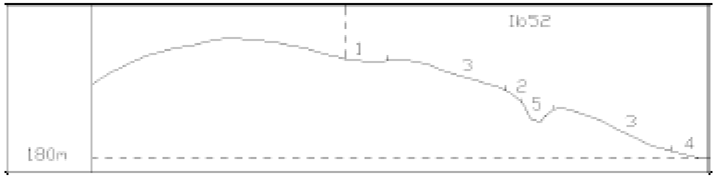
Inventory by *Inventaris deur* :
BHA Schloms, F Ellis & B Stehr

Modal Profiles *Modale profiele* :
None / Geen

Terrain uni *Terreineenhei* :	1	2	3	4	5
% of land type % *van landtipe* :	35	2	52	5	6
Area *Oppervlakte (ha)* :	3783	216	5621	540	649
Slope / *Helling (%)* :	3 - 6	>100	30 - 60	2 - 7	0 - 3
Slope length *Hellingslengte (m)* :	300 - 500	30 - 40	300 - 1000	190 - 200	80 - 100
Slope shape *Hellingsvorm* :	Y	Z	Y	Y-Z	X
MB0, MB1 (ha) :	0	0	0	0	0
MB2 - MB4 (ha) :	3784	216	5621	540	649

Soil series or land classes *Grondseries of landklasse*	**Depth** *Diepte* (mm)	MB	1 ha	1 %	2 ha	2 %	3 ha	3 %	4 ha	4 %	5 ha	5 %	**Total** *Totaal* ha	Total %	Clay content % *Klei-inhoud %* A	E	B21	Hor	**Texture** *Tekstuur* Class / *Klas*	**Depth limiting material** *Diepte-beperkende materiaal*
Soil-rock complex																				
Grond-rotskompleks:																				
Rock/Rots		4	3253	86	216	100	3373	60	54	10			6897	63.8						
Amabele Cf10, Waterridge Cf20	200-400	2	189	5			1124	20	81	15	19	3	1414	13.1	0-6	0-6	6-10	E	fi/meSa	R
Elgin Hh10, Albertinia Hh20	200-400	2	113	3			618	11	81	15	13	2	826	7.6	0-6	0-6	6-10	E	fi/meSa	rh
Mispah Ms10	<100	3	151	4			281	5	297	55	65	10	795	7.4	0-6			A	fi/meSa	R
Coarse deposits/Growwe afsettings		2	76	2			225	4	27	5	32	5	360	3.3						
Stream beds/Stroombeddings		4									519	80	519	4.8						

Terrain type *Terreintipe* : C5
Terrain form sketch *Terreinvormskets*



For an explanation of this table consult LAND TYPE INVENTORY (table of contents)
Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Mainly shale and siltstone of the Bokkeveld Group as well as quartzitic sandstone of Table Mountain Group.

Geologie Hoofsaaklik skalie en sliksteen van die Bokkeveld Groep asook kwartsitiese sandsteen van die Tafelbe Groep.

Remark(s): Soils are very variable and difficult to quantify.
Opmerking(s): Gronde is hoogs varieerend en moeilik om te kwantifiseer.

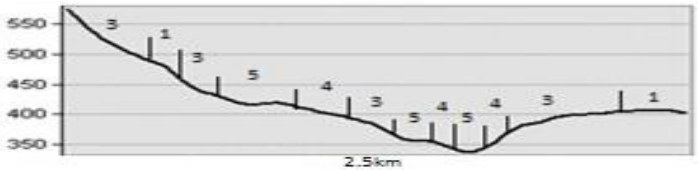
Updated Land Type information for the Korentepoort Catchment

Land Type	**Ib52 C**		**Occurrence 3420 Riversdale, Korentepoort Dam Catchment**
Climate Zone	786W		
Area	2948	ha	

Terrain Unit	1	3	4	5
% of land type	16	45	16	23
Area (ha)	471.68	1326.6	471.68	678.04
Slope (%)	0 - 8	15 - 100	3 - 15	0 - 8
Slope Length (m)	300-400	250-700	150-200	80-200
Slope Shape	Y	Y	Y-Z	X

	Depth									**Total**		**Clay Content (%)**		
Soil Series or Land Classes	**(mm)**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**A**	**E**	**B**
Cartref	300-800	19	4	27	2					45	1.5	4	6	
Concordia	500-900			27	2	28	6			55	1.9	4		
Dundee	1000-1500							237	35	237	8.1	8	10	1
Estcourt	500-1200			305	23	71	15			376	12.8	8	8	35
Fernwood	350-800	71	15	93	7	71	15			234	8.0	4	6	
Glenrosa	100-300			40	3					40	1.4	4		
Houwhoek	500-900	71	15	40	3	47	10			158	5.4	4	6	28
Katspruit	200-600			27	2					27	0.9	13	45	
Klapmuts	250-600	71	15	106	8					177	6.0	13	12	30
Kroonstad	200-600			27	2					27	0.9	8	10	45
Mispah	<100	38	8	40	3					78	2.6	4		
Nomanci	<300			27	2					27	0.9	4		
Oakleaf	300-1400	94	20	305	23	118	25	176	26	694	23.5	8	10	15
Pinegrove	500-1100	71	15							71	2.4	4		
Sterkspruit	300-600	38	8	159	12	47	10	88	13	332	11.3	8	35	
Swartland	550-1200					71	15			71	2.4	17	27	24
Sweetwater	400-700			27	2					27	0.9	6	10	15
Valsrivier	450-800			40	3	19	4	88	13	147	5.0	17	27	24
Vilafontes	500-1000			40	3			88	13	128	4.3	8	8	15

Terrain Type:



Geology: Mainly shale and siltstone of the Bokkeveld Group as well as quartzitic sandstone of Table Mountain Group

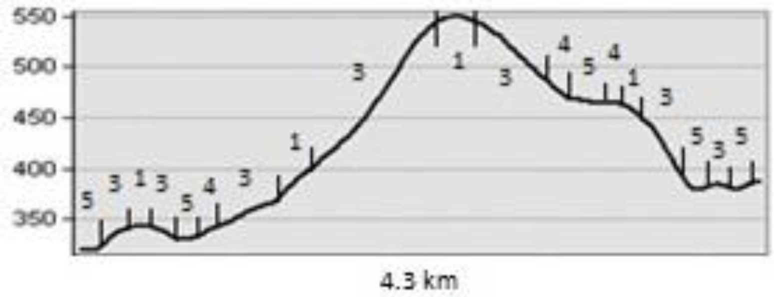
Remarks (s) Soils are very variable and difficult to quantify.

Land Type	**Ib53 C**		**Occurrence 3420 Riversdale, Korentepoort Dam Catchment**
Climate Zone	1738H		
Area	1083	ha	

Terrain Unit	1	3	4	5
% of land type	17	53	8	22
Area (ha)	184.11	573.99	86.64	238.26
Slope (%)	0 - 10	10 - 50	2 - 10	0 - 6
Slope Length (m)	100-400	150-800	50-250	75-150
Slope Shape	Y	Y-X	X-Z	X

Soil Series or Land Classes	**Depth (mm)**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**Total ha**	**%**	**Clay Content (%) A**	**E / B1**	**B2**
Dundee	800-1500							142.956	60	142.96	13.2	8	10	1
Estcourt	500-1200					17.328	20	59.565	25	76.89	7.1	8	8	35
Fernwood	350-800	46.0275	25	86.0985	15	21.66	25			153.786	14.2	4	6	
Mispah	<100	92.055	50	430.493	75	8.664	10			531.212	49.05	4		
Rock		46.0275	25	28.6995	5					74.727	6.9			
Oakleaf	300-1400			28.6995	5	17.328	20	35.739	15	81.7665	7.55	8	10	15
Sterkspruit	300-600					8.664	10			8.664	0.8	8	35	
Swartland						12.996	15			12.996	1.2	17	27	24

Terrain Type:



Geology: Quartzitic sandstone and subordomate shale of the Table Mountain Group

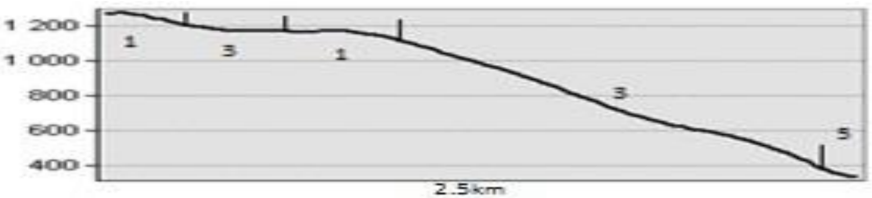
Remark (s) Soils are very variable and difficult to quantify

