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Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

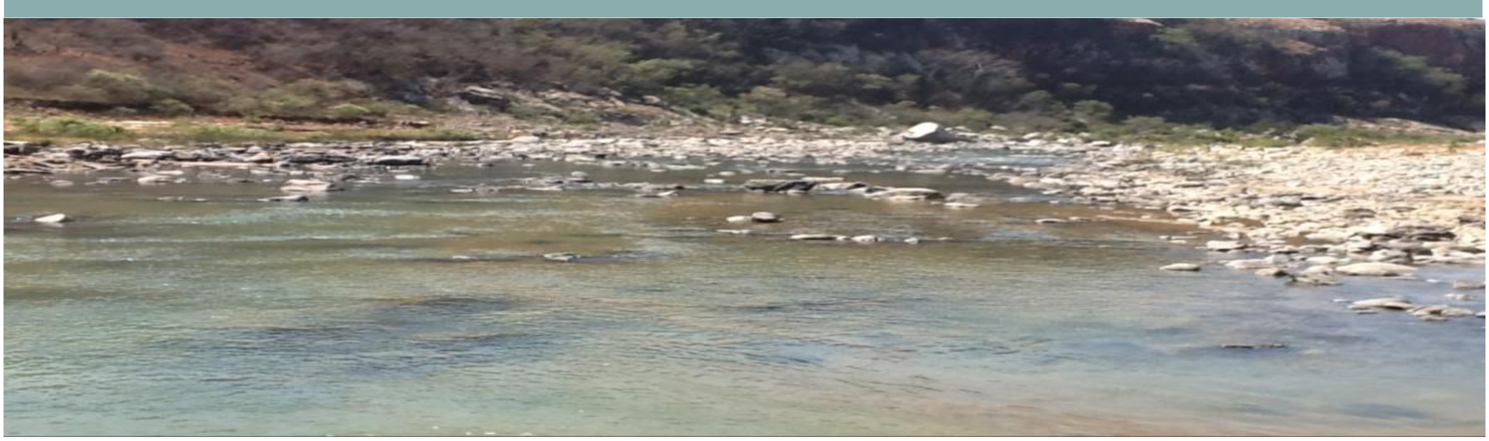
RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTU/MHLATUZE WATER MANAGEMENT AREA
WP 10544

GROUNDWATER: MAIN FINDINGS AND CONCEPTUALISATIONS

FINAL

SEPTEMBER 2014

Report No. RDM/WMA6/CON/COMP/0513



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Department:
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REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS

CONTRACT NO. WP 10544

RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTU/MHLATUZE WATER MANAGEMENT AREA:

GROUNDWATER: MAIN FINDINGS AND CONCEPTUALISATIONS

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PURPOSE OF REPORT

This report was prepared by the Study Team in order to summarise and understand the functioning of the groundwater system and its contribution to the aquatic ecosystems in the study area. This report was compiled from existing reports and literature.

Contract Title:	Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Usutu - Mhlathuze Water Management Area
Report Title	Groundwater: main findings and conceptualisations

Revision	**Date**	**Report Status**
Draft 1.1	18 August 2014	Draft for internal use
1.2	30 September 2014	Final

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ABBREVIATIONS AND ACRONYMS

DWA	Department of Water Affairs
DWAF	Department of Water Affairs & Forestry
DWS	Department of Water and Sanitation
EWR	Ecological Water Requirements
KZN	KwaZulu-Natal
RU	Resource Units
NWA	National Water Act
TDS	Total Dissolved Solids
WMA	Water Management Area

GLOSSARY OF TERMS

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

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

AQUATIC ECOSYSTEMS: not defined by the National Water Act (Act No. 36 of 1998), but defined elsewhere as the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones and reservoirs, lakes, wetlands and fringing vegetation.

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

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

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

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

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

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

ESTUARY: a partially or fully enclosed body of water, that is open to the sea permanently or periodically, and within which the sea water can be diluted, to an extent that is measurable, with fresh water drained from the land [from National Water Act (Act No. 36 of 1998)].

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

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

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

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

GEOHYDROLOGY: the study of the properties, circulation and distribution of groundwater; in practice used interchangeably with hydrogeology; but in theory hydrogeology is the study of geology from the perspective of its role and influence in hydrology, while geohydrology is the study of hydrology from the perspective of the influence on geology.

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

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

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

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

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

RECHARGE AREA: an area over which recharge occurs.

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

UNSATURATED ZONE: that part of the geological stratum above the water table where interstices and voids contain a combination of air and water; synonymous with zone of aeration or vadose zone.

WETLAND: land that is transitionary between terrestrial and aquatic systems, where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil [from National Water Act (Act No. 36 of 1998)].

1 INTRODUCTION

1.1 Background to the study

The Chief Directorate: Resource Directed Measures issued an open tender invitation for the "Appointment of a Professional Service Provider to undertake Reserve Determinations for selected Surface water, Groundwater, Estuaries and Wetlands in the Usutu to Mhlatuze Basins". The focus on this area was a result of the high conservation status and importance of various water resources in the basin and the significant development pressures in the area affecting the availability of water.

Preliminary Reserve determinations are required to assist the DWA in making informed decisions regarding the authorisations of future water use and the magnitude of the impacts of the proposed developments on the water resources in the WMA, and to provide the input data for Classification of the area's water resources, and eventual gazetting of the Reserve (DWA 1998).

DWA appointed Tlou Consulting to undertake the project in July 2013.

1.1.1 Study objectives

The objectives of the study are to:

- determine the Ecological Reserve (DWAF 1998), at various levels of detail, for the Nyoni, Matigulu, Mlalazi, Mhlatuze, Mfolozi, Nyalazi, Hluhluwe, Mzinene, Mkuze, Assegaai and Pongola Rivers;
- determine the Ecological Reserve, at an Intermediate level for the Pongola floodplain;
- determine the Ecological Reserve, at an Intermediate level for the St Lucia/Mfolozi, Estuary System;
- determine the Ecological Reserve, at an Rapid level for the Mlalazi Estuary;
- determine the Ecological Reserve, at a Rapid level for the Amatikulu Estuary;
- determine the Ecological Reserve, at an Intermediate level for Lake Sibaya;
- determine the Ecological Reserve, at a Rapid level for Kozi Lake and Estuary;
- classify the causal links between water supply and condition of key wetlands;
- incorporate existing EWR assessments on the Mhlatuze (river and estuary) and Nhlabane (lake and estuary) into study outputs;
- determine the groundwater contribution to the Ecological Reserve, with particular reference to the wetlands;
- determine the Basic Human Needs Reserve for the Usutu/Mhlatuze WMA;
- outline the socio-economic water use in the Usutu/Mhlatuze WMA;

- build the capacity of team members, DWA Officials and stakeholders with respect to EWR determinations and the ecological Reserve.

1.1.2 This report

The Kwa-Zulu Natal coastal plain aquifer has received considerable attention from geohydrologists over the years. This report attempts to summarise their main findings and conceptualisations, in as much as they pertain to the interplay between groundwater and the aquatic ecosystems in the area, and the potential threats that they face. No new data were collected and no new thinking is presented. Details on the geology and geomorphology of the area are available in the documents listed in the references.

This area was the subject of a “high level” Groundwater Reserve Assessment (Denis and Denis 2009). Among other things, that assessment described the groundwater relevant aspects of the catchments and delineated groundwater resource units. In the interests of not unnecessarily repeating DWS-funded work, much of the information presented in Section 2, including the groundwater resource units (Section 4) is taken directly from Denis and Denis (2009; see italicised sections).

This information is important in understanding the eco-hydrological functioning of the rivers, estuaries and coastal lakes that are the focus of this Reserve Determination study but also in conceptualizing and designing interventions aimed at protecting the groundwater contributions to the EWRs for these systems.

2 OVERVIEW OF THE STUDY AREA

The study area is situated in the northern portion of KwaZulu-Natal Province, and comprises the former Usuthu-Mhlatuze WMA.

2.1 Topography

The study area covers approximately 45 000km², of which c. 6000 km² comprises the Zululand Coastal Plain. Elevation in the area varies from sea level in the east to an average of some 100 m over the width of the Zululand Coastal Plain, inland of which the meridionally-trending Lebombo range rises to some 700 m, inland, and falls abruptly to only some 250 m in the similarly-trending 'Lowveld' further inland, where it rises progressively to a maximum elevation of some 1700 m on the Great Escarpment on the north-western boundary of the WMA.

Physiographically, the inland portion of the WMA comprises a number of low-standing, generally east or south-east trending basins of the major rivers that are separated by elevated interfluve ridges. The coastal portion of the area in the south, and the inland portion of the area west of the Zululand Coastal Plain, are generally characterised by a steep and strongly dissected topography.

2.2 Climate

The climate in the coastal areas of KwaZulu-Natal is subtropical. It varies from cool near the western escarpment to sub-tropical along the coast. Summers are generally hot with temperatures often exceeding 35°C. Winters are cold, particularly in the west and north, where temperatures fall below freezing and frost occurs regularly. Along the coast, conditions are generally more temperate.

Rainfall is expected mainly from October to April and particularly in the summer months of December, January and February. Rainfall is strongly orographical, with the elevated portions of the area experiencing greater rainfall than the more low-lying areas, **except along the coast**. Annual rainfall is >1000 mm along the coast, and declines progressively westward and inland to the margin of the coastal plain to about 600 mm. Rainfall in elevated terrain inland of the coastal plain is in the region of 900 mma^{-1}.

