

Classification of water resources within Quaternary Catchment C22K

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ABSTRACT

The Vaal Barrage was built by Rand Water downstream of the Vaal Dam. The Vaal River Scheme, in many respects, brought about a change in the environment along the Vaal River between the Barrage and Vereeniging. Vereeniging is located in the lower reaches of the Klip River (Gauteng), close to its confluence with the Vaal Barrage. This town was established on coal mining and steel industries and also hosts Rand Water's purification works.

This study focused on the classification of water resources and associated aquatic ecosystems within catchment C22K. The reason for the selection of this catchment was the concerns regarding large-scale industrial activities in the catchment and also within catchment's tributaries. In addition many waste water treatment plants are malfunctioning. System operations are declining especially sewage treatment (DWA, 2011). Sewage discharges often far exceeds the standards and conditions demanded by licences (DWAF, 2004). These key water quality parameters are threshold concentrations which, if regularly exceeded, can result in harmful impacts on aquatic ecosystems and human health (Dabrowski & de Klerk, 2013). Mining activities are polluting both surface water and groundwater resources. An additional concern is the growing number of agricultural activities in the area. Expanding populations and climate change in the region have put additional pressure on the quality of Vaal Barrage water (Riemann *et al.*, 2017). The current state of the water resources and associated ecosystems were determined and management classes were set for the above mentioned.

Return flows from domestic and industrial effluent discharges and surface run-off from urban contribute to increase Total Dissolved Solids (TDS). TDS is an important parameters water quality indicator and refers to the degree of salinity of water. In 2016 the TDS value went up to 461mg/l at the Vaal Barrage. TDS value at the Vaal Dam is 116 mg/l. The quality of the surface water at the Vaal Barrage was not natural anymore but good for the ecosystem due to continuous dilution of natural water quality from the Vaal Dam, and the water resource should managed by class I to ensure the water below the Vaal Barrage is fit for use. A vulnerability assessment based on risk and hazard description using local and scientific expertise (DRASTIC approach) (DWAF, 2005) indicates the pollution potential of groundwater quality to the surface water mining being moderately hazardous, Geo-interaction requires management class II response. Increased pollution wash-off and human activity makes the environment less habitable, resulted in moderately modified habitat and water quality degradation. Habitat loss associated with management class II.

Key terms: Water Quality, Vulnerability, Habitat, Classification.

ABBREVIATIONS/ACRONYMS

BHN – Basic Human Need

CBM – Chloride Mass Balance

DEAT – Department of Environmental Affairs

DWA – Department of Water Affairs

DWAF –Department of Water Affairs and Forestry

DWS –Department of Water and Sanitation

DRASTIC – Depth to groundwater, Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, Conductivity

EC – European Commission

EC – Electrical Conductivity

ELM - Emfuleni Local Municipality

EMC – Ecological Management Class

EWR – Ecological Water Requirements

IWRM – Integrated Water Resource Management

MAP – Mean Annual Runoff

MC – Management Class

mamsl – metre above mean sea level

NFWEPA – National Fresh Water Ecosystem Priority Areas

NWA – National Water Act

NWRS – National Water Resource Strategy

PES – Present Ecological Status

PS – Present State

RC – Reference Condition

RDM – Resource Directed Measures

RW – Rand Water

RQOs – Resource Quality Objectives

SA – South Africa

SANBI – South African National Biodiversity Institute

SAWQG – South Africa Water Quality Guideline

TDS – Total Suspended Solids

UAs – Unit of Analysis

WRC – Water Research Commission

WWTP – Waste Water Treatments Plants

TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	I
ABSTRACT	II
ABBREVIATIONS/ACRONYMS	III
CHAPTER 1: INTRODUCTION	1
1.1 Historical Background.....	1
1.2 Problem statement and substantiation.....	2
1.3 Aims and Objectives	3
1.3.1 Research Aims	3
1.3.2 Objectives.....	4
CHAPTER 2: LITERATURE STUDY	5
2.1 Socio-Economic Environment.....	5
2.2 Pollution	6
2.3 Water Resource Management Approaches	7
2.3.1 Australia	7
2.3.2 Brazil	7
2.3.4 South Africa.....	8
2.4 Resource Directed Measures	9
2.5. Tools used in the classifying of Resources	11
2.5.1 Wetlands	11
2.5.2 Surface water	12
2.5.3 Groundwater.....	12

2.5.4 Vulnerability	13
 CHAPTER 3 BACKGROUND TO STUDY AREA	 14
3.1 Location	14
3.2 Climate	15
3.3 Surface Water	16
3.4 Groundwater.....	19
3.5 Wetlands	21
3.6 Land Cover.....	21
3.7 Soil Types	22
3.8 Geology	23
3.9 Impacts on water resources within study area	24
 CHAPTER 4 METHODOLOGY	 26
4.1 Data	26
4.2 Water Resource Classification System (WRCS) Process	27
4.2.1 Present State for the Study Area	27
4.2.2 River Health Classification Process and Ecological Management Classes (MCs).....	27
4.3 Assessment method approach	28
4.3.1 Stress Index (quantifying water use).....	29
4.3.2 Water quality	30
4.3.3 Land Cover.....	30
4.3.4 Vulnerability of Water Resources.....	30
4.3.5 Ecological Water Requirement (EWR) – use ecological guidelines.....	31

CHAPTER 5 CLASSIFICATION OF THE WATER RESOURCES WITHIN THE VAAL BARRAGE CATCHMENT	31
5.1 Assumptions.....	32
5.1.1 The hydrological monitoring network: Vaal Barrage.....	34
5.2 Classification	34
5.2.1 Groundwater Use Classification.....	34
5.2.1 Surface Water Stress Classification.....	35
5.2.2 Surface Water Quality Classification.....	35
5.2.2 Groundwater Quality Classification.....	37
5.2.4 Landcover Classification.....	37
5.2.5 Vulnerability of Surface Water Resources	38
5.2.6 Vulnerability of Groundwater Resources.....	39
5.2.7 Ecological Status of rivers, associated wetlands and riparian zones.....	40
CHAPTER 6 CONCLUSION AND RECOMMENDATION.....	42
6.1 Introduction	42
6.1.1 Hydro- morphology.....	42
6.1.2 Locality , Topograph and Rivers System	42
6.1.3 Expected Impact and Potential Ecological	43
6.2 Assessment of Catchment.....	43
6.2.1 Expected Impact on Water Resource Quality and System Operations.....	43
6.2.2 Ecological Status of the Water Resource and Water Resource Management.....	44
6.3 Integrated Water Management	44
6.4 Assessment and Classification Results	44

6.4.1 Assessment Level	44
6.4.2 Classification Results	44
6.5 Recommendations.....	46
 CHAPTER 7 BIBLIOGRAPHY	 48
 CHAPTER 8 ANNEXURES	 54
Annexure 1: Tools	54
Annexure 2: Land cover	56
Annexure 3: Assessment Outcome	57

LIST OF TABLES

Table 1: Resource Management Class (MC) (DWA, 2010)	11
Table 2: Link between landscape and water transfer mechanisms for wetlands (RAMSAR, 2005).....	11
Table 3: Vulnerability (Parsons & Wentzel, 2007)	13
Table 4: Information regarding flow stations (Obtained from DWS web site)	17
Table 5: Information concerning the Vaal Dam and the Vaal Barrage (DWAF, 2009a)	19
Table 6: Soil layers (DWAF, 2004)	22
Table 7: Data Sources taken from Dennis <i>et al.</i> , 2012	26
Table 8: Ecological status classification and colour code from EC:Directive (2006)	27
Table 9: Process of setting MCs	28
Table 10: Guideline Status Category assessment based on groundwater Stress (Dennis <i>et al.</i> , 2012; Parsons & Wentzel, 2007)	29
Table 11: Guide for determining the level of flow for Water Stress of a Resource (Spanhoff <i>et al.</i> , 2012)	30
Table 12: Resource stress due to Land Use.....	30
Table 13: Ecological status classification (Kleynhans <i>et al.</i> , 2008) and colour code adapted from EC:Directive (2006)	31
Table 14: Water quality at the Vaal Barrage	36
Table 15: Vaal Barrage: Present Status Category for assessment based on potential or expected resource water contamination	39
Table 16: The DRASTIC ratings and weights used (Lynch <i>et al.</i> , 1984)	39
Table 17: Vulnerability classes	40
Table 18: Surface Water Ratings.....	40

Table 19: Ecological classification	41
Table 20: Generic ecological categories for EcoStatus components (Kleynhans and Louw, 2007).....	54
Table 21: Weighting values used for the DRASTIC method	55
Table 22: Settlement classification in-terms of level of development in catchment area (Dube <i>et al.</i> , 2017)	56
Table 23: Land based activities (Parsons & Wentzel, 2007)	57
Table 24: Present Ecological Status of Water Resource and Management Class	57

LIST OF FIGURES

Figure 1: Study Area	2
Figure 2: Vaal Barrage Dam: Developmental attributes and demography (Meyer & Strauss, 2014).....	5
Figure 3: Vereeniging Statistic Population since the construction of Vaal Barrage (Statssa, 2016; Tempelhoff, 2001).	6
Figure 4: IWRM in South Africa, (Grobler & Belcher, 2011)	9
Figure 5: Level of confidence (Parsons and Wentzel, 2007)	10
Figure 6: Location of study area	14
Figure 7: Average monthly rainfall	15
Figure 8: Temperature (Timeanddat.com, 2018)	16
Figure 9: Topography, rivers and flow gauges	17
Figure 10: Qualitative Trend in the condition of the WR quality for Vaal Barrage (Kleynhans <i>et al.</i> , 2005)	18
Figure 11: Vaal Dam	19
Figure 12: Aquifers	20
Figure 13: Groundwater levels.....	20
Figure 14: Wetlands	21
Figure 15: Land cover	22
Figure 16: Geology	24
Figure 17: Main Economic since the construction of Vaal Barrage (DWAF, 2004; Statssa, 2016).....	25
Figure 18: Time series graph of TDS (as Salinity) and PH on the Vaal River at Barrage (monitoring C2R008).....	33

Figure 19: Seasonal Variation of System Variable and Non-constituent behaviour of the present time at Vaal Barrage : Time series graph of EC and PH on the Vaal River at Barrage (monitoring C2R008)	33
Figure 20: Classification of Salinity in Vaal Barrage Water Quality	36
Figure 21: EC values for Groundwater	37
Figure 22: Activities and Potential for future growth in the Johannesburg-Vereeniging-Vanderbijlpark	38
Figure 23: Different flow components in the Vaal Barrage River in the Upper Vaal Water Management Area (Tlou & Consulting, 2012).....	42

CHAPTER 1: INTRODUCTION

1.1 Historical Background

Two hundred and fifty million years ago, prehistoric plants, such as the Glossopteris, flourished in swamplands that dominated the area around Vereeniging. After a carbonisation period of a few million years, the plants were transformed into coal. Vereeniging was established in the 1880s, after coal was discovered in the area. The Vaal Barrage was founded on these fossilised coal formations that provided the raw material to the huge industries in 1878. George William Stow discovered coal south of the Vaal River in the region of the confluence of Taaiboschspruit and the Vaal River in the then Northern Orange Free State and adjoining the Transvaal (currently named Gauteng Province), (Tempelhoff, 2001).

George William Stow and the Honourable Samuel Marks formed the company called “De Zuid-Afrikaansche en Oranje Vrijstaatse Kolen en Mineralen Vereeniging. The name of the company was too long and it was referred to as “De Vereeniging” by the man on the street, with the town officially being registered as Vereeniging in 1892 (Tempelhoff, 2001).

The name Vereeniging was derived from the Dutch word meaning "association" or "union". Vereeniging is a city in the Gauteng Province, South Africa, situated where the Klip River flows into the northern loop of the Vaal River which flows from the Vaal Dam and then downstream in the Vaal Barrage as shown in Figure 1.

Three rivers namely the Suikerbosrand, the Klip and the Rietspruit, reflect the health or ill-health of the Barrage catchment C22K and it is therefore of cardinal importance to monitor.

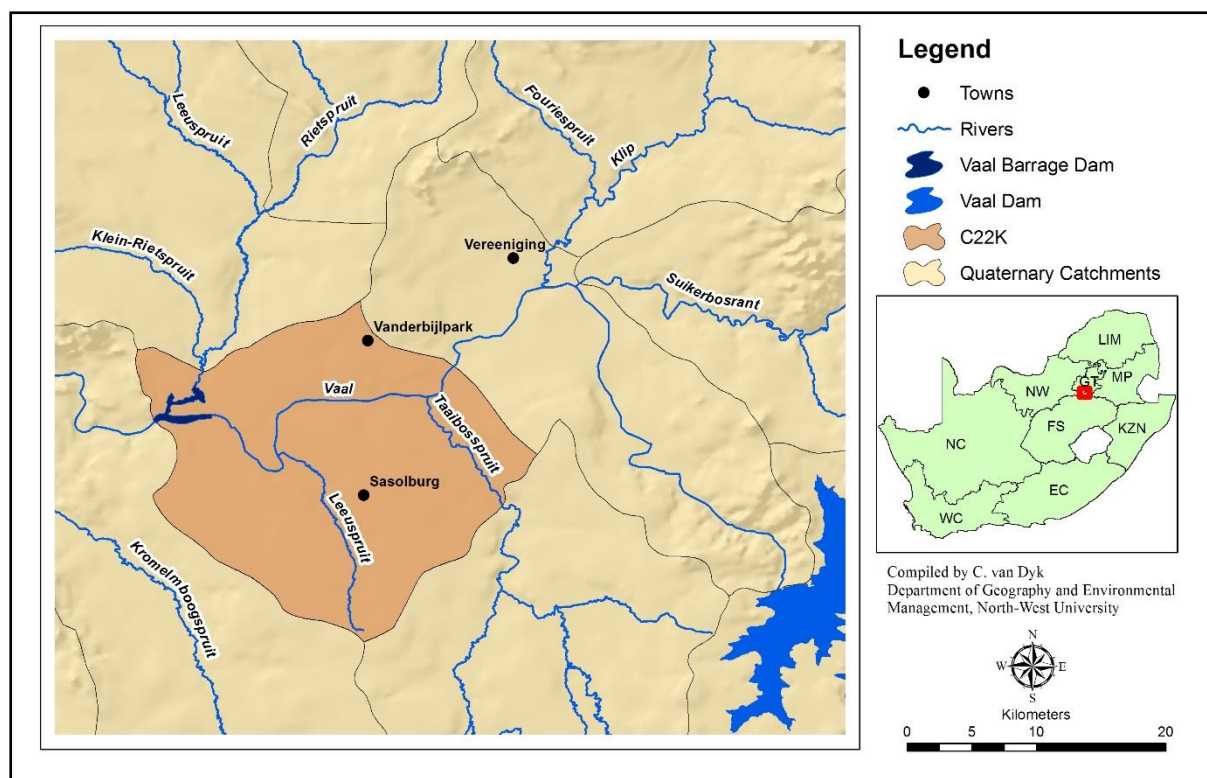


Figure 1: Study Area

1.2 Problem statement and substantiation

Dallas and Rivers-Moore (2014) stated that predicted climate change conditions for some Southern African regions would lead to the exacerbation of salinisation by the year 2050. The existence of regions with limited human impact have become extremely rare, as the majority of river systems and associated aquatic ecosystems in the world have been disturbed or altered in some way and thus have subsequently lost their pristine characteristics. Dallas and Rivers-Moore (2014) found that water quality changes affect water temperature, solubility of oxygen and other gases, chemical reaction rates and toxicity, as well as microbial activity. These impacts have been attributed to economic development (Hofmann *et al.*, 2015).