Land Type	**Ib168-C**		**Occurrence 3420 Riversdale, Korentepoort Dam Catchment**
Climate Zone	1738H		
Area	4213	ha	

Terrain Unit	1	3	4	5
% of land type	21	67	7	5
Area (ha)	884.73	2822.71	294.91	210.65
Slope (%)	0 - 12	12 - 100	6 - 15	5 - 15
Slope Length (m)	100 - 300	150 - 1000	50 - 150	30 - 150
Slope Shape	Y	X	X	X

Soil Series or Land Classes	**Depth (mm)**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**Total ha**	**%**	**Clay Content (%) A**	**E**	**B**
Cartref	300-800	88.473	10	705.678	25			10.5325	5	804.68	19.1	4	6	
Glenrosa	100-300	44.2365	5	705.678	25	73.7275	25	52.6625	25	876.30	20.8	4		
Houwhoek	500-900	44.2365	5	846.813	30	29.491	10			920.541	21.85	4	6	28
Mispah	<100	88.473	10	564.542	20	73.7275	25	42.13	20	768.873	18.25	4		
Rock		619.311	70			117.964	40	105.325	50	842.6	20			

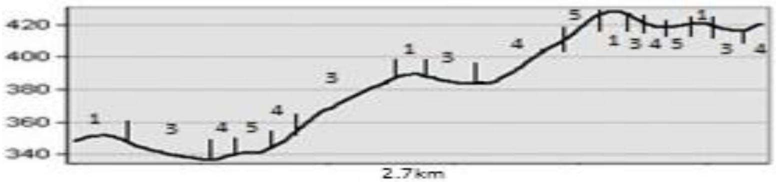
Terrain Type:



Geology: Quartzitic sandstone, siltstone, shale , conglomerate and grit of the Table Mountain Group

Land Type	Db123 C										**Occurrence: 3420 Riversdale (Korentepoort Dam)**			
Climate Zone	790H													
Area	879	ha												
Terrain Unit			1		3		4		5					
% of land type			20		40		26		14					
Area (ha)			175.8		351.6		228.54		123.06					
Slope (%)			0 - 8		10 - 35		2 - 10		0 - 4					
Slope Length (m)			200 - 500		400 - 800		100 - 350		50 - 120					
Slope Shape			Y-Z		Y		X		X					
Soil Series or Land Classes	**Depth**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**Total ha**	**%**	**Clay Content (%) A**	**E**	**B**
Estcourt	500-1200			52.7	15	45.7	20	61.5	50	160.0	18.2	8	8	35
Fernwood	350-800	35.2	20	17.6	5	22.9	10			75.6	8.6	4	6	
Glenrosa	100-300	52.7	30	28.1	8					80.9	9.2	4		
Klapmuts	250-600			28.1	8	11.4	5	24.6	20	64.2	7.3	13	12	30
Kroonstad	200-600			38.7	11	11.4	5	12.3	10	62.4	7.1	8	10	
Mispah	<100	70.3	40	17.6	5					87.9	10	4		
Oakleaf	300-1400	17.6	10	87.9	25			12.3	10	117.8	13.4	8	10	15
Sterkspruit	300-600			38.7	11	22.9	10	6.2	5	67.7	7.7	8	35	
Swartland	550-1200					22.9	10	6.2	5	29.0	3.3	17	27	24
Tukulu	300-1200					57.1	25			57.1	6.5	6	11	
Valsrivier	450-800			21.1	6	11.4	5			32.5	3.7	17	27	24
Vilafontes	500-1000			21.1	6	22.9	10			44.0	5	8	8	

Terrain Type:



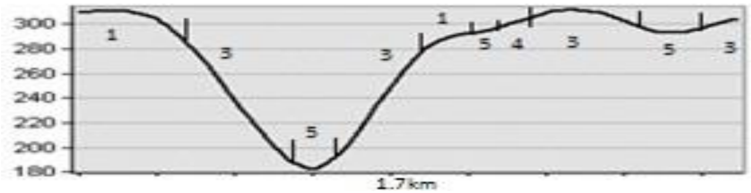
Geology: Shale of the Bokkeveld Group

Land Type Fa43 C **Occurrence 3420 Riversdale, Korentepoort Dam Catchment**
Climate Zone 789H
Area 1357 ha

Terrain Unit	1	3	4	5
% of land type	17	56	5	22
Area (ha)	230.69	759.92	67.85	298.54
Slope (%)	0 - 12	12 - 80	4 - 8	0 - 4
Slope Length (m)	100-300	25-300	20-150	60-110
Slope Shape	Y	Y	Y	X

Soil Series or Land Classes	**Depth (mm)**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**Total ha**	**%**	**Clay Content % A**	**E / B1**	**B2**
Cartref	300-800	12	5	76	10					88	6.5	4	6	
Dundee	600-1500							90	30	90	6.6	8	10	
Estcourt	500-1200	18	8	114	15	10	15	45	15	187	13.8	8	8	35
Fernwood	350-800	12	5	15	2	7	10			34	2.5	4	6	
Glenrosa	100-300	35	15	38	5					73	5.4	4		
Klapmuts	250-600			38	5					38	2.8	13	12	30
Mispah	<100	23	10	23	3	7	10			53	3.9	4		
Oakleaf	300-1400	92	40	228	30	10	15	134	45	465	34.3	8	10	15
Sterkspruit	300-600			76	10	10	15			86	6.4	8	35	
Swartland	550-1200	23	10	114	15					137	10.1	17	27	24
Tukulu	300-1200					24	35	30	10	54	4.0	6	11	
Valsrivier	450-800	16	7	38	5					54	4.0	17	27	24

Terrain Type:



Geology: Manly Quartzitic sandstone of the Table Mountain Group

APPENDIX C

Hydrological Response units Defined according to SWAT. Land Use code refers to predetermined Land Uses selected in the model, which are individually modified to represent the local vegetation. RNGE: Natural veld, RNGB: Grazed veld, WETL: Wetlands, Pine: Pine forest, WWHT: Non irrigated commercial land, AGRL: Irrigated commercial land, WATR: waterbodies, WPAS: Irrigated pastures, FRST: Forest

