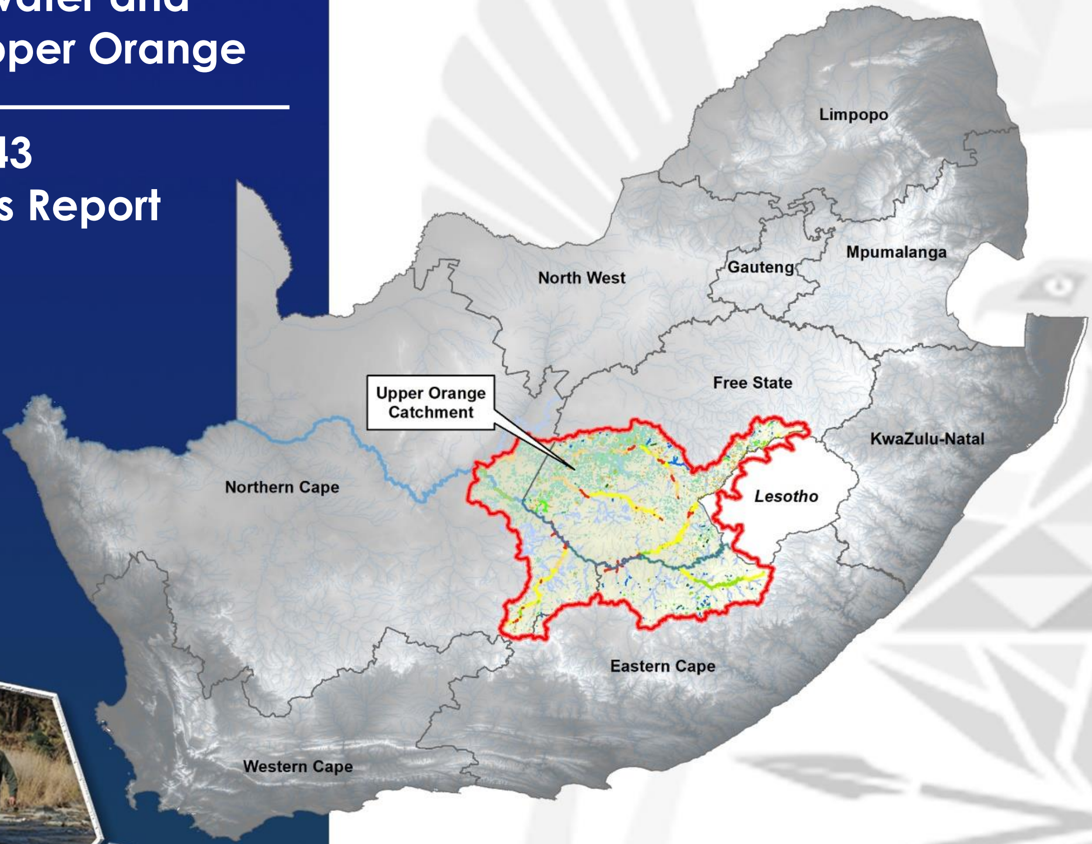
DEPARTMENT OF WATER AND SANITATION

A High Confidence Reserve Determination Study for Surface Water, Groundwater and Wetlands in the Upper Orange

WP11343
Gaps Analysis Report



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LIST OF ACRONYMS

AEH	Aquatic Ecosystem Health
BDI	Biological Diatom Index
BHN	Basic Human Needs
CD: WEM	Chief Directorate: Water Ecosystems Management
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
EFR	Environmental Flow Requirements
EI	Ecological Importance
ES	Ecological Sensitivity
EWR	Ecological Water Requirements
FBIS	Freshwater Biodiversity Information System
FRAI	Fish Response Assessment Index
GIS	Geographic Information System
GBIF	Global Biodiversity Information Facility
HAI	Hydrological Driver Index
IWRMP	Integrated Water Resource Management Plan
ISO	International Organization for Standardization
JBS	Joint Basin Survey
MAE	Mean Annual Evaporation
MIRAI	Macroinvertebrate Response Assessment Index
NFEPA	National Freshwater Ecosystem Priority Areas
NCMP	National Chemical Monitoring Programme
NWA	National Water Act
ORASECOM	Orange-Senqu River Commission
PES	Present Ecological State
RDM	Resource Directed Measures
RHP (REMP)	River Health Programme; River Ecostatus Monitoring Programme
RQIS	Resource Quality Information Services

RQO	Resource Quality Objectives
RU	Resource Units
RWQO	Resource Water Quality Objectives
SASS5	The South African Scoring System Version 5
SPI	Specific Pollution sensitivity Index
SWSA	Strategic Water Source Areas
TDS	Total Dissolved Solids
VEGRAI	Vegetation Response Assessment Index
WMA	Water Management Area
WMS	Water Management System
WR2012	Water Resources 2012
WRCS	Water Resources Classification System

EXECUTIVE SUMMARY

The Reserve has priority over other water use in terms of the NWA and should be determined before license applications are processed, particularly in stressed and over utilised catchments. Accordingly, the CD: WEM identified the need to determine the Reserve for the ecosystems (rivers, wetlands and groundwater) of the Upper Orange Catchment in the Orange Water Management Area (WMA 6). The aim is to provide adequate protection for (i) possible hydraulic fracturing (HF) activities, (ii) assessment of various water use license applications, and (iii) evaluation of impacts of current and proposed developments on the availability of water.

Several studies have been undertaken for the Upper Orange Catchment, although most have been on a basin-scale and not focussed on the study area, especially on the smaller tributaries. However, information from these studies will be useful and will be used as a basis, to collect additional data during the surveys to ensure high confidence results in this study.

Based on the review and analysis of the available datasets, GIS layers, information from previous studies, the project team has a better understanding of the availability, accessibility and usefulness of the information and data sources. However, various gaps do exist, of which some of these will be addressed during the study, through the collection of additional data during the seasonal field surveys.

The major gaps that will not be addressed during this study, as long-term monitoring is required are:

- Lack of adequate gauging weirs in the study area and the consequent lack of long-term flow data, especially daily data that is invaluable for the setting of EWRs; and
- Recent water quality data to determine the present state. However, data available from the 2021 JBS3 study, coupled with the planned surveys forming part of this study, will assist with mitigating this gap.

Accessibility to the rivers may further be problematic, as experienced during the JBS3 and recon surveys in October 2021. Specific attention will be given to contacting stakeholders/ farmers/ landowners before the surveys, to ensure accessibility to their properties.

Thus, the best available, sensible data and information sources will be used to meet the objectives of this study, with guidance from the DWS where specific project direction is required.

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1. INTRODUCTION

1.1 Background

The National Water Act (No. 36 of 1998) (NWA) is founded on the principle that the National Government has overall responsibility for and authority over water resource management for beneficial public use without seriously affecting the functioning and sustainability of water resources. Chapter 3 of the NWA enables the protection of water resources by the implementation of Resource Directed Measures (RDM). As part of the RDM process, an Ecological Reserve must be determined for a significant water resource to ensure a desired level of protection.

The Reserve (water quantity and quality) is defined in terms of (i) Ecological Water Requirements (EWR) based on, the quantity and quality of water needed to protect aquatic systems; water quantity, quality, habitat and biota in a desired state and (ii) Basic Human Needs (BHN), ensuring that the essential needs of individuals dependant on the water resource is provided for. These measures collectively aim to ensure that a balance is reached between the need to protect and sustain water resources while allowing economic development.

The Chief Directorate: Water Ecosystems Management (CD: WEM) of the Department of Water and Sanitation (DWS) is responsible for coordinating all Reserve Determination studies in terms of the Water Resource Classification System (WRCS). These studies include the surface water (rivers, wetlands and estuaries) and groundwater components of water resources.

The Reserve has priority over other water use in terms of the NWA and should be determined before license applications are processed, particularly in stressed and over utilised catchments. Accordingly, the CD: WEM identified the need to determine the Reserve for the ecosystems (rivers, wetlands and groundwater) of the Upper Orange River catchment in the Orange Water Management Area (WMA 6). The aim is to provide adequate protection for (i) possible hydraulic fracturing (HF) activities, (ii) assessment of various water use license applications, and (iii) evaluation of impacts of current and proposed developments on the availability of water.

1.2 Purpose of this study

The purpose of this study is to determine the Reserve (quantity and quality of the EWR and BHN) for priority rivers[1], wetlands and groundwater areas at a high level[2] of confidence in the Upper Orange

[1] Priority rivers are selected through the process of assessing water use impacts (quantity and quality) to determine the integrated water use index (IWUI) or water stress and (ii) integrated ecological index (IEI) that considers the PES and the ecological importance (EI) and ecological sensitivity (ES) of each sub-quaternary reach. Through the process, priority resource units are identified where the EWRs need to be quantified.

[2] High confidence study referring to a combination of different river level assessments, from desktop extrapolation to intermediate assessments. Furthermore, a wider coverage of the catchment will be undertaken, not only the main stem Orange River and major tributaries, but inclusive of the smaller tributaries within the catchment. In addition, groundwater and wetland priority resources throughout the catchment and their interactions will be assessed.

Catchment. The results from the study will guide the Department to meet the objectives of maintaining, and if possible, improving the state of the water resources within this catchment. The primary deliverable will be the preparation of the Reserve templates for the Upper Orange Catchment, specifying the ecological water requirements for the priority rivers, wetlands and groundwater areas.

1.3 Purpose of this report

The purpose of this report is to document the data, information and water resources models available from previous studies and monitoring activities and to identify the gaps relevant to the determination of the Reserve for the rivers, wetlands and groundwater in the Upper Orange Catchment.

2. *STUDY AREA*

The study area of the Upper Orange Catchment, forming part of the Orange WMA6 is illustrated in Figure 2-1 and includes the main stem Orange River with its major tributaries of the Kraai, Caledon and Seekoei Rivers. The Modder-Riet River drain into the Vaal River however, due to their interconnectivity (i.e. water transfers) with the Upper Orange River, are included in this study.

The Upper Orange Catchment forms part of the Orange-Senqu River Basin and is a shared water course with Lesotho in the upper reaches while the Lower Orange River catchment is shared with Botswana and Namibia. Henceforth, a consideration of the international responsibilities/commitments and bilateral agreements is imperative.

The Orange River main stem originates in the Eastern Highlands of Lesotho, where it is known as the Senqu River. The main stem flows west for approximately 2 200 km, where it drains into the Orange River Mouth and flows into the Atlantic Ocean at Alexander Bay. The Orange-Senqu River Basin is constituted by the Vaal, Upper Orange and Lower Orange catchments. However, for this study, only the main stem Orange River from the Lesotho Border to the confluence with the Vaal River and its main tributaries and the Modder-Riet Rivers will be considered.

The Gariep and Vanderkloof Dams on the main stem Orange River are two of the country’s largest reservoirs with main uses the generation of hydropower, transfers of water and releases for irrigation and other demands, including estuarine requirements, before reaching its confluence with the Vaal River. No major dams are situated on the lower Orange River and releases for downstream water demands and for the estuary are made from the Gariep and Vanderkloof Dams. Thus, cognisance will be taken of these demands during the determination of the Reserve.

Current infrastructure for water use is mainly for irrigation, transfer of water within the study area (Caledon River to Modder River, Vanderkloof Dam to the Riet River, Marksdrift on Orange River to Modder-Riet Rivers) and to other WMAs (e.g. transfer to Great Fish River in the Eastern Cape), domestic use, stock watering and power generation at the Gariep and Vanderkloof Dams. The Bloemfontein metropolitan area is the largest in the study area with smaller towns scattered throughout the catchment. Larger towns include Herscell/ Sterkspruit, Aliwal North, Burgersdorp, Ficksburg, Ladybrand, Botshabelo, Kimberly and Colesberg.