Annual evaporation varies between c. 1800 mm at the coast and c. 2300 mm on the inner margin of the coastal plain (Maud 1998).

2.3 Natural vegetation

Distinctly different vegetation types occur over the water management area – from savannah grassland in the north-west, to dense coastal and swamp forests in the east. A huge amount of the natural vegetation has been destroyed due to farming and forestry. However, Ngongoni veld is still found in the upper less developed areas, and coastal forest and thorn veld in the coastal and more developed areas.

Both these veld types are more than 70% transformed from their natural state.

Important afromontane natural forests are found along the southern fringes of the WMA. The Acocks veld types are shown in Figure 2-1.

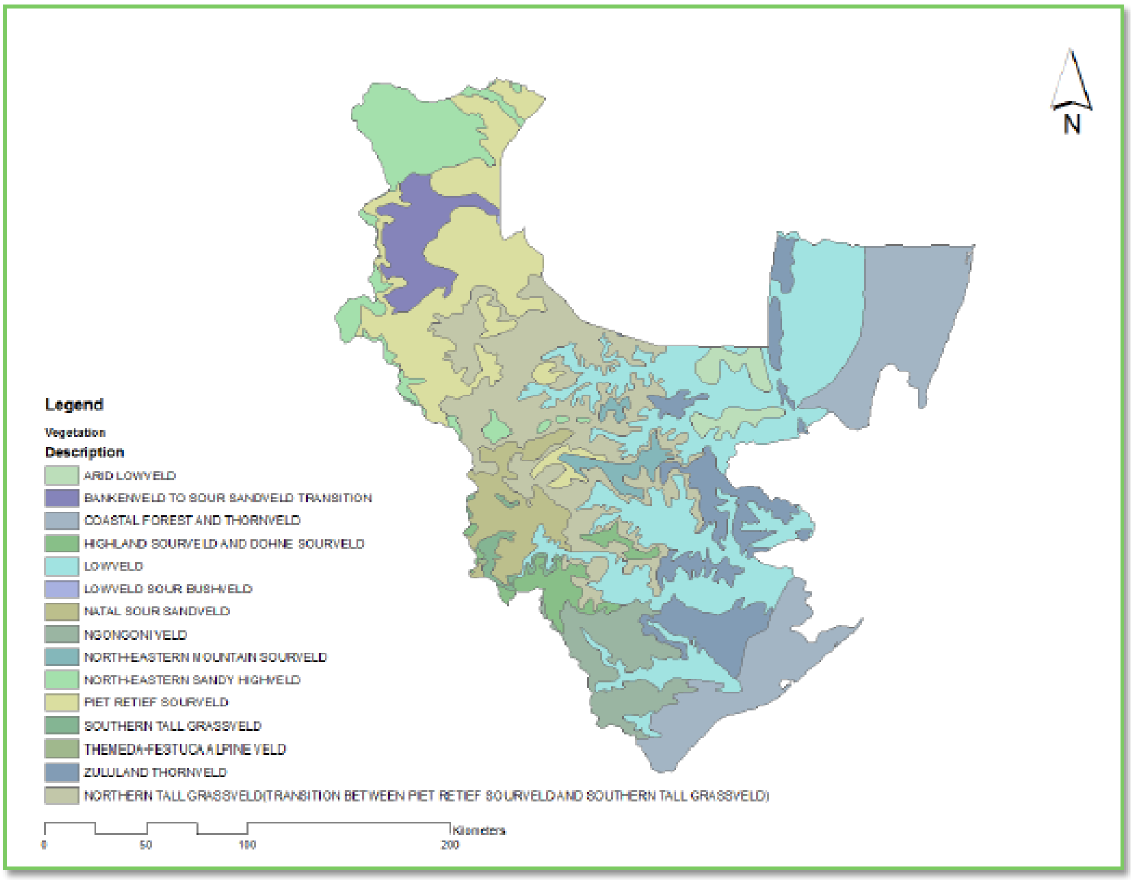

Figure 2-1 Acocks veld types- Usuthu-Mthlatuze WMA study area (Denis and Denis 2009)

2.3.1 Soils

The soil is a complex mixture of eroded rock, mineral nutrients, decaying organic matter, water, air and billions of organisms, most of which are microscopic decomposers. To see the soils characteristics of the study area, refer to Figure 2-2.

The average size of the spaces or pores in a soil determines soil permeability, i.e. the rate at which water and air move from the upper to lower soil layers. Soil permeability is also influenced by soil structure: how soil particles are organised and clumped together. Soils vary in clay (very fine particles), silt (fine particles), sand (medium size particles), and gravel (coarse to very coarse particles) content. The proportion of the different sizes and types of mineral particles determines the soil texture. Loam soils comprised roughly equal mixtures of clay, sand silt and humus, are the best soils for growing most crops.

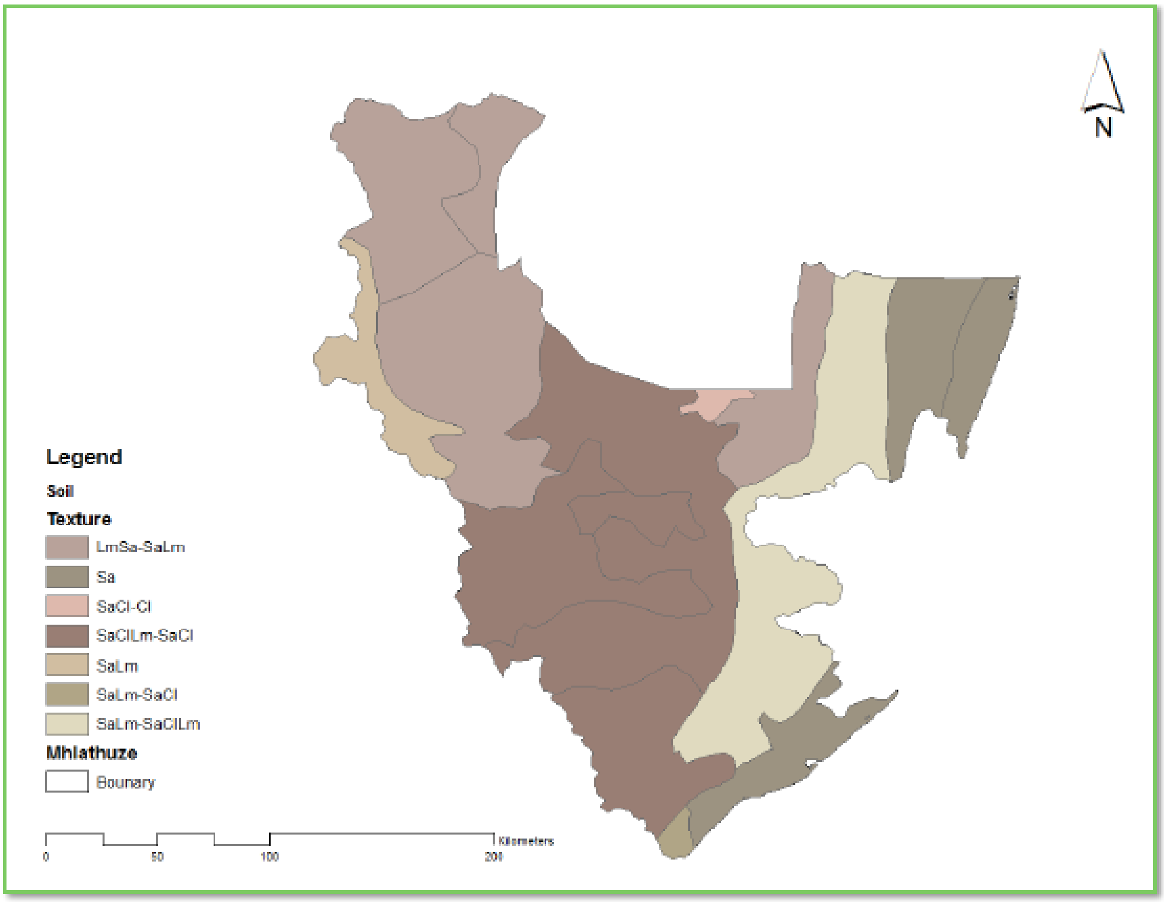

Figure 2-2 Soils- Usuthu-Mthlatuze WMA study area (Denis and Denis 2009)

2.4 Geology

Summarised by Denis and Denis (2009) from geology.ukzn.co.za. See Figure 2-3 for the geology of study area.