SUBBASIN	LAND USE	SOIL CODE	SLOPE CLASS	MEAN_SLOPE (%)	AREA (Ha)	UNIQUE COMBINATION
1	RNGE	RECHARGE	1.5-20	13.51317024	1.89	1_RNGE_RECHARGE_1.5-20
1	RNGE	RECHARGE	20-9999	53.80630112	33.70	1_RNGE_RECHARGE_20-9999
1	RNGE	Response	20-9999	54.02428818	19.10	1_RNGE_Response_20-9999
1	RNGB	Response	20-9999	54.62430954	76.33	1_RNGB_Response_20-9999
1	RNGB	RECHARGE	20-9999	61.88523865	168.73	1_RNGB_RECHARGE_20-9999
1	RNGB	Response	1.5-20	13.30553246	6.15	1_RNGB_Response_1.5-20
1	WETL	RECHARGE	20-9999	44.05938339	2.62	1_WETL_RECHARGE_20-9999
1	RNGB	RECHARGE	1.5-20	13.93049526	3.77	1_RNGB_RECHARGE_1.5-20
1	RNGE	Response	1.5-20	15.40528965	1.23	1_RNGE_Response_1.5-20
1	RNGB	Response	0-1.5	1.39728868	0.08	1_RNGB_Response_0-1.5
1	RNGE	Response	0-1.5	1.39728868	0.08	1_RNGE_Response_0-1.5
2	RNGE	RECHARGE	20-9999	64.74700165	181.68	2_RNGE_RECHARGE_20-9999
2	RNGB	RECHARGE	20-9999	50.78591919	193.00	2_RNGB_RECHARGE_20-9999
2	RNGB	RECHARGE	1.5-20	13.23215675	16.40	2_RNGB_RECHARGE_1.5-20
2	RNGB	RECHARGE	0-1.5	1.140505791	0.16	2_RNGB_RECHARGE_0-1.5
2	RNGB	Response	20-9999	55.99129486	72.89	2_RNGB_Response_20-9999
2	RNGB	Response	1.5-20	13.6017561	15.25	2_RNGB_Response_1.5-20
2	RNGE	Response	20-9999	55.24393845	64.69	2_RNGE_Response_20-9999
2	RNGE	RECHARGE	1.5-20	15.41542625	3.36	2_RNGE_RECHARGE_1.5-20
2	RNGE	Response	1.5-20	14.4341259	9.84	2_RNGE_Response_1.5-20
2	RNGB	Response	0-1.5	1.39728868	0.08	2_RNGB_Response_0-1.5
2	RNGE	Response	0-1.5	1.249773026	0.08	2_RNGE_Response_0-1.5
3	RNGB	Response	20-9999	89.05256653	17.05	3_RNGB_Response_20-9999
3	RNGB	RECHARGE	1.5-20	15.29111767	12.22	3_RNGB_RECHARGE_1.5-20
3	RNGB	RECHARGE	20-9999	52.85652542	128.06	3_RNGB_RECHARGE_20-9999
3	RNGB	Response	1.5-20	17.01661682	0.57	3_RNGB_Response_1.5-20
3	RNGE	Response	20-9999	71.51412964	0.16	3_RNGE_Response_20-9999
3	RNGB	INTERFLOW	20-9999	37.21583557	25.01	3_RNGB_INTERFLOW_20-9999
3	RNGB	INTERFLOW	1.5-20	15.26520348	3.94	3_RNGB_INTERFLOW_1.5-20
3	RNGE	INTERFLOW	20-9999	33.25452805	5.00	3_RNGE_INTERFLOW_20-9999
3	RNGE	INTERFLOW	1.5-20	15.45249557	2.13	3_RNGE_INTERFLOW_1.5-20
3	RNGE	RECHARGE	20-9999	28.484869	13.53	3_RNGE_RECHARGE_20-9999
3	RNGE	RECHARGE	1.5-20	12.79234219	8.28	3_RNGE_RECHARGE_1.5-20
3	WETL	RECHARGE	20-9999	62.11573029	0.08	3_WETL_RECHARGE_20-9999
3	WETL	INTERFLOW	20-9999	34.87761307	0.82	3_WETL_INTERFLOW_20-9999
3	WETL	INTERFLOW	1.5-20	12.54873657	1.07	3_WETL_INTERFLOW_1.5-20
3	WETL	INTERFLOW	0-1.5	0.624886513	0.08	3_WETL_INTERFLOW_0-1.5
3	RNGE	RECHARGE	0-1.5	0.624886513	0.08	3_RNGE_RECHARGE_0-1.5
3	RNGB	RECHARGE	0-1.5	0.674058378	0.25	3_RNGB_RECHARGE_0-1.5
4	RNGE	Response	1.5-20	14.65860653	2.46	4_RNGE_Response_1.5-20
4	RNGE	RECHARGE	20-9999	59.65368271	204.23	4_RNGE_RECHARGE_20-9999
4	RNGE	RECHARGE	1.5-20	14.77313805	8.85	4_RNGE_RECHARGE_1.5-20
4	RNGE	Response	20-9999	66.97850037	69.28	4_RNGE_Response_20-9999
4	RNGB	Response	20-9999	61.55211258	108.55	4_RNGB_Response_20-9999
4	RNGB	RECHARGE	20-9999	59.88384628	192.09	4_RNGB_RECHARGE_20-9999
4	RNGB	Response	1.5-20	15.17379665	3.12	4_RNGB_Response_1.5-20
4	RNGB	RECHARGE	1.5-20	15.08268356	12.30	4_RNGB_RECHARGE_1.5-20
4	WETL	RECHARGE	20-9999	47.6626358	2.21	4_WETL_RECHARGE_20-9999
4	RNGE	INTERFLOW	20-9999	41.87685776	3.61	4_RNGE_INTERFLOW_20-9999
4	RNGB	INTERFLOW	20-9999	45.20353317	6.15	4_RNGB_INTERFLOW_20-9999
4	RNGB	INTERFLOW	1.5-20	10.55304718	0.41	4_RNGB_INTERFLOW_1.5-20
5	RNGB	RECHARGE	20-9999	54.01246262	562.10	5_RNGB_RECHARGE_20-9999
5	RNGB	Response	1.5-20	14.15818405	15.17	5_RNGB_Response_1.5-20
5	RNGB	Response	20-9999	58.39348221	171.93	5_RNGB_Response_20-9999
5	RNGB	RECHARGE	1.5-20	12.2431488	87.07	5_RNGB_RECHARGE_1.5-20
5	RNGB	RECHARGE	0-1.5	0.927309394	1.89	5_RNGB_RECHARGE_0-1.5
5	RNGE	RECHARGE	20-9999	41.85125732	38.29	5_RNGE_RECHARGE_20-9999
5	RNGE	Response	20-9999	47.57622528	20.82	5_RNGE_Response_20-9999
5	RNGE	RECHARGE	1.5-20	14.5373354	5.66	5_RNGE_RECHARGE_1.5-20
5	RNGE	Response	1.5-20	13.9706068	1.80	5_RNGE_Response_1.5-20
5	RNGB	Response	0-1.5	1.39728868	0.08	5_RNGB_Response_0-1.5
5	RNGB	INTERFLOW	20-9999	29.87675667	47.96	5_RNGB_INTERFLOW_20-9999
5	RNGB	INTERFLOW	1.5-20	10.24889565	74.28	5_RNGB_INTERFLOW_1.5-20
5	RNGE	INTERFLOW	1.5-20	8.907666206	1.23	5_RNGE_INTERFLOW_1.5-20
5	RNGB	INTERFLOW	0-1.5	0.965945899	1.23	5_RNGB_INTERFLOW_0-1.5
5	PINE	INTERFLOW	20-9999	30.27564621	17.55	5_PINE_INTERFLOW_20-9999
5	PINE	RECHARGE	20-9999	29.39724731	39.85	5_PINE_RECHARGE_20-9999
5	PINE	RECHARGE	1.5-20	12.10441494	76.49	5_PINE_RECHARGE_1.5-20
5	PINE	INTERFLOW	1.5-20	11.19558334	19.43	5_PINE_INTERFLOW_1.5-20
5	PINE	RECHARGE	0-1.5	1.050868511	0.98	5_PINE_RECHARGE_0-1.5
5	PINE	INTERFLOW	0-1.5	0.83113426	0.41	5_PINE_INTERFLOW_0-1.5
6	RNGB	RECHARGE	1.5-20	13.95450878	25.66	6_RNGB_RECHARGE_1.5-20
6	RNGB	Response	1.5-20	14.00456333	11.89	6_RNGB_Response_1.5-20