The study area consists of 129 quaternary catchments (see Table 2-1), covering approximately 106 000 km^2 and stretching across the Northern Cape, Free State and Eastern Cape provinces. It is divided into four distinct sub-areas (see Figure 2-2) within secondary catchments D1, D2, D3 and C5, namely:

i. The Orange River from the Lesotho Border to the Gariep Dam, including the main tributaries: Kornetspruit, Sterkspruit, Stormbergspruit and Brandwaterspruit;
ii. The Caledon River from its headwaters and its tributaries to the Gariep Dam;
iii. The Kraai River catchment; and
iv. The Orange River from the Gariep Dam, Vanderkloof Dam to Marksdrift weir, and just upstream from the confluence with the Vaal River. This includes the Seekoei River in the south and the Modder-Riet River (main tributaries of the Vaal River system) in the north.

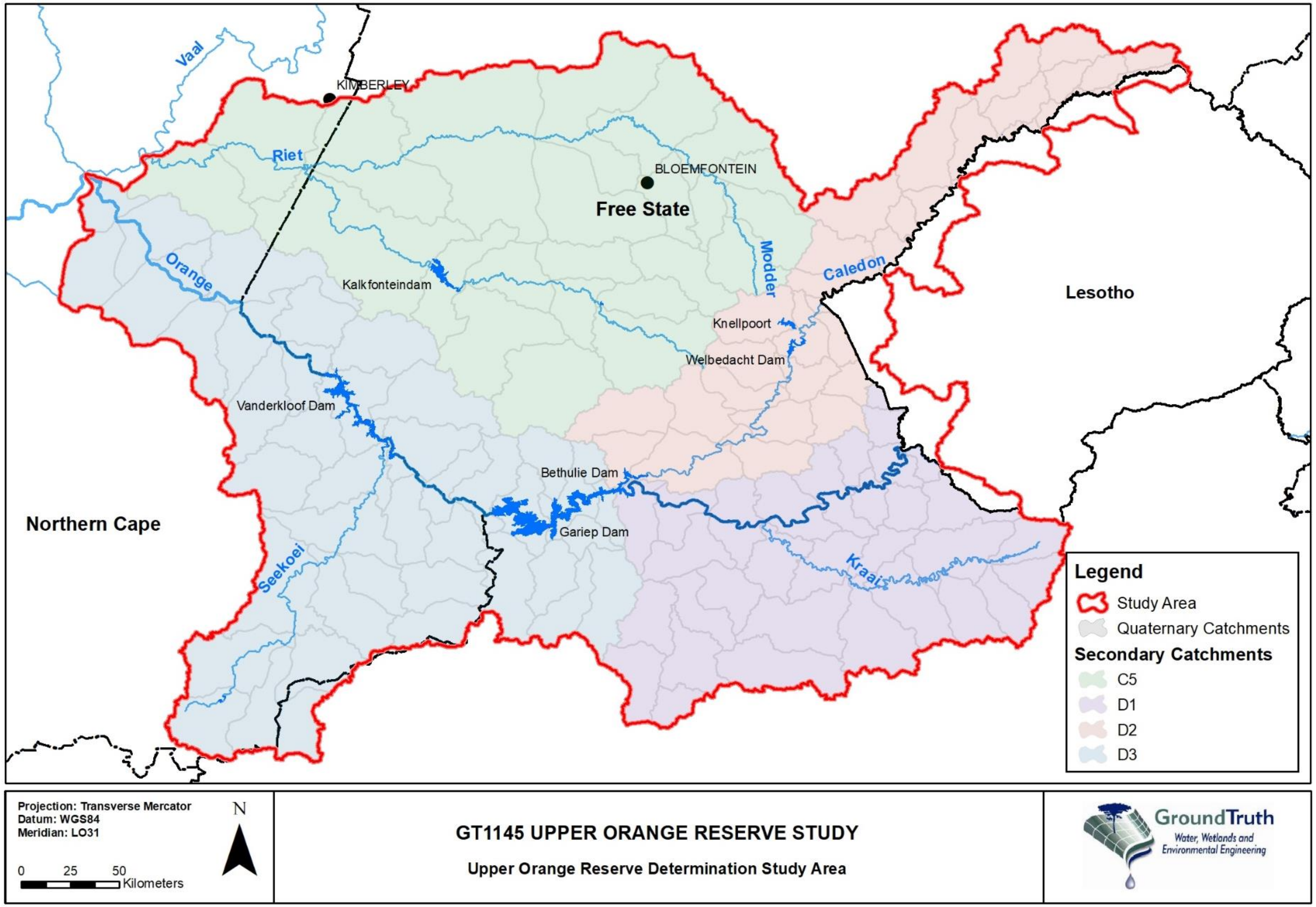

Figure 2-1: Upper Orange Catchment

Table 2-1: The sub-catchment areas and rivers within the study area

Sub-catchment	Main River	Tributaries	Catchment Area (km^2) (1)	Quaternary catchments
D12	Upper Orange	Hendrik Smitstroom, Kromspruit, Sterkspruit, Mpongo, Mhlangeni, Bamboesspruit, Gryskopspruit, Winnaarspruit, Knoffelspruit, Wilgespruit, Beeskraalspruit, Nuwejaarspruit	2 978	D12A – D12F
D13	Kraai	Rifle Spruit, Bokspruit, Sterkspruit Koffiehoekspruit, Bamboeshoekspruit, Langkloofspruit, Vrouenshoekspruit, Rytjiesvlaktespruit, Joggemspruit, Vlooikraalspruit, Three Drifts, Diepspruit, Klein-Wildebeesspruit, Saalboomspruit, Vaalhoek, Noodshulpspruit, Wasbankspruit, Wolwespruit, Rooihoogte se Loop, Holspruit, Kromspruit, Telemachusspruit, Skulpspruit, Braklaagtespruit, Leeuspruit, Karringmelkspruit, Bossielaagtespruit, Oslaagte, Rondefonteinspruit, Windvoelspruit, Elandspruit, Klipspruit	9 382	D13A – D13M
D14	Upper Orange	Sanddrifspruit, Melkspruit, Stormbergspruit, Wilgespruit, Wonderhoekspruit, Bamboesbergspruit, Buitendagspruit, Klein-Buffelsvleispruit, Witkopspruit, Barnardspruit, Mooiplaasspruit, Kop-en-pootjiespruit, Modderbulrspruit, Palmietspruit	6 175	D14A – D14K
D15 (SA only)	Makhaleng	Mantikoana, Deklerkspruit, Makhaleng (mainly in Lesotho), Worsfonteinspruit	848	D15G, D15H
D18 (SA only)	Upper Orange	Tele (border between Lesotho and RSA), Blikana, Pelandaba, KwaSijoa, KwaNomlengaba, Sidwadwa	1 549	D18K, D18L
D21	Caledon	Little Caledon, Brandwater, Swartspruit	2 183	D21A, D21C – D21H
D22	Caledon	Meulspruit, Moolmanspruit, Rantsho, Mopeli, Morakabi, McCabes Spruit, Beytelspruit, Modderpoortspruit, Tenniskopspruit, Tweelingspruit	4`103	D22A – D22L
D23	Caledon	Appledore Spruit, Klein-Leeu, Leeu, Mokopu, Bokpoortspruit, Sandspruit, Montsoane, Klipspruit, Rietspruit, Nuwejaarspruit, Bloemspruit	4 927	D23A, D23C - J

Sub-catchment	Main River	Tributaries	Catchment Area (km^2) [(1)]	Quaternary catchments
D24	Caledon	Boesmanskopspruit, Witspruit, Klipspruit, Elandspruit, Witspruit, Blaasbalkspruit, Wilgeboomspruit, Vaalspruit, Vinkelspruit, Grahamstadspruit, Leeuspruit, Eldoradospruit, Skulpspruit, Groenspruit, Slykspruit,	6 644	D24A – D24L
D31	Middle Orange	Hondeblaf, Diepsloot, Berg, Kattegatspruit	4 948	D31A – D31E
D32	Middle Orange	Seekoei, Klein-Seekoei, Elandskloof, Soetvlei se Loop, Noupoortspruit, Elands, Gansgatspruit	9 227	D32A – D32K
D33	Middle Orange	Lemoenspruit	9 647	D33A – D33K
D34	Middle Orange	Oorlogspoort, Klipfonteinspruit, Rietkuilspruit, Vanderwaltsfonteinspruit, Paaiskloofspruit, Otterspoortspruit	5 054	D34A – D34G
D35	Upper Orange	Oudagspruit, Broekspruit, Winnaarsbakenspruit, Broekspruit, Bossiespruit, Brakspruit, Swarthoekspruit, Suurbergspruit, Orange	5 672	D35A – D35K
C51	Riet	Leeuspruit, Fouriespruit, Kroonspruit, Ruigtespruit, Ospoortspruit, Holspruit, Kromellenboogspruit, Prossesspruit, Vanzylspruit	17 568	C51A – C51M
C52	Modder	Kromspruit, Bo-Kromspruit, Gannaspruit, Klein-Modder, Sepane, Kgabanyane, Wildebeesspruit, Steynspruit, Korannaspruit Matjiespruit, Koringspruit, Klein-Osspruit, Osspruit, Renosterspruit, Bloemspruit, Dardoringspruit, Keeromspruit, Doringspruit, Rietspruit, Stinkhoutspuit, Kaalspruit, Klein-Kaalspruit	10 682	C52A – C52L