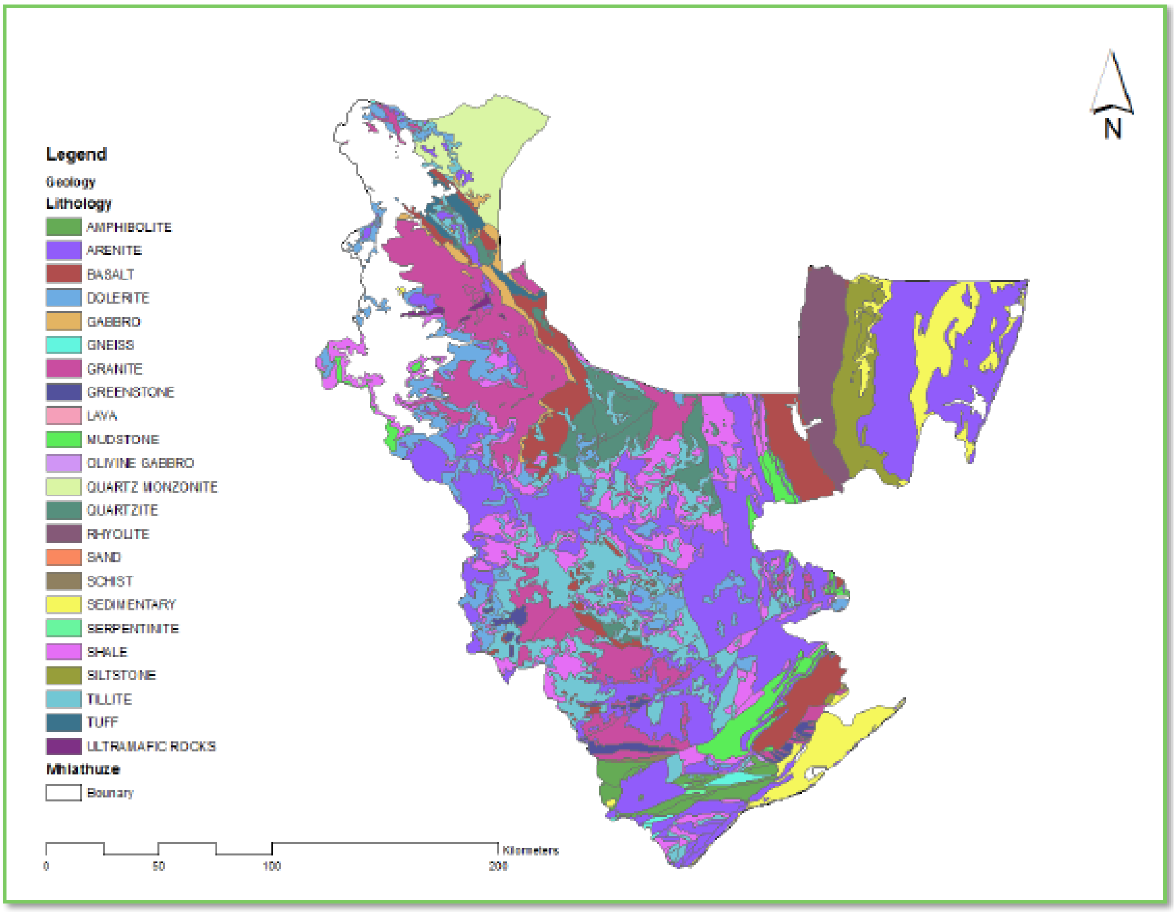

Figure 2-3 Geology - Usuthu-Mthlatuze WMA study area (Denis and Denis 2009)

The foundations of KwaZulu-Natal comprise two distinct geological units; the Kaapvaal Craton and the Natal Metamorphic Province. These form separate continental blocks that have influenced the geological history, scenery and economic potential of the region. North of the great Tugela River lies the most ancient crustal block in southern Africa, the Archaean Kaapvaal Craton (3000 million years old). It was formed when the Earth's basaltic crust was intruded by granite. The basalts are 3500 million years old and are preserved as greenstone fragments within the granite. Granite can be seen in the valley between Melmoth and Vryheid, and at quarries inland of Richards Bay. Basalt of the Nondweni Greenstone Belt south of Vryheid preserves ancient 'pillow structures'.

After formation, the Kaapvaal Craton was uplifted and exposed to the atmosphere. This resulted in weathering, erosion and transport of sediment into shallow basins. Both the Pongola Supergroup and the similar gold-rich Witwatersrand rocks were deposited in these early basins. The lower part of the Pongola Supergroup (Nsuze Group) is a succession of basalt, sandstone and minor limestone. North of the Tugela Fault, the Pongola Supergroup rocks are gently dipping and relatively unaltered. Near the Tugela Fault, these rocks are folded and deformed during collision of the basement. Some limestone units in the Nsuzi

Group contain stromatolites - fossils of 2900 million year old-algal colonies which thrived in a shallow, warm ocean.

Overlying the Nsuze Group is a thick succession of sedimentary rocks called the Mozaan Group, which contains gold-bearing conglomerate. Old gold workings can be seen at Denny Dalton, between Vryheid and Melmoth. Vein gold is also mined near the Swaziland border. In northern KwaZulu-Natal and Swaziland, the Pongola Supergroup was intruded by granite. As these intrusions cooled, the surrounding rock was metamorphosed.

Approximately 1000 million years ago, subduction and collision along the southern margin of the Kaapvaal Craton produced the rocks of the Natal Metamorphic Province. The rocks were heated and deformed into a mountain range many thousands of kilometres long. Once plate collision with the Kaapvaal Craton had ceased, a long period of erosion exposed the deep mountain roots of granite and gneiss. The granite is quarried for dimension stone at a number of localities.

The first sedimentary sequence deposited on the new basement was the Cambrian to Ordovician Natal Group (490 million years ago). Structures preserved in these sandstones indicate that the sediments were transported and deposited by rivers that drained highlands to the north-east. Close to their source, in northern KwaZulu-Natal, deep valleys were infilled with thick accumulations of boulders and pebbles. Further south, the sediment is finer-grained and forms resistant sandstone cliffs.

The Dwyka Group forms the lowermost and oldest deposit in the Karoo Supergroup basin. The group consists mainly of diamictite (tillite), which is generally massive with little jointing, but may be stratified in places. Subordinate rock types are conglomerate, sandstone, rhythmite and mudrock (both with and without dropstones). The Dwyka diamictite and shale have very low hydraulic conductivities [~ 10 $_{-11}$ to 10 $_{-12}$ m/s], and virtually no primary voids. The Dwyka Group constitutes a very low-yielding fractured aquifer, and water is confined within narrow discontinuities like jointing and fracturing. They therefore tend to form aquitards rather than aquifers. Since the Dwyka sediments were mainly deposited under marine conditions, the water in these aquifers tends to be saline.

As Gondwana moved north towards the equator, thick clay and silt beds were laid down in a large sea that occupied the Karoo basin. These sediments now form shales of the Pietermaritzburg Formation (Ecca Group). The shales are easily weathered and often present slope stability problems.

Overlying the shale is a thick sequence dominated by light grey sandstones, called the Vryheid Formation. These sandstones were deposited along ancient sandy shorelines, behind which lay vast swamplands with numerous Glossopteris plants. Vegetation buried in the swamps eventually formed coal, which is mined in the Vryheid area. Since the shales *are very dense, they are often overlooked as significant sources of groundwater. The deltaic sandstones represent a facies of the Ecca sediments, in which one would expect to find high-yielding boreholes. Unfortunately the permeability of these sandstones are also usually very low.*

Dramatic outpourings of lava spread across much of Gondwana about 180 million years ago heralded the start of the Gondwana breakup. Remnants of these once extensive lavas now form the Lesotho Highlands and Lebombo Mountains. Crystallisation of magma within these fractures formed dolerite sills and dykes. Sills are horizontal intrusions of igneous rock. Dolerite sills are common throughout inland KZN in sedimentary rocks of the Karoo Supergroup. The final volcanic event produced rhyolite lava, which now forms the Lebombo mountains. These volcanic events were followed by uplift and faulting that eventually separated Africa and Antarctica. Evidence for this rifting is seen by the numerous faults concentrated along coastal KwaZulu-Natal. The largest of these - the Tugela Fault, has exploited the weakness between the Kaapvaal Craton and Natal Metamorphic Province.

The first deposits (Zululand Group) formed in the newly opened Indian Ocean were silt- and sandstone of Cretaceous age (145-65 million years ago). During this time, huge snail-like animals up to a metre in size, called ammonites, thrived in the warm ocean. Their shells are common in almost all exposures of Cretaceous rocks, such as along the shorelines surrounding Lake St Lucia. During the Cenozoic, sea levels began to fall from the high levels experienced during the Cretaceous. A series of large coast-parallel dune complexes developed along most of the KwaZulu-Natal coastline. In most areas, deep weathering of old dunes has produced dark red coloured sand called the Berea Red Sand. In more recent times, fluctuations in the sea level have continued to shape the KwaZulu-Natal coastline.

Recent coastal dunes contain economic concentrations of minerals such as ilmenite, rutile and zircon, which are mined near Richards Bay. The ilmenite and rutile is smelted to produce titanium metal and white pigments (mostly for paint). The zircon is used for glazing on tiles and pottery, and as a metal alloy. During the last glacial period, approximately 18 000 years ago, the Earth was much colder and the sea level was more than 100 m below the present level. The coastline at that time would have been far out to sea and many of the larger rivers cut deep valleys along the coast. As the Earth warmed and the sea level rose, the valleys were filled with unconsolidated estuarine muds and shelly sands.

2.5 Geohydrology

Vegter (1995) divided the South Africa into 64 homogeneous hydrogeological regions based on lithology and climatology[1]. At least three of these regions fall either wholly or largely within the study area: These are the (after DWAF 2008):

[1] Colloquially these hydrogeological regions are referred to as the Vegter-regions (DWAF 2008).

- Northern Zululand Coastal Plain, which (as it name suggests) covers the coastal plain from Mtunzini in the south to Ndumo in the north. The geology consists of unconsolidated coastal deposits (aquifer type is intergranular; Table 2-1) and the development potential is shown as low to medium.
- Southern Lebombo, which covers the middle portion of the study area from Eshowe in the north to the Swaziland border in the south. The region is underlain by clay, and sand intrusive rocks. The aquifer type is mapped as inter-granular and fractured with a low to medium development potential.
- Northeastern Middleveld, which covers the central north central parts of the study area, extending into the Usuthu catchment in the north. The aquifer types are mapped (Vryheid) as intergranular and fractured with a low development potential. Sedimentary rocks form the fractured aquifers and the sand and clay deposits form the intergranular portions of the aquifer.