6	RNGB	Response	20-9999	74.12081146	177.58	6_RNGB_Response_20-9999
6	RNGB	RECHARGE	20-9999	64.16716766	328.68	6_RNGB_RECHARGE_20-9999
6	RNGE	Response	20-9999	59.81324005	6.23	6_RNGE_Response_20-9999
6	RNGE	RECHARGE	20-9999	41.77301407	1.23	6_RNGE_RECHARGE_20-9999
6	RNGE	Response	1.5-20	13.7240057	1.72	6_RNGE_Response_1.5-20
6	RNGB	Response	0-1.5	0.937329769	0.16	6_RNGB_Response_0-1.5
6	RNGB	INTERFLOW	20-9999	34.77737808	20.41	6_RNGB_INTERFLOW_20-9999
6	RNGB	INTERFLOW	1.5-20	11.4863863	21.89	6_RNGB_INTERFLOW_1.5-20
6	RNGE	RECHARGE	1.5-20	16.72335243	1.97	6_RNGE_RECHARGE_1.5-20
6	RNGE	INTERFLOW	20-9999	30.2233181	0.25	6_RNGE_INTERFLOW_20-9999
6	PINE	INTERFLOW	1.5-20	12.81711864	30.33	6_PINE_INTERFLOW_1.5-20
6	PINE	RECHARGE	1.5-20	11.0152359	67.97	6_PINE_RECHARGE_1.5-20
6	PINE	RECHARGE	20-9999	28.45946312	38.45	6_PINE_RECHARGE_20-9999
6	PINE	INTERFLOW	20-9999	28.10926056	10.74	6_PINE_INTERFLOW_20-9999
6	PINE	INTERFLOW	0-1.5	0.624886513	0.08	6_PINE_INTERFLOW_0-1.5
6	PINE	RECHARGE	0-1.5	0.917143881	1.39	6_PINE_RECHARGE_0-1.5
6	RNGB	INTERFLOW	0-1.5	1.075796723	0.33	6_RNGB_INTERFLOW_0-1.5
6	RNGB	RECHARGE	0-1.5	1.249773026	0.08	6_RNGB_RECHARGE_0-1.5
7	RNGB	Response	20-9999	65.22748566	6.07	7_RNGB_Response_20-9999
7	RNGB	Response	1.5-20	17.82014656	0.41	7_RNGB_Response_1.5-20
7	RNGB	RECHARGE	20-9999	45.29674911	85.59	7_RNGB_RECHARGE_20-9999
7	RNGB	RECHARGE	1.5-20	12.75888062	50.09	7_RNGB_RECHARGE_1.5-20
7	RNGB	INTERFLOW	1.5-20	13.18081284	27.88	7_RNGB_INTERFLOW_1.5-20
7	RNGB	INTERFLOW	20-9999	25.1833725	18.94	7_RNGB_INTERFLOW_20-9999
7	PINE	RECHARGE	1.5-20	8.734830856	15.50	7_PINE_RECHARGE_1.5-20
7	RNGB	INTERFLOW	0-1.5	0	0.08	7_RNGB_INTERFLOW_0-1.5
7	RNGE	INTERFLOW	1.5-20	13.51517677	1.48	7_RNGE_INTERFLOW_1.5-20
7	WWHT	RECHARGE	1.5-20	9.654661179	10.25	7_WWHT_RECHARGE_1.5-20
7	RNGE	INTERFLOW	20-9999	24.32086754	0.49	7_RNGE_INTERFLOW_20-9999
7	WWHT	RECHARGE	20-9999	22.8466568	3.61	7_WWHT_RECHARGE_20-9999
7	RNGB	RECHARGE	0-1.5	0.624886513	0.08	7_RNGB_RECHARGE_0-1.5
7	RNGE	RECHARGE	1.5-20	14.87596893	2.05	7_RNGE_RECHARGE_1.5-20
7	WWHT	INTERFLOW	20-9999	26.103508	0.08	7_WWHT_INTERFLOW_20-9999
7	AGRL	INTERFLOW	1.5-20	12.19270992	7.46	7_AGRL_INTERFLOW_1.5-20
7	AGRL	INTERFLOW	20-9999	24.6570549	1.39	7_AGRL_INTERFLOW_20-9999
7	AGRL	RECHARGE	20-9999	23.55813789	6.23	7_AGRL_RECHARGE_20-9999
7	AGRL	RECHARGE	1.5-20	12.88310719	21.07	7_AGRL_RECHARGE_1.5-20
7	WWHT	RECHARGE	0-1.5	1.360409737	0.33	7_WWHT_RECHARGE_0-1.5
7	RNGE	RECHARGE	20-9999	21.64813232	0.16	7_RNGE_RECHARGE_20-9999
7	AGRL	INTERFLOW	0-1.5	1.249773026	0.08	7_AGRL_INTERFLOW_0-1.5
7	WATR	RECHARGE	1.5-20	13.93074036	0.49	7_WATR_RECHARGE_1.5-20
7	WATR	RECHARGE	20-9999	20.35442543	0.08	7_WATR_RECHARGE_20-9999
7	FRST	RECHARGE	1.5-20	9.505822182	10.00	7_FRST_RECHARGE_1.5-20
7	AGRL	RECHARGE	0-1.5	1.011087656	0.16	7_AGRL_RECHARGE_0-1.5
7	FRST	RECHARGE	20-9999	24.59965706	1.56	7_FRST_RECHARGE_20-9999
7	PINE	RECHARGE	20-9999	25.19351006	3.53	7_PINE_RECHARGE_20-9999
8	RNGB	Response	20-9999	78.91458893	30.01	8_RNGB_Response_20-9999
8	RNGB	Response	1.5-20	16.06297874	0.90	8_RNGB_Response_1.5-20
8	RNGB	RECHARGE	1.5-20	12.60787964	33.94	8_RNGB_RECHARGE_1.5-20
8	RNGB	RECHARGE	20-9999	55.52457809	64.44	8_RNGB_RECHARGE_20-9999
8	RNGB	INTERFLOW	20-9999	24.68318939	13.36	8_RNGB_INTERFLOW_20-9999
8	RNGB	INTERFLOW	1.5-20	13.44200897	44.52	8_RNGB_INTERFLOW_1.5-20
8	WWHT	RECHARGE	1.5-20	12.06315899	10.17	8_WWHT_RECHARGE_1.5-20
8	WWHT	INTERFLOW	1.5-20	15.68993282	2.62	8_WWHT_INTERFLOW_1.5-20
8	RNGE	RECHARGE	1.5-20	14.8485117	1.23	8_RNGE_RECHARGE_1.5-20
8	WWHT	RECHARGE	0-1.5	0.883722961	0.08	8_WWHT_RECHARGE_0-1.5
8	WATR	RECHARGE	1.5-20	12.33655739	1.56	8_WATR_RECHARGE_1.5-20
8	WWHT	RECHARGE	20-9999	24.48272705	0.66	8_WWHT_RECHARGE_20-9999
8	WWHT	INTERFLOW	20-9999	22.13339615	0.41	8_WWHT_INTERFLOW_20-9999
9	RNGB	Response	20-9999	95.62757874	1.31	9_RNGB_Response_20-9999
9	RNGB	RECHARGE	20-9999	47.73840714	106.01	9_RNGB_RECHARGE_20-9999
9	RNGB	Response	1.5-20	13.36207008	0.16	9_RNGB_Response_1.5-20
9	RNGB	RECHARGE	1.5-20	14.11763096	24.19	9_RNGB_RECHARGE_1.5-20
9	RNGB	INTERFLOW	1.5-20	13.06228924	8.94	9_RNGB_INTERFLOW_1.5-20
9	RNGB	INTERFLOW	20-9999	37.32365799	17.38	9_RNGB_INTERFLOW_20-9999
9	RNGE	RECHARGE	20-9999	48.87785339	41.32	9_RNGE_RECHARGE_20-9999
9	RNGE	INTERFLOW	20-9999	42.61312866	3.61	9_RNGE_INTERFLOW_20-9999
9	RNGE	RECHARGE	1.5-20	10.30149937	19.43	9_RNGE_RECHARGE_1.5-20
9	WETL	INTERFLOW	20-9999	37.38637161	0.41	9_WETL_INTERFLOW_20-9999
9	WETL	INTERFLOW	1.5-20	8.441980362	0.49	9_WETL_INTERFLOW_1.5-20
9	WETL	INTERFLOW	0-1.5	1.249773026	0.08	9_WETL_INTERFLOW_0-1.5
9	RNGE	INTERFLOW	1.5-20	16.21350098	0.74	9_RNGE_INTERFLOW_1.5-20
9	RNGB	INTERFLOW	0-1.5	1.249773026	0.08	9_RNGB_INTERFLOW_0-1.5
9	RNGB	RECHARGE	0-1.5	1.39728868	0.16	9_RNGB_RECHARGE_0-1.5
9	WETL	RECHARGE	20-9999	62.22356033	2.95	9_WETL_RECHARGE_20-9999
9	RNGE	RECHARGE	0-1.5	0.976351798	0.90	9_RNGE_RECHARGE_0-1.5
10	RNGE	Response	1.5-20	14.8737793	0.33	10_RNGE_Response_1.5-20
10	RNGE	Response	20-9999	30.51184464	0.49	10_RNGE_Response_20-9999
10	RNGB	Response	20-9999	89.35903931	8.53	10_RNGB_Response_20-9999
10	RNGB	Response	1.5-20	11.83554268	0.16	10_RNGB_Response_1.5-20
10	RNGB	RECHARGE	20-9999	54.68595123	64.69	10_RNGB_RECHARGE_20-9999
10	RNGB	RECHARGE	1.5-20	11.76495552	52.88	10_RNGB_RECHARGE_1.5-20
10	RNGB	INTERFLOW	20-9999	28.89506149	16.56	10_RNGB_INTERFLOW_20-9999
10	RNGB	INTERFLOW	1.5-20	12.16781235	17.55	10_RNGB_INTERFLOW_1.5-20
10	PINE	RECHARGE	1.5-20	8.988951683	16.97	10_PINE_RECHARGE_1.5-20
10	PINE	RECHARGE	20-9999	25.02876854	0.90	10_PINE_RECHARGE_20-9999
10	PINE	INTERFLOW	20-9999	25.49812508	0.08	10_PINE_INTERFLOW_20-9999