[(1)] *Based on WRC (2012) data*

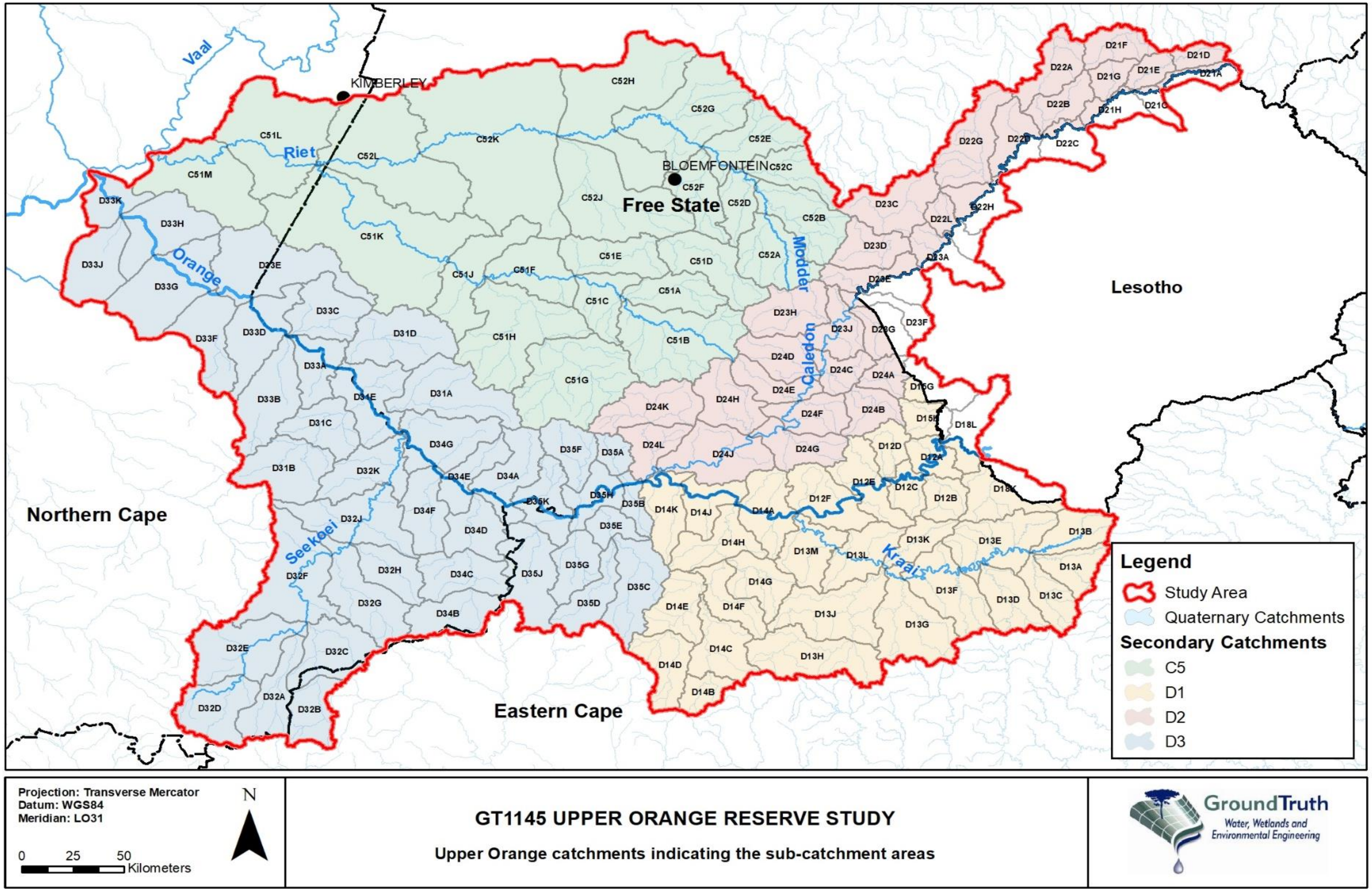

Figure 2-2: Upper Orange Catchment: indicating the sub-catchment areas

2.1 Major dams and transfer schemes

The Upper Orange Catchment is characterised by some of the country's largest dams, providing a pivotal role in supplying water to users in the catchment, as well as strategically important neighbouring catchments, namely the Upper Vaal WMA (DWA, 2009).

The major storage dams are the Gariep and Vanderkloof Dams, two of the largest reservoirs in South Africa and which also supply hydroelectric power. There are numerous other smaller dams within the catchment. The dams in the catchment have impacted the availability of flows, flow patterns and subsequently the wellbeing of the water resources. These impacts have been exacerbated by the generation of power, particularly at Gariep Dam where the daily flows have become highly variable. The larger dams in the Upper Orange Catchment are listed in Table 2-2 below.

Table 2-2: Storage dams in the Upper Orange catchment

Dam	Associated River	Volume (ML)	Surface area (km^2)
Major storage dams			
Gariep	Orange River	5 340 600	352.162
Vanderkloof		3 171 300	133.402
Smaller storage dams			
Armenia	Caledon River and tributaries	13 000	3.933
Egmont		9 300	2.442
Welbedacht		10 200	10.185
Knellpoort	Off-channel storage dam supplementing water supply to Bloemfontein from Caledon River	130 000	9.854
Rustfontein	Modder River	72 200	11.585
Mockes		-	-
Krugersdrift		66 000	18.525
Tierpoort	Riet River	34 000	9.11
Kalkfontein		325 100	37.697

The water resources of the Upper Orange Catchment are used to support requirements for water in other parts of the country with large transfer schemes both from and within this catchment. These include the Orange-Fish transfer from Gariep Dam to the Fish / Tsitsikamma WMA, the Orange-Riet transfer from downstream Vanderkloof Dam to the Riet River, the Caledon-Modder transfer from Knellpoort Dam to the Modder River and the Orange-Vaal transfer from Marksdrift Weir on the Orange to the lower Vaal River.

Finally, although not directly within this study area, though do influence the availability of flows within the study area, the following water transfers listed below will be considered:

- Transfers from the Senqu River (Lesotho Highlands Water Project) through the Katse and Mohale Dams, including the proposed Polihali Dam, transferred to the Upper Vaal WMA; and
- Transfer from Muela Dam in Lesotho to the Caledon River, particularly during droughts, with the aim to supply water to Maseru and surrounding areas.

3. *WATER RESOURCE COMPONENTS*

The main components included in this study to determine the Reserve are rivers, wetlands and groundwater.

3.1 Rivers

The selection of priority rivers for the determination of the ecological Reserve will be guided by considering those systems currently under stress due to reduced or altered flows and quality. The river reaches with little information from previous studies will also be considered, especially where the 2014 Desktop PES/EI/ES study (DWS, 2014) indicated that these reaches are still in a good ecological state. Rivers identified as Strategic Water Source Areas will be a priority to ensure the long-term protection of these resources. Rivers identified for proposed future developments, e.g. dams, will be included in the final selection of priority rivers.

Firstly, the mainstem Orange River and its major tributaries, as well as the Modder-Riet Rivers, will be considered. These include:

- Upper Orange to Gariep Dam (D12, D14, D35)
- Kraai River (D13)
- Caledon River (D21 – D24)
- Seekoei River (D32)
- Orange River from Gariep Dam to confluence with Vaal River (D31, D33, D34)
- Modder-Riet River (C51, C52)

Large wetland systems and groundwater areas contributing significantly to the base flows of the rivers will be included if little or no information is available.

3.2 Wetlands

Depression wetlands are some of the more common wetland types found within the Upper Orange Catchment, which is largely associated with a combination of geology, rainfall and temperature. Overall, a total of 2,868 wetlands were identified by the National Wetlands Map (NWM5) spatial layer (Van Deventer *et al.,* 2018), covering a total area of 74,378ha. The majority of the identified wetlands are located within the Upper Karoo Bioregion, followed by the Mesic Highveld Grassland Bioregion.

Most of the identified wetlands were categorised as Least Concern followed by Vulnerable based on the vulnerability of the wetland type and vegetation with more than half of the identified wetlands in a largely natural state with limited modifications.

Furthermore, the Modder River, a tributary of the Riet River has a large density of high priority National Freshwater Ecosystem Priority Areas (NFEPA), consisting largely of depression wetlands (Nel *et al.,* 2011). Important wetlands also occur between the Orange and Riet Rivers.

Some of the main modifications affecting the integrity of the wetlands within the Upper Orange Catchment is associated with multiple land use impacts such as irrigated commercial croplands, bare areas associated with mining operations and populated areas (hardened surfaces).

Large areas of the study area have highly dispersive soils that are a key consideration for the selection of wetlands of importance for protection and maintenance since many of these systems are already highly degraded and at risk of eroding beyond any rehabilitation opportunities. For these reasons, those wetlands that have degraded beyond a D category (at most) will be re-prioritised below those wetlands in better ecological conditions. In the Eastern Cape specifically, areas associated with subsistence farming and urban villages are surrounded by eroded areas (dongas). This relationship is a phenomenon that will need to be considered and noted during the final wetland prioritisation process. Additional impacts are likely to include poor land use management practises and over-grazing within all three provinces.

3.3 Groundwater

The regional geology is dominated by the Karoo Supergroup that was deposited in the Karoo Basin with a surface area of 200,000 km^2 (Aarnes *et al.,* 2011). The Karoo Supergroup was formed through sedimentation within an intracratonic, foreland basin on Gondwanaland, during the Carboniferous, Permian, Triassic and early Jurassic ages, about 300 Ma to 160 Ma ago (Truswell, 1970). The main Karoo Basin covers a large part of the central and eastern parts of South Africa, and according to Du Toit (1954), the Karoo Basin has a maximum thickness in the southern parts of the Northern Cape Province and Lesotho.

The Upper Orange catchment is covered exclusively by the Karoo Supergroup sedimentary rocks. Widespread volcanism ended the Karoo sedimentation during the early Jurassic Age (Tankard *et al.,* 1982). According to Botha (*et al.,* 1998), the magmatic activity is divided into two phases, i.e. an extrusive phase associated with the outpour of Drakensberg lavas, as well as the intrusive phase associated with numerous linear dolerite dykes/sills and kimberlites in the Karoo formations. The intrusion of dolerite dykes resulted in the formation of fractures and contact metamorphism within the sedimentary host rock (Aarnes *et al.,* 2011).

Following WRC (2012), the aquifer types associated with the Karoo Supergroup are mainly "fractured" and "fractured and intergranular". The fractured nature of the Karoo Supergroup sediments is due to the brittle nature of the rocks in response to deformational processes. The intergranular and fractured aquifers are mainly represented in the area by the dolerite sills and dykes, which exhibit a dual porosity within the upper weathered and lower fractured zone respectively.

The Upper Orange-Senqu River basin coincides with a major transboundary aquifer, i.e. The Karoo Sedimentary Aquifer. The Stormberg Group of the Karoo Supergroup underlying the trans-boundary area comprises horizontal to sub-horizontal dipping sedimentary rocks of the Burgersdorp, Molteno, Elliot and Clarens Formations. These include fluvio-deltaic mudstones, siltstones and sandstones with dolerite ring dyke intrusions. Formation groundwater storage and flow are functions of porosity. Primary effective porosities are low due to sediment cementation and the fine-grained nature of the sediment, as well as compaction and high mudstone contents. Secondary porosities are enhanced by fracturing and dolerite dyke intrusion. The highest borehole yields are associated with the fractured dolerite and thick sandstone contacts and where these contacts are covered by alluvium. The alluvium plays an important role to enhance recharge to the subsurface lithologies. The borehole yields are variable in the catchment and range from 0.1 L/s to >5.0 L/s, dependent on the underlying geological group.

The groundwater quality varies over the catchment area. Using the Electrical Conductivity (EC) as an overall groundwater quality indicator, groundwater quality is mainly good over the eastern parts of the catchment (0 – 70mS/m) but deteriorates slightly towards the western parts of the catchment (70 – 300mS/m) (WRC, 2012). A similar spatial distribution is observed with groundwater recharge, which is highest along the Lesotho Highlands areas (maximum of 94mm/annum) and lowest to the west and southwest (minimum of 4mm/annum). The total available groundwater, known as the Utilisable Groundwater Exploitation Potential (UGEP), varies from about 26 000$m^3/km^2/a$ in the east to about 1900$m^3/km^2/a$ in the west. The UGEP is regarded as the sustainable potential yield that may be used for planning purposes in the rural, domestic, municipal, industrial, and agricultural water use sectors.

According to WRC (2012), the total groundwater use in the catchment is estimated at about 132Mm^3/a, of which 80% is being used for agriculture, 13% for agricultural livestock and 3% for municipal. Stressed catchments have been identified in several quaternary catchments in the south-eastern parts of the catchment (see Figure 3-1). In these quaternaries, the total abstraction and baseflow exceed the estimated recharge. The remainder of the catchment appears to have surplus groundwater available for development. In the drier western and southern parts of the catchment, groundwater constitutes the main source of water for rural domestic supplies and stock watering. According to DWS (2003), severe over-exploitation of groundwater is experienced in some peri-urban areas, i.e. Bainesvlei smallholdings near Bloemfontein, as well as Petrusburg in the Modder-Riet sub-area due to increasing irrigation from groundwater in the area.

It is important to add continuing on this study is that the received latest groundwater use (allocation) data from the Department's WARMS database will further be assessed to identify further stressed catchments.