In South Africa (SA), water is not always available at the right time and in the right place to meet developmental demands. Because of the pressure to grow the economy, SA became a resource-driven economy and the flow regimes of water resources at the Vaal Barrage were altered by means of abstraction, and the construction of the Vaal Barrage and weirs (NWRS, 2013). The Socio-economic growth and development in the Upper Vaal River has led to deterioration in the water quality of the water resources in the system.

The 63 kilometres from the Vaal Dam to the Vaal Barrage constitutes less than 5% of the total catchment (Wepener *et al.*, 2011), however run-off water from Johannesburg, (where there are wet industries, dysfunctional waste water treatment works and gold mining activities) flows into the Vaal River in the Barrage catchment. In addition the Vaal Barrage is seriously impacted (Jordaan & Bezuidenhout, 2013; Wepener *et al.*, 2011), due to continued degradation and pollution of the three main tributaries (Wepener *et al.*, 2011) namely the Klip (Rimayi *et al.*, 2016), Suikersborand, and Rietspruit (Jordaan & Bezuidenhout, 2013; Wepener *et al.*, 2011). Operating collieries are located in the Vaal-Triangle (Vereeniging-Vanderbijlpark-Sasolburg) area adjacent to the Vaal River. Acidic waters entering the system due to mine flooding contribute to the deteriorating water quality in the study area (Tempelhoff *et al.*, 2007; Wepener *et al.*, 2011). This has led to salinisation and eutrophication being identified as two major water quality problems being experienced (Dallas & Rivers-Moore, 2014; DWAF, 2009c; Jordaan & Bezuidenhout, 2013).

Water resources need an adequate water quality to sustain ecological processes and the associated species (Valero, 2012). Therefore in this case, management interventions are needed to ensure that the water quality is of an acceptable class and is available to all users in the system (DWAF, 2009c; Jordaan & Bezuidenhout, 2013; Wepener *et al.*, 2011).

Strategic actions and programmes are required to ensure that the water resources of Vaal River System are managed to meet the needs of all water users, at the same time protecting the level of in-stream resource quality (EC:Directive, 2006). In 2009, the DWAF (2009c) implemented a structured bio-monitoring programme to determine the exact sensitivity and health status of the Vaal River. This was in line with the National Water Act (NWA, 1998), stipulating regulatory guidelines and criteria to ensure the country's water resources are fit for use (Jordaan & Bezuidenhout, 2013).

The classification of the rivers and streams is the basis of all future sustainable management of natural water resources (Spanhoff *et al.*, 2012).

1.3 Aims and Objectives

1.3.1 Research Aims

- Identify water quantity and quality issues within the proposed study area (Quaternary catchment C22K)
- Determine the current state (class) of the water resources

- Propose a management class (MC) to be able to manage the resources in a sustainable way

1.3.2 Objectives

The overall objective of this assessment is to identify the water quality/quantity issues / aspects that have an impact on ecological and physico-chemical parameters / status of the catchments C22K.

To achieve the overall objective, the specific objectives are:

1. To determine the pristine current water quantity and quality conditions of Catchment C22K, in terms of water quality, pollution sources and key water users.
2. To provide a firm basis for protecting water resources and associated ecosystems.

CHAPTER 2: LITERATURE STUDY

2.1 Socio-Economic Environment

The Vaal Barrage falls under the Emfuleni Local Municipality (ELM), in the Sedibeng District, Gauteng Province, South Africa. The different phases of the construction of the Barrage are summarised as (Figure 2):

- A. Morphology structure of Barrage in the Vaal River at time of inauguration in 1923 (Tempelhoff *et al.*, 2007).
- B. Vaal Barrage Construction phase. The width of the Vaal River varied according to the season and as a result it was more difficult to cross the river during the rainy summer season. During the summer the width was wider, and depth deeper than winter periods. When the Vaal River Barrage was built in 1923 the width of the river expanded. Infiltration of water also increased due to the wider river (Meyer & Strauss, 2014).
- C. After Construction Phase. Current form of Barrage in the Vaal River.

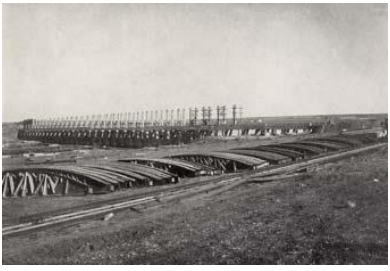
		
A – Bottom of Reservoir	B – Construction Phase	C – After Construction Phase
Active from 1923-01-01: Latitude 26°44'17"S; Longitude 27°35'31"E		

Figure 2: Vaal Barrage Dam: Developmental attributes and demography (Meyer & Strauss, 2014)

The construction of the Vaal Barrage leads to the urban expansion of the upstream town of Vereeniging as shown in Figure 3. This coal mining town, which had a population of 2000 people in 1911 had grown to 5443 residents in 1921. In 2015 the Vereeniging had 1159947 residents. This indicated an increasing trend in population growth of 10% from 2001 to 2011 and a 60% increase in population growth from 2011 to 2015. The construction of the Vaal Barrage stimulated local commerce, industrial development, farming operations and urban

development (Tempelhoff, 2001). However problems also arose, such as the industrial sectors requiring a larger supply of water in order for development and progress to take place.

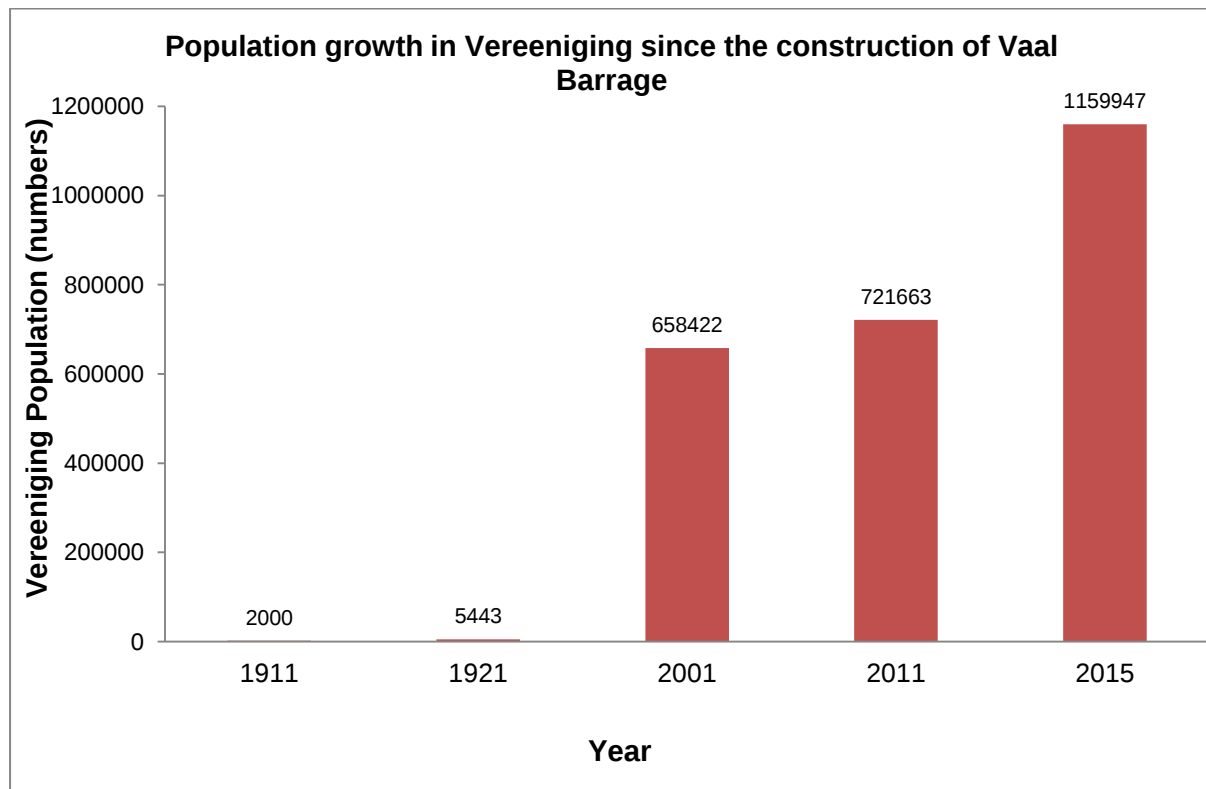


Figure 3: Vereeniging Statistic Population since the construction of Vaal Barrage (Statssa, 2016; Tempelhoff, 2001).

The Vaal Barrage was once used to supply water to Johannesburg but no longer does so, because the quality of its water is deteriorating due to the pollution (DWAF, 2009c; Jordaan & Bezuidenhout, 2013; Wepener *et al.*, 2011). The ELM (2017) admitted that it was faced with challenges to provide quality clean water and removal of waste in all areas of Emfuleni. Rand Water (RW) had reduced its water pressures by 20% which has adversely affected urban areas and the township.

2.2 Pollution

The water pollution crisis that had been lurking since the 1960s was addressed after a concerned environmental scientist, turned whistle-blower disclosed how the industry had polluted the water supplies in parts of the Vaal Triangle. This pollution, which had been the order of the day for years, had severely affected the Vaal River Barrage (Gouws *et al.*, 2007).

In the late 1980s, the government had informally lifted urban influx control. This caused a housing crisis and contributed to a major sanitary crisis. Many of the informal settlements were situated in the catchment areas of the Klip and the Suikerbosrand rivers (Wepener *et al.*, 2011). In 1992, there were 6105 sewer blockages in parts of the Vaal Barrage catchment area. In 2017, the ELM were faced with a challenge of unreliable waste collections. In addition, RW released a media statement stating that it would reduce its supply of water to ELM due to non-payment (Wepener *et al.*, 2011).

The ongoing environmental crisis of the Vaal Barrage had been monitored by RW which had, up to the passing of the NWA (1998), been responsible for managing the Vaal Barrage (Tempelhoff *et al.*, 2007).

2.3 Water Resource Management Approaches

2.3.1 Australia

Australia relies on a range of legislation, and the two key pieces of legislations are the Water Management Act (WMA) 2000 and Water Act 1912 Seago (2016). The WMA (2000) is for the sustainable and integrated management of the state's water for the benefit of both present and future generations Seago (2016). The WMA (2000) is based on the concepts of ecological sustainable development; it is driven by the decline in health of rivers (Seago, 2016). Australian water resource assessments assist understanding the impacts of past and present water management practices. It provides consistent, scientifically robust water information. Research by Seago (2016) found that the Australian water resource assessment highlight patterns in the water situation at regional to national scales and over time periods of months to decades. These results are published regularly.

2.3.2 Brazil

Brazilian classification also makes it possible to link water quality and quantity management. The classification system of the Brazilian water bodies are usually established according to legal standards. Seago (2016) states that the classification of water bodies provides a firm basis for protecting water quality and to improve the quality where required.

2.3.4 South Africa

There are 2 pieces of legislation in South Africa that govern water:

- NWA (1998) deals with the management of water resources. Its legal framework is to ensure that the nation's water resources are protected, used, controlled, managed, conserved and developed in a sustainable and equitable manner, for the benefit of all.
- Water Services Act (1997): This Acts provide the right to access basic water supply and sanitation. It also provides the framework for delivery of these water services to the people.

The NWA (1998) promotes complimentary approaches to achieve Integrated Water Resource Management (IWRM). Figure 4 displays the South African IWRM schematic diagram used in classification of significant water resources. The catchment vision describes the state of water resources, while the catchment assessment also includes current state of the water resource and the desired state thereof. Catchment management strategies address Resource Directed Measures (RDM) and other use (international obligations, inter-basin transfers, or future use). The Department of Water and Sanitation (DWS) has developed targets and Resource Quality Objectives (RQOs) for the management of water resources. Water can then be allocated for use.

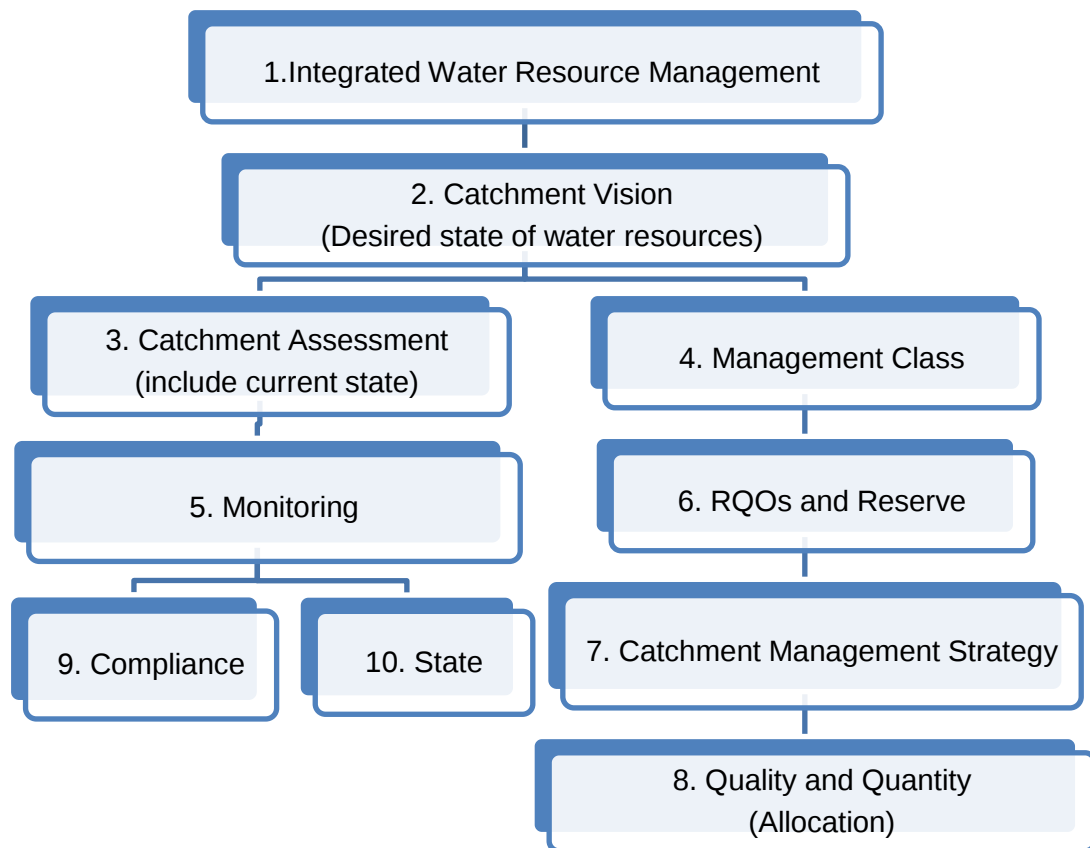


Figure 4: IWRM in South Africa, (Grobler & Belcher, 2011)

2.4 Resource Directed Measures

Chapter 3 of the NWA (1998) provides legal decision-making tools for attaining a balance between protecting and using water resources. RDM is an IWRM tool developed to protect the health of water resources. The RDM method is based on scientific principles, and provides estimates of the water quantity and quality required (Grobler, 2017). The RDM includes the following (Dennis *et al.*, 2012):

- Classification systems for water resources
- The determination of the Reserve for water resources
- Setting RQOs

The first step in the RDM process is to initiate a study by deciding on the study area and the level of confidence that is needed in for the study. However before this can be done the resources in the area must be defined. According to Dennis *et al.* (2012), the resources can be defined:

- *“the possible geographical extent of the study area and a brief description thereof*

- *the role of the resource in terms of sustaining other components of the hydrological system (baseflow to rivers, surface water contribution to groundwater, wetlands and estuaries)*
- *the degree of resource dependence (both social and environmental), including volumes of water abstracted*
- *any identified stresses (quantity and quality)*
- *data and information available”.*

It is however important to note that data availability will play a large role in determining the confidence level. Low confidence level studies are normally desktop studies using readily available data. On the other hand high confidence studies are based on site-specific data collected by a team of specialists.