10	PINE	INTERFLOW	1.5-20	9.707994461	7.30	10_PINE_INTERFLOW_1.5-20
10	RNGE	RECHARGE	1.5-20	13.6660862	12.05	10_RNGE_RECHARGE_1.5-20
10	RNGE	RECHARGE	20-9999	36.64673615	16.07	10_RNGE_RECHARGE_20-9999
10	PINE	RECHARGE	0-1.5	0.829312682	0.74	10_PINE_RECHARGE_0-1.5
10	RNGE	INTERFLOW	20-9999	30.02662659	1.39	10_RNGE_INTERFLOW_20-9999
10	RNGE	INTERFLOW	1.5-20	14.95090866	0.82	10_RNGE_INTERFLOW_1.5-20
10	RNGB	RECHARGE	0-1.5	0.908695936	1.15	10_RNGB_RECHARGE_0-1.5
10	PINE	INTERFLOW	0-1.5	1.39728868	0.08	10_PINE_INTERFLOW_0-1.5
10	RNGE	RECHARGE	0-1.5	0.883722961	0.08	10_RNGE_RECHARGE_0-1.5
10	RNGB	INTERFLOW	0-1.5	1.39728868	0.08	10_RNGB_INTERFLOW_0-1.5
11	RNGB	Response	20-9999	89.56214142	12.13	11_RNGB_Response_20-9999
11	RNGE	Response	1.5-20	12.8060503	6.23	11_RNGE_Response_1.5-20
11	RNGE	Response	20-9999	41.19909286	2.05	11_RNGE_Response_20-9999
11	RNGB	Response	1.5-20	10.70687008	6.72	11_RNGB_Response_1.5-20
11	RNGB	RECHARGE	20-9999	41.23872375	90.51	11_RNGB_RECHARGE_20-9999
11	RNGB	RECHARGE	1.5-20	10.06982231	164.14	11_RNGB_RECHARGE_1.5-20
11	RNGE	RECHARGE	20-9999	24.26543617	17.63	11_RNGE_RECHARGE_20-9999
11	RNGB	INTERFLOW	20-9999	23.25230217	8.20	11_RNGB_INTERFLOW_20-9999
11	RNGB	INTERFLOW	1.5-20	7.628973961	103.14	11_RNGB_INTERFLOW_1.5-20
11	RNGE	RECHARGE	1.5-20	12.39904881	72.97	11_RNGE_RECHARGE_1.5-20
11	RNGE	INTERFLOW	1.5-20	12.23320961	9.59	11_RNGE_INTERFLOW_1.5-20
11	RNGE	INTERFLOW	20-9999	21.72018623	1.39	11_RNGE_INTERFLOW_20-9999
11	RNGB	INTERFLOW	0-1.5	1.024416447	5.08	11_RNGB_INTERFLOW_0-1.5
11	RNGB	RECHARGE	0-1.5	1.219234347	2.62	11_RNGB_RECHARGE_0-1.5
11	WPAS	RECHARGE	1.5-20	10.79870701	46.73	11_WPAS_RECHARGE_1.5-20
11	WPAS	RECHARGE	20-9999	24.17053223	6.64	11_WPAS_RECHARGE_20-9999
11	WPAS	Response	20-9999	21.49579239	0.16	11_WPAS_Response_20-9999
11	WPAS	Response	1.5-20	9.944749832	0.74	11_WPAS_Response_1.5-20
11	PINE	RECHARGE	0-1.5	0.979246438	0.66	11_PINE_RECHARGE_0-1.5
11	PINE	RECHARGE	1.5-20	10.76330566	68.46	11_PINE_RECHARGE_1.5-20
11	PINE	INTERFLOW	1.5-20	6.881324768	27.14	11_PINE_INTERFLOW_1.5-20
11	PINE	INTERFLOW	0-1.5	1.080015659	2.87	11_PINE_INTERFLOW_0-1.5
11	RNGE	RECHARGE	0-1.5	1.011087656	0.16	11_RNGE_RECHARGE_0-1.5
11	RNGE	Response	0-1.5	0.754304767	0.16	11_RNGE_Response_0-1.5
11	PINE	RECHARGE	20-9999	22.37760162	8.44	11_PINE_RECHARGE_20-9999
11	PINE	INTERFLOW	20-9999	21.41635895	1.72	11_PINE_INTERFLOW_20-9999
11	WPAS	RECHARGE	0-1.5	1.00505507	0.49	11_WPAS_RECHARGE_0-1.5
11	PINE	Response	1.5-20	13.91938019	0.74	11_PINE_Response_1.5-20
12	RNGB	RECHARGE	1.5-20	10.59423923	67.47	12_RNGB_RECHARGE_1.5-20
12	RNGB	RECHARGE	0-1.5	1.16139102	0.98	12_RNGB_RECHARGE_0-1.5
12	WPAS	RECHARGE	1.5-20	10.87455177	46.98	12_WPAS_RECHARGE_1.5-20
12	WPAS	RECHARGE	0-1.5	1.249773026	0.08	12_WPAS_RECHARGE_0-1.5
12	RNGB	RECHARGE	20-9999	23.67592239	20.58	12_RNGB_RECHARGE_20-9999
12	WPAS	RECHARGE	20-9999	23.91730309	10.66	12_WPAS_RECHARGE_20-9999
12	WPAS	Response	1.5-20	10.16357136	2.95	12_WPAS_Response_1.5-20
12	RNGB	Response	1.5-20	10.75485039	2.13	12_RNGB_Response_1.5-20
12	PAST	RECHARGE	1.5-20	11.86496258	11.07	12_PAST_RECHARGE_1.5-20
12	PAST	RECHARGE	20-9999	20.15198326	0.08	12_PAST_RECHARGE_20-9999
13	PINE	INTERFLOW	1.5-20	11.13685036	18.86	13_PINE_INTERFLOW_1.5-20
13	PINE	RECHARGE	1.5-20	10.16093826	32.47	13_PINE_RECHARGE_1.5-20
13	PINE	INTERFLOW	20-9999	24.22549629	5.49	13_PINE_INTERFLOW_20-9999
13	PINE	RECHARGE	0-1.5	1.367785573	0.41	13_PINE_RECHARGE_0-1.5
13	PINE	RECHARGE	20-9999	22.66961098	3.61	13_PINE_RECHARGE_20-9999
13	RNGB	RECHARGE	1.5-20	11.62380695	12.54	13_RNGB_RECHARGE_1.5-20
13	RNGB	Response	1.5-20	7.130632877	0.82	13_RNGB_Response_1.5-20
13	RNGB	RECHARGE	20-9999	24.48806381	3.53	13_RNGB_RECHARGE_20-9999
13	WPAS	Response	1.5-20	12.99540234	0.25	13_WPAS_Response_1.5-20
13	WPAS	RECHARGE	1.5-20	13.44302177	26.48	13_WPAS_RECHARGE_1.5-20
13	RNGB	INTERFLOW	1.5-20	11.10418224	3.77	13_RNGB_INTERFLOW_1.5-20
13	WPAS	RECHARGE	20-9999	24.23040962	10.33	13_WPAS_RECHARGE_20-9999
13	RNGB	RECHARGE	0-1.5	1.011087656	0.16	13_RNGB_RECHARGE_0-1.5
13	RNGB	INTERFLOW	20-9999	23.36552048	0.57	13_RNGB_INTERFLOW_20-9999
13	WPAS	RECHARGE	0-1.5	1.39728868	0.08	13_WPAS_RECHARGE_0-1.5
13	PINE	INTERFLOW	0-1.5	1.011087656	0.16	13_PINE_INTERFLOW_0-1.5
13	WETL	RECHARGE	1.5-20	16.94600487	0.16	13_WETL_RECHARGE_1.5-20
13	WETL	INTERFLOW	1.5-20	15.37513638	0.16	13_WETL_INTERFLOW_1.5-20
13	WATR	INTERFLOW	1.5-20	3.966097593	0.41	13_WATR_INTERFLOW_1.5-20
13	WATR	RECHARGE	1.5-20	7.424003124	0.49	13_WATR_RECHARGE_1.5-20
13	WATR	RECHARGE	20-9999	22.69991875	0.25	13_WATR_RECHARGE_20-9999
13	WETL	RECHARGE	20-9999	22.74621201	0.08	13_WETL_RECHARGE_20-9999
14	PINE	RECHARGE	0-1.5	1.021200776	1.07	14_PINE_RECHARGE_0-1.5
14	PINE	RECHARGE	1.5-20	11.97406578	54.60	14_PINE_RECHARGE_1.5-20
14	PINE	INTERFLOW	1.5-20	10.69291592	4.92	14_PINE_INTERFLOW_1.5-20
14	RNGB	RECHARGE	1.5-20	5.314310074	0.66	14_RNGB_RECHARGE_1.5-20
14	PINE	INTERFLOW	0-1.5	1.249773026	0.08	14_PINE_INTERFLOW_0-1.5
14	PINE	RECHARGE	20-9999	26.40174675	22.30	14_PINE_RECHARGE_20-9999
14	FRST	RECHARGE	20-9999	27.15980148	38.21	14_FRST_RECHARGE_20-9999
14	FRST	RECHARGE	1.5-20	12.66146564	55.01	14_FRST_RECHARGE_1.5-20
14	FRST	INTERFLOW	1.5-20	13.61969471	12.05	14_FRST_INTERFLOW_1.5-20
14	FRST	INTERFLOW	20-9999	26.11126328	6.15	14_FRST_INTERFLOW_20-9999
14	FRST	RECHARGE	0-1.5	0.817987084	0.33	14_FRST_RECHARGE_0-1.5
14	PINE	INTERFLOW	20-9999	24.71967506	2.71	14_PINE_INTERFLOW_20-9999
14	FRST	INTERFLOW	0-1.5	0.624886513	0.08	14_FRST_INTERFLOW_0-1.5
14	RNGB	INTERFLOW	20-9999	38.88536835	0.16	14_RNGB_INTERFLOW_20-9999
14	RNGB	INTERFLOW	1.5-20	13.87473202	0.08	14_RNGB_INTERFLOW_1.5-20
15	PINE	RECHARGE	1.5-20	9.56021595	11.40	15_PINE_RECHARGE_1.5-20
15	PINE	INTERFLOW	1.5-20	11.67569637	1.72	15_PINE_INTERFLOW_1.5-20