Table 2-1 Descriptions of aquifer types (after Vegter 1995)

Aquifer type	Description
Intergranular	Water is stored in the inter-granular pores and can be transmitted to borehole and springs.
Fractured Aquifer	Associated with hard rocks, where water occurs in fractures, faults, joints or fissures.
Intergranular and Fractured Aquifer	Water occurs in both the upper decomposed rock zone and the fractured but fresh rock formation below. These zones are in hydraulic contact. Weathering of crystalline rock can lead to the formation of this aquifer type.

Two other regions touch on the study area:

- Northwestern Middleveld, which impinges on the study area in the northwest. The underlying geology is mostly sandstone of the Ecca Formation. The 1: 500 000 scale hydrogeological map indicates the aquifer type as intergranular and fractured with an extremely low to medium development potential.
- Eastern Highveld, which slightly impinges on the study area in the north. The rocks found here belong to the Ecca Formation, which forms part of the Karoo Supergroup. The rocks were formed during the Permian eratem, which was an extremely wet period, hence the coal deposits which occur throughout this region. The hydrogeological map shows this area as having inter-granular and fractured aquifer with a low to medium development potential.

Of these, the most relevant to this EWR study is the coastal aquifer, as it supports an array of fresh and estuarine habitats. However, the groundwater in other areas also contributes to, or draws water from, the rivers and wetlands.

2.6 The coastal plain aquifer

The coastal plain aquifer stretching from Mtunzini on the Zululand coast up through Maputaland and along the Mozambique coast is the largest primary aquifer in southern Africa (Kelbe et al. 2001).

The region is characterized by numerous estuaries, e.g., Lake St Lucia, Kosi Lake, Nhlabane[2], and almost countless freshwater lakes. Many of the lakes are remnants of estuarine systems that have become closed during recent geological periods (Kelbe and Germishuyse 2010). The lakes can be divided into:

- Coastal lakes driven almost exclusively by the aquifer. Examples include (south to north): Qubhu, Isigonyane, Mzingazi, Bangazi, Bhangazi, Mogobezeleni, Shazibe, Sibaya, Vasi, Kuzionde.
- Off-channel lakes along the Mhlathuze and other rivers (Nseleni), which are controlled by a combination of surface runoff into and groundwater seepage out of the lake. Examples include: Mpangeni, Sigwenyaneni, Mangeza, Nsezi, Teza.

The topography of the coastal plain is flat with highly permeable soils, which promote rapid recharge of the aquifer following rain (Kelby et al. 2001). Consequently, most of the rainfall infiltrates and the hydrology of the lakes is assumed to be controlled by the groundwater system. This suggests that, although possible infrequent, the lakes and estuaries in the area do receive surface flow at times, even if there are no clearly defined runoff channels entering them[3].

"*The groundwater situation existing on the coastal plain is unique in respect of groundwater conditions present in the Kwa-Zulu Natal province as a whole*" (Maud 1998).

The primary coastal aquifers in the Usuthu-Mhlatuze catchments are characterized by:

- The main stratigraphic units defining the aquifer are (after Maud 1998; Kelbe et al. 2001; Weitz and Demlie 2013):
    - the deep layer of Cretaceous siltstone, which can be taken as the impermeable lower boundary of the aquifer. The Cretaceous sediments are not a viable aquifer both in respect of quality and quantity of water;

2 Lake Nhlabane was an estuary draining directly into the Indian Ocean, but the construction of a weir restricted the marine connection (Kelby et al. 2001).
3 This is important because surface runoff, and a water level above that of groundwater, is probably needed to maintain mouth conditions.

  - the Miocene layers, which overlie the siltstone and comprise a semi-confined aquifer (confined by the overlying Port Durnford). The Miocene Uloa aquifer is potentially high yielding, although little is presently (1998) known about its extent or sustainability in terms of recharge (Maud 1998).
  - the surface permeable, porous KwaMbonambi Formation dune sands, which comprise the high-yielding unconfined primary coastal aquifer.

Groundwater quality in the WMA is variable, being best in the higher rainfall portions and poorest in the lower rainfall portions, as in the major river basins of the interior and in the 'rain shadow' or 'Lowveld' area immediately inland of the Lebombo range. In the higher rainfall portions of the WMA, the groundwater generally has a TDS of 200 mg/l or less. In the lower rainfall portions, however, as in the Lebombo 'Lowveld', underlain by the Letaba Basalt and Vryheid Formations to the south, TDS are much higher and generally in the order of 600mg/l, it being much higher in places locally (up to 700mg/l). The quality of the groundwater in both the 'deep' and 'shallow' aquifers of the Zululand Coastal Plain is generally very good, with a TDS value of 200mg/l or less (Denis and Denis 2009).

2.6.1 The shallow primary aquifer

- The shallow primary aquifer has a maximum depth of about 30 m under the coastal dune belt but a maximum elevation c. 20 mamsl (Kelbe and Germishuyse 2010).
- The porosity of unconsolidated sands is high with a storage coefficient of 0.1 (Botha and Singh 2012).
- Rainfall is the principle recharge mechanism[4]. A conceptual recharge model proposed by Rawlins and Kelbe (1993) for this region assumes that:
  - 5-day accumulations of rainfall are lost to unsaturated surface processes (interception and evaporation) at a rate of 2 mm/day so that all 5 day events exceeding 10 mm (but < 50 mm) contribute to recharge;
  - daily rainfall in excess of 50 mm does not enter the groundwater system but is released through surface runoff processes.
- Recharge of groundwater has been calculated at between 5% and 18% of mean annual rainfall (EMATEK-CSIR 1995).
- The coastal lakes are an integral part of the primary aquifer. There are direct hydraulic links between groundwater and the water levels in the lakes, i.e., water levels in the lakes are an expression of levels in the adjacent groundwater.
- Lake and groundwater levels fluctuate markedly over seasons and longer intervals in response to rainfall.
- Fluctuations in the groundwater table have a dynamic effect on the distribution of (particularly small) wetlands on the coastal plain.
- There is a strong west-east flow in the aquifer from the inland recharge areas to the sea.
  - In line with this, the lakes display strong 'flow-through' characteristics with seepage into the lakes from the west and out to sea in the east. Generally,

[4] Decreasing water levels across the whole area from 1981 to mid-1983 correspond to the below average rainfall inputs during this period, and to groundwater storage reduced in a similar manner to the period 1978 to 1981 (Rawlins 1991).

this seepage rate is greatest at the surface shoreline and decreases exponentially with distance underneath the lake (Townley et al. 1993; Kelby et al. 2001; Weitz and Demlie 2013).

- The regional ground water flow dynamics could be simulated as a single unconfined aquifer controlled by the main surface water bodies.
- The seasonal fluctuation of groundwater level requires deep drilling to at least 30-50m below the water table (Vegter 1995).
- Layered aquifers also occur on the coastal plain and it is possible that they may contain water from different catchments (Maud 1998).
- Groundwater can be found in roughly two banks: one along the inner edge of the coastal plain and another halfway out along the coastal plain (Maud 1998).

2.6.2 Potential sensitivities

The potential sensitivities of the groundwater systems of the coastal lakes to anthropogenic influences include:

- Extremely sensitive to landuse manipulation. In particular commercial plantations.
  - Rawlins (1991) estimated that, during extreme dry periods (low rainfall) when inflows to groundwater are already low (100 x 10^6 m^3; Hutchison and Pitman 1973), c. 5000 ha of pine planation reduced the recharge into the aquifer by c. 30%.
  - There was a significant reduction in the seepage into the Indian Ocean along the southern dunes and into the water bodies (estuaries and lakes) prior to 2005 as a result of plantations in the upper catchment (Kelbe and Germishuyse 2010). Removal of commercial pine over the past decade has resulted in the expansion of wetlands (Vaeret 2008).
- Direct abstraction from freshwater lakes:
  - may result in salt water intrusion into these systems (Kelbe et al. 2001; Weitz and Demlie 2013) or into the floodplain groundwater (van Tonder et al. 1986)[5];
  - may dampen the response of the water levels in these systems to regional rainfall, i.e., once depleted beyond a certain level recovery may be sluggish, even with a cessation of pumping and good rainfall.
- Sensitive to climate change. The shallow coastal aquifer may go through repeated shifts in the boundary conditions, i.e. a change from fresh to marine conditions and vice versa as groundwater rises in response to sea-level rise, thereby considerably reducing the volume of fresh groundwater available. 2100 sea level predictions for the Maputaland coast include a *c*. 0.4-m sea-level rise due to the climatic effect of a 2-3°C temperature rise and ~10% increase in rainfall (Vaeret 2008).
- Vulnerable to pollution from urban, agricultural and industrial activities (DWAF 2008).

[5] For instance, van Tonder et al. (1986) found that if Lake Mzingazi water-levels were to drop to lower than 1.5 mamsl, the toe of the saline wedge could reach a distance of more than 200 m in the flood plain after 1 200 days.

2.6.3 Ecological response to salinity changes

Salinity is a major factor in determining the ecological state of the lake system as it dictates whether the system will be dominated by marine or freshwater species.

The ecological response to changing salinities in these systems is time-dependent and resource-limited (Kelbe and Germishuyse 2010). The change from an ecological state with freshwater species to a state with marine species, or vice versa, requires sufficient time for initial populations of each species to become established and increase in abundance. This will of course differ markedly from species to species, dependent on fecundity and longevity issues.