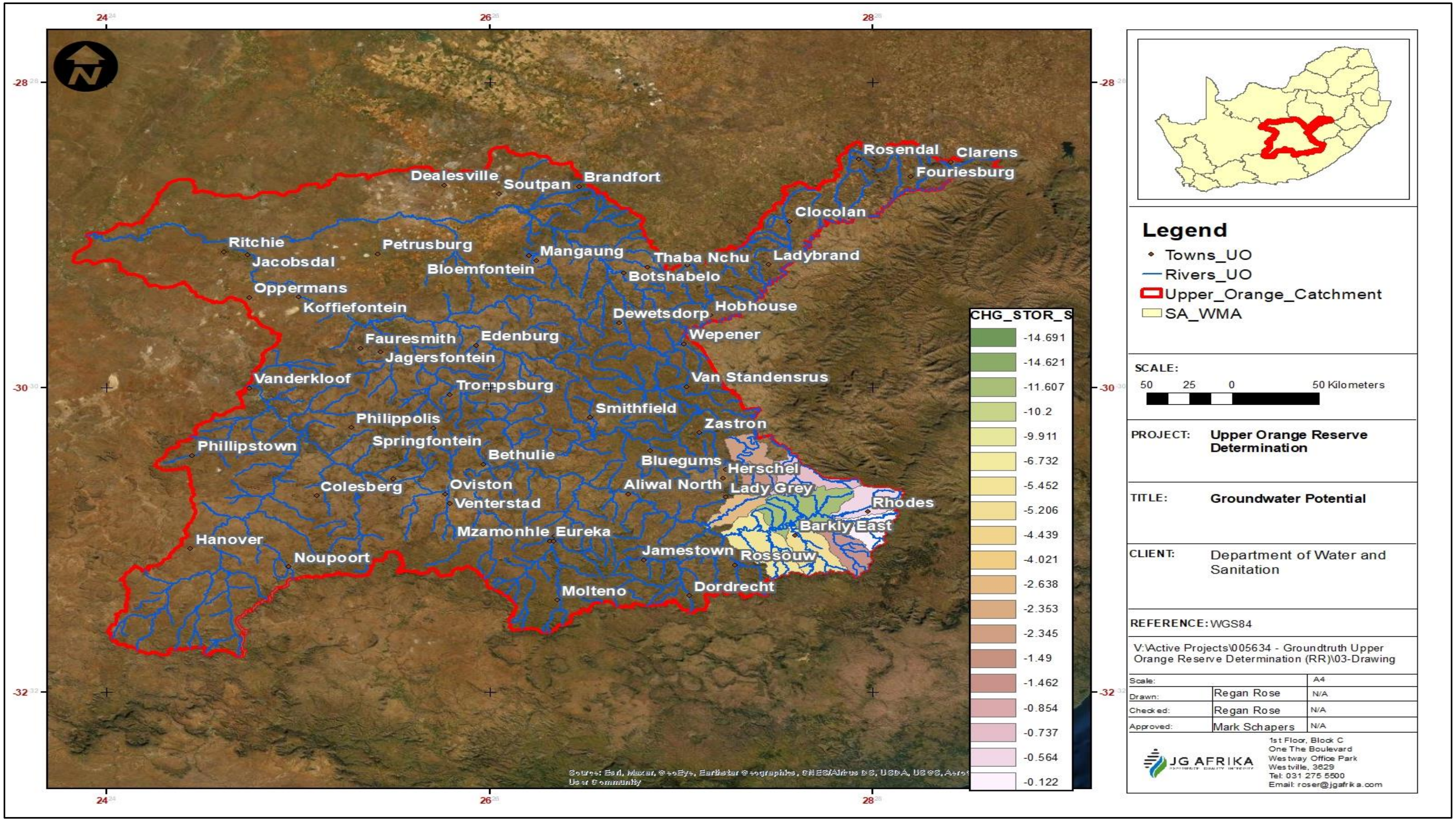

Figure 3-1: Stressed groundwater catchments

4. INFORMATION REVIEW

4.1 Previous studies and databases from monitoring programmes

Several studies have been conducted for the Upper Orange Catchment, mainly focussed on the long-term planning of the water resources of the entire river basin. Some of these studies were undertaken by DWS or in association with Lesotho, especially with the development of the Senqu River catchment for water transfers to the Upper Vaal system. Studies were also undertaken by ORASECOM for the development of basin-wide Integrated Water Resource Management Plans (IWRMP). Reconciliation strategies have been developed by DWS for the study area that considered various options for water supply from surface and groundwater and the management of these resources, including the Reserve requirements for the study area. These include the development of a reconciliation strategy for the Greater Bloemfontein Area with a Catchment Management Strategy for the Modder-Riet Rivers in 2010, the All-Towns Reconciliation Strategies developed in 2012 and the 2014 reconciliation strategy for Large Bulk Water Supply Systems: Orange River. An Integrated Water Quality Management Strategy for the Upper Orange River has been developed by DWS in 2009 that will provide baseline information and guidelines for the setting of water quality specifications as part of the Reserve.

Several monitoring initiatives are undertaken in the study area. These include (i) monitoring of flows and water quality for rivers and groundwater and (ii) aquatic biomonitoring/Aquatic Ecosystem Health (AEH) monitoring through various platforms and programmes namely:

- The River Eco-Status Monitoring Programme (REMP; previously the RHP) by DWS;
- Management of the biomonitoring data, using the Freshwater Biodiversity Information System (FBIS) by the South African National Biodiversity Institute (SANBI); and
- ORASECOM undertake Aquatic Ecosystem Health (AEH) monitoring every 5 years (2010, 2015 and 2021) through the Joint Basin Survey (JBS) throughout the Orange-Senqu River Basin, which includes a groundwater monitoring campaign.

The information and data from the Desktop PES/EI/ES assessment (DWS, 2014), will form the basis for the initial assessment of the rivers on a sub-quaternary level. This will be augmented with information from the selected EWR sites, where detailed surveys and assessments will be undertaken.

The groundwater component of this study will draw on the data and information available from the WR2012 study for a detailed level of delineation of the groundwater resource units (WRC, 2012). Additional information from surveys and local knowledge will be required to identify certain “hot spot” or critical areas, notably where the groundwater potential is low, and the demand is high.

Various national spatial layers relating to wetlands, their importance and possible delivery of specific ecosystem services are available for wetlands (Nel *et al.,* 2011; Van Deventer *et al.,* 2018). However, as most of these spatial layers have been created at a national scale, the extent and associated attributes may not be accurate at a fine scale. As such, infield verification will be necessary to review the characteristics of the wetlands that have been prioritised, and amend the final prioritisation accordingly. Some of the main sources of information for wetlands include the NWM 5 spatial dataset, the NFEPAs wetland shapefile, GIS coverages of important water supply dams, wetlands that interact with the surface and groundwater strategic water source areas (SWSAs) and the HGM unit type, which was used to determine the level to which each system may provide ecosystem services (Nel *et al.,* 2011; Van Deventer *et al.,* 2018).

An extensive list of previous studies, available information and datasets has been included in the Inception Report (DWS, 2021). These will be used as key information sources for this Reserve study. Any gaps identified from these studies and data sources will be discussed in the next section of the report.

4.2 Reserve Studies

Several Reserve studies have been undertaken for the rivers of the Upper Orange catchment, although at various levels of detail and not for the entire catchment. These include:

- Rapid level 3 studies pre 2005 on the mainstem Caledon River and tributaries with very little information available for this study;
- An intermediate Environmental Flow Requirements (EFR) study was undertaken for ORASECOM in 2010 and included a site on the Kraai River, two sites on the Caledon River and one site on the Orange River at Hopetown. Although information available from this study will improve the confidence of the results of this Reserve study, additional EWR sites on an intermediate and rapid levels will be selected to provide a more comprehensive assessment of the EWRs (ORASECOM, 2010);
- A study was undertaken for the Modder-Riet system pre 2010 on a rapid level 3 at four EWR sites. Information from this study will be used and additional surveys undertaken to provide ecological input for the management of this highly regulated system. This formed part of DWAF (2006) study;
- A high confidence study was undertaken at four sites on the Seekoei River from 2006 to 2010. Available information will be used to enhance the confidence in the final Reserve of the Seekoei River (Seaman *et al.,* 2009);
- A comprehensive site was selected on the lower reaches of the Riet River (originally part of the Modder-Riet River study) as part of the Vaal comprehensive Reserve study in 2006 to 2010 (DWA, 2010a, DWA, 2010b); and
- Ad hoc rapid level 3 studies were undertaken for water resource developments, including tributaries of the Karringmelkspruit and Wilgespruit in D12E and D13K and on the main stem Caledon River in D22D (Stassen *et al.,* 2017, Stassen *et al.,* 2021).

Most of the previous studies were undertaken more than 10 years ago and the present state of these systems might have changed due to water use impacts. Thus, surveys will be undertaken at these sites to confirm and update the present state and re-assess the EWRs. The locality of the EWR sites from the previous sites are presented in the table below.

Table 4-1: Locality of EWR sites from previous studies

Site no.	Site name	River	Latitude	Longitude	Level & Date
EFR 01	Hopetown	Orange	-29.516000	24.009270	Intermediate, 2010
EFR C5	Upper Caledon	Caledon	-28.650800	28.387500	Intermediate, 2010
EFR C6	Lower Caledon	Caledon	-30.452300	26.270880	Intermediate, 2010
EFR K7	Lower Kraai	Kraai	-30.830600	26.920560	Intermediate, 2010
Vaal_EWR19	Lillydale Lodge	Riet	-29.038417°	24.502833°	Comprehensive, 2008
Zach_EWR1	-	Tributary of Wilgespruit	-30.695700°	27.169000°	Rapid 3, 2017
Karn_EWR1	-	Tributary of Karringmelkspruit	-30.714300°	27.3086°	Rapid 3, 2017
Modder_EWR3	-	Modder	-28.901712°	25.925395°	Rapid 3, pre-2010
Riet_EWR2	-	Riet	-29.589286°	25.698148°	Rapid 3, pre-2010
Riet_EWR4	-	Riet	-29.489458°	25.196783°	Rapid 3, pre-2010
Cal_EWR2	-	Caledon	-28.908000°	27.785000°	Rapid 3, 2021**
EWR1	-	Seekoei	D32E*		Intermediate, 2010
EWR2	-	Seekoei	D32F*		Intermediate, 2010
EWR3	-	Seekoei	D32J*		Intermediate, 2010
EWR4	-	Seekoei	D32J*		Intermediate, 2010
Site 1	-	Little Caledon	-28.526944°	27.785000°	Rapid 3, 2003
Site 4	-	Little Caledon	-28.611389°	27.546401°	Rapid 3, 2003
Site 2	-	Groot	-28.680556°	27.532074°	Rapid 3, 2003
Site 6	-	Leeu	-29.521944°	27.532074°	Rapid 3, 2003

Site no.	Site name	River	Latitude	Longitude	Level & Date
Site 3	-	Caledon	-29.722222°	27.532074°	Rapid 3, 2003
Site 5	-	Caledon	-29.113889°	27.532074°	Rapid 3, 2003

**Co-ordinates have been requested*
***A Rapid 3 survey was conducted at site Cal_EWR2 in the middle of 2021 as part of a Lesotho study undertaken by GroundTruth. We will be asking the client permission as to whether we can utilise the data collected from that site for the purpose of this study.*

4.3 Hydrological Data and Modelling

The natural or reference hydrology of the Upper Orange catchment has been extended for the period 1920 to 2004 as part of the study to support Phase 2 of the ORASECOM basin-wide integrated water resources management plan, 2010. This hydrology and the model configurations were used during the WR2012 study when the hydrology was further extended to 2009 (WRC, 2012). Thus, the natural flows used for the determination of the EWRs will be based on the quaternary level WR2012 hydrology for the period 1920 to 2009. These will be disaggregated to the selected EWR sites. A summary of the natural flows per major basin is shown in Table 4-2 below.