There is no formal method to determine the level of confidence for a RDM study, however Parsons and Wentzel (2007) proposed a guide based on stress and impact as seen in .

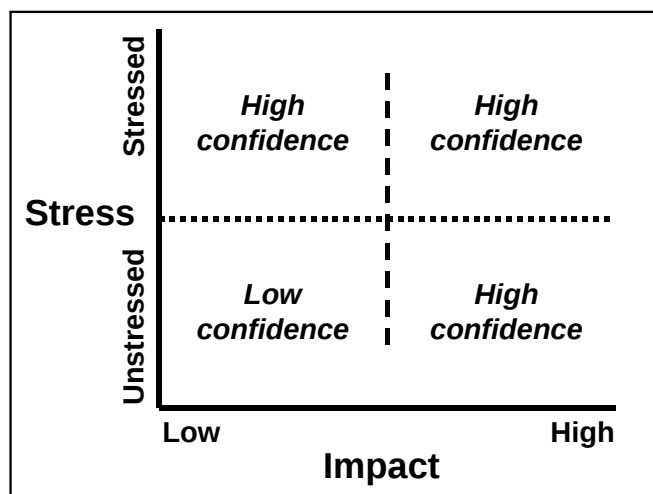


Figure 5: Level of confidence (Parsons and Wentzel, 2007)

The next step in the RDM method is classification, which is the focus of this study. Classification is one of the tools used to protect resources. Each class needs to describe the impacts on the resources and if they are acceptable or not acceptable in order to protect the resource. Thereafter the MC is set (Table 1). Classification is to ensure that the resource can be utilised sustainably if the proposed class is adhered to. In order to classify the resource to determine how stressed/impacted it is, units of analysis must be delineated. These units of analysis (UA) have similar characteristics and take into account factors such

as land use, population information, and significant water resources, infrastructure and water use (Dennis *et al.*, 2012).

Once the classification process has been complete, the Reserve for Basic Human Needs (BHNS) and ecological water requirements (EWRs) needs to be set. The Reserve for BHNS is currently set at 25 l/p/d. EWRs is the quantity and quantity of water that is required to maintain the water resource in its assigned ecological category/class (Parsons and Wentzel, 2007).

The last step is to set RQOs which are measures that are implemented to ensure the set Reserve and associated class are maintained.

Table 1: Resource Management Class (MC) (DWA, 2010)

Class I (Excellent)	Resource is one which is minimally used, and the overall condition of that resource is minimally altered from its pre-development condition;
Class II (Good)	Resource is one which is moderately used, and the overall condition of that resource is moderately altered from its pre-development condition;
Class III (Fair)	Resource is one which is heavily used, and the overall condition of that resource is significantly altered from its pre-development condition.

2.5. Tools used in the classifying of Resources

2.5.1 Wetlands

A wetland is defined as “*land which is transitional 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*” (DWAF, 1999).

According to the RAMSAR (2005), there are seven types of wetlands, which are based on landscape location and water transfer mechanisms. Their possible interactions are indicated in Table 2.

Table 2: Link between landscape and water transfer mechanisms for wetlands (RAMSAR, 2005)

Landscape location	Subtype based on water transfer mechanism
--------------------	---

Flat upland wetlands	Upland surface water-fed
Slope wetlands	Surface water-fed Surface and groundwater-fed Groundwater-fed
Valley bottom wetlands	Surface water-fed Surface and groundwater-fed Groundwater-fed
Underground wetlands	Groundwater-fed
Depression wetlands	Surface water-fed Surface and groundwater-fed Groundwater-fed
Flat lowland wetlands	Lowland surface water-fed
Coastal wetlands	Surface water-fed Surface and groundwater-fed Groundwater-fed

There are two methods that can be used to determine the class of a wetland one of which is the Wetland-IHI. This method determines the Wetland Index of Habitat Integrity (Annexure A: Table 20). The results provide a score for the Present Ecological Status (PES) of the habitat integrity of the wetland. This model is designed for a quick assessment of floodplain and channelled valley bottom wetlands. The final product is an ecological category score of A to F, where A means Natural and F means critically modified (Annexure A: Table 20).

The second method is the WET- Health tool which uses geomorphology, hydrology and vegetation as indicators of wetland health (Macfarlane et al., 2008). Wetland health is the deviation of wetland structure and function from the wetland's natural condition. The WET-Health tool is used in assessing the PES of a wetland. There are two levels of complexity: Level 1 is used for assessment at a broad catchment level and Level 2 provides detail and confidence for individual wetlands based on field assessment of indicators of degradation (Macfarlane et al., 2008). However as geomorphology was not available for the study area, this method was not utilised.

2.5.2 Surface water

The surface water flow and associated water quality can be obtained from the DWS webpage (DWS, 2018). The South African Water Quality Guidelines (DWAF, 1996) can be used to assess the quality of the water.

2.5.3 Groundwater

Aquifer systems are mainly recharged via preferential pathways such as fractures, dykes, bedding planes and highly weathered zones. The recharge from rainfall was estimated using

the Chloride Mass Balance (CMB) method and is expressed as a percentage of the Mean Annual Precipitation (MAP). The method is based on the following equation (Bredenkamp *et al.*, 1995):

$$\% \text{Recharge} = (\text{Chloride concentration in rainfall} / \text{chloride concentration in groundwater}) \times 100$$

2.5.4 Vulnerability

Vulnerability methods are used to determine potential impacts. The first vulnerability method is a table developed by Parsons & Wentzel (2007) to classify the potential impacts of land use on water resources.

Table 3: Vulnerability (Parsons & Wentzel, 2007)

EXPECTED LAND USE	Vulnerability			
	Impact	Low	Medium	High
	Low Impact	A	B	C
	Moderate Impact	B	C	D
	High Impact	C	D	E

The second method is the DRASTIC method which determines the vulnerability of groundwater systems. DRASTIC refers to the seven factors utilised in the rating system — depth to groundwater, recharge rate (net), aquifer media, soil media, topography, impact on vadose zone, and hydraulic conductivity. Each of these is assigned a value based on a rating. These factors are adjusted by a weighting factor and summed to calculate the pollution potential or DRASTIC index Lynch *et al.* (1984). The DRASTIC formula for groundwater in South Africa according to Lynch *et al.* (1984) is documented in Annexure A, together with the weighting factors and the rating Table 21.

CHAPTER 3 BACKGROUND TO STUDY AREA

3.1 Location

The Vaal Barrage is located in quaternary catchment C22K (see Figure 6). Vanderbijlpark is located to the north-east of the area and Sasolburg is located in the southern section of the catchment. The study area is located in the Vaal Triangle, south of the city of Johannesburg, in the interior high-plateau of SA known as the Highveld. The Vaal River slopes gently from approximately 1800 mamsl in the east at its origin to 1460 mamsl near the Vaal Barrage. The town of Vereeniging to the north east of the study area is situated where the Klip River tributary (flow gauge C2H071) empties into the northern loop of the Vaal River flowing from Vaal Dam downstream (flow gauge C2H122) into Vaal Barrage catchment (flow gauge, C2H008). The Rietspruit flows from the north west at approximately 1430 mamsl before entering into Vaal Barrage catchment at flow gauges C2H008/C2H140.

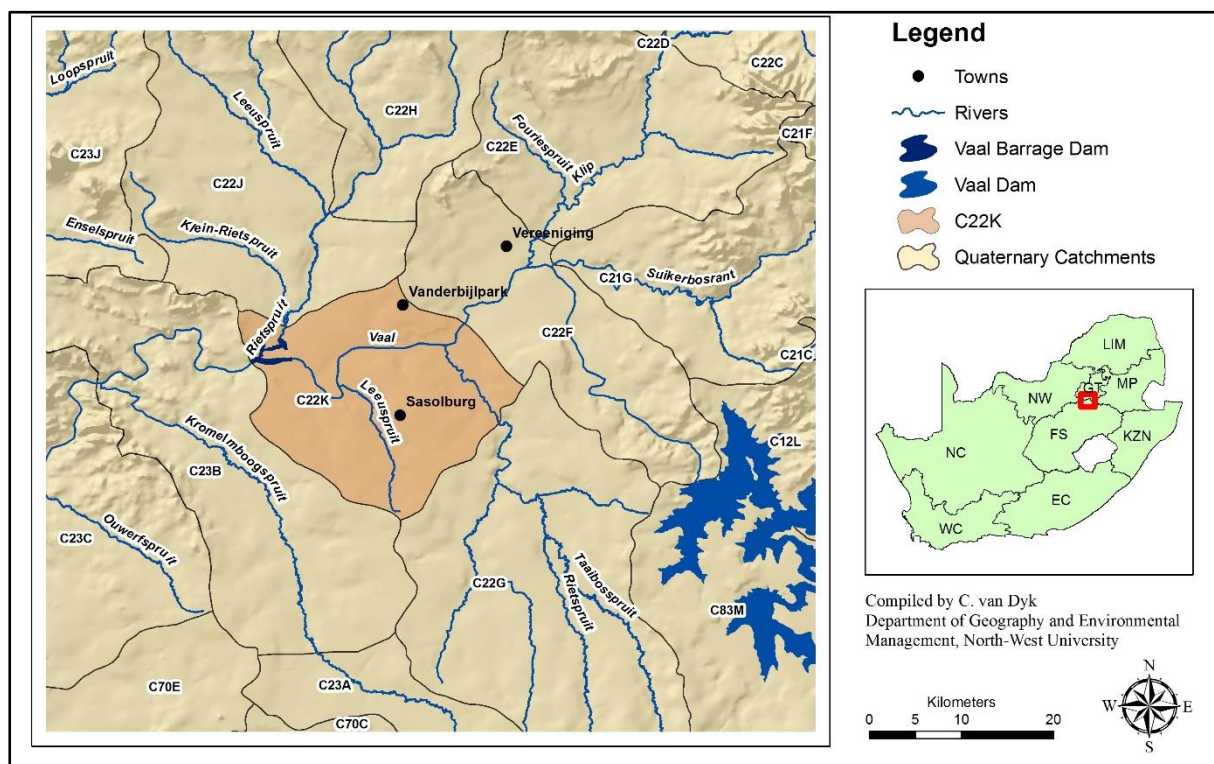


Figure 6: Location of study area

The natural topography of the catchment is largely modified by manufacturing industries such as Sasol, waste dumps from metal industries, ash waste dumps from an old power station and general waste dumps and mine dumps.

3.2 Climate

The study area lies within a strongly seasonal rainfall area with most rain occurring in the summer period (October to March). Rainfall mainly occurs in the form of convective thunderstorms and is sometimes accompanied by hail. The average monthly rainfall as obtained from Water Resources of SA (2012) is plotted in Figure 7. The mean annual average is approximately 644 mm/a.

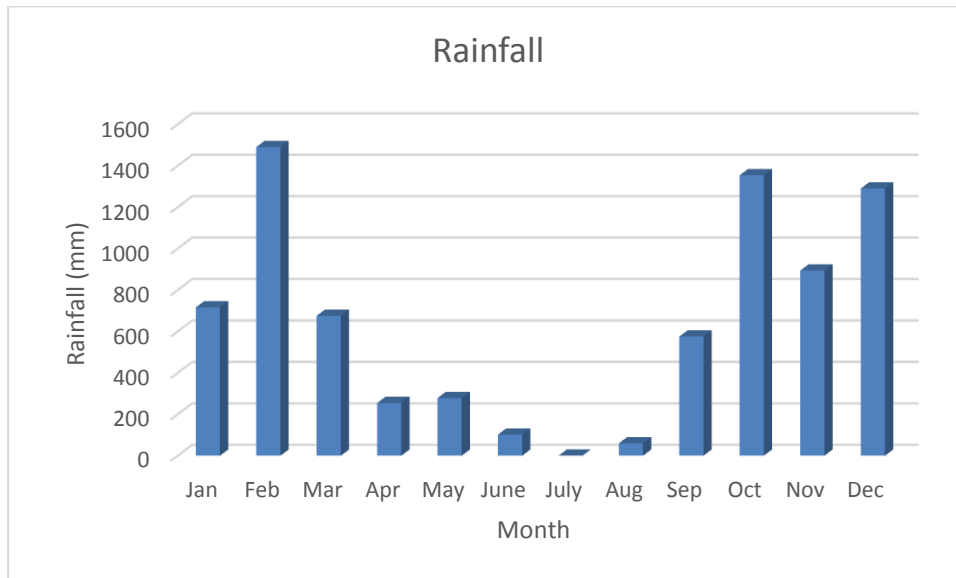


Figure 7: Average monthly rainfall

The average daily temperature varies from approximately 16 °C to 29 °C in January (summer) and from 1°C to 20 °C in July (winter). Wind speeds are generally light in the area with an average wind speed of 9km/h. The windiest month is October with an average wind speed of 13km/h. The winter season tends to be dry, with crisp cold mornings (frost in June and July), although the days are warm and sunny. The Barrage experiences warm to hot sunny days in the spring and summer with temperatures often reaching 27 °C to 29°C (see Figure 8).

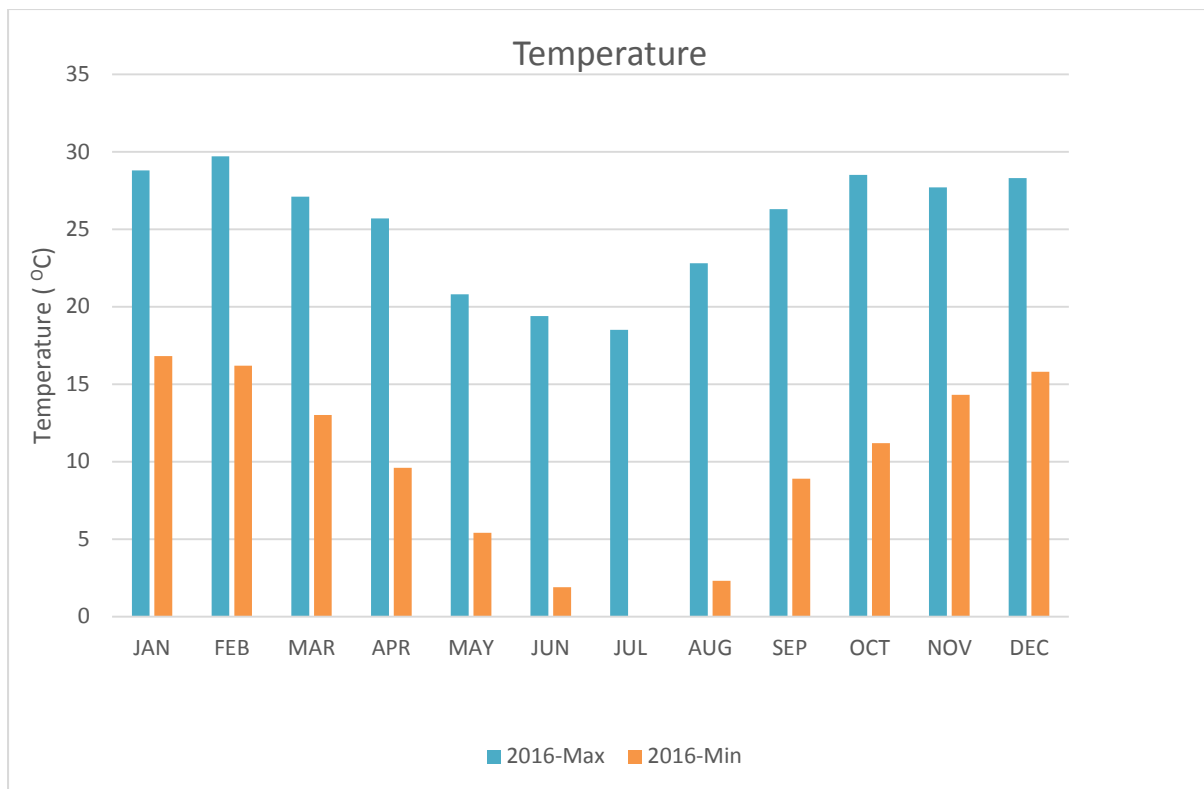


Figure 8: Temperature (Timeanddat.com, 2018)

3.3 Surface Water

According to the Department of Environmental Affairs and Tourism (DEAT), the Vaal River is 1120 km in length, with a 192 000 km² catchment area (DEAT, 2007). The Vaal River originates in the Drakensberg mountains approximately 240 km from the Indian Ocean. The river then flows 900 km west-south-west to join the Orange River near Douglas. The Vaal River forms the border between Gauteng, Mpumalanga and the North West Provinces on the northern bank and the Free State on the southern bank (Braune and Rogers, 1987).