15	PINE	RECHARGE	20-9999	32.85977936	4.43	15_PINE_RECHARGE_20-9999
15	WATR	INTERFLOW	0-1.5	0	0.41	15_WATR_INTERFLOW_0-1.5
15	WATR	INTERFLOW	1.5-20	6.339011669	2.95	15_WATR_INTERFLOW_1.5-20
15	RNGB	INTERFLOW	1.5-20	12.83835697	17.79	15_RNGB_INTERFLOW_1.5-20
15	WPAS	INTERFLOW	1.5-20	12.69137764	22.71	15_WPAS_INTERFLOW_1.5-20
15	WATR	RECHARGE	1.5-20	5.071054459	2.13	15_WATR_RECHARGE_1.5-20
15	WATR	RECHARGE	0-1.5	0.165441364	1.31	15_WATR_RECHARGE_0-1.5
15	RNGB	RECHARGE	1.5-20	13.73705482	3.03	15_RNGB_RECHARGE_1.5-20
15	WPAS	INTERFLOW	20-9999	22.05108261	1.97	15_WPAS_INTERFLOW_20-9999
15	RNGB	INTERFLOW	20-9999	23.21610641	1.72	15_RNGB_INTERFLOW_20-9999
15	RNGB	RECHARGE	20-9999	23.10286522	0.82	15_RNGB_RECHARGE_20-9999
15	WPAS	RECHARGE	1.5-20	11.48269463	2.79	15_WPAS_RECHARGE_1.5-20
15	WPAS	RECHARGE	20-9999	20.1228981	0.08	15_WPAS_RECHARGE_20-9999
15	RNGB	INTERFLOW	0-1.5	1.39728868	0.08	15_RNGB_INTERFLOW_0-1.5
16	PINE	INTERFLOW	0-1.5	0.992892623	1.15	16_PINE_INTERFLOW_0-1.5
16	PINE	INTERFLOW	1.5-20	8.649282455	19.59	16_PINE_INTERFLOW_1.5-20
16	PINE	RECHARGE	0-1.5	1.149383187	0.66	16_PINE_RECHARGE_0-1.5
16	PINE	RECHARGE	1.5-20	12.00226879	78.30	16_PINE_RECHARGE_1.5-20
16	RNGB	INTERFLOW	1.5-20	7.981928349	4.92	16_RNGB_INTERFLOW_1.5-20
16	PINE	RECHARGE	20-9999	27.45697784	32.22	16_PINE_RECHARGE_20-9999
16	PINE	INTERFLOW	20-9999	25.62424469	5.66	16_PINE_INTERFLOW_20-9999
16	RNGB	INTERFLOW	20-9999	25.24626732	0.74	16_RNGB_INTERFLOW_20-9999
16	RNGB	INTERFLOW	0-1.5	1.103113532	0.66	16_RNGB_INTERFLOW_0-1.5
16	RNGB	RECHARGE	20-9999	28.02145386	1.23	16_RNGB_RECHARGE_20-9999
16	RNGB	RECHARGE	1.5-20	14.98599625	0.41	16_RNGB_RECHARGE_1.5-20
16	WATR	INTERFLOW	0-1.5	0.075529121	3.03	16_WATR_INTERFLOW_0-1.5
16	WATR	RECHARGE	1.5-20	10.22551727	3.44	16_WATR_RECHARGE_1.5-20
16	WETL	INTERFLOW	1.5-20	4.818555832	0.25	16_WETL_INTERFLOW_1.5-20
16	WATR	INTERFLOW	1.5-20	8.266963005	1.07	16_WATR_INTERFLOW_1.5-20
16	WATR	RECHARGE	20-9999	25.73633957	0.66	16_WATR_RECHARGE_20-9999
16	WATR	RECHARGE	0-1.5	0	3.03	16_WATR_RECHARGE_0-1.5
16	WATR	INTERFLOW	20-9999	23.64737511	0.33	16_WATR_INTERFLOW_20-9999
17	FRST	RECHARGE	1.5-20	13.03499889	8.36	17_FRST_RECHARGE_1.5-20
17	FRST	RECHARGE	20-9999	33.14126968	23.53	17_FRST_RECHARGE_20-9999
17	FRST	RECHARGE	0-1.5	0.624886513	0.08	17_FRST_RECHARGE_0-1.5
17	RNGB	RECHARGE	20-9999	39.85638809	27.55	17_RNGB_RECHARGE_20-9999
17	RNGB	RECHARGE	1.5-20	14.01608562	6.23	17_RNGB_RECHARGE_1.5-20
17	RNGB	INTERFLOW	1.5-20	11.58878613	28.29	17_RNGB_INTERFLOW_1.5-20
17	RNGB	INTERFLOW	20-9999	29.68425751	23.04	17_RNGB_INTERFLOW_20-9999
17	RNGE	INTERFLOW	20-9999	26.72454834	13.20	17_RNGE_INTERFLOW_20-9999
17	RNGE	INTERFLOW	1.5-20	13.59722042	9.59	17_RNGE_INTERFLOW_1.5-20
17	RNGE	RECHARGE	20-9999	29.24852562	0.90	17_RNGE_RECHARGE_20-9999
17	RNGE	RECHARGE	1.5-20	9.57303524	0.57	17_RNGE_RECHARGE_1.5-20
17	RNGB	INTERFLOW	0-1.5	1.140505791	0.16	17_RNGB_INTERFLOW_0-1.5
18	RNGB	INTERFLOW	1.5-20	9.981795311	13.53	18_RNGB_INTERFLOW_1.5-20
18	RNGB	RECHARGE	1.5-20	12.36730099	9.10	18_RNGB_RECHARGE_1.5-20
18	RNGB	INTERFLOW	0-1.5	1.39728868	0.08	18_RNGB_INTERFLOW_0-1.5
18	WWHT	RECHARGE	1.5-20	10.41782951	17.55	18_WWHT_RECHARGE_1.5-20
18	WWHT	INTERFLOW	1.5-20	9.757707596	11.07	18_WWHT_INTERFLOW_1.5-20
18	PINE	RECHARGE	20-9999	31.44926834	2.30	18_PINE_RECHARGE_20-9999
18	PINE	RECHARGE	1.5-20	14.68017673	3.61	18_PINE_RECHARGE_1.5-20
18	RNGB	INTERFLOW	20-9999	35.25559235	6.07	18_RNGB_INTERFLOW_20-9999
18	FRST	RECHARGE	1.5-20	11.21863937	8.85	18_FRST_RECHARGE_1.5-20
18	PINE	INTERFLOW	20-9999	25.41444397	0.74	18_PINE_INTERFLOW_20-9999
18	WWHT	INTERFLOW	20-9999	20.00613022	0.08	18_WWHT_INTERFLOW_20-9999
18	WWHT	INTERFLOW	0-1.5	0.883722961	0.08	18_WWHT_INTERFLOW_0-1.5
18	PINE	INTERFLOW	1.5-20	12.80846405	5.25	18_PINE_INTERFLOW_1.5-20
18	FRST	INTERFLOW	1.5-20	8.963622093	0.98	18_FRST_INTERFLOW_1.5-20
18	FRST	INTERFLOW	0-1.5	0.624886513	0.08	18_FRST_INTERFLOW_0-1.5
18	RNGB	RECHARGE	20-9999	42.54801178	25.17	18_RNGB_RECHARGE_20-9999
18	WWHT	RECHARGE	0-1.5	1.066748023	0.16	18_WWHT_RECHARGE_0-1.5
18	FRST	RECHARGE	20-9999	30.28489494	1.89	18_FRST_RECHARGE_20-9999
18	FRST	RECHARGE	0-1.5	1.39728868	0.08	18_FRST_RECHARGE_0-1.5
18	RNGE	RECHARGE	1.5-20	12.48879814	0.16	18_RNGE_RECHARGE_1.5-20
18	RNGE	RECHARGE	20-9999	33.11898422	0.08	18_RNGE_RECHARGE_20-9999
19	WPAS	RECHARGE	1.5-20	12.87215424	102.32	19_WPAS_RECHARGE_1.5-20
19	WPAS	RECHARGE	20-9999	23.71571541	30.91	19_WPAS_RECHARGE_20-9999
19	PAST	RECHARGE	1.5-20	11.68961811	18.36	19_PAST_RECHARGE_1.5-20
19	WPAS	RECHARGE	0-1.5	1.110592008	0.41	19_WPAS_RECHARGE_0-1.5
19	RNGB	RECHARGE	1.5-20	11.83596325	27.96	19_RNGB_RECHARGE_1.5-20
19	RNGB	RECHARGE	20-9999	29.04550743	15.74	19_RNGB_RECHARGE_20-9999
19	WETL	INTERFLOW	1.5-20	7.16341877	0.66	19_WETL_INTERFLOW_1.5-20
19	WATR	INTERFLOW	1.5-20	6.067071915	1.48	19_WATR_INTERFLOW_1.5-20
19	WATR	INTERFLOW	0-1.5	1.075796723	0.33	19_WATR_INTERFLOW_0-1.5
19	PAST	RECHARGE	20-9999	22.61111259	3.69	19_PAST_RECHARGE_20-9999
19	RNGB	INTERFLOW	1.5-20	13.85870647	54.27	19_RNGB_INTERFLOW_1.5-20
19	RNGB	INTERFLOW	20-9999	30.57966042	93.22	19_RNGB_INTERFLOW_20-9999
19	RNGB	INTERFLOW	0-1.5	1.323530912	0.16	19_RNGB_INTERFLOW_0-1.5
19	RNGB	RECHARGE	0-1.5	0.674058378	0.25	19_RNGB_RECHARGE_0-1.5
19	WPAS	INTERFLOW	1.5-20	12.46912479	41.98	19_WPAS_INTERFLOW_1.5-20
19	WPAS	INTERFLOW	20-9999	23.62708664	7.21	19_WPAS_INTERFLOW_20-9999
19	PAST	Response	1.5-20	6.663680077	2.46	19_PAST_Response_1.5-20
19	RNGB	Response	1.5-20	11.20398998	12.13	19_RNGB_Response_1.5-20
19	WPAS	Response	1.5-20	10.01417446	2.30	19_WPAS_Response_1.5-20
19	PAST	RECHARGE	0-1.5	1.249773026	0.08	19_PAST_RECHARGE_0-1.5
19	PAST	Response	0-1.5	1.39728868	0.08	19_PAST_Response_0-1.5
19	RNGB	Response	20-9999	31.98390198	3.53	19_RNGB_Response_20-9999