Table 4-2: Summary of the incremental natural runoff for the Upper Orange Basin (WR2012)

Tertiary Catchment	Catchment Area (km^2)		MAP (mm)	MAE (mm)	Natural Incremental Runoff (1920 -2009)
	Gross**	Nett***			$10^6 m^3/a$
Riet-Modder	34 815	20 738	443	1744	326.8
Caledon	21 884	21 884	677	1466	1405.9
Kraai	9 354	9 354	646	1583	684.2
Seekoei	9 081	9 081	313	1909	37.75
Orange Upper*	36 669	29 961	521	1670	710.4

**Only include quaternaries within SA*
***Physical area when delineated contributing to run-off*
****The actual area that contributes to run-off*

The WRYM configuration available from the 2010 ORASECOM study will be used and adjusted to the EWR sites. Water demands from the 2018 DWS planning model will be incorporated into the WRYM. Specific management scenarios that have been identified and modelled during the development of the basin-wide Integrated Water Resource Management Plan and Reconciliation strategies, including selection of additional scenarios relevant to the ecological function or well-being of the water resources, will be evaluated.

5. GAP IDENTIFICATION

An assessment and review of data and information availability from previous studies, various monitoring databases and GIS spatial layers for the Upper Orange Catchment was undertaken, as per information review above. This identified data gaps to ensure that these are collected during this study to enhance information on the confidence, level of ecological specifications and management conditions. Furthermore, this supports the selection of practicable indicators for compliance monitoring and monitoring of the ecological health and integrity of the water resources. This assessment forms part of Task 2 of the scope of work (see Figure 5-1 below).

The evaluation of information gaps per component was undertaken according to criteria for each component (rivers, wetlands and groundwater) based on the data availability and suitability for use, along with proposed solutions and/or mitigations, in which to address these identified data gaps.

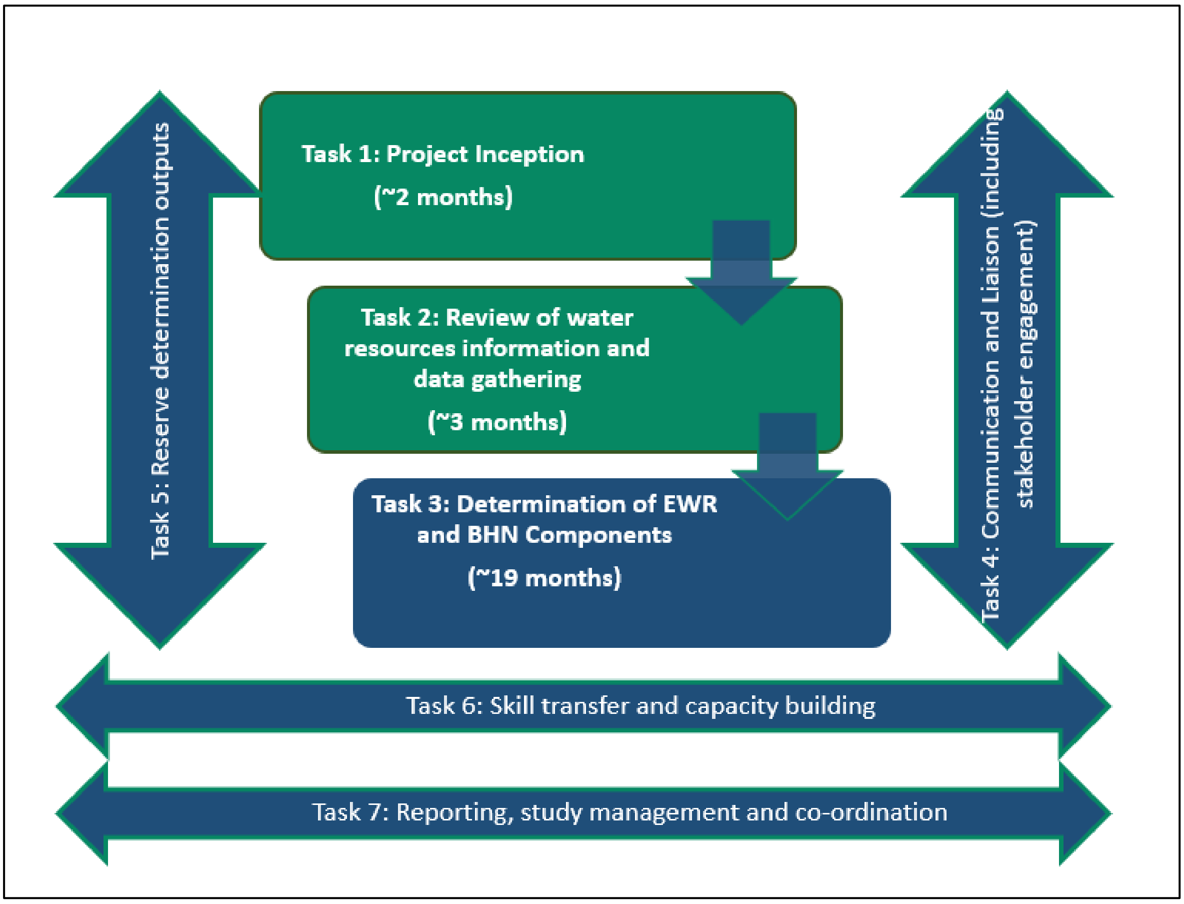

Figure 5-1: Proposed scope of work and approximate timelines

5.1 Rivers

5.1.1 Aquatic Biota

(i) Fish

The use of aquatic biota to detect, measure and track changes in the environment is based on the premise that the presence or absence of biotic assemblages at a given site reflects its level of environmental quality. Depending on their diversity, fish species assemblages provide convenient and potentially full-time monitors of the aquatic environment as they integrate their responses through time and react to all synergistic and antagonistic effects of combined pollutants and stressors imposed on their environment. Fish species display differing tolerances and preferences to environmental attributes, allowing the assessment of the fish assemblage to infer potential impacts.

Fish-based indices of biotic integrity have been developed and used in Southern Africa for bioassessments and biomonitoring purposes for several years, with the current approach being the Fish Response Assessment Index (FRAI) (Kleynhans, 2007). The FRAI is essentially an assessment index based on the environmental intolerances and preferences of the reference fish assemblage and the response of the constituent species of the assemblage to particular groups of environmental determinants or drivers. Although the FRAI uses essentially the same information as its predecessor (the Fish Assemblage Integrity Index, or FAII) (Kleynhans, 1999), it does not follow the same procedure. The FAII was developed for application in the broad synoptic assessment required for the River Health Programme (now the River EcoStatus Monitoring Programme, or REMP) and does not have a particularly strong cause-and-effect basis. The purpose of the FRAI, on the other hand, is to provide a habitat-based cause-and-effect underpinning to interpret the deviation of the fish assemblage from the perceived reference condition.

During the recent assessment of the Upper Orange River catchment as part of the ORASECOM's Joint Basin Survey 2 (JBS2) and Joint Basin Survey 3 (JBS3), the ecological state of the fish assemblage within the Orange River were determined to be representative of a moderately to largely modified state (Ecological Category C to D). In contrast, the Caledon River was noted to be mostly representative of a largely to seriously modified system (Ecological Category D to E), with the middle reaches in a poorer state than the upper and lower reaches. To a large degree, tributaries of the Orange River and Caledon River fared better than the main stem rivers, representing primarily moderately modified states (Ecological Category C). In general, primary drivers of change impacting much of the Upper Orange River systems were identified as being greatly altered sediment dynamics (including increased sediment input within the upper reaches) and altered flows, with the presence of alien fish species also noted to contribute to the ecological categories obtained.

(ii) Macroinvertebrates

Macroinvertebrate families vary in their pollution tolerances. Due to the diversity of taxa, this makes them ideal indicators of water quality in freshwater ecosystems, and which react quickly to pollution events and can colonise previously disturbed/polluted habitats if conditions improve. Additionally, they integrate water quality conditions over time and account for synergistic and additive effects of different water quality parameters.

The South African Scoring System version 5 (SASS5) (Dickens and Graham, 2002) was developed as a rapid technique for determining aquatic ecosystem health using aquatic macroinvertebrates as bio-indicators. The SASS5 technique has been accredited to ISO 17025 standards and forms part of one of the DWS river eco-classification models for EcoStatus determination. This protocol is a biotic index to determine the condition of a river or stream, based on the resident macroinvertebrate community, whereby each taxon is allocated a score according to its level of tolerance to river health degradation (specifically organic impacts) (Dallas, 2007). Information generated by the SASS is used in the MIRAI (Macroinvertebrate Response Assessment Index) that enables assessment of macroinvertebrate information beyond physicochemical evaluation to use in e-flow requirements for lotic systems and setting of biomonitoring objectives (Thirion, 2007). The MIRAI will be used for this study.

Changes and responses within the aquatic macroinvertebrate (and fish) communities are a result of impacts on primary system drivers (hydrology, physicochemical conditions and geomorphology) that culminates in changes to flow velocities, habitat availability and ecological water quality. Long-term anthropogenic pressures, system modifications, through high sedimentation loads, dams, irrigation and water transfer schemes, and widespread urbanisation, continues to affect the health and integrity of the macroinvertebrate communities in the catchment.

The biotic integrity of the macroinvertebrate communities, as per the JBS2 results ranged from moderately modified (Category C) to largely modified (Category D) throughout the Upper Orange catchment (ORASECOM, 2015). The communities within the lower reaches of the Kraai and Seekoei Rivers were both moderately modified (Category C). The Caledon River improved from moderately modified in the upper reaches to moderately/ largely modified further downstream, associated with substrate smothering caused by high sediment loads. The communities within the Orange River indicated an improvement in a downstream direction from largely to moderately modified, associated with flow modifications in the upper reaches of the Senqu River and dams in Lesotho.

5.1.2 Geomorphology

(i) Sediment dynamics

The Orange River is one of the most turbid rivers on the continent due to its high suspended sediment load (Compton and Maake, 2007). Most of the sediment is produced from soils underlain by Karoo sedimentary rocks (mudstones and shales of the Stormberg and Beaufort groups) where rainfall is relatively high and vegetation cover is relatively low (Compton and Maake, 2007; Kriel, 1972). Compton et al. (2010) estimate a tenfold increase in sediment yield since European settlement due to farming and grazing practices on soils derived from the Karoo sedimentary rocks. This could imply a 100-fold increase in erosion rate due to relatively low sediment delivery ratios (Compton et al., 2010).

The Caledon River is the major source of fine suspended sediment to the upper Orange River (Compton and Maake, 2007), as can be seen from the silting of the Welbedacht Dam. Basin-wide soil erosion risk mapping by Le Roux *et al.* (2008) shows high erosion potential along the eastern, higher-lying parts of the catchment (Figure 5-2). This is in line with observations of high turbidity along the Caledon River. Sediment tracing studies confirm high soil loss from areas underlain by Karoo sedimentary rocks where rainfall is relatively high and vegetation cover is poor.