The location of the flow gauges are shown in Figure 9 and more information regarding these gauges is documented in Table 4. The flow gauges were selected in the upper and middle Vaal Barrage catchment, as well as the Vaal River downstream of the catchment. The Vaal Dam Catchment is an important source of water for the area, supplying a continuous flow of good quality water.

All gauges have licensed weirs and barriers on waterways in the Vaal Barrage. All sites have both flow and water quality data. Tributary sites, were also chosen in order to identify the main sub-catchments responsible for high loading of pollutants into the main stem of the Vaal River and Barrage Dam (Dabrowski & de Klerk, 2013).

Due to the underlying dolomites and associated geological structures in the Vereeniging area, the Vaal River can be considered as a source of groundwater. (DWA, 2011). A noted concern is the recharge from the coal and gold mines that causes pollution of the groundwater and where decanting, pollution of the Vaal River. The change in water quality with time at the Vaal Barrage is shown in Figure 10.

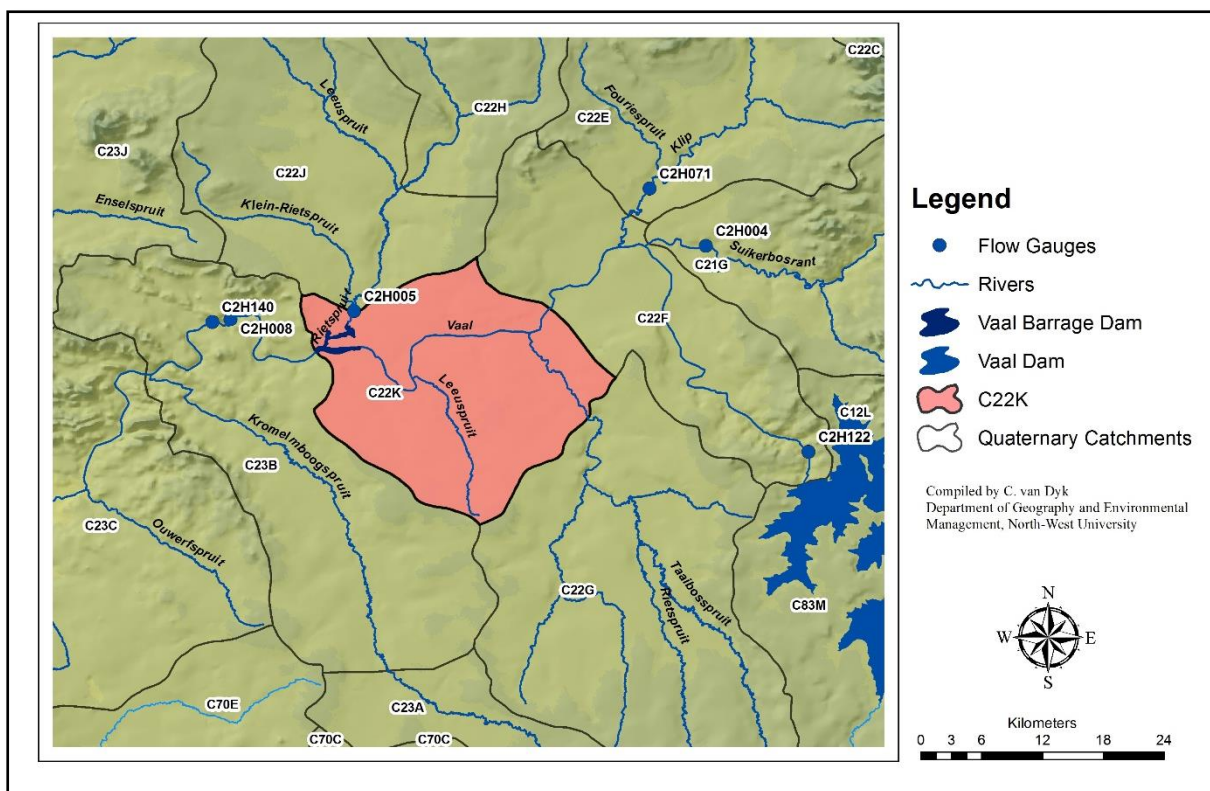


Figure 9: Topography, rivers and flow gauges

Table 4: Information regarding flow stations (Obtained from DWS web site)

Flow gauge	Quaternary catchment	Active from	Catchment area
C2H122	C22F	1981-01-20	38620 km ²
C2H004	C21G	1923-01-01	3474 km ²
C2H071	C22E	1982-01-01	1121 km ²
C2H005	C22J	1923-01-01	1121 km ²
C2H008/C2H140	C23B	1923-01-01 /1995-08-31	47222 km ²

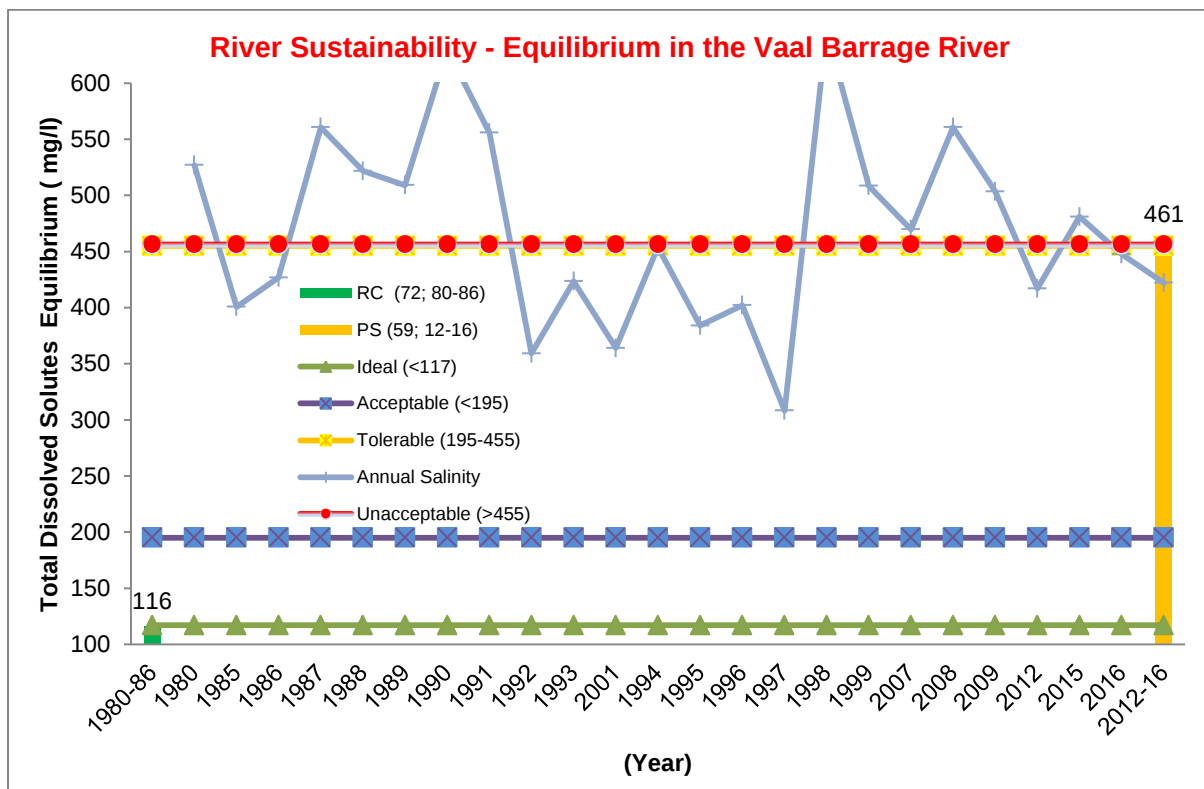


Figure 10: Qualitative Trend in the condition of the WR quality for Vaal Barrage (Kleynhans et al., 2005)

There are two dam gauges namely the Vaal Dam (Figure 11), upstream of the study area and, the Vaal Barrage which falls within the study area. These dams were the forerunners of the great barrages and dams, which today control the river on which the gold fields of the Witwatersrand and the surrounding industrial complex depend so heavily. Information regarding their status was attached in Table 5.



Figure 11: Vaal Dam

Table 5: Information concerning the Vaal Dam and the Vaal Barrage (DWAF, 2009a)

Dam Name	Quaternary Catchment	Monitoring Point	Drainage Region	River	Purpose	Full Storage Capacity (Mm ³)
Vaal Dam	C22F	C2H122Q01	C21	Vaal	Domestic	2 609.8
Vaal Barrage	C22K	C2R008Q01	C22	Vaal	Domestic	55.4

3.4 Groundwater

The groundwater relation to surface water based on data available indicates that groundwater contribution to base flow as a % of the total flow for study area is between 10 and 20%. The highest groundwater contribution to base flow is in the Klip River (13%) seconded by Vaal Dam (12%), and lowest is at the Vaal Barrage (11%) (DWAF, 2005).

The study area is underlain with intergranular rocks with a groundwater yield of 2 – 5 l/s. There is also some high yielding karst formations to the north-east of the study area as seen in Figure 12. The depth to groundwater is approximately 1 – 4 m below surface (Figure 13).

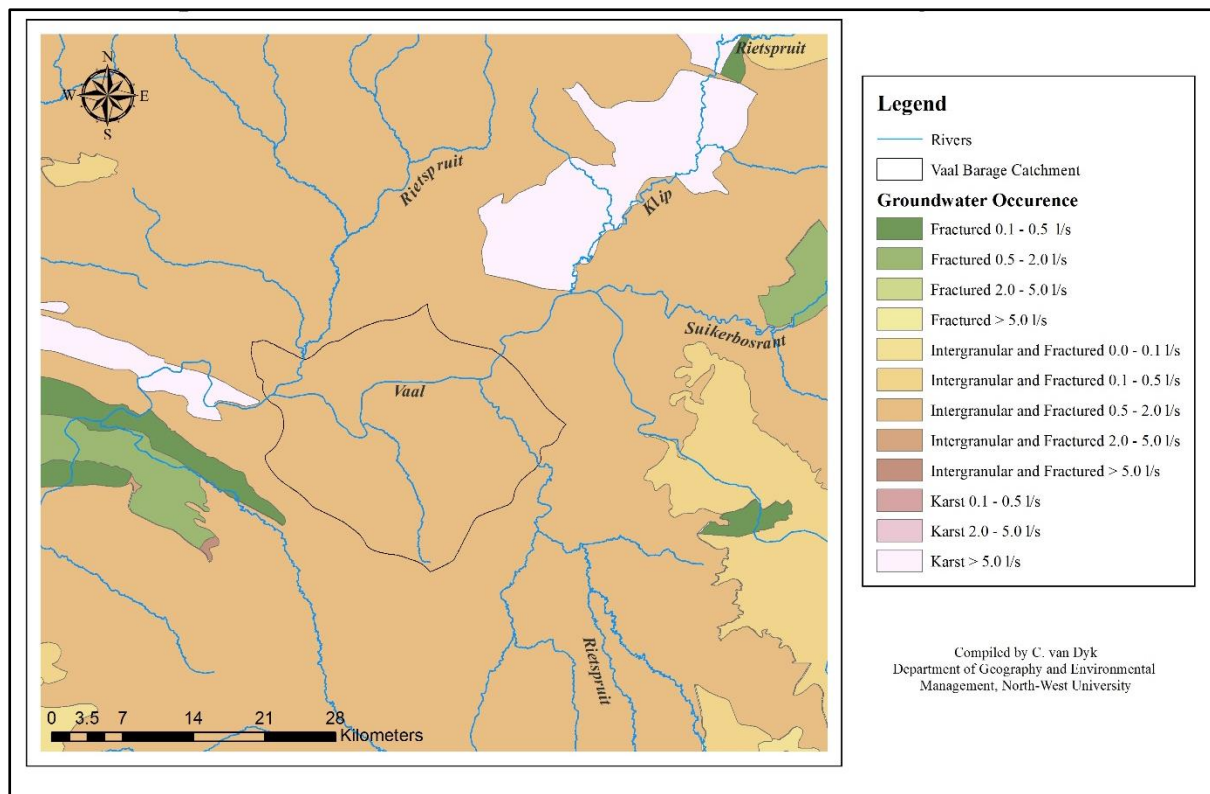


Figure 12: Aquifers

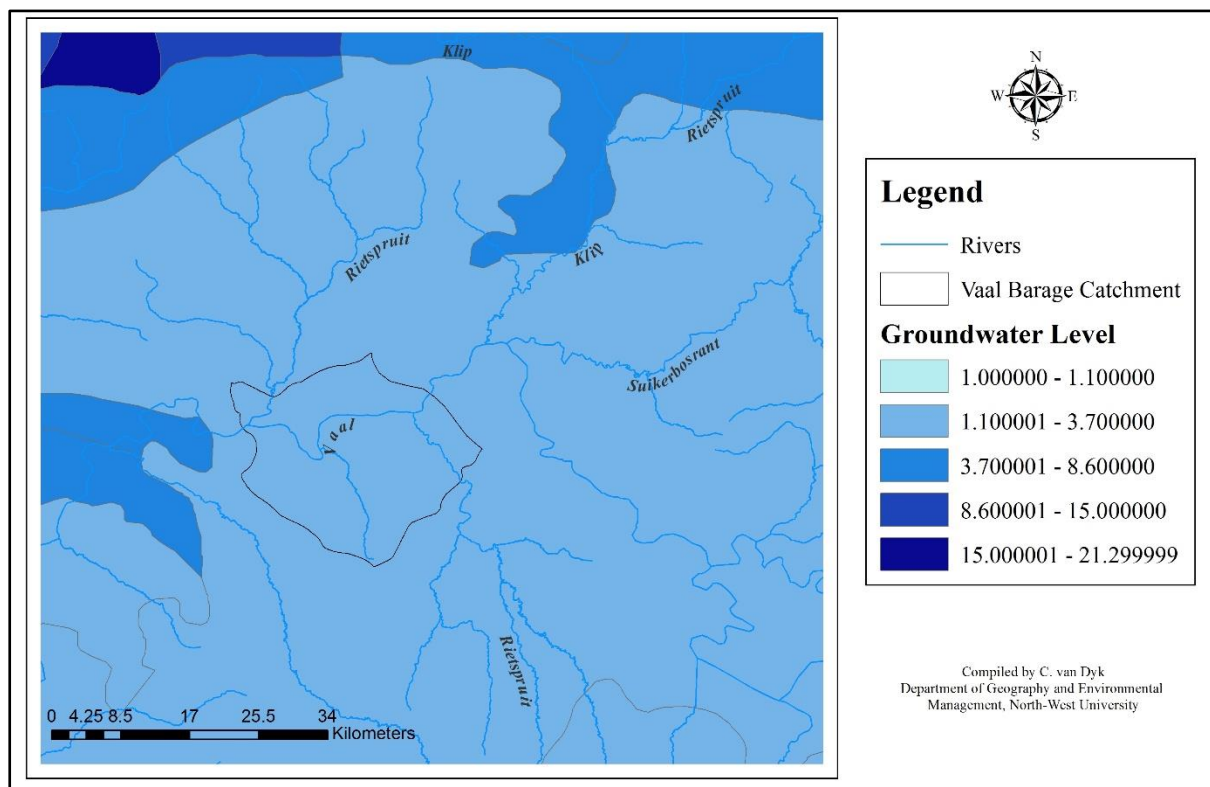


Figure 13: Groundwater levels

3.5 Wetlands

The South African National Biodiversity Institute (SANBI) in 2011 mapped wetlands during the National Freshwater Ecosystem Priority Areas Project (NFEPA). This project was initiated to identify national fresh water ecosystem priority areas. These wetlands for the study area are shown in Figure 14. As can be seen there are significant terrestrial wetlands within Vaal Barrage study area. Important wetlands occur along the Klip River and there are several vlei areas throughout the study area.