However, Taylor (1993) showed that the recovery rate from a hypersaline to freshwater state can be faster than traditional growth curves suggest, provided that:

- micro habitat (refugia) sites exist where species are able to survive through adverse condition and provide a seed population for recolonisation once conditions are more favourable;
- groundwater seepage/surface inflow that provides sufficient freshwater for species survival in the refugia.

3 LAKE-GROUNDWATER INTERACTIONS: LAKE SIBAYA

With a surface area of approximately 65 km^2 (Miller, 2001), Lake Sibayi is South Africa's largest coastal freshwater lake. It is situated on the seaward margin of the Maputaland Coastal Plain, along the northern KwaZulu-Natal coastline (Figure 3-1; Weitz and Demlie 2013). The lake is situated approximately 180 km north of Richards Bay and 60 km from the Mozambique border, falling within the Umkhanyakude District Municipality. The rural towns of Mbazwana and Mseleni are located around the lake's periphery.

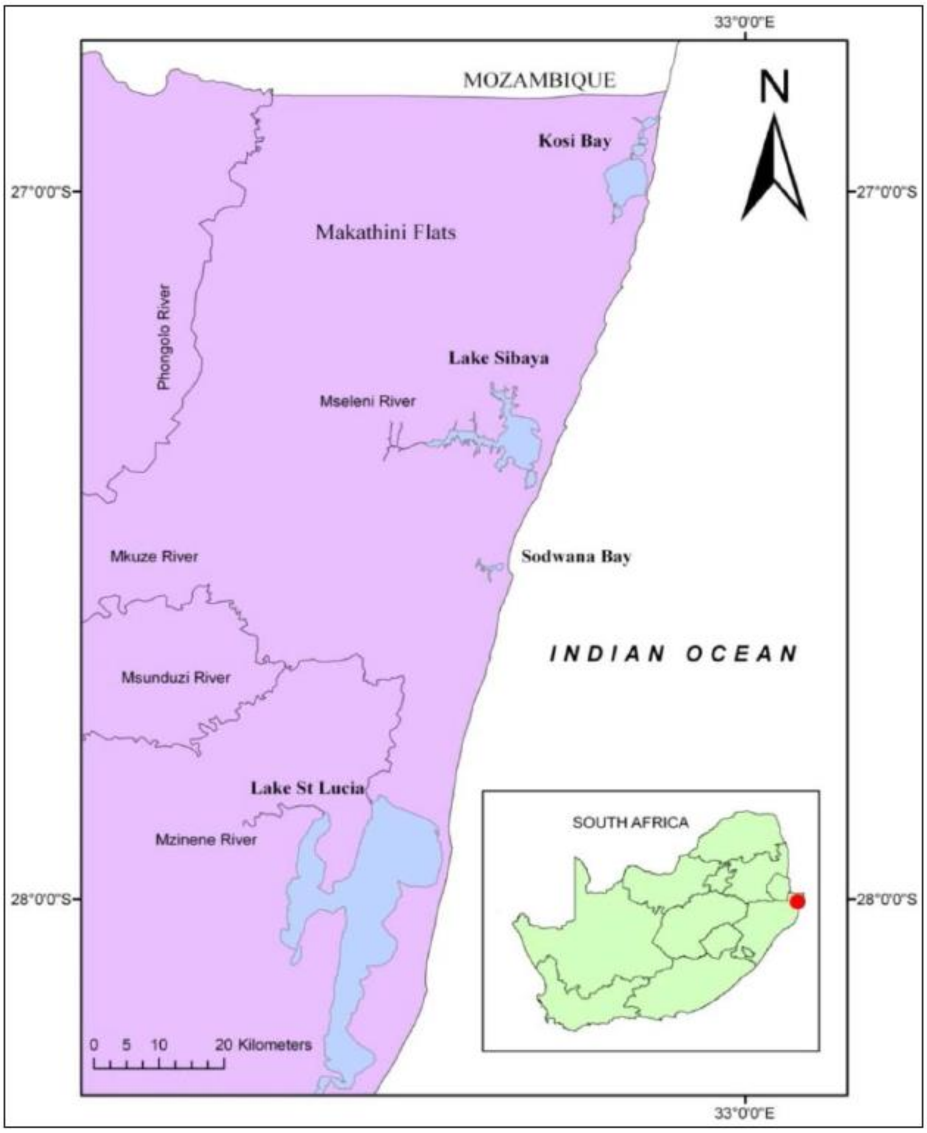

Figure 3-1 Map showing the location of Lake Sibayi and other coastal Lakes of the Zululand coastal plane

The total catchment area is estimated at 530 km², of which 60-70 km² is taken up by the lake itself (http://www.ngo.grida.no/soesa/nsoer/resource/wetland/sibaya_ris.htm; accessed 10.07.2014).

Between the eastern shore of the lake and the sea is a range of high dunes (c. 160 m). To the west of the dunes the land is very flat, and consequently the boundary of the catchment feeding the lake is difficult to define (Meyer and Godfrey 2003).

Lake Sibaya is fed almost exclusively by groundwater seepage from the surrounding catchment. The bulk of the groundwater movement in the region is west-east from the higher lying parts of the catchment, through Lake Sibaya and to the sea (Meyer, *et al*. 2001), although around Lake Sibaya the regional pattern is somewhat distorted by some flow towards the lake (Weitz and Demile 2013). The water level in the lake is a reflection of the local groundwater level (Meyer *et al*. 2001; Weitz and Demile 2013), and the presence of the lake because the surface topography is below that of the local groundwater level.

The water level of the lake fluctuates by just over one metre around an average of *c*. 20 mamsl (DWAF 2002). The most recent bathymetry of the lake indicates that it has a maximum depth of 41 m (Miller 2001). Based on the bathymetry (Miller 2001) and a lake water level elevation of 19.82 mamsl, the Council for Geoscience calculated the volume of the lake to be 818.5 x 10^6 m^3 (Perrit *et al*. 2002). This is approximately a third of the full supply capacity of the nearby Jozini Dam (2500 x110^6 m^3; DWAF 1986).

Weitz and Demlie (2013) present a conceptual model of the hydrological conditions in the study catchment (Figure 3-2). They stress that this is a work in progress. Nonetheless, it provides a useful summary of the major components of the geohydrological setting of Lake Sibaya. These major components are:

Inflows to Lake Sibaya:

- Precipitation: 42.7 x $10^6 m^3$;
- Recharge: 54.5 x $10^6 m^3$;
- Runoff (into Lake Sibaya): 32.9 x $10^6 m^3$;

Outflows/abstractions:

- Open-water evaporation: 86.9 x $10^6 m^3$;
- Seepage to the sea: 22.1 x $10^6 m^3$;
- Groundwater abstraction: 0.041 x $10^6 m^3$;
- Direct abstraction from lake: 1.42 x $10^6 m^3$.

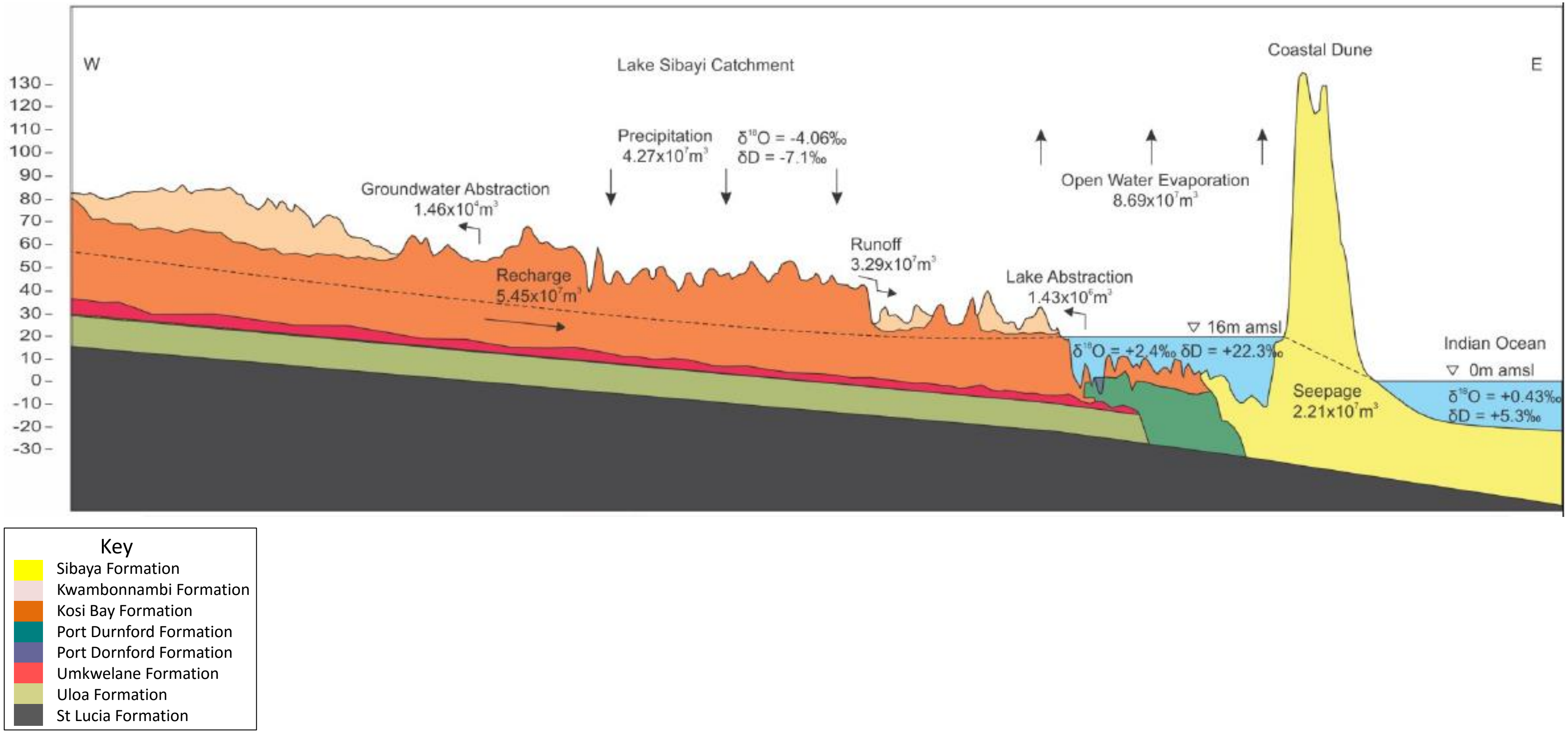

Figure 3-2 Hydrogeological Conceptual Model of the Lake Sibaya catchment (Weitz and Demlie 2013).