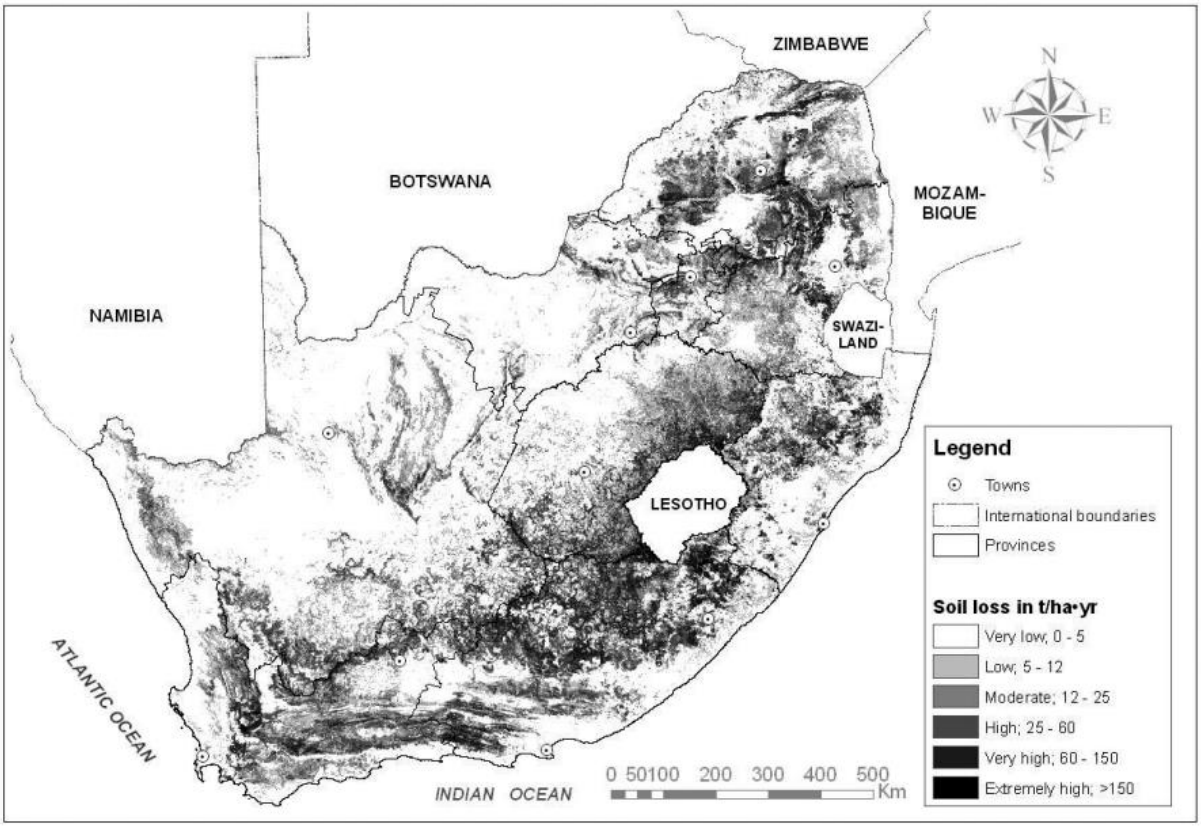

Figure 5-2: Water erosion risk model for South Africa (Le Roux et al., 2008)

The sediment that is deposited on the bed of the Welbedacht Dam is in the fine sand range (0.1 mm), with the finer particles remaining largely in suspension, allowing the fine suspended sediment to travel downstream (De Villiers and Basson, 2007). Lower downstream at the Gariep Dam, the annual sediment volume is estimated at 32 Mm^3, of which 90% is deposited behind the dam (Kriel, 1972). Coarse silt, sand and gravels are largely deposited in the Gariep and Vanderkloof Dams, resulting in the Orange River immediately downstream of the dams to be starved of bedload (Compton and Maake, 2007).

Sediment is largely transported during the austral summer high flows (November to March), with a reduction in sediment concentrations towards the end of the wet season (March to May) (Slabbert, 2007). The inter-basin transfer from the Caledon to the Modder River does not increase the turbidity of the Modder River significantly, as sedimentation takes place in the Knellpoort Dam before water is released into the Modder River (Slabbert, 2007). Bed and bank erosion downstream of the Caledon-Modder outfall could increase sediment loads in the Modder River due to channel erosion, but the eroded sediment will be trapped by dams downstream (Slabbert, 2007).

Along the Bell River, a headwater tributary to the Kraai River, river straitening and braiding has taken place over the past 70 years due to increased catchment sediment input, exotic woody vegetation stabilising and narrowing the meandering river channel (Rowntree and Dollar, 1996). The increase in sediment supply is mainly attributed to European settlement and overgrazing over the past century, with no observable change to rainfall patterns, thus climate change was discounted as a driver of the changes observed in the river system (Dollar and Rowntree, 1995).

Changes to river channel shape and river composition downstream of dams are common as flows and longitudinal sediment supply are largely impeded or buffered. Bed and bank erosion downstream of the dams is expected as the sediment load is significantly reduced by impoundments (Kriel, 1972). Due to reductions in flow variability (over a period of ~ 40 years) downstream of the Gariep Dam, the channel bars were stabilised by encroaching riparian vegetation due to smaller and lower frequency flood events and as a result the active channel narrowed (Rountree, 2011). Beck and Basson (2003) state a 5% reduction in channel width downstream of the Gariep Dam.

Channel geodiversity (channel form and substrate) within the inundation zone of dams and weirs is largely uniform and featureless due to blanket fine sediment deposition along the lower Seekoei River (Dollar, 2005). This type of habitat degradation, associated with the inundation footprint of impoundments, is common throughout the upper Orange River basin.

In conclusion, there is a moderate amount of information on soil erosion and sediment sources within the catchment and some of the habitat modification related to fine sediment deposition and dam-induced bed sediment starvation. These are likely variable in time in space, so further research is needed on these topics. The impacts of the dams are described for the lower Seekoei River (inundated by the Gariep Dam) and Orange River downstream of Gariep Dam, thus gaps exist for the other rivers, such as the Caledon, Modder, Riet and mainstem Orange River upstream of the Gariep Dam and downstream of the Vanderkloof Dam.

(ii) Sediment quality

Fine sediment is often a vector for various toxins, such as metals and Persistent Organic Pollutants (POP) and Polycyclic Aromatic Hydrocarbons (PAH). Sediment was sampled throughout the basin in 2010 (JBS1), and sites of concern were monitored in 2015 (JBS2) and 2021 (JBS3) (References). In 2010 the Upper Orange sites showed low concentrations of POPs. Sites with high PAH concentrations were associated with pyrogenic sources, typically either coal or smelter operations associated with industrial areas, as is found around Maseru in Lesotho.

Several studies have looked at metal pollutants in sediment in the upper Orange River basin. Bouwman and Pieters (2011), as part of JBS1 in 2010, collected sediment from 61 sites across the larger Orange River basin in 2010. Pollution levels were highest along the eastern part of the basin (Upper Orange and Vaal), decreasing towards the west (Lower Orange). The highest levels were observed for the Riet and Modder Rivers, Molopo Eye and two sites in Lesotho (see list below). The metals that warrant further investigation were Se (selenium), As (arsenic) and Cr (chromium) due to relatively high observed concentrations. In general, the observed metal concentrations in sediment in 2010 were below the sediment quality guideline threshold (low probability of toxic effect) used for the Netherlands (Bouwman *et al.,* 2011). The main areas of concern within the upper Orange River basin were as follows (after Bouwman and Pieters (2011)):

- The areas associated with the Riet River and Koranna Spruit (Sites 14 – Lower Riet; 39 Modder; 41 – Koranna; 43 – Riet upstream of Modder confluence and 44 - Kromellenboog) due to a combination of higher-than-average levels of several elements,
- The Caledon and Makbomatso Rivers draining into the Senqu and Orange-Senqu Rivers (JBS Sites 49 – Orange upstream of Gariep Dam; 50 – Stormberg; 55 – Upper Caledon; 57 –

Makbamatso; 58 -Matsuku; and 60 - Kelekeque) due to a combination of higher-than-average levels of several elements.

Concentrations of POPs were relatively low in the sediment, but PAHs were associated with industrial areas in Lesotho (Sites 54 – Caledon downstream of Maseru and 60 - Kelekeque) were of concern (Bouwman *et al.,* 2011). The tributaries of the Caledon River where several commercial orchid nurseries are located show a presence of herbicides associated with sediment (George, 2014).

The Metal and POPs monitoring of sediment was included in the JBS2 study (2015) and JBS3 study (2021). Based on the Bouwman and Pieters (2011) study, only 16 sites of concern (of the 61 sampled in 2010) were included in the JBS2 study of 2015 at The Orange River basin scale. For the Upper Orange River catchment these included Sites: 11 – Orange upstream of Douglas; 39 – Modder upstream of Krugersdrif Dam; 51 – Orange upstream of Stormberg confluence; 55 – Upper Caledon and 60 - Kelekeque. The results of the monitoring suggest a deterioration of the sediment quality (POPs, BAH and elemental concentrations) between 2010 and 2015 for many of the sites (Bouwman and Pieters, 2015). The overall pattern regarding sediment pollution remains the same despite the variability in elemental concentrations that were measured between 2010 and 2015. More details are available in Bouwman and Pieters (2015).

The results of the JBS3 study will be available in 2022 with updates on the sediment quality monitoring at the selected sites.

In conclusion, there is a moderate volume of data on fine sediment quality issues at a basin scale. The exact sources of pollutants are not always evident (e.g. limited to a single sample representing a sub-catchment), and thus, at this stage cannot inform management effectively. These sediment quality issues are likely variable in time and space, therefore further monitoring and research are needed to improve adaptive management.

(iii) Geomorphic ecostatus assessment and flow requirements

Geomorphic assessments were done in 2010 and 2011 by Rountree for the following upper Orange and lower Vaal River sites:

- Orange River at Hopetown (Rountree, 2011)
- Upper Caledon River (Rountree, 2011)
- Lower Caledon River (Rountree, 2011)
- Kraai River (Rountree, 2011)
- Lower Riet River (Rountree, 2010)

The assessment included the ecoclassification (descriptions of available data, the reference condition, the current condition, the present ecological state category, and trends) and determining flow requirements (based on morphological ques, sediment transport modelling, geomorphologically effective flows where conditions allowed). Fieldwork was done during the low flows of 2010, with planform, morphology and sediment size data presented. Available historical aerial photos were used to help reconstruct the pre-dam river planform.

Table 5-1: Summary of the Geomorphology Present Ecological State and effective flow requirements as defined by Rountree (2011, 2010)

River reach	Reference condition	PES	Daily average (m3/s)			
			Flow 1	Flow 2	Flow 3	Flow 4
Orange River at Hopetown (O1)	Yes	C/D (59%)	No flows set for this site	-	-	-
Upper Caledon River (C5)	Yes	C (68%)	9.63 (0.2 to 5mm transport)	31.86 (100mm transport)	-	-
Lower Caledon River (C6)	Yes	C/D (54.6 %)	260.02 (0.2 to 1mm transport)	-	-	-
Kraai River (K7)	Yes	A/B (90.6%)	125.74 (0.2-10mm transport)	303.67 (50 mm transport)	-	-
Riet (EWR19)	No	C	2 (flush fine sediment; 5 events per year)	20 (Transport small gravel and inundate lower bench; 1 event per year)	100 (scour bed; activate upper bench and activate flood channel; 1:2-year event)	230 (Scour bed, move cobbles; 1:5-year event)

In conclusion, there are geomorphic PES scores for the Orange (downstream of Vanderkloof Dam), Riet, Kraai, and Caledon (upper and lower) Rivers and geomorphic flow requirements for the Riet, Kraai, and Caledon Rivers (upper and lower). These were done around 2010 and covers the larger rivers in the upper Orange River basin. These assessments will be updated and include additional geomorphic assessments along the Orange River main stem and some of the smaller but significant tributaries, such as the Seekoei and Modder Rivers.

5.1.3 Riparian vegetation

Riparian vegetation comprises plant communities that are associated with the areas adjacent to rivers. These plant communities often become established into zones running roughly parallel along the banks of the river channel that change with distance away from the edge of the water's edge. The plant communities within the riparian zones are generally distinct from more terrestrial areas, particularly along perennial rivers. Riparian vegetation is an important component of river ecosystems, particularly in terms of determining the structure and function of rivers. It has both direct and indirect influences on processes within the active river channel, for example, organic/inorganic inputs, water temperature regulation, water quality and quantity control, as well as providing habitat for adult aquatic invertebrates (Knight and Botterff, 1981).