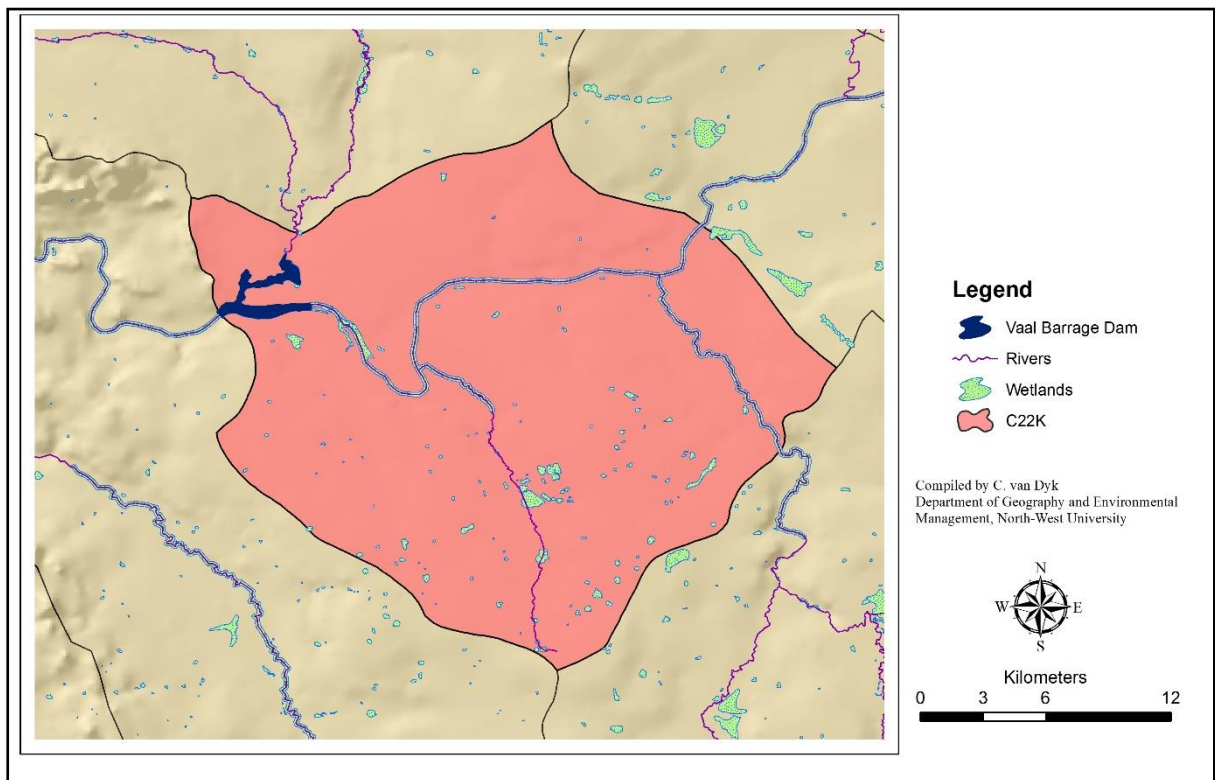


Figure 14: Wetlands

3.6 Land Cover

Vegetation serves to slow the flow of water and increase its infiltration into soil and groundwater storages. This enables the water to flow more gradually into watercourses over a longer period. Without the vegetation, increased flow generally results in erosion and scouring of receiving watercourses. Figure 15 shows that large areas of natural vegetation have been replaced by agricultural activities and urbanisation. The vegetation in the Vaal Barrage area is dominated by grassland. The order of prominence is grassland, low shrubs, urban small holdings, low vegetation/grass and urban small holdings with low vegetation, cultivated commercial fields and cultivated subsistence farming.

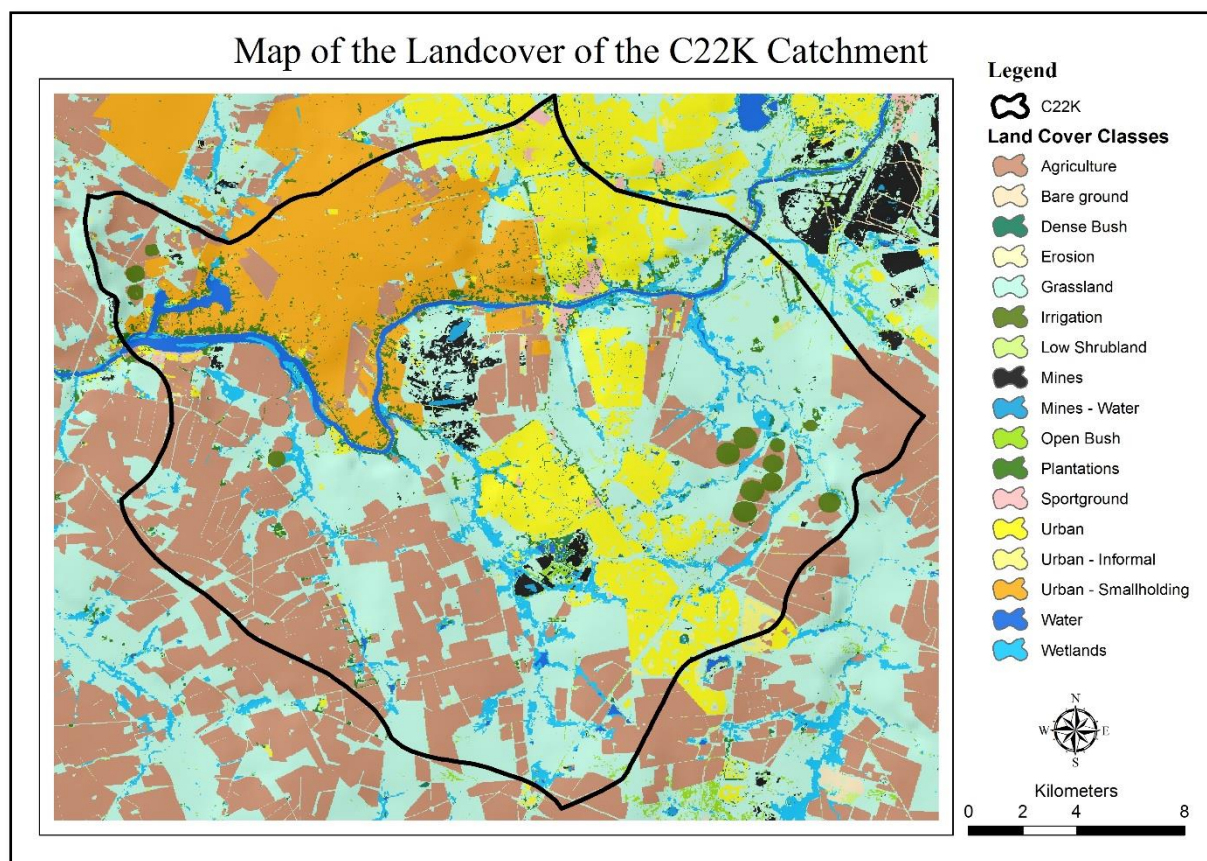


Figure 15: Land cover

3.7 Soil Types

Seven soil/geological layers were identified within the Vaal Barrage Study Area. These soil characterisations are documented Table 6. The subsoil thicknesses partially reflects features of the underlying geology (Schulze & Horan, 2006).

Table 6: Soil layers (DWAF, 2004)

	Layer	Depth
1	Dolomite & limestone	Deep Surface
2	Porous unconsolidated and consolidate sedimentary	Subsurface
3	Intercalated arenaceous and argillaceous strata	Sub-Surface
4	The intercalated assemblage of compact sedimentary	Top-surface
5	Un-differential assemblage of compact sedimentary	Top-surface
6	Basic /Mafic lavas	Top Surface
7	Acid and intermediate intrusive	Seepages

Soil depths are generally moderate too deep within the study area. The main soil dominant in the study area consists of clayey loamy (DWAF, 2004) and the dominant lithologies are dolomite (>42%) and sedimentary strata (30-40%).

3.8 Geology

The Vaal River meanders over geological formations belonging to: Banded Iron Formation (Witwatersrand Supergroup)

- Carbonate rocks (limestone and dolomite) (Transvaal Supergroup)
- Granites and granitic gneisses (Witwatersrand and Ventersdorp Supergroup, Archean granites)
- Felsic, mafic, and ultramafic volcanic rocks (Witwatersrand Supergroup)
- Siliclastic sediments (Karoo Supergroup)

Alluvium underlies most of the river courses.

In the Upper Vaal the Karoo formation is underlain by fine to coarse-grained sandstone, shale and coal (Figure 16) which covers about 80 % of the catchment (Braune & Rogers, 1987).

The underlying geology can influence the water quality (Huizenga, 2011).

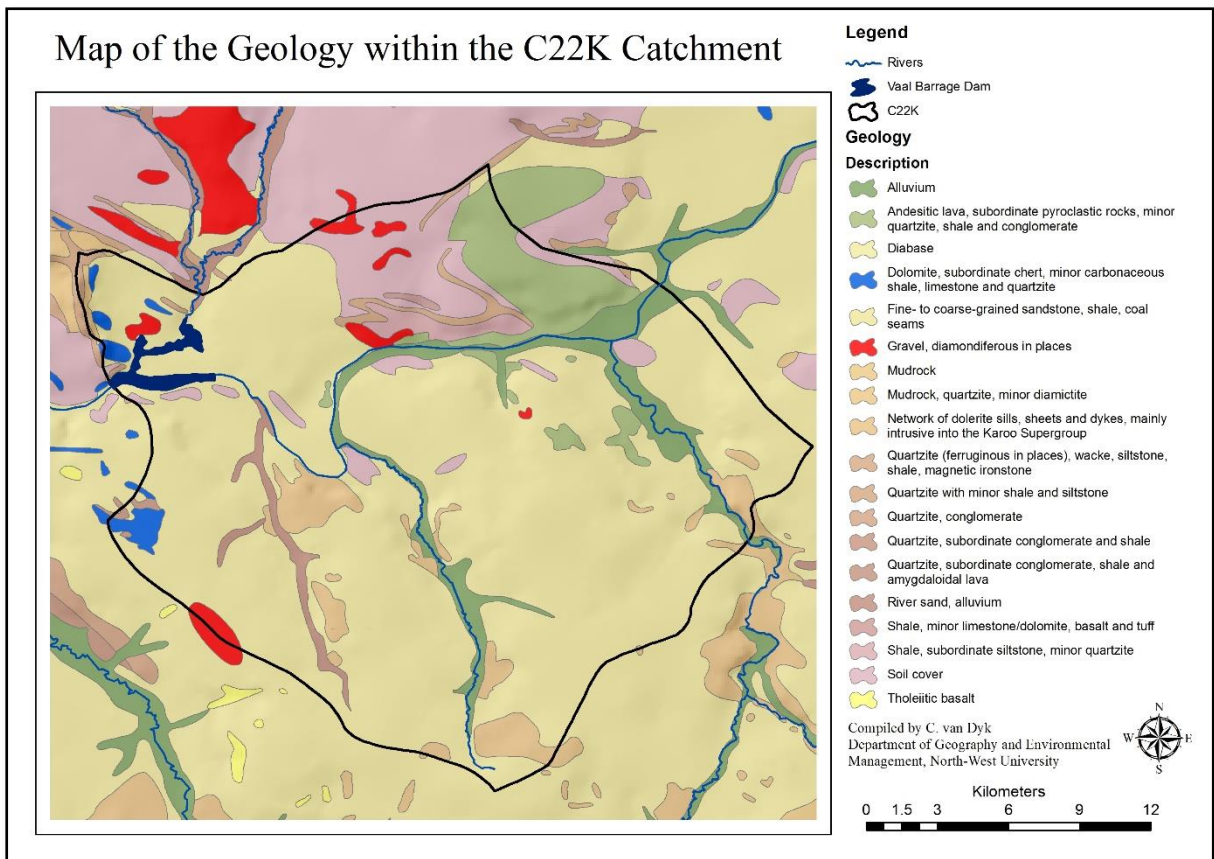


Figure 16: Geology

3.9 Impacts on water resources within study area

Figure 17 displays the main economic activities in the vicinity of the Vaal Barrage. The building of the Barrage directly stimulated local commerce, industrial development, farming operations and urban development (Tempelhoff, 2001). The main economics was with 42% manufacturing as main land use, seconded by 26% of community services and lowest land use being 3% of strategic electricity generator. The major industries include AMSA (previous called Iscor) near Vanderbijlpark (Iron & steel products), Sasol at Sasolburg (petrochemicals) (DWAF, 2004).

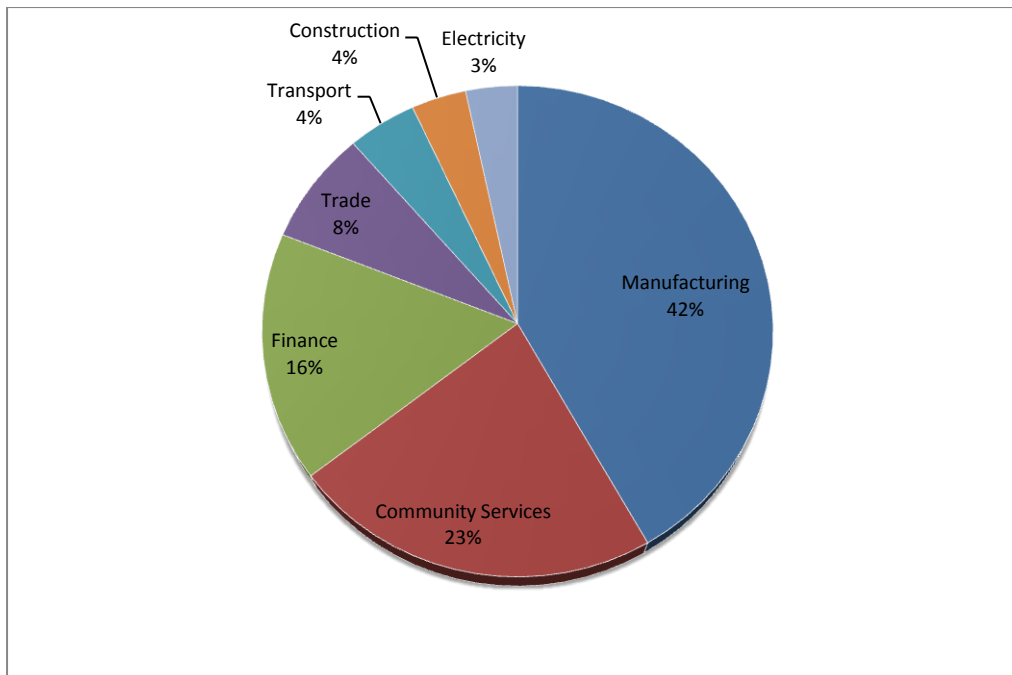


Figure 17: Main Economic since the construction of Vaal Barrage (DWAF, 2004; Statssa, 2016)

In 2007 more than 650 000 people (approximately 90% of the population had access to clean drinking water, while 84% had access to piped sewerage facilities (Gouws et al., 2007). Activities dependant on water include: irrigation, mining, bulk industries (e.g. ArcelorMittal), waste water treatment works, power stations (e.g. Lethabo Power Station) (DWAF, 2009a; DWAF, 2009b; DWAF, 2009c).