19	WPAS	Response	20-9999	21.87102699	0.08	19_WPAS_Response_20-9999
19	PAST	INTERFLOW	20-9999	21.93307686	1.80	19_PAST_INTERFLOW_20-9999
19	PAST	INTERFLOW	1.5-20	15.14369106	5.90	19_PAST_INTERFLOW_1.5-20
19	WPAS	INTERFLOW	0-1.5	0.883722961	0.08	19_WPAS_INTERFLOW_0-1.5
19	RNGE	INTERFLOW	20-9999	42.1457901	7.95	19_RNGE_INTERFLOW_20-9999
19	RNGE	RECHARGE	20-9999	39.79505539	1.89	19_RNGE_RECHARGE_20-9999
19	RNGE	Response	20-9999	42.11389542	4.51	19_RNGE_Response_20-9999
19	RNGE	RECHARGE	1.5-20	13.57404804	0.33	19_RNGE_RECHARGE_1.5-20
19	RNGE	Response	1.5-20	13.9296875	1.31	19_RNGE_Response_1.5-20
20	RNGB	RECHARGE	1.5-20	11.82403469	2.95	20_RNGB_RECHARGE_1.5-20
20	RNGB	RECHARGE	20-9999	50.13504791	14.35	20_RNGB_RECHARGE_20-9999
20	RNGE	RECHARGE	1.5-20	16.88350296	0.08	20_RNGE_RECHARGE_1.5-20
20	RNGB	RECHARGE	0-1.5	1.39728868	0.08	20_RNGB_RECHARGE_0-1.5
20	RNGE	RECHARGE	20-9999	39.84657288	2.21	20_RNGE_RECHARGE_20-9999
20	RNGB	INTERFLOW	20-9999	29.72044182	2.54	20_RNGB_INTERFLOW_20-9999
20	RNGB	INTERFLOW	1.5-20	14.46259594	0.98	20_RNGB_INTERFLOW_1.5-20
20	RNGE	INTERFLOW	20-9999	21.94862556	0.25	20_RNGE_INTERFLOW_20-9999
20	RNGE	INTERFLOW	1.5-20	11.19166946	1.80	20_RNGE_INTERFLOW_1.5-20
21	RNGB	RECHARGE	1.5-20	9.475996971	59.52	21_RNGB_RECHARGE_1.5-20
21	RNGB	RECHARGE	20-9999	31.8685379	12.79	21_RNGB_RECHARGE_20-9999
21	RNGB	INTERFLOW	1.5-20	8.644726753	31.40	21_RNGB_INTERFLOW_1.5-20
21	RNGB	INTERFLOW	0-1.5	1.00787878	0.41	21_RNGB_INTERFLOW_0-1.5
21	RNGE	RECHARGE	1.5-20	9.190625191	13.69	21_RNGE_RECHARGE_1.5-20
21	RNGB	RECHARGE	0-1.5	1.376214981	0.57	21_RNGB_RECHARGE_0-1.5
21	WATR	RECHARGE	1.5-20	13.65234566	0.25	21_WATR_RECHARGE_1.5-20
21	WWHT	INTERFLOW	1.5-20	8.691224098	25.66	21_WWHT_INTERFLOW_1.5-20
21	WWHT	RECHARGE	20-9999	20.65909195	0.08	21_WWHT_RECHARGE_20-9999
21	WWHT	RECHARGE	1.5-20	9.465200424	10.99	21_WWHT_RECHARGE_1.5-20
21	WATR	INTERFLOW	1.5-20	7.964212418	0.57	21_WATR_INTERFLOW_1.5-20
21	WWHT	INTERFLOW	0-1.5	1.110592008	0.41	21_WWHT_INTERFLOW_0-1.5
21	RNGE	INTERFLOW	1.5-20	5.734324932	13.86	21_RNGE_INTERFLOW_1.5-20
21	RNGE	INTERFLOW	0-1.5	1.230283976	1.07	21_RNGE_INTERFLOW_0-1.5
21	WWHT	RECHARGE	0-1.5	0.883722961	0.08	21_WWHT_RECHARGE_0-1.5
21	RNGE	RECHARGE	0-1.5	1.033586502	0.74	21_RNGE_RECHARGE_0-1.5
21	RNGB	INTERFLOW	20-9999	36.40360641	4.84	21_RNGB_INTERFLOW_20-9999
21	RNGE	RECHARGE	20-9999	28.61166191	5.49	21_RNGE_RECHARGE_20-9999
21	RNGE	INTERFLOW	20-9999	27.11561584	1.48	21_RNGE_INTERFLOW_20-9999
22	PINE	RECHARGE	1.5-20	11.60923767	10.08	22_PINE_RECHARGE_1.5-20
22	PINE	RECHARGE	20-9999	31.6126709	12.87	22_PINE_RECHARGE_20-9999
22	FRST	INTERFLOW	20-9999	35.70612717	0.08	22_FRST_INTERFLOW_20-9999
22	RNGB	RECHARGE	20-9999	35.91417313	47.39	22_RNGB_RECHARGE_20-9999
22	RNGB	INTERFLOW	20-9999	29.31142616	69.20	22_RNGB_INTERFLOW_20-9999
22	RNGB	INTERFLOW	1.5-20	13.08256626	87.32	22_RNGB_INTERFLOW_1.5-20
22	RNGB	RECHARGE	1.5-20	12.61687374	30.50	22_RNGB_RECHARGE_1.5-20
22	WATR	RECHARGE	0-1.5	0.091917053	1.80	22_WATR_RECHARGE_0-1.5
22	WATR	INTERFLOW	0-1.5	0.126385957	1.31	22_WATR_INTERFLOW_0-1.5
22	PINE	INTERFLOW	1.5-20	12.53512096	1.39	22_PINE_INTERFLOW_1.5-20
22	PINE	INTERFLOW	20-9999	27.83779526	2.87	22_PINE_INTERFLOW_20-9999
22	WATR	RECHARGE	1.5-20	10.33685493	1.48	22_WATR_RECHARGE_1.5-20
22	WATR	INTERFLOW	1.5-20	8.032867432	0.57	22_WATR_INTERFLOW_1.5-20
22	WATR	INTERFLOW	20-9999	20.63072014	0.08	22_WATR_INTERFLOW_20-9999
22	PINE	RECHARGE	0-1.5	1.011087656	0.16	22_PINE_RECHARGE_0-1.5
22	RNGE	INTERFLOW	20-9999	30.98747826	39.19	22_RNGE_INTERFLOW_20-9999
22	RNGB	INTERFLOW	0-1.5	0.833182037	0.25	22_RNGB_INTERFLOW_0-1.5
22	RNGE	INTERFLOW	1.5-20	15.20541	19.68	22_RNGE_INTERFLOW_1.5-20
22	WPAS	INTERFLOW	1.5-20	10.86119461	34.27	22_WPAS_INTERFLOW_1.5-20
22	WPAS	INTERFLOW	20-9999	23.33846855	3.61	22_WPAS_INTERFLOW_20-9999
22	WPAS	RECHARGE	1.5-20	12.5796833	10.49	22_WPAS_RECHARGE_1.5-20
22	RNGE	RECHARGE	1.5-20	11.90233612	2.95	22_RNGE_RECHARGE_1.5-20
22	WPAS	RECHARGE	20-9999	24.17728615	1.07	22_WPAS_RECHARGE_20-9999
22	RNGE	RECHARGE	20-9999	24.86090851	2.30	22_RNGE_RECHARGE_20-9999
22	RNGB	RECHARGE	0-1.5	1.011087656	0.16	22_RNGB_RECHARGE_0-1.5
22	RNGE	Response	20-9999	37.90297318	0.41	22_RNGE_Response_20-9999
22	RNGB	Response	20-9999	35.69029617	3.20	22_RNGB_Response_20-9999
22	RNGE	Response	1.5-20	13.52648067	1.64	22_RNGE_Response_1.5-20
22	RNGB	Response	1.5-20	9.691318512	2.54	22_RNGB_Response_1.5-20
23	RNGE	RECHARGE	20-9999	31.12137222	0.41	23_RNGE_RECHARGE_20-9999
23	RNGB	INTERFLOW	20-9999	36.5499649	16.23	23_RNGB_INTERFLOW_20-9999
23	RNGB	RECHARGE	20-9999	47.69450378	21.23	23_RNGB_RECHARGE_20-9999
23	RNGB	RECHARGE	1.5-20	12.97718239	1.97	23_RNGB_RECHARGE_1.5-20
23	RNGB	INTERFLOW	1.5-20	11.67745018	17.96	23_RNGB_INTERFLOW_1.5-20
23	RNGE	INTERFLOW	1.5-20	11.9923296	5.99	23_RNGE_INTERFLOW_1.5-20
23	RNGE	INTERFLOW	20-9999	22.91065025	1.07	23_RNGE_INTERFLOW_20-9999
23	RNGB	Response	20-9999	39.27404785	1.56	23_RNGB_Response_20-9999
23	RNGB	Response	1.5-20	9.900001526	2.05	23_RNGB_Response_1.5-20
24	RNGE	RECHARGE	0-1.5	0.970863104	0.82	24_RNGE_RECHARGE_0-1.5
24	RNGE	RECHARGE	1.5-20	9.012494087	20.99	24_RNGE_RECHARGE_1.5-20
24	RNGB	RECHARGE	1.5-20	9.691329002	65.02	24_RNGB_RECHARGE_1.5-20
24	RNGE	INTERFLOW	1.5-20	8.090359688	11.40	24_RNGE_INTERFLOW_1.5-20
24	RNGE	INTERFLOW	0-1.5	1.164292932	0.98	24_RNGE_INTERFLOW_0-1.5
24	RNGB	INTERFLOW	1.5-20	8.943907738	26.89	24_RNGB_INTERFLOW_1.5-20
24	RNGB	RECHARGE	0-1.5	1.059731722	1.80	24_RNGB_RECHARGE_0-1.5
24	RNGB	INTERFLOW	0-1.5	1.167309284	0.33	24_RNGB_INTERFLOW_0-1.5
24	RNGE	RECHARGE	20-9999	53.87158585	46.90	24_RNGE_RECHARGE_20-9999
24	RNGB	RECHARGE	20-9999	49.54518509	60.67	24_RNGB_RECHARGE_20-9999
24	RNGB	INTERFLOW	20-9999	37.30984497	9.84	24_RNGB_INTERFLOW_20-9999
24	RNGE	INTERFLOW	20-9999	40.31995773	7.95	24_RNGE_INTERFLOW_20-9999