Hydrology is considered the principal driver of riparian vegetation composition and structure (Naiman *et al.,* 2005) with plant communities continuously responding to periods of regular inundation and/or infrequent flooding and drought flows. Geomorphology is also considered an important driver along with flow, which together determine the patterns of water availability and fluvial disturbance (Merritt *et al.,* 2010). Thus, riparian vegetation is expected to respond to changes in water level as follows:

- A 'blurring' of the distinctions between zones on the vertical plain (up the bank), which may result in the loss of some vegetation zones;
- Encroachment of upper zone species into lower zones or even the encroachment of terrestrial species into the riparian areas;
- Changes in relative cover and abundance of various vegetation components (i.e. woody and non-woody) and growth forms (e.g. trees, shrubs, reeds, sedges, grasses, forbs/herbs, etc.) and;
- The loss of certain riparian species and/or the gain of new species, in particular invasive alien plants.

These changes in vegetation composition and structure may lead to degradation of the riparian zone resulting in loss of ecosystem functioning, notably the loss of bank stability and erosion, with concomitant influences on instream habitats and biota. Riparian areas are also utilised by local communities for cultivation, livestock foraging, wood supply, thus further impacting riparian vegetation.

Riparian vegetation within the Upper Orange Catchment has been affected by a long history of anthropogenic pressures and system alterations, ranging from complete removal of vegetation to enable various land use activities (e.g. cultivation, construction of dams, urbanization, roads, bridges, etc.) to indirect changes caused by hydrological and geomorphological alterations. The building of large impoundments such as the Gariep and Vanderkloof Dams have drastically affected the flow and sediment regimes downstream. Most notably, the reduction of the magnitude and frequency of floods has caused a shift in the structure and composition of riparian vegetation. The extent to which riparian vegetation has changed depends on the various system drivers compared to the derived natural (or reference) state.

Mucina and Rutherford (2006) broadly describe and map the various vegetation types that characterize the Upper Orange Catchment in a natural state (i.e. without influences from human-induced impacts). These include two riverine vegetation types, namely Upper Gariep Alluvial Vegetation and Highveld Alluvial Vegetation, however, there will be influences from the adjacent terrestrial vegetation types (e.g. Northern Upper Karroo, Eastern Upper Karroo, Besemkaree Koppies Shrubland, Bloemfontein Dry Grassland, Kimberley Thornveld, Western Free State Clay Grassland, Xhariep Karroid Grassland), particularly for the smaller tributaries in the system. Each of the respective vegetation types include indicator species that can be expected under more natural/unimpacted conditions. Some of these will include plant species that are more tolerant of disturbance and/or pioneer species that can quickly establish within riparian areas (e.g. *Vachellia karroo* and *Diospyros lycioides).*

5.1.4 Water quality

Information from the DWS Resource Quality Information Services (RQIS) water quality database and the Water Management System (WMS) will be used as the primary source of the water quality data for the assessment and analysis for the Upper Orange Catchment. In terms of the water quality data assessment, the water quality monitoring stations are largely concentrated on main stem rivers and major tributaries. Data gaps do potentially exist where monitoring has been discontinued and for the smaller tributaries with largely natural present states and ecologically important and sensitive. Also, some of the monitoring sites may not be situated in prioritised RU's. Furthermore, the adequacy and reliability of data might be a gap, particularly the more recent data where we are aware that there have been some challenges with laboratory analyses at RQIS.

Wherever possible, other data sources (theses, reports, surveys (e.g. ORASECOM JBSs), previous Reserve studies, the FBIS biological database (which sometimes records basic in situ chemical analyses), diatom samples at selected smaller tributaries, etc.) will be used to infill on some of these gaps.

The requirements of the various water users and aquatic ecosystems in the catchment and the potential impacts need to be assessed. Some localised water quality issues around the towns with non-functional wastewater treatment works, general littering and related to agricultural practices have been identified. These are key to understanding the extent of the impact on the larger catchment and ultimately on the aquatic ecosystems and where particular requirements will be specified. These ecological specifications can then be used for the development of RQOs and numerical limits. Lack of recent monitoring information may impact the process. Although some baseline information is available from assessments with the development of the ORASECOM IWRMP, the Reconciliation strategies and setting of RWQOs, these are mainly based on large-scale catchments and do not provide the detailed information required for smaller tributaries.

The WMS database primarily includes monitoring data for several parameters/ variables, including Electrical Conductivity (EC), Total Dissolved Salts (TDS), pH, Sodium, Magnesium, Calcium, Hardness, Potassium, Fluoride, Chloride, Sulphate, Phosphate as P, Total Alkalinity as $CaCO_3$, Ammonium as N, Nitrate + Nitrite as N, Chemical Oxygen Demand (COD), and *E. coli*. The monitoring points of the National Chemical Monitoring Programme (NCMP) (WMS data) within the catchment are primarily located on the main stem Orange River and the major tributaries. Specific indicators will be selected to assess the status quo and for setting ecological specifications. These will be informed by specific catchment developments and guided by those RWQOs that were set by DWS and incorporated into the Reconciliation strategies. There is uncertainty that there has been sampling and analyses by RQIS since early 2018.Thus, determination of the current water quality conditions will possibly be at least partly reliant on data collected through the 2021 JBS3 survey and the surveys to be undertaken as part of this study. However, the frequency and extent of monitoring vary considerably, as does the integrity and reliability of the more recent data. A challenge posed for this study is the determination of the water quality status at more remote sites where no monitoring is currently undertaken – specifically if a sub-quaternary reach is identified in a smaller tributary catchment with a high PES/EI/ES.

The gap analysis based on the information assessment for the river's component (Section 4) is illustrated in Table 5-2.

Table 5-2: Evaluation of information available and identification of gaps for rivers

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
EWR information				
EWR site details	Available for most of the previous studies	Yes	Only site coordinates available for most of the rapid level 3 studies done pre-2005	Results from these studies are outdated and existing sites will be re-visited to undertake the various surveys
PES/EI/ES and REC	Available from most of the previous studies and the 2014 Desktop PES/EI/ES per SQ reach	Yes	-	-
EWR output (rule & tab tables)	Only available from some of the previous studies	There may be a need to adjust for existing sites - depending on the changes to PES and REC and reference hydrology	Summary tables are not available for all the sites, especially the rapid studies undertaken pre-2005	Re-assess the sites and generate summary tables
Ecological specifications	Limited information available, except for intermediate studies	Will be used as an indication of how the system has changed over time	Outdated as studies were undertaken 10 years ago	Will be updated with more recent data
Site selection				
Site access	-	-	Accessibility constraints particularly to upper reaches of	Liaise with Stakeholder engagement team for farmer

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
			Seekoei / Kraai, farmlands / along the main stem Orange due to extensive land use being irrigation agriculture or game farming	contact details and arrange site access
Hydraulics				
Benchmarks	Not available	-	No benchmarks available	Re-survey
Hydraulics model and output	Where previous intermediate data is available and the channel has not been modified (compare Google Earth imagery between 2010 - 2021), use existing data	Yes, for some with no channel modification since 2010	-	Re-survey
Geomorphology				
Reference conditions	Short descriptions for the Orange at Hopetown, upper Caledon, lower Caledon and Kraai Rivers. No description for the Riet	Yes	No description for Riet in previous study. No descriptions for smaller tributaries or upper parts of the Orange River	Use site slope to determine Geomorphological Zone. Apply Rowntree and Wadeson (1999) descriptions to fill in expected reference characteristics

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
GAI (Geomorphic Assessment Index) (Rowntree, 2013) PES output	Yes, available for the Orange at Hopetown, upper Caledon, lower Caledon, Kraai and Riet Rivers	Yes, but 10+ years old	PES needs to be updated No descriptions for smaller tributaries or upper parts of the Orange River	Include GAI PES assessments for all intermediate sites
Flow requirements	Yes, for the Riet, Kraai, upper Caledon and lower Caledon	Yes, but 10+ years old	No requirements for the Orange mainstem or some of the larger tributaries	Include the Orange mainstem and larger tributaries for all intermediate sites
Sediment quality	Yes, for JBS1, JBS2 and JBS3 sites	Yes, broad overview of catchment	Single samples representing large sub catchments	Needs detailed monitoring and tracing study to find source areas. This is beyond the scope of this Reserve study.
Fish				
Reference species	Available from most of the previous/Reserve studies and the PES /EI/ES 2014 JBS1 (2010), JBS2 (2015) and JBS3 (2021) data (fish species abundance and diversity and ecological categories) for primarily the main stems (i.e.	Yes The PES EI/ES will provide a good indication of the state, sensitivity and importance of the smaller tributaries per SQ reach that have not been assessed as part of previous/Reserve studies	Data retrieved during the Reserve studies at 4 sites along the Seekoei River and 1 site on the Kraai River were done more than 10 years ago. Limited data on the smaller tributaries within the catchment.	Sites along the upper reaches of the Seekoei, Kraai and smaller tributaries will be selected where Rapid 3 assessments will be undertaken. This will provide additional and present state information on the water resources

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
	Orange, Caledon, lower reaches of Seekoei and Kraai) Freshwater Biodiversity Information System (FBIS). Global Biodiversity Information Facility (GBIF)			
FRAI model setup & output	FRAI models already set up from JBS3 (October 2021), and also include previous JBS1 and JBS2 data	Yes	Ecoregions with limited to no data, including the upper reaches of the Seekoei/Kraai systems and smaller tributaries will not have FRAI models set up	Following data collection from additional selected sites for this study – FRAI models to be set up and run
Macroinvertebrates				
Reference taxa	Available from most of the previous/Reserve studies PES/EI/ES 2014 Reference macroinvertebrate data from River Health Programme (RHP)	Yes The PES/EI/ES will provide a good indication of the state, sensitivity, and importance of the smaller tributaries per SQ reach that have not been assessed as part of previous/Reserve studies	Data retrieved during the Reserve studies at 4 sites along the Seekoei River and 1 site on the Kraai River were done more than 10 years ago. Limited data on the smaller tributaries within the catchment	Sites along the upper reaches of the Seekoei, Kraai and smaller tributaries will be selected whereby Rapid 3 assessments should be undertaken. This will provide additional and present state

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
	JBS1 (2010), JBS2 (2015), JBS3 (2021) data (SASS5 scores, ASPT, number of taxa and ecological categories) for primarily the main stems (i.e. Orange, Caledon, lower reaches Seekoei and Kraai) REMP data (quarterly results) FBIS SANParks data (Mokala National Park and Golden Gate Highlands National Park)			information on the water resources.
MIRAI setup & output	MIRAI models already set up from JBS3 (October 2021), and also include previous JBS1 and JBS2 data	Yes	Ecoregions and sites with limited to no data, including the Seekoei system. Some seasonal limitations from the JBS's, which were carried out largely during winter months.	A site will be selected whereby a Rapid 3 assessment will be undertaken on the lower reaches of the Seekoei to provide additional and present state information. Additional sites will be identified within those ecoregions, whereby

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
				monitoring points for the JBS3/REMP were not selected as part of those programmes. Following data collection from additional selected sites, – MIRAI models to be set up and run.
Riparian vegetation				
Reference vegetation types	National vegetation types mapping and classification of Mucina and Rutherford (2006). Reference vegetation for VEGRAI (Vegetation Response Assessment index, reference) available from most of the previous/Reserve studies JBS1 (2010), JBS2 (2015), JBS3 (2021) data for primarily the mainstems (i.e. Orange, Caledon, lower reaches of Seekoei and Kraai), Modder-Riet.	Yes	None	None