On the basis of volumetric water balances, the current abstractions are small relative to the large volumes flowing into and out of the lake. However, the water level records from the lake suggest that these may be more vulnerable to abstraction than is suggested by the water balance.

As already mentioned, water levels in the lake measured by DWA at W7R001 (Figure 3-3) historically fluctuated between 18 and 20.5 masl (Figure 3-4). Water levels fluctuations are closely linked to rainfall (Figure 3-5) and tend to occur on a monthly or annual basis, reflecting the attenuation of rainfall events via the groundwater.

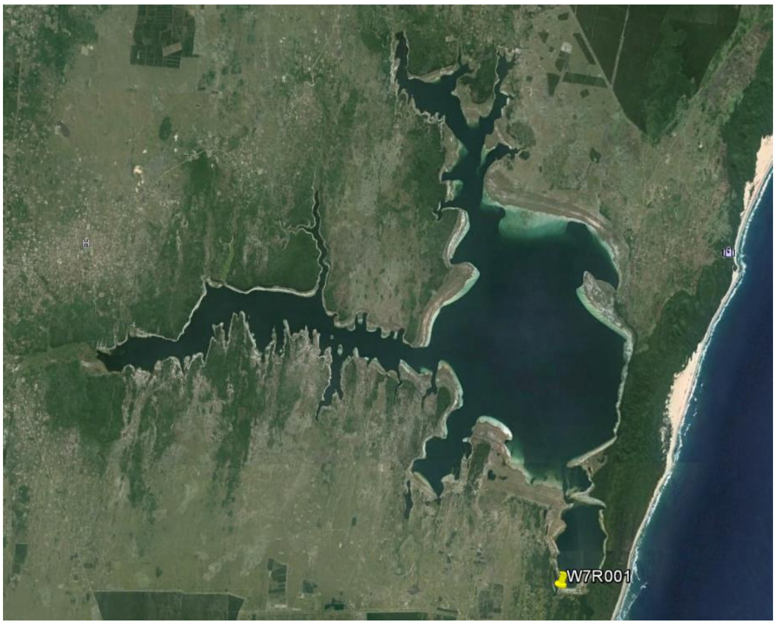

Figure 3-3 Google image of Lake Sibaya showing location of W7R001

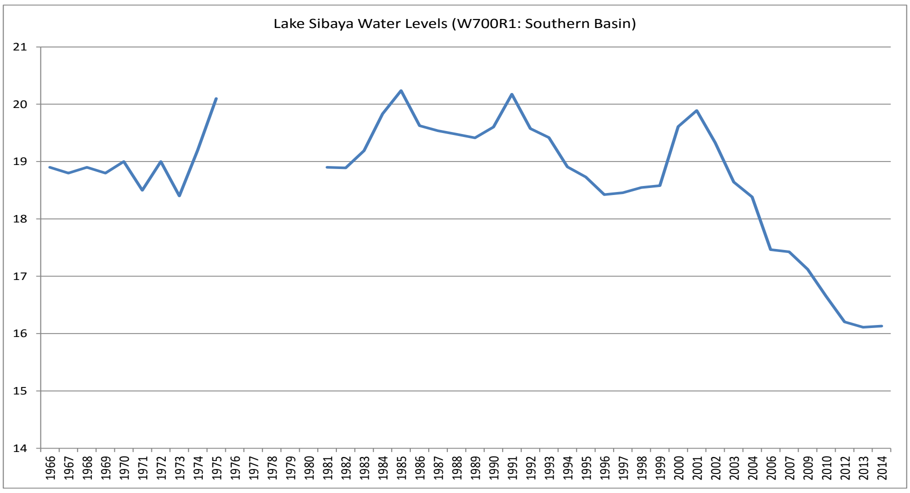

Figure 3-4 Water levels in Lake Sibaya (1966-2014)

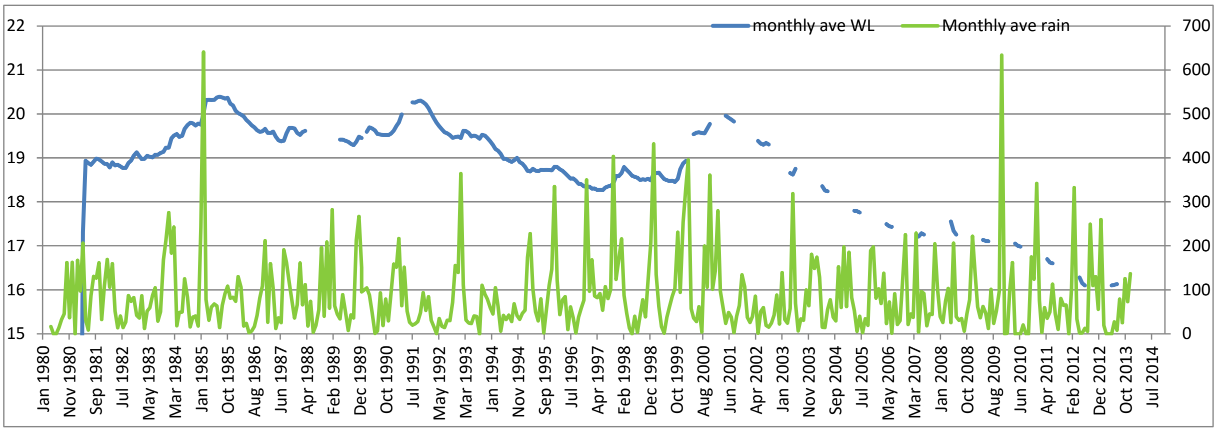

Figure 3-5 Water levels in Lake Sibaya and rainfall in the surrounding catchment (1966-2014)

However, since the commencement of direct bulk water abstraction from the lake (c. 2000)[6], water levels have declined steadily and are currently c. 2 m lower than any measurement recorded previously. Whether this is a direct result of abstraction or a result of climatic changes is not resolved but the evidence certainly suggests that lake levels are vulnerable to relatively low-level surface water abstraction (as previously predicted by Meyer *et al*. (2001) and Weitz and Demile (2013)).

Regardless of what is driving changes therein, water levels appear to be key in defining morphology and preventing saltwater intrusion, and in dictating the biotic communities that inhabit the lake.

Furthermore, the relatively long lead time between rainfall and changes in lake water level, also suggest that recovery from dangerously low water levels is likely to be slow, i.e., in the region of months to years. This makes it extremely important that this does not occur as any altered adverse state that arises is likely to endure for a sufficiently long time to kill all but the hardiest of the biota. This would mean that even once water levels return to their previous levels, the ecology of Lake Sibaya will have been fundamentally altered – and recovery from this, if indeed possible, could take centuries. An additional cause for concern is that the latest large rainfall event in the catchment (2010) did not result in a corresponding increase in water levels, as was the case with large rainfall events before that.

[6] Mbazwana Water Supply Scheme is supplied by the Mbazwana Water Treatment Works (WTW), which gets its raw water from Lake Sibaya.

4 GROUNDWATER RESOURCE UNITS

Denis and Denis (2009) divided the study area into smaller sub-regions, called Resource Units (RU). Resource units are areas of similar physical or ecological properties that are grouped or typed to simplify the Reserve determination process.

A 'groundwater resource unit' (or 'groundwater unit') is defined as a groundwater system that has been delineated or grouped into a single significant water resource, based on one or more characteristics that are similar across that unit. Other components of the water cycle, such as wetlands and rivers, must also be considered at this stage, to assess possible interdependency and promote the integrated water resource management vision of the NWA (DWAF 1998).

4.1 The delineation process

The first step in the delineation process was to divide the study area into six sub-catchments, as seen in Figure 4-1.

Each area was then divided into smaller Resource Units after taking consideration of aspects such as:

- *Geology*
- *Climate*
- *Recharge*
- *Surface water and groundwater stresses.*

4.2 The Groundwater Resource Units

The groundwater Resource Units delineated by Denis and Denis (2009) are summarised in Table 4-1 and depicted in Figure 4-2.