CHAPTER 4 METHODOLOGY

4.1 Data

Wide ranges of data were collected. Typical data sets and the sources thereof are documented in Table 7.

Table 7: Data Sources taken from Dennis *et al.*, 2012

Data needed	Information	Source
Study area	Quaternary catchment boundaries	WR2012
Population data	Population statistics	Stats SA, regional and local municipalities
Conservation areas		DWS
Water sources and water quality	Flow gauging stations	DWS
Physiography	Topographical maps Satellite images Aerial photographs	Dir. Surveys and land information
Climatic data	Rainfall data Evaporation data	Weather Bureau WR2012 SA Atlas of Agrohydrology and Climatology Local communities, mines and industry DWS
Geology	Geological maps - 1:250 000 - 1:50 000	Council for Geoscience DWS Consultants Mines
Soils	Soil maps	DWS Agricultural Research Council WR2012
Drainage	Flow data	DWS

4.2 Water Resource Classification System (WRCS) Process

As already mentioned, the water resource classification process helps facilitate a balance between protection and use. Chapter 3 of the NWA (1998) discusses classification procedure to protect the health of South Africa's water resources. The aim of protecting water resources is to ensure, water is available for current and future use. Protection involves the sustaining of a certain quantity and quality of water to maintain the overall ecological functioning of rivers (Dennis *et al.*, 2012).

4.2.1 Present State for the Study Area

The Vaal Barrage classification should consist of two processes, namely:

- a. Present State/Class (PES)
- b. Recommended Category/Class (REC)

The PES should describe the study area according to ecological status, quantity, quality and health. The current state must be compared to the natural conditions. The REC is a derived target status usually maintained or improved the PES (Louw & Niekerk, 2016).

4.2.2 River Health Classification Process and Ecological Management Classes (MCs)

Rivers are grouped in terms of their state of health into five classes. The key outcome of the classification is to define the water resource and the associated ecological state for the Vaal Barrage water catchment. The four types of MCs are summarised in Table 8.

Table 8: Ecological status classification and colour code from EC:Directive (2006)

Water Resource Classification (Health Class)	Colour code	Management Classes
Natural (unmodified)	Blue	I - Excellent
Good (largely natural)	Green	II - Good
Fair (moderately modified)	Yellow	III -Fair
Poor (largely modified)	Orange	
Bad (seriously/extremely modified)	Red	

The above mentioned table can then be expanded (see Table 9). To include more detail to assist with the determination of MCs.

Table 9: Process of setting MCs

Present State	Ecological Categorization (EWR-Class)	Water Resource Classification		Management Classes
A	A-Unmodified natural	Natural		I - Excellent
B	B-Large natural	Good		II - Good
C	C-Moderate modified			
D	D-Large modified	Upper	Fair	III -Fair
		Lower		
E	E - Seriously Modified	Poor		
F	F - Critically Modified			

These six ecological water requirement classes are used to describe the PES of the Vaal Barrage, but only Classes A-D describe the Ecological Management Class (EMC). Class E-F are not acceptable (Kleynhans *et al.*, 2008). The DWS classification for natural condition of river degradation and goods and services affected for E-F classes are no longer providing suitable services (Louw & Kleynhans, 2009).

4.3 Assessment method approach

The level of change from natural conditions are assessed, using a set of guiding tables (AfriDev., 2006; Parsons & Wentzel, 2007). The assessment is based on outcome ratings for the following:

- Water resource usage (surface water and groundwater)
- Water quality
- Morphological conditions
- Potential/expected land use/cover
- Vulnerability of water resource
- Ecological status of the water resource

The assessment approach for the classification of the Vaal Barrage is discussed in Sections 4.3.1 to 4.3.5. Please note the morphological conditions were not taken into account in this assessment as only existing information/data was used in the study.

4.3.1 Stress Index (quantifying water use)

Calculating the stress index for groundwater, the variability of annual groundwater contribution to baseflow is considered in the sense that more than 65% of the average annual baseflow can be allocated on a catchment scale. Water abstraction usage is heavily used when the stress index is $> 65\%$; moderately used when stress index ranges from between 20%-65%, and minimally used when stress index is $\leq 20\%$. The present class for groundwater usage is documented in Table 10.

A similar approach is followed when classifying surface water abstraction. A water usage of more than $1/3$ of the mean discharge of the stream will be classified as moderately stressed as seen in Table 11 (Spanhoff *et al.*, 2012).

Table 10: Guideline Status Category assessment based on groundwater Stress (Dennis *et al.*, 2012; Parsons & Wentzel, 2007)

Present State	Management Class	Stress Index $= \frac{\text{Abstraction}}{\text{Recharge}} \times 100$	Description	Guide
A	I	<0.05	Unstressed/Slightly stressed	$\leq 20\%$
B		$0.05-0.20$		
C	II	$0.2-0.40$	Moderately stressed	20% – 65%
D		$0.4-0.65$		
E	III	$0.6-0.95$	Stressed	$>65\%$
F		>0.95		

Table 11: Guide for determining the level of flow for Water Stress of a Resource (Spanhoff et al., 2012)

Present State	Management Class	Stress Index $= \frac{\text{Abstraction}}{\text{Recharge}} \times 100\%$	Description	Guide
A	I	<5	Unstressed/Slightly stressed	≤20%
B		5-0.20		
C	II	20-0.40	Moderately stressed	20% – 65%
D		40-0.65		
E	III	65-0.95	Stressed	>65%

4.3.2 Water quality

The South African Water Quality Guidelines will be used to assess the water quality of the resource.

4.3.3 Land Cover

The land use/cover within the study area has great impacts on the quality of the water resources within the study area. The water quality of water resources may degrade due to the changes in the land cover as human activities increase. A change in the land cover is a major factor in the changes in water resource systems.

A proposed rating table, similar to those of the stress index, is documented in Table 12.

Table 12: Resource stress due to Land Use

Present State	Management Class	% landuse change	Description	Guide
A	I	<0.05	Unstressed/Slightly stressed	≤20%
B		0.05-0.20		
C	II	0.2-0.40	Moderately stressed	20% – 65%
D		0.4-0.65		
E	III	0.6-0.95	Stressed	>65%

4.3.4 Vulnerability of Water Resources

The methods to determine the vulnerability of groundwater and surface water have been documented in Section 2.5.4 together with the associated classification table.

4.3.5 Ecological Water Requirement (EWR) – use ecological guidelines

The approach followed by King *et al.*, (2008) can be used as a guide during the classification process. The impact of land use and anthropogenic activities on the Vaal Barrage must also be considered (Dabrowski & de Klerk, 2013). The ecological classification from physico-chemical monitoring results was determined using Table 13. The classification of the ecological status for each body of water, colour-coded in accordance with the six column to reflect the ecological status classification of the body of water (EC:Directive, 2006).

Table 13: Ecological status classification (Kleynhans *et al.*, 2008) and colour code adapted from EC:Directive (2006)

Rating	Present State	Ecological Status (EWR-Class)	Water Resource Classification (Health Class)		Colour code	Management Classes
0: close to reference	A	A-Unmodified natural	Natural		Blue	I - Excellent
1: Small modification from reference	B	B-Large natural	Good		Green	II - Good
2: Moderate modification from reference	C	C-Moderate modified				
3: Large modification from reference	D	D-Large modified	Upper	Fair	Yellow	III -Fair
			Lower			
4: Serious modification from reference	E	E - Seriously Modified	Poor and Bad		Orange	
5: Extreme modification from reference	F	F - Critically Modified			Red	

CHAPTER 5 CLASSIFICATION OF THE WATER RESOURCES WITHIN THE VAAL BARRAGE CATCHMENT

5.1 Assumptions

Understanding the role of water resources in sustaining the environment is always a challenge. To be able to undertake Resource Directed Measures (RDM) assessments and quantify the volume of water required to meet Classification requirements a number of assumptions are made:

- Surface water systems are generally resilient and can normally recover from most perturbations. However, it is accepted that groundwater contamination can persist over decades and centuries.
- As only existing data is taken into account the confidence in the results will be low to medium.
- The study is based on existing data, this data is assumed to be correct.
- Due to this study only focusing on existing data the geomorphology of the study area was not taken into account.
- It is assumed that quaternary catchment C22K will form the Unit of Analysis (UA), however the impacts of the following up stream sub-catchments will be taken into account: Suikerbosrand River, Klip River and Rietspruit.
- Only wetlands associated with rivers/stream will be taken into account.
- The seasonal variability (Figure 18 and Figure 19) of the system is not taken into account.

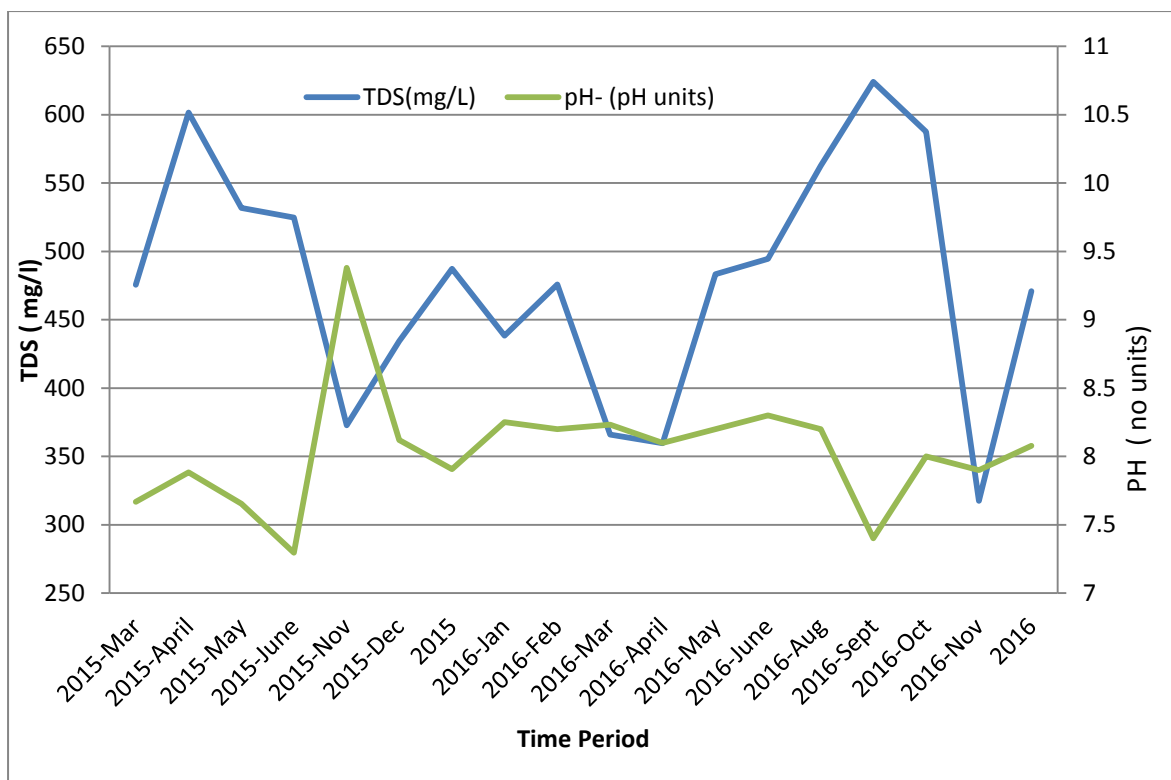


Figure 18: Time series graph of TDS (as Salinity) and PH on the Vaal River at Barrage (monitoring C2R008)

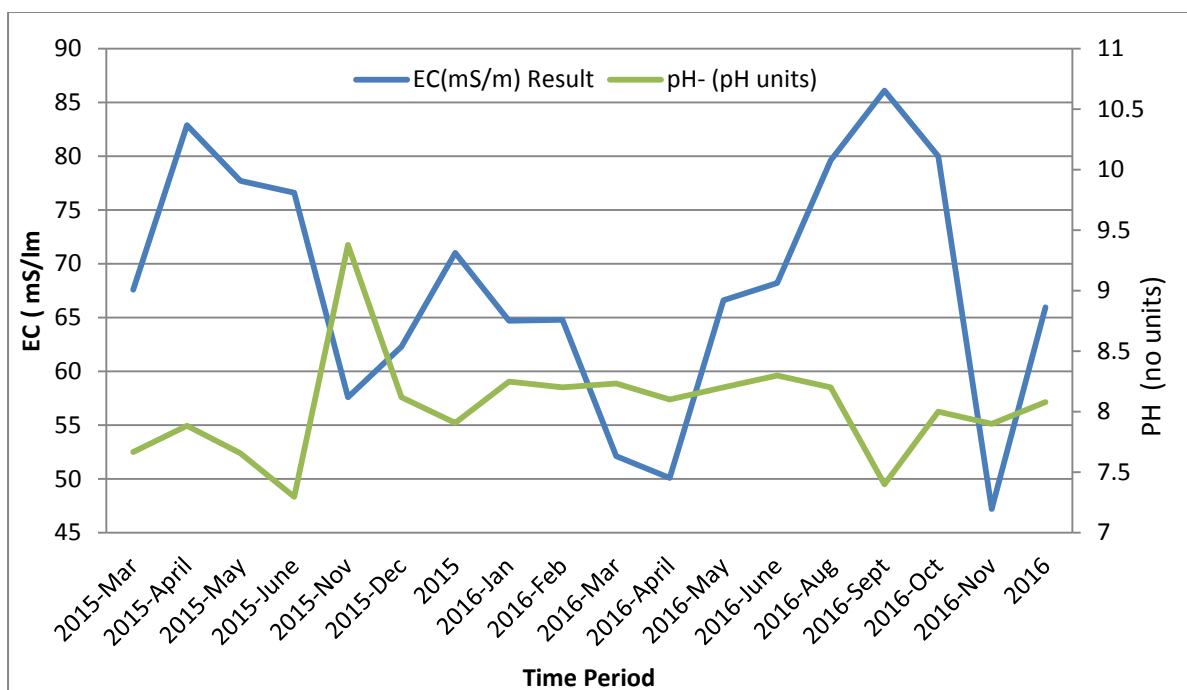


Figure 19: Seasonal Variation of System Variable and Non-constituent behaviour of the present time at Vaal Barrage : Time series graph of EC and PH on the Vaal River at Barrage (monitoring C2R008)

5.1.1 The hydrological monitoring network: Vaal Barrage

The ecological flow of the Vaal Barrage has been modified between 10 and 20% (actual 11%). The modified flow at the Vaal barrage was due to 13% higher flow from middle reach-Klip River tributary. The Suikerbosrand and Rietspruit are close to the natural, and less than 3% modified, with the Rietspruit being the lowest with less-than 2% King *et al.* (2008).

The upper reach (Vaal Dam) is the the main water tower with a mean annual runoff (MAR) of 15.9 m³/s (2015- 2016), and middle reaches (sub-catchment Klip River) has a MAR of 13.0m³/s. The Rietspruit tributary is lower with a MAR of 2.8 m³/s (2015-2016).

The long term 2016 year average monitored discharge of the Vaal Barrage was approximately 13.3 m³/s at the outlet of the catchment (gauge station 26°44'17"S, 27°35'31"E). More than 80%, approximately 13.3 m³s for year 2016 of the flow has been retained at the Vaal Barrage.