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
	REMP data (quarterly results however only for some catchments)			
VEGRAI/IHI setup & output	VEGRAI and IHI (Index of Habitat Integrity; instream and riparian, reference.) models already set up from JBS3 (October 2021), and also include previous JBS1 and JBS2 data.	Yes	Ecoregions and sites with limited to no data, including the Seekoei system. Some seasonal limitations from the JBS's, which were carried out largely during winter months. Limited integration of geomorphic processes and how this influences riparian vegetation under reference and present conditions.	A site will be selected whereby a Rapid 3 assessment will be undertaken on the lower reaches of the Seekoei to provide additional and present state information of the riparian vegetation. Additional sites will be identified within those ecoregions, whereby monitoring points for the JBS3/REMP were not selected as part of those programmes. JBS3 surveys conducted in October provide better seasonal data regarding riparian vegetation. Current assessments will provide an opportunity to

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
				integrate geomorphology data and information.
Diatoms				
Reference species Specific Pollution sensitivity Index (SPI) Biological Diatom Index (BDI) percentage of pollution tolerant valves (%PTV)	JBS1, JBS2, JBS3 data and October 2021 re-con survey conducted by the team for this study	Yes	Ecoregions with limited to no data, including the Seekoei system.	Sites will be identified within those ecoregions/ tributaries, whereby monitoring points for the JBS3/re-con survey were not selected
Water quality				
Water quality linkages with gauging stations (refer to hydrological data information below). However, indications are that much of this monitoring data stopped in around early 2018. This is a major limitation for this study.	The historical data will give at least some trends and indications of the major drivers of WQ in the catchment	The more recent monitoring data is deficient in many areas, partly due to a lack of analyses by RQIS laboratories. This lack of data is most evident from around 2018 onwards	Current water quality status unknown	Where possible, sourcing of other data via theses, inference from on-site diatom collections, and interrogation of the national diatom collection (housed at NWU – Potchefstroom), etc will be undertaken. Determine the current water quality conditions with data collected through the 2021 JBS3 survey and the surveys to

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
				be undertaken as part of this study
Basic Human Needs (BHN)				
Census data	Data from 2011 Population Census. 2020 mid-year population estimates and population growth rates from Stats SA (based on municipal demarcations in place for 2011).	Yes, although outdated and not per quaternary catchment boundary.	Census data outdated – current estimates of population numbers available, but population profiles outdated. Municipal demarcations (as at 2011) rather than quaternary catchment.	Using GIS to overlay municipal and quaternary catchment boundaries to estimate population per quaternary, using population growth rate estimates to update outdated census populations. Will result in a broad estimate and lower confidence.
Integration with groundwater use	2011 census, 2016 community survey information on water use and information available in municipal documents, WARMS data.	Yes, although outdated.	Data might not be up to date and accurate.	Integration between information from groundwater use and population dependent on groundwater.
Socio-Economics				
Dependence on water resources	2011 Census data, StatsSA and Wazimap, Integrated Development Plans and other reports on municipal service	Yes	Municipal demarcations not aligned with quaternaries. Outdated datasets and information may reduce	Using GIS to overlay municipal and quaternary catchment boundaries to estimate population per quaternary,

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
	delivery, Reconciliation Strategy 2014, WARMS data.		confidence levels of quantitative data.	however this will be a broad estimate and lower confidence.
Scenario analysis	ORASECOM Management Plan (2010), Municipal strategies and plans.	Yes	Lack of quantitative data on socio-economic benefits of ecosystem goods and services.	Provide broad/conceptual statement on the socio-economic consequences for scenarios.
Hydrological data (see also Figure 5-3 and Table 5-3 for more information)				
Gauged daily data	Not many gauges with good low flow data, rely mostly on dam balances for information on main stem river. Gauges not accurate for low flows due to high sedimentation loads in the rivers, especially in the Caledon.	Yes - although most of the gauging weirs not having good low flow data or short historical records	Limited gauges and low-quality data with a number of these gauges No recent reliable data only historical data	Monitoring of long-term flow data falls outside the scope of this study. Will use where available and indicate confidence in results
Monthly natural flows	Updated monthly hydrology on a quaternary catchment level for period 1920 – 2009 available from WR2012	Yes	-	Quaternary flows will be disaggregated to smaller catchments where required using the ORASECOM IWRMP hydrological setups.
Hydrological Driver Assessment Index (HAI) output	Not available for previous studies	-	No HAI results available	Do HAI for all selected intermediate sites

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
Water Resources Model				
Model configuration	Various model configurations are available for the study area.	Yes - integrated and use for the modelling of scenarios	-	Use WRYM from ORASECOM IWRPM 2010 study and include 2018 water demands
Management scenarios	Management scenarios and planned water resources developments available from ORASECOM and Reconciliation strategies	Yes – will adjust after discussions with DWS to select specific scenarios for modelling	-	-
Water demands (current & future)	Latest water use estimates for 2018 available from the Planning Model for Annual Operating Analysis Studies	Yes – will transfer these demands to the WRYM and disaggregate where necessary	-	-

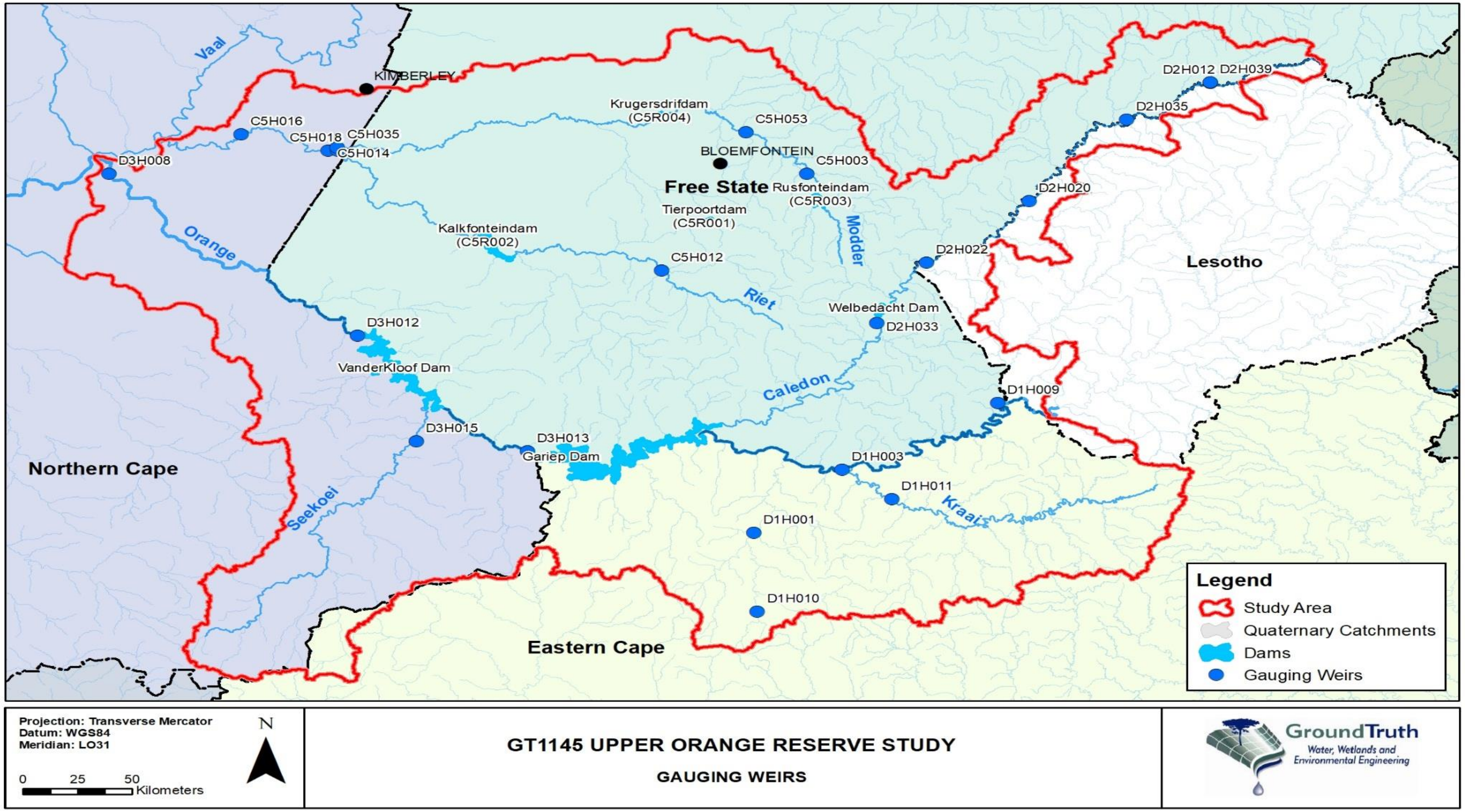

Figure 5-3: Location of gauging weirs in the Upper Orange Catchment

Table 5-3: Summary of gauging weirs and data availability in the Upper Orange Catchment

Gauge	River	Record period	Confidence		Comments
			Low flows	Floods	
Caledon River and main tributaries: Gauging station for mainly flood monitoring (low flows are measured inaccurately) on Caledon in upper reaches with some data available from downstream Welbedacht Dam Various gauges with varying quality of hydrology data available Limited gauges with recent daily data available					
D2H012	Little Caledon	1968-2021	Not accurate	Medium	Low accuracy
D2H020	Caledon	1982-2010	Not accurate	Accurate	Flood section
D2H022	Caledon	1988-2021	Not accurate	Accurate	Flood section
D2H035	Caledon	1991-2021	Not accurate	Accurate	Flood section
D2H039	Caledon	2004-2021	Not accurate	Accurate	Flood section
D2H033 Welbedacht	Caledon	1991-2021	Accurate	Medium	Welbedacht dam downstream component
Kraai River: Gauging weir in lower reaches of the river (~15km from confluence of Orange River) with good data					
D1H011	Kraai	1965-2021	Accurate	Accurate	Very good Gauge
Stormbergspruit:					
D1H010	Stormbergspruit	1962-1983	Unknown	Unknown	Currently inactive
D1H001	Wonderboomspruit	1912-1921	Medium	Good	Very old gauge
Orange upstream Gariep: Oranjedraai gauge with good data, measuring all inputs from Lesotho/Senqu River Gauge at Aliwal North not good data					
D1H009	Orange	1958-2021	Excellent	Excellent	Best gauge on the upper Orange
D1H003	Orange	1907-2021	Bad	Medium	Huge canal from the weir which is not measured
Seekoei River: Gauge in lower reaches, although major sedimentation impacts affecting station and thus inaccurate measurements					
D3H015	Seekoei	1980-2021	Good	Good	Good record, some sedimentation problems

Gauge	River	Record period	Confidence		Comments
			Low flows	Floods	
Gariep and Vanderkloof Dams: Dam balances with lower confidence in the low flows Orange downstream VanderKloof Dam: Marksdrift weir (at the confluence of the Vaal and Orange rivers) – although data influenced by high sedimentation					
D3H008	Orange	1962-2021	Good	Good	Good record
D3H012 VanderKloof	Orange	1981-2021	Inaccurate	Good	Dam downstream component
D3H013 Gariep	Orange	1973-2021	Inaccurate	Good	Dam downstream component
Modder/ Riet: Mostly dam balances data, low flow estimates are low confidence Modder – some good gauges, e.g. at Tweeriviere, however, no recent data available Mostly short record periods for gauges on Modder and Riet Rivers Limited data available for smaller tributaries					
C5H003	Modder	1918-2021	Good	Good	Good record
C5H018	Modder	1960-1999	Good	Good	Good record. No recent data
C5H035	Modder	1989-2021	Good	Good	Good record
C5H053	Modder	1999-2021	Inaccurate	Good	Fair gauge
C5H012	Riet	1936-2021	Medium	Medium	Influenced