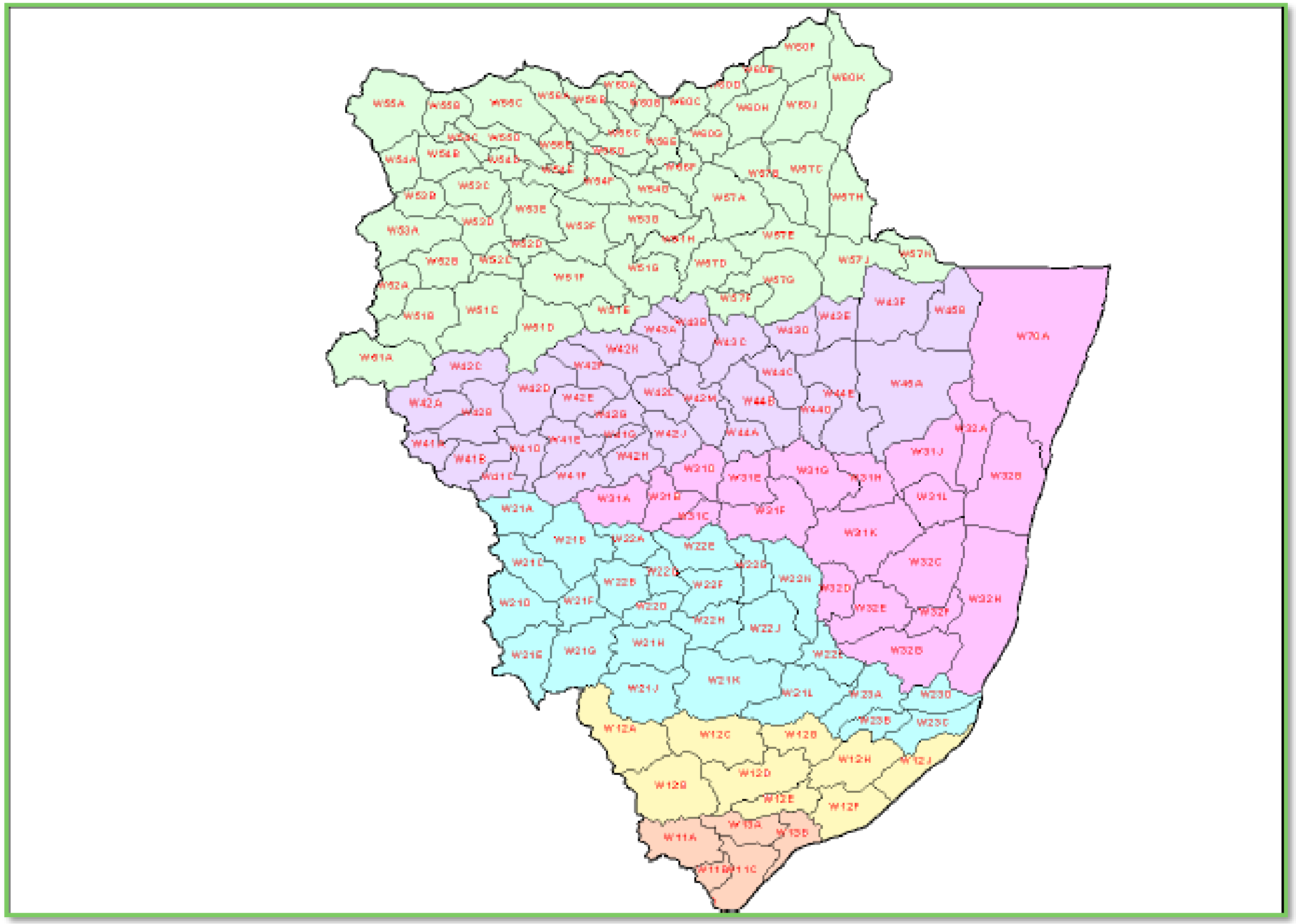

Figure 4-1 Main sub-catchments in the Usuthu-Mhlatuze WMA study area (Denis and Denis 2009)

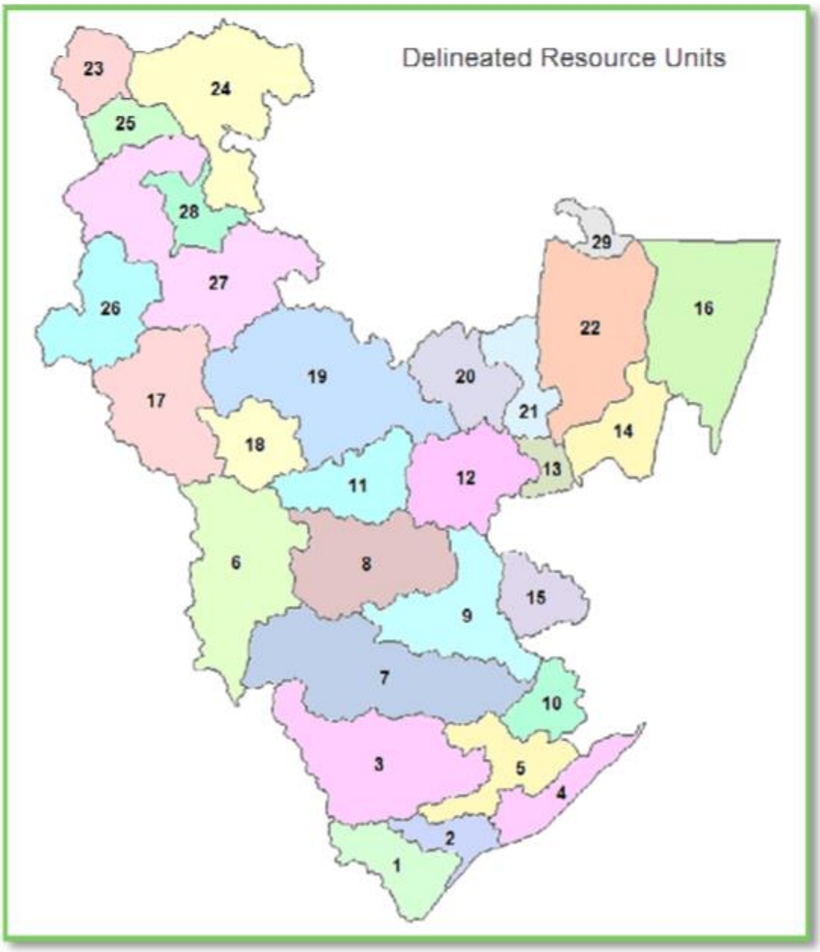

Figure 4-2 Delineated Resource Units in the Usuthu-Mhlatuze WMA study area (Denis and Denis 2009)

Table 4-1 Summary of the Groundwater Resource Units delineated by Denis and Denis (2009)

Resource	Sub-catchments	Location	Landuse	surface water	Climate	Present Status	Recharge			Reserve			Allocation	
							Total Area	Effective Area	Recharge	Baseflow	BHN	Reserve	Allocation	Current Use
							km^2	km^2	Mm^3/a	Mm^3/a	Mm^3/a	% Recharge	Mm^3/a	Mm^3/a
MRU-1	W11A, W11B and W11C	Main towns: Entumeni, Nyoni, Amatikulu and Gingindlovu. Protected areas: Amatikulu Park, Dlinza Forest, Entumeni Park, Longhurst Park, Arcadia Park and Rocky Ridge Park.	Primarily conservation, sugarcane, timber and cattle, and some light industry	Matigulu River & wetlands	Rainfall: 750 to 1300 mm p.a. Mean Temp: Jan 22°C Jul 14°C	B/C	723,1	477,1	26,042	2,260	0,090	9%	23,208	0,483
MRU-2	W13A and W13B	Main towns: Mtunzini and Eshowe. Protected areas: Port Dunford, Ongoyi and Umlalazi.	Primarily conservation, sugarcane, timber and cattle.	Mtunzini River & wetlands	Rainfall: 750 to 1300 mm p.a. Mean Temp: Jan 22°C Jul 14°C	B/C	2589,0	1916,0	156,863	57,735	0,091	37%	65,857	33,179
MRU-3	W12A, W12B, W12C and W12D	Main town: Osborn, Melmoth, Randalhurst Ndundulu and Nkwalini. Protected areas: Mooiplaas, Matshenezimpisi and Nkandla.	Light industry, mining, sugarcane, timber and cattle. Citrus and avocado pears also significant	Mhlathuze and Mfule River	Rainfall: 750 to 1300 mm p.a. Mean Temp: Jan 22°C Jul 14°C	B	1901,0	1860,4	178,254	65,310	0,019	37%	110,837	2,088
MRU-4	W12F and W12J	Main towns: Richards Bay & Flexiton. Protected area: section of Port Dunford	Forestry, sugarcane, industries, incl. sugar mills, paper mills, chemicals, gas plants. Port of Richards Bay, with coal exports. Mining of titanium and sand.	Mhlathuze & Mzingazi Rivers and estuaries, wetlands	Rainfall: >1000mm p.a Mean temp: Jan 25°C Jul 17°C	C/D	884,6	884,6	66,498	26,980	0,030	41%	34,945	4,542
MRU-5	W12E, W12G and W12H	Main towns: Empangeni, Mposa and Kwa Mbonambi. Protected areas: Ongoyi and Mfazi Parks	Protected areas of Ongoyi and Mfazi Parks; sugarcane and forestry; industries and mining, including building making works, a Titanium plant. A gas pipeline runs from Secunda to Durban via Empangeni.	Mhlathuze, Mhtatuzana and Nseleni Rivers and wetlands	Rainfall: 750 to 1300 mm p.a. Mean Temp: Jan 22°C Jul 14°C	C/D	3247,0	2666,0	224,301	89,734	0,181	40%	125,755	8,631
MRU-6	W21A, W21B, W21C, W21D, W21E and W21F	Main tonws: Vryheid and Nondweni. Protected areas: Ongoyi and Mfazi Parks	Land use includes mining (coal and granite) and farming (mainly broilers, forestry, maize, sheep and cattle). Large feedlots	Head water of the White Mfolozi River & tributaries	Rainfall: 600 to 900 mm p.a. Mean Temp: Jan 22°C Jul 10°C	C	1036,8	973,4	26,846	1,231	0,057	5%	16,398	9,160
MRU-7	W21G, W21H, W21J, W21K and W21L	Main towns: Ulundi & Umunywana. Protected areas: Goudhoek Farm, Matshitsholo, Ophathe and the Hlhuluwe-Mfolozi Game Park	Conservation areas, agriculture & mining	White Mfolozi River & tributaries	Rainfall: 650 to 1000 mm p.a. Mean Temp: 16^{0}C	B	711,4	550,4	29,514	0,751	0,000	3%	23,363	5,400
MRU-8	W22A, W22B, W22C, W22D, W22E, W22F and W22G	No major towns. Nlazatshe, Kwasceza, Nongoma, Swart Umfolozi and Gluckstadt are all small villages in area. Protected areas: Rensburg cycad colony and Ngome Park	Conservation area, agriculture, forestry, coal mines	Black Mfolozi River	Rainfall: 800 to 900 mm p.a. Mean Temp: Jan 24°C Jul 16°C	C	2428,9	2390,5	48,354	3,030	0,196	7%	27,324	17,804
MRU-9	W22H, W22J, W22K and W22L	Only village: Umunywana. Protected area: Hlhuluwe-Mfolozi Game Park	Coservation area, cattle and game farming, sugarcane & sub-tropical fruit	Black and White Mfolozi Rivers join to form Mfolozi River	Rainfall: 800 to 900 mm p.a. Mean Temp: Jan 24°C Jul 16°C	B	688,7	688,7	41,674	3,427	0,016	8%	19,573	18,658