5.2 Classification

5.2.1 Groundwater Use Classification

According to the Water Resources of SA (2012) the total groundwater use is 300000 m³/a. The recharge is calculated using the Chloride Mass Balance (CBM) method in Section 2.5.3. The chloride value in rainfall is assumed to be 1 mg/l and the recharge is calculated as 4% of mean annual precipitation. Therefore when considering the stress index calculations in Table 10, the groundwater stress index is calculated as:

$$\text{Stress Index} = \frac{\text{abstraction}}{\text{Recharge}} \text{ --- (1)}$$

$$\text{Stress Index} = \frac{0.3 \text{ Mm}^3/\text{a}}{11.17 \text{ Mm}^3/\text{a}} \times 100 \text{ --- (2)}$$

$$\text{Stress Index} = 3\% \text{ --- (3)}$$

This results indicate a stress index of 3% which means the current class is an A (Unstressed). The MC is set at class I.

5.8.1 Surface Water Stress Classification

Natural discharge regime and flow diversity depend on the stream flow (Spanhoff *et al.*, 2012). According to the Water Resources of SA (2012) the total surface water use is approximately 12186315 m³/a Vaal. In addition Water Resources of SA (2012) also states that the mean discharge is 1286315 m³/a.

The volume of abstraction /Mean discharge of the river must be less than 1/3 of the mean discharge of the stream, if it greater than 1/3 of the mean discharge of the stream should be regarded as significant pressure.

$$\text{Flow for ecological} = \frac{12.19 \text{ Mm}^3/\text{a}}{157.5 \text{ Mm}^3/\text{a}} \times 100 = \text{--- (1)}$$

$$\text{Flow for ecological} = 7.7\% = \text{--- (2)}$$

The volume abstraction was less-than than 2/3 of mean discharge of the stream (Spanhoff *et al.*, 2012), and total surface water abstraction was approximately 8%. Based on guide for determining the level if stress (Table 11) of the resource, the resource is unstressed/slightly stressed, and Present Class for Stress Index based on usage will be Class B. The associated MC will also be class I.

5.2.2 Surface Water Quality Classification

The South African Water Quality Guidelines from DWAF (1996) was used to determine the water quality of the resource. Figure 20 displays the present status of the salinity in the Vaal Barrage. Total Dissoved Solids (TDS) is an important parameter as a water quality indicator and refers to the degree of salinity of water. The TDS in Figure 20 indicates that the water quality is just above the target guideline of 0 – 450 mg/l (SA Water Quality Guidelines, 1996). The current class is therefore a B with the MC being a class I. This is confirmed by the water quality results documented in Table 14.

It is important to note that return flows from domestic and industrial effluent discharges and surface run-off from urban will contribute to increased unacceptable concentration of TDS. In 2016 the TDS value went up to 461mg/l at Vaal Barrage. The TDS value at the Vaal Dam is 116 mg/l. Most parameters are well within the target guidelines (natural), however there are some parameters whose values are slightly higher.

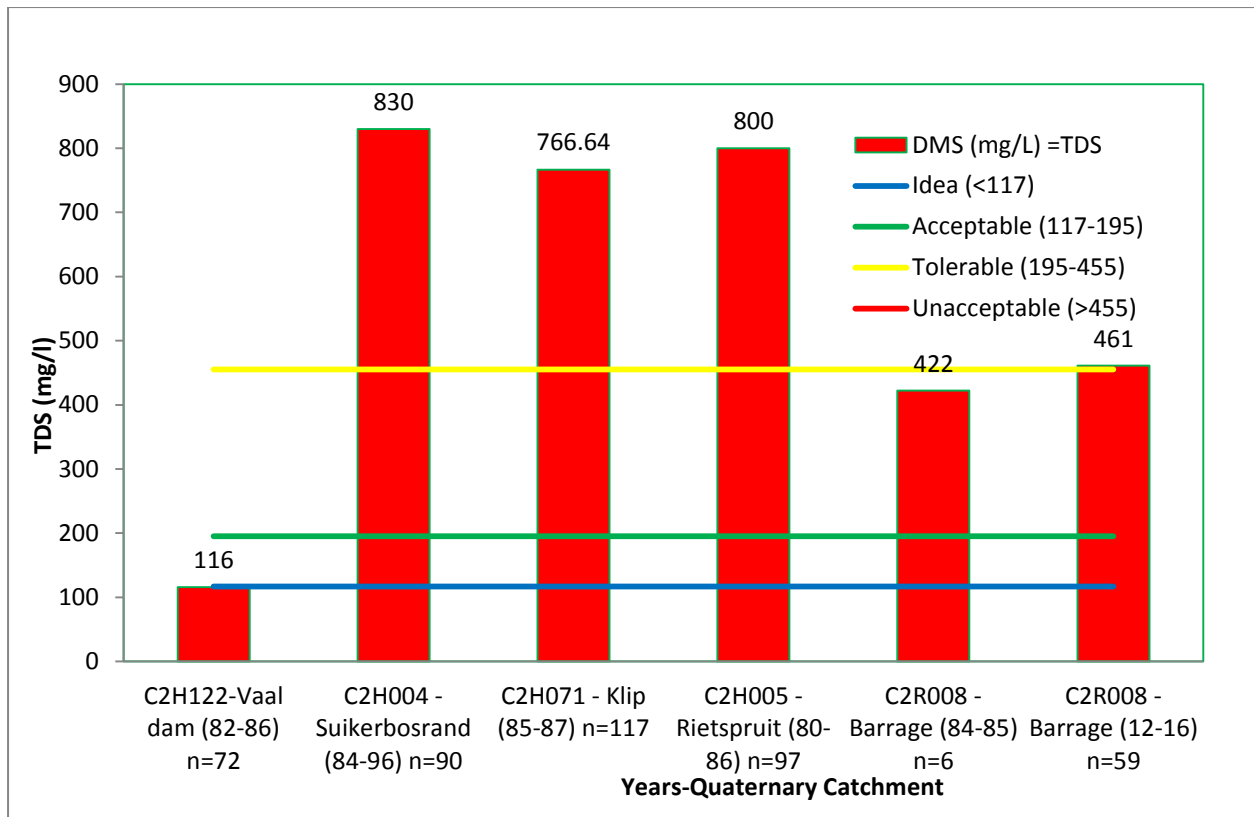


Figure 20: Classification of Salinity in Vaal Barrage Water Quality

Table 14: Water quality at the Vaal Barrage

Parameter	C2R008 -Vaal Barrage	Natural	Good	Fair	Poor
Calcium (mg/L)	56		x		
Magnesium (mg/L)	19.5	x			
Potassium (mg/L)	10.1	x			
Sodium (mg/L)	52.4	x			
Sulphate (mg/L)	139.1	x			
Nitrate/Nitrite (mg/L)	2.91	x			
Ammonia (mg/L)	0.46	x			
Chloride (mg/L)	45.6	x			
Fluoride (mg/L)	0.44		x		
Iron (mg/L)			x		
pH-	8.08	x			
TDS (mg/L)	471		x		

5.2.2 Groundwater Quality Classification

Electrical conductivity (EC) values were obtained from the DWS (2018). The frequency plot of the EC values for groundwater are shown in Figure 21. It can be seen from this plot that the majority of the groundwater EC values fall within the natural and good categories. Therefore the current class is a B with the MC being a class I.

It is important to note that there can be 'hot spots' in the catchment due to some of the activities taking place such as mining and industries. In these areas the groundwater quality can be a class D/E with a MC of III.

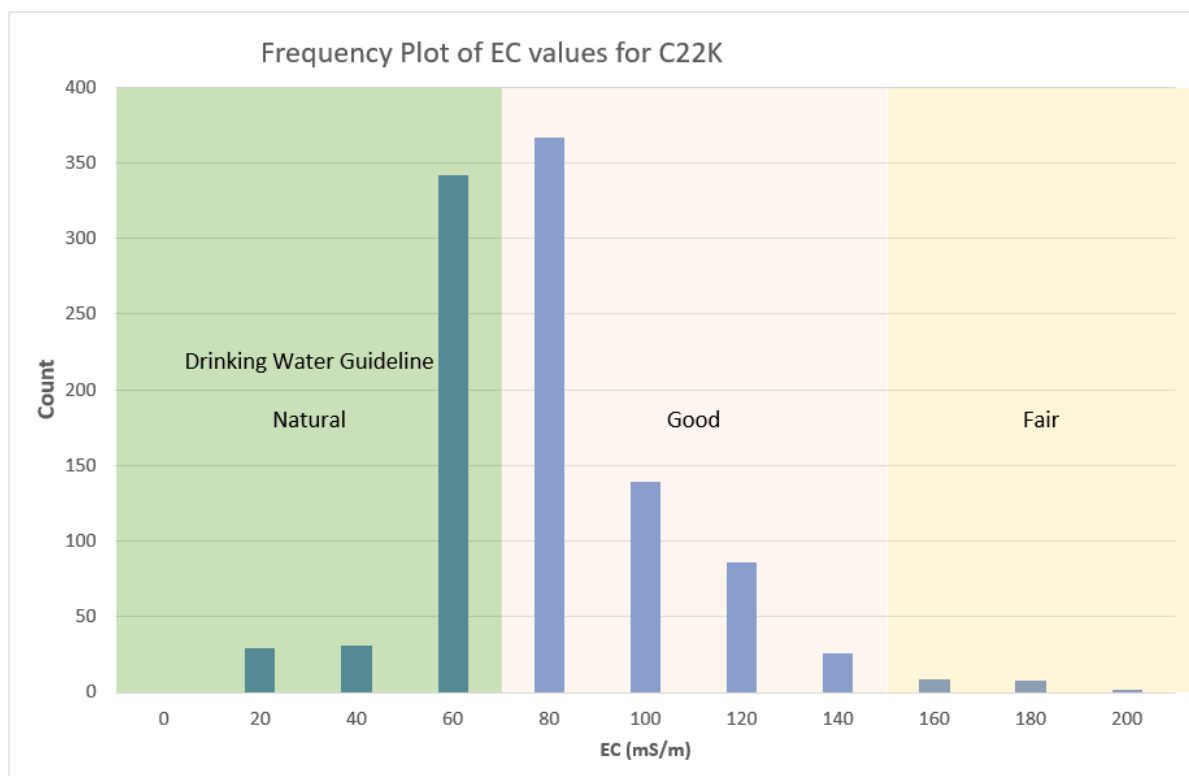


Figure 21: EC values for Groundwater

5.2.4 Landcover Classification

Land use upstream of the Vaal Barrage is dominated by cultivated dry land, which occurs throughout the catchment with high density areas in the Vaal Dam to Vaal Barrage sub areas with the main crops being maize and wheat (DWAF, 2004; DWAF, 2009d; DWAF, 2009e).

Figure 22 in the text shows several land and water use activities that take place in the upper Vaal Barrage River system which were of strategic importance to SA. These stressors include mining, industrial activities, coal-fired power generation.

				
Witwatersrand Gold mining	Vaal mining	Power Generator at Lethabo	Vereeniging ArcelorMittal	Vanderbijlpark Complex
Johannesburg	Vereeniging			Vanderbijlpark

Figure 22: Activities and Potential for future growth in the Johannesburg-Vereeniging-Vanderbijlpark

These economic activities based at Johannesburg-Vereeniging-Vanderbijlpark generated substantial return flow volumes in the form of treated effluent from the urban areas and mine dewatering that discharged into the river system. These discharges had a significant impact on the water quality in the present Vaal Barrage Catchment (DWAF, 2004).

Approximately 80% of the study area land cover has been altered (see Figure 15). Therefore when considering the current class it will be a class E (severely stressed) with the MC set as class III.

For more information regarding land cover/land use refer to Annexure 2: Table 22 and Table 23.

5.2.5 Vulnerability of Surface Water Resources

Due to the poor classification of land use/land cover, the vulnerability of surface water bodies to pollution, degradation and alteration is high. Using the vulnerability matrix developed by Parson and Conrad (1998) it is determined that the vulnerability's current class is an E (Table 15) with the MC being a class III.

Table 15: Vaal Barrage: Present Status Category for assessment based on potential or expected resource water contamination

	Surface water vulnerability (Adapted from Parsons and Wentzel, 2007)			
EXPECTED LAND USE		Low	Medium	High
	Low Impact	A	B	C
	Moderate Impact	B	C	D
	High impact	C	D	E 

5.2.6 Vulnerability of Groundwater Resources

The groundwater vulnerability methodology is discussed in Section 2.5.4 and the weighting and rating scores are documented in the annexures in Chapter 8.

The parameters used in the vulnerability calculation are documented in Table 16.

Table 16: The DRASTIC ratings and weights used (Lynch *et al.*, 1984)

Parameter	Range	Rating	Weight	Rating x weight
Depth of water table (D)	1.1 -3 m (Figure 13)	10	5	50
Recharge (R)	26 mm Calculated (see Section 5.2.1)	6	4	24
Aquifer Material (A)	Intergranular (Figure 16)	8	3	24
Soil	Sandy clay loam and loam	4	2	8
Topography and slope (T)	0.17 (calculated)	10	1	10
Impact of the Vadose zone (I)	(Figure 16)	4	5	
Total				136

Table 17 can now be used to determine the current vulnerability class which is a C (moderate) and the associated MC II.

Table 17: Vulnerability classes

Class	Description	Score
A	Natural	10 to less than 30
B	Low	30 to less than 100
C	Moderate	100 to less than 200
D	High hazard to groundwater quality	200 to less than 400
E	Very high hazard to groundwater quality	400 and up

5.2.7 Ecological Status of rivers, associated wetlands and riparian zones

Conversion of riparian vegetation to cultivated lands decreases infiltration and increase overland flow volumes and peak runoff rates. Land is also utilised by humans and animals. Specific direct human uses include cutting of trees, pruning of trees, harvesting of reeds or medicinal plants are also included. Grazing also altered hydrologic regimes. The final present class category is a C, however because of the importance of the resource it must be managed to a Class II (Kleynhans *et al.* (2008).

Water Quality for Aquatic Ecosystems

The South African Water Quality guidelines for Aquatic Ecosystems from DWAF (1996) were used in the evaluation. The surface water qualities are documented in Table 18. The main concern is the TDS value and therefore the Present class of water quality will be a C for the Vaal Barrage Area and be managed by Class II.

Table 18: Surface Water Ratings

Parameter	C2R008 -Vaal Barrage	Natural	Good	Fair	Poor
Nitrate/Nitrite (mg/L)	2.91				
Ammonia (mg/L)	0.46	x			
Chloride (mg/L)	45.6				
Fluoride (mg/L)	0.44	x			
pH-	8.08		x		
TDS (mg/L)	471			x	

Habitat Integrity

Modification was limited to very few localities and was very small. While instream quality impact to vegetation removal showed moderate modification (Present Class =C. The present class of instream flow habitat and instream quality habitat for the Vaal Barrage area would be B and C respectively.

The vegetation response based on ratings of riparian, quality and quantity of land use resulted in moderate impact class, therefore the Present State (PS) of vegetation response would be C for the Vaal Barrage Area and be managed by Class II (Kleynhans *et al.*, 2008).

Table 19: Ecological classification

Rating	Present State	Ecological Status (EWR-Class)	Water Resource Classification (Health Class)		Colour code	Management Classes
0: close to reference	A	A-Unmodified natural	Natural		Blue	I - Excellent
1: Small modification from reference		B	B-Large natural	Good	Green	II - Good 
2: Moderate modification from reference	C	C-Moderate modified 	Upper			
3: Large modification from reference	D	D-Large modified	Lower			
4: Serious modification from reference	E	E - Seriously Modified	Poor and Bad		Orange	
5: Extreme modification from reference	F	F - Critically Modified			Poor	

CHAPTER 6 CONCLUSION AND RECOMMENDATION

6.1 Introduction

6.1.1 Hydro- morphology

The Vaal Barrage and its associated quaternary catchment C22K have been exposed to a number of changes over a period of time. This is mainly due to factors such as changes in land cover and land use and also due to poor quality water from its tributaries. The significant changes in Mean Annual Runoff (MAR) over the years is shown in Figure 23.

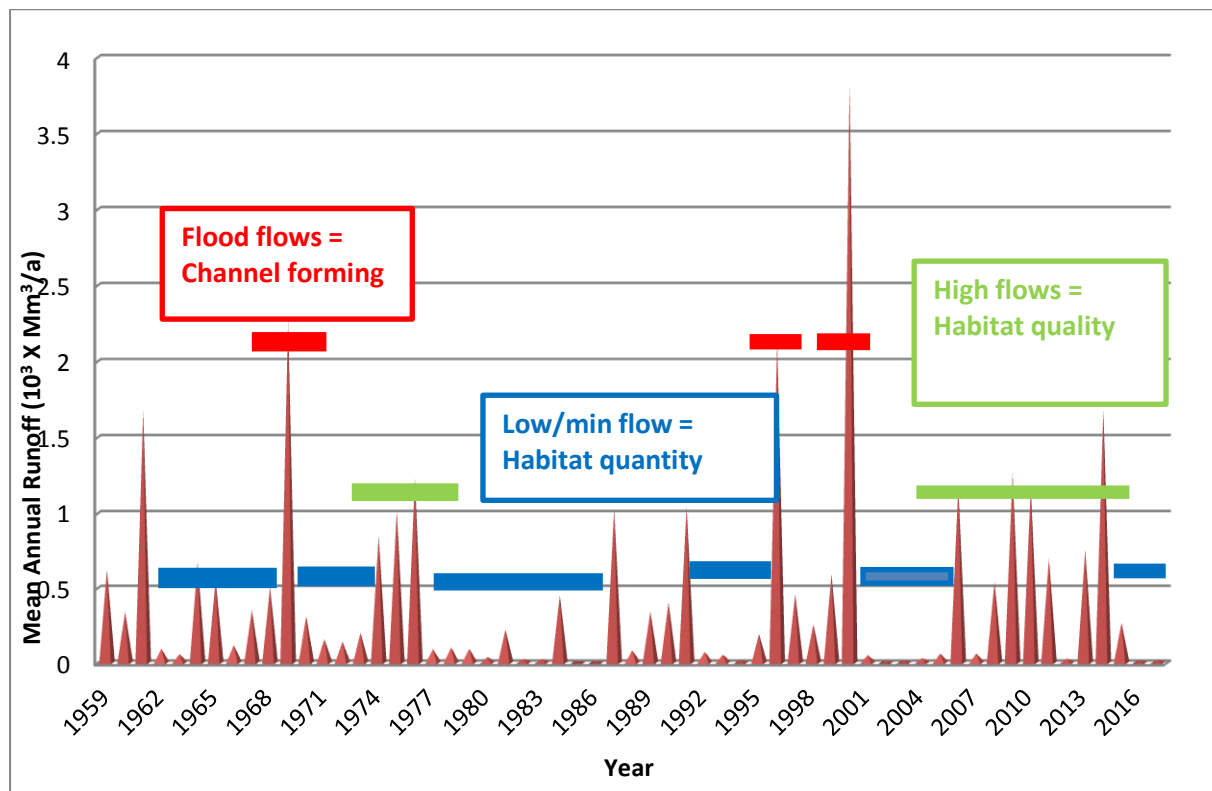


Figure 23: Different flow components in the Vaal Barrage River in the Upper Vaal Water Management Area (Tlou & Consulting, 2012)

6.1.2 Locality , Topograph and Rivers System

The locality of Vaal Barrage monitoring point (C2H008/140) is downstream of the EWR Site at the Vaal Dam (DWAf, 2004). The Vaal Barrage is located within quaternary catchment C22K. This catchment is a medium sized catchment ($>100\text{km}^2$). The Vaal Barrage is situated at a high altitude ($>800\text{ mamsl}$) (EC:Directive, 2006). The Vaal Barrage is a dam located in the Vaal River which is a perennial river (Spanhoff *et. al.*, 2012). The three main

tributaries of the Vaal Barrage are the Suikerbosrand, Klip River and Rietspruit. Vaal Dam as one body of stored surface water which continue topping up the flow. Approximately 20-30 % of the good quality (initial run-off from the Vaal Dam) is evaporated between Vaal Vereeniging – Barrage. Discharge of water and sediment supplied by tributaries and main stem Vaal Dam determines Vaal Barrage channel form and associated water quality (Tlou & Consulting, 2012).

6.1.3 Expected Impact and Potential Ecological

The frequency and intensity of extreme drought events have been increased because of climate change. Climate change is the results of human activities and industrialisation (Dallas & Rivers-Moore, 2014). The occurrence of flood pattern in every 5 years (1997 and 2001) has been observed including altered rainfall pattern. Changes in inflow patterns is the results of flood and altered rainfall pattern (NWRS, 2013). This in turn affects the quality of the habitat and abundance (NWRS, 2013).

6.2 Assessment of Catchment

6.2.1 Expected Impact on Water Resource Quality and System Operations

The water quality within a Vaal Barrage catchment received water from multiple tributaries (namely – Suikerbosrand, Klip River and Rietspruit) and upstream catchment C2H122. The Klip River was the most important source of saline load pollution entering the Vaal Barrage.

This study focused on the classification of water resources and associated aquatic ecosystems within catchment C22K. The reason for the selection of this catchment was the concerns regarding large-scale industrial activities in the catchment and also within catchment's tributaries. In addition many waste water treatment plants are malfunctioning System operations are declining especially sewage treatment (DWA, 2011). Sewage discharges often far exceeds the standards and conditions demanded by licences(DWAF, 2004). These key water quality parameters are threshold concentrations which, if regularly exceeded, can result in harmful impacts on aquatic ecosystems and human health (Dabrowski & de Klerk, 2013). Mining activities are polluting both surface water and groundwater resources. An additional concern is the growing number of agricultural activities in the area. Expanding populations and climate change in the region have put additional pressure on the quality of Vaal Barrage water (Riemann *et al.*, 2017).

6.2.2 Ecological Status of the Water Resource and Water Resource Management

Recreational water users at the Vaal Barrage experience a range of impacts due to changes in water quality. Ecological condition of that water resource is altered from its pre-development condition (DWA, 2010). Water management provides ongoing challenges (Marjanović et al., 2011). Therefore this project focused on the classification of water resources and associated aquatic ecosystems within the catchment in order to set management goals.

6.3 Integrated Water Management

The NWA (1998) recognises that water in South Africa is a scarce resource. National Government continue to manage, protect and sustain the Barrage water resources and their use by means integrated water catchment management of all aspects of water resources and, where appropriate, the delegation of management functions to a regional or catchment level so as to enable everyone to participate, (Nealer & Annandale, 2011), measures includes Classification and RQOs (NWA, 1998; Seago, 2016), with the focus of this study being the classification of the water resources and associated ecosystems.

6.4 Assessment and Classification Results

6.4.1 Assessment Level

The assessment method was a multi-metric approach, indicating specific stressors affecting the status of the water resource (Spanhoff *et al.*, 2012). Only existing data were used in the study, therefore the confidence in the results is low to medium.

6.4.2 Classification Results

Classification of water resources within quarternary catchment C22K were summarised, results of Present Ecological Status and Management Class were documented in Table 24, Annexure 3. The details results can be summarised as follows:

The South African Water Quality guidelines for Aquatic Ecosystems from DWAF (1996) were used in the evaluation. The surface water qualities are documented in Table 18. The main concern is the TDS value and therefore the Present class of water quality will be a C for the Vaal Barrage Area and be managed by Class II.

The groundwater usage is low and therefore the current class is an A (unstressed). The MC is set at class I.

Electrical conductivity values were obtained from DWS (2018). The majority of the groundwater EC values fall within the natural and good categories. Therefore the current class is a B with the MC being a class I. It is important to note that there can be 'hot spots' in the catchment due to some of the activities taking place such as mining and industries. In these areas the groundwater quality can be a class D/E with a MC of III.

The surface water use is higher than that of groundwater and therefore the resource is unstressed/slightly stressed, and class for usage will be Class B. The associated MC will be class I.

The South African Water Quality Guidelines are used to assess the surface water quality of the resource. The TDS values are just above the target guideline of 0 – 450 mg/l (DWAF, 1996). The current class is therefore a B with the MC being a class I.

Land use upstream of the Vaal Barrage is dominated by cultivated dry land, which occurs throughout the catchment with high density areas in the Vaal Dam to Vaal Barrage sub areas with the main crops being maize and wheat (, 2004; DWAF, 2009d; , 2009e). Economic activities based at Johannesburg-Vereeniging-Vanderbijlpark generated substantial return flow volumes in the form of treated/untreated effluent from the urban areas and mine dewatering that discharged into the river system. These discharges had a significant impact on the water quality in the present Vaal Barrage Catchment (DWAF, 2004).

Approximately 80% of the study area land cover has been altered. Therefore when considering the current class it will be a class E (severely stressed) with the MC set as class III.

Due to the poor classification of land use/land cover, the vulnerability of surface water bodies to pollution, degradation and alteration is high. Using the vulnerability matrix developed by Parson and Conrad (1998) it is determined that the vulnerability's current class is an E with the MC being a class III.

The DRASTIC approach was used to determine groundwater vulnerability to pollution. The current vulnerability class which is a C (moderate) and the associated MC II.

Conversion of riparian vegetation to cultivated lands decreases infiltration and increase overland flow volumes and peak runoff rates. Land is also utilised by humans and animals. Specific direct human uses include cutting of trees, pruning of trees, harvesting of reeds or medicinal plants are also included. Grazing also altered hydrologic regimes. The final

present class category is a C, however because of the importance of the resource it must be managed to a class II (Kleynhans *et al.* (2008).

The South African Water Quality Guidelines for Aquatic Ecosystems (1996) was used in the evaluation for aquatic ecosystems. The main concern is the TDS value and therefore the Present class of water quality will be a C for the Vaal Barrage area and be managed by class II.

Modification of the instream quantity impact was limited to a few, very small localities. While instream quality impact to vegetation removal showed moderate modification (Present Class =C). The present class of instream flow habitat and instream quality habitat for the Vaal Barrage area would be B and C respectively.

The vegetation response based on ratings of riparian, quality and quantity of land use resulted in moderate impact class, therefore the PS of vegetation response would be C for the Vaal Barrage Area and be managed by Class II (Kleynhans *et al.*, 2008).

6.5 Recommendations

This research proved a degree of modification in the study area. MCs have been set and associated monitoring programs are required to improve the confidence of the assessment process. The three recommended strategies to lower salinity in the Vaal Barrage were identified. The following practical steps should be taken to prevent any further deterioration of the status of water resource:

- The Klip River (upstream tributary of the Barrage River) south of Johannesburg has been an important asset to the city, initially as a source of water, and later as a purifier of polluted water, especially from mining sources and sewage treatment. This water must be treated/diluted with clean water before entering the study area. The water containing sulphide materials from mining areas should be pumped to the surface and neutralised (DWAF, 2009d).
- Over the years the Vaal Barrage stream has been served as a comprehensive and unpolluted catchment area, but due to the socio-economic growth and development path in certain instances reflected a sign of being unsustainable in the long-term. The altered flow regime has led to deterioration in the water quality of the river system. An appropriate delegation of management on a regional scale is necessary to ensure that water quality of an acceptable class is available to all users in the

system (DWAF, 2009c; Jordaan & Bezuidenhout, 2013; Wepener *et al.*, 2011). RQs must be set to ensure the MCs are adhered to.

- The implemented water resource classification I, II & III programmes by DWA (2010) should be regulated more effectively to enforce control and improve in water quality and effluent management (Nel & Wessels, 2010).

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CHAPTER 8 ANNEXURES

Annexure 1: Tools

Ecological descriptors

Table 20: Generic ecological categories for EcoStatus components (Kleynhans and Louw, 2007)

ECOLOGICAL CATEGORY	DESCRIPTION	SCORE (% OF TOTAL)
A	Unmodified , natural.	90 – 100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80 – 89
C	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60 – 79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred	40 -59
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	20 – 39
F	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0 – 19

Information regarding the DRASTIC methodology

$$\text{DRASTIC INDEX} = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w$$

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

Depth to groundwater (D_w) = 5

Recharge (R_w) = 4

Aquifer media (A_w) = 3

Soil media (S_w) = 2

Topography (% slope) (T_w) = 1

Impact of vadose zone (I_w) = 5

A guideline for the ratings is provided in

Table 21.

Table 21: Weighting values used for the DRASTIC method

Depth to groundwater (D_R)	
Range (m)	Rating
0 – 5	10
5 – 15	7
15 – 30	3
>30	1
Aquifer media	
Range	Rating
Dolomite	10
Integrular	8
Fractured	6
Fractured and weathered	3
Net recharge (R_R)	
Range	Rating
0 – 5	1
5 – 10	3
10 – 50	6
50 – 100	8
>100	9
Soil media (S_s)	
Range	Rating
Sand	8 – 10
Shrinking and/or aggregated clay	7 – 8
Loamy clay	6 – 7
Sandy clay loam and loam	5 – 6
Silty clay loam, sandy clay and silty loam	4 – 5
Clay loam and silty clay	3 – 4
Topography	
Range (% slope)	Rating
0 – 2	10
2 – 6	9
6 – 12	5
12 – 18	3
>18	1
Impact of the vadose zone	
Range	Rating
Gneiss, Namaqua metamorphic rocks	3
Ventersdorp, Pretoria, Griqualand West, Malmesburt, van Rhynsdorp, Uitenhage, Bokkeveld, Basalt	4
Karoo (southern)	5
Table Mountain, Witteberg, Granite, Natal, Witwatersrand, Rooiberg	6
Greensrone, Dominion, Jozini	9
Dolomite	9
Beach sands and Kalahari	10

Annexure 2: Land cover

Table 22: Settlement classification in-terms of level of development in catchment area (Dube et al., 2017)

State the level of development in catchment area of the river in an urban setting	Description
Densely built-up city central business district with offices, high rise building, congested roads, transportation network centers	Vereeniging
Densely populated regional town centre, or city with large volume of day visitors but relatively low level of infrastructure	Vereeniging
Low Density or high income residential suburbs	Three River, Vaal park & SE1-SE8 at Vanderbijlpark
Medium Density residential area with smaller stands suburbs	Miami at Vanderbijlpark
High density residential townships	Urban area – (African townships such as Sharpeville (1942), Bophelong (1955), Boipatong (1955), Sebokeng (1965) and Zamdela (1976), had been

	established. General Water Site (Boipatong Township Urban Area), General Water Site (Palm Springs Sebokeng Township Urban Area (5) Sewage works –large (greater than 20 ML/d) – at Sebokeng Township Urban Area
Informal Settlement	Upstream of Rietspruit at Poriki
Plots and Commercial farms	Lochvaal
Mining settlements	Mine dumps from Vaal coal colliers. Waste site-large (Vaal dump site, (USCO, currently AMSA), Klip dump site (USCO, currently AMSA), Ash Dump site old Power Station (SNS-Bricks)
Industrial areas	Chemical Sasol synthetic fuel from coal.
Retail and shopping centers	Three River Mall in Vereeniging and Vaal Mall in Vanderbijlpark

Table 23: Land based activities (Parsons & Wentzel, 2007)

Examples of land based activities that can affect the water resources and associated ecosystems within the study area	Waste site Hazardous
	Industrial area
	Mine Dumps
	Urban area
	Waste site-large (greater than 20 ML/d)
	Sewage works
	Underground storage tanks
	Industrial area
	Power generation

Annexure 3: Assessment Outcome

Table 24: Present Ecological Status of Water Resource and Management Class

Classification	Driver Component and Response	PES	MC
Ground Water	Hydrology	A	I
	Quality	B	I
Surface Water	Hydrology	B	I
	Quality	B	I
Vulnerability	Geomorphology	C	II
Response	Vegetation	C	II
Habitat	Instream	B	II
	Riparian	C	