25	RNGB	RECHARGE	1.5-20	12.85434246	29.60	25_RNGB_RECHARGE_1.5-20
25	RNGB	RECHARGE	20-9999	46.03891754	65.43	25_RNGB_RECHARGE_20-9999
25	RNGB	INTERFLOW	1.5-20	10.40332317	6.31	25_RNGB_INTERFLOW_1.5-20
25	RNGB	INTERFLOW	20-9999	38.03989029	11.56	25_RNGB_INTERFLOW_20-9999
25	RNGB	Response	1.5-20	11.24808788	4.02	25_RNGB_Response_1.5-20
25	RNGB	Response	20-9999	38.21656799	3.85	25_RNGB_Response_20-9999
25	RNGB	RECHARGE	0-1.5	0.726474524	0.33	25_RNGB_RECHARGE_0-1.5
25	WWHT	INTERFLOW	1.5-20	3.506155968	2.95	25_WWHT_INTERFLOW_1.5-20
25	WWHT	INTERFLOW	0-1.5	1.19250536	0.57	25_WWHT_INTERFLOW_0-1.5
25	WWHT	RECHARGE	20-9999	22.01339531	0.08	25_WWHT_RECHARGE_20-9999
25	WWHT	RECHARGE	0-1.5	0.883722961	0.08	25_WWHT_RECHARGE_0-1.5
25	WWHT	RECHARGE	1.5-20	3.884913445	0.16	25_WWHT_RECHARGE_1.5-20
25	RNGB	INTERFLOW	0-1.5	1.127756357	0.25	25_RNGB_INTERFLOW_0-1.5