Resource	Sub-catchments	Location	Landuse	surface water	Climate	Present Status	Recharge			Reserve			Allocation	
MRU-10	W23A andW23B, (Part of St Lucia W23C and W23D)	Just inland of Lake St Lucia. No towns in RU. Protected area: Lake Eteza	Protected area, sugarcane, timber, fruit such as pineapples.	Mfolozi& Msunduzi Rivers which join to flow into Lake St Lucia	Rainfall: >1000 mm p.a. Mean Temp: Jan 25°C Jul 17°C	B/C	2434,5	2434,5	195,502	130,012	0,495	67%	49,706	15,289
MRU-11	W31A, W31B, W31C and W31D	Small towns: Hlobane, Alpha and Ngome. Protected area: Hlomo Hlomo Cycad Colony	Mining & forestry	Head waters of Mkuze River, few wetlands	Rainfall: 600 to 900 mm p.a. Mean Temp: Jan 22°C Jul 10°C	C	533,0	533,0	36,268	4,340	0,002	12%	24,166	7,760
MRU-12	W31E, W31F and W31G	small towns: Kongolana, Thokazi and Mahlangasi	Cattle & game farming, sugarcane & subtropical fruit farming & mining.	Mkuze River & tributary Nkunzana River. Few wetlands	Rainfall: 800 to 900 mm p.a. Mean Temp: Jan 24°C Jul 16°C	B	1409,9	1409,9	95,851	14,975	0,005	16%	75,420	5,450
MRU-13	W31H, (Part of St Lucia W31L and W31K)	Town of Mkuze. Protected area: Lebombo Mountains	Cattle & game farming, sugarcane & subtropical fruit	Mkuze River & wetlands	Rainfall: 800 to 900 mm p.a. Mean Temp: Jan 24°C Jul 16°C	B/C	3212,2	3172,6	233,433	48,318	0,369	21%	164,612	20,134
MRU-14	W31J and W32A	No major towns. Mkuze Game Reserve and Sodwana are protected within the RU	Cattle & game farming & ecotourism	Mouth of Mkuze River	Rainfall: 500 to 750 mm p.a. Mean Temp: Jan 24°C Jul 17°C	C	611,8	611,8	46,303	9,071	0,050	20%	35,429	1,753
MRU-15	W32D and W32E	Only town is Hlabasi. Hluhluwe-Mfolozi Game Park	Cattle and game farming, sugar cane and subtropical fruit. Forests	Nzimane & Hluhluwe Rivers flow into Hlhuhluwe Dam. Wetlands	Rainfall: 800 to 900 mm p.a. Mean Temp: Jan 24°C Jul 16°C	B	301,0	205,2	11,808	0,933	0,007	8%	10,380	0,488
MRU-16	W70A	Main places: Sodwana Bay and Emangusi. The Tembe Elephant Park, Sileza, Mabaso Tribal Park, Manguze Park, Lake Sabayi and the Coastal Park are all protected in the RU	Game parks, subsistence agriculture, livestock and use of natural resources	No major rivers. Numerous wetlands, most important being Kosi Bay & Lake Sibayi	Rainfall: >1000 mm p.a. Mean Temp: Jan 25°C Jul 17°C	C	0,0	0,0	2417,668	0,000	3,691	0%	0,000	0,000
MRU-17	W41A, W41B, W41C, W42A, W42B and W42C	Towns include: Luneberg, Braunschweig, Grootspruit and Mpemvana. Luiperd Kloof and Pongola Bush Park are protected in area	Forestry, grazing and ecotourism	Head waters of Pongola River and wetlands	Rainfall: 700 to 1100 mm p.a. Mean Temp: 15°C	B	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-18	W41D, W41E and W41F	Main town: Bivane	Forestry, grazing, ecotourism and coal mining	Bivane and Manzana tributaries of Pongola River	Rainfall: 700 to 1100 mm p.a. Mean Temp: 15°C	B	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-19	W42D, W42E, W42F, W42G, W42H, W42J, W42K, W42L, W42M, W43A, W43B, W43C and W44A	Main towns: Paulpietersburg, Commondale and Berbice. Protected areas: Itala and Pongola Game Parks, and Witbad	Forestry, grazing, ecotourism and coal mining	Pongola, Wit, Mozana, Ithalu Rivers and some wetlands	Rainfall: 700 to 1100 mm p.a. Mean Temp: 15°C	B	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-20	W44B, W44C and W44D	Main towns: Pongola and Golela. Protected areas: Pongola Dam and Leeukop	Cattle & game farmining, ecotourism, cultivation of subtropical fruit, vegetables and sugarcane. Forestry and sand mining. Sugar mill in Pongola.	Pongola River and tributaries. Wetlands	Rainfall: 450 to 800 mm p.a. Mean Temp: 22°C	C	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-21	W44E	Main towns: Lavumisa and Jozini	ecotourism, game and cattle farming, and the cultivation of subtropical fruit, cotton, vegetables and sugarcane	Pongola River	Rainfall: 550 to 600 mm p.a. Mean Temp: 22°C	C	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-22	W43F, W45A and W45B	Main town: Ingwavuma. Protected areas: Hlatikulu, Ndumo and Tembe Elephant Parks.	cattle and game farming, forestry and ecotourism	Pongola River, tributaries and wetlands	Rainfall: 450 to 700 mm p.a. Mean Temp: 23°C	C	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000

Resource	Sub-catchments	Location	Landuse	surface water	Climate	Present Status	Recharge			Reserve			Allocation	
MRU-23	W55A	Main town: Chrissiemeer	Forestry, grazing, ecotourism and coal mining	Head waters of Usutu River, lakes and pans. Chrissiesmeer	Rainfall: 700 to 1100 mm p.a. Mean Temp: 15ºC	D	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-24	W53E, W54C, W54D, W55B, W55C, W55D, W55E, W56A and W56B	Main towns: Lotair, Lochiel and Waverley. Along Swaziland border	Forestry and associated paper mills; grazing and ecotourism	Headwaters of the Little Usutu River	Rainfall: 700 to 1100 mm p.a. Mean Temp: 15ºC	C	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-25	W54A and W54B	Southern part of Lotair included in RU	Crop production, with natural vegetation heavily used for grazing by sheep and cattle. Mining and forestry	Headwaters of Great Usutu River; Sandcliff and Westoe Dams; wetlands	Rainfall: 700 to 950 mm p.a. Mean Temp: 15ºC	C/D	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-26	W51A, W51B and W52A	Main town: Drikiesdorp	Crop production, with natural vegetation heavily used for grazing by sheep and cattle. Mining.	Assegaai River, Heyshope dam and wetlands	Rainfall: 700 to 950 mm p.a. Mean Temp: 15ºC	B/C	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-27	W51C, W51D, W51E, W51F, W52B, W53A, W53B and W53C	Main towns: Sheepmoor, Panbult, Iswepe, Anysspruit, Amsterdam, Piet Retief, Wittenberg and Sicunusa. Protected areas: Jericho and Morgenstond Dams.	Forestry, grazing, ecotourism & coal mining.	headwaters of the Ngwempisi and Assegaai Rivers. Jericho & Morgenston Dams. Wetlands	Rainfall: 700 to 1100 mm p.a. Mean Temp: 15ºC	C	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-28	W52C and W52D	No towns or protected areas	Forestry	Hlelo River	Rainfall: 700 to 1100 mm p.a. Mean Temp: 15ºC	B	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000
MRU-29	W57K	Protected area: Ndumo Park	cattle and game farming, sugarcane and subtropical fruit	Great Usutu River, wetlands	Rainfall: 800 to 900 mm p.a. Mean Temp: Jan 24ºC Jul 16ºC	B	0,0	0,0	0,000	0,000	0,000	0%	0,000	0,000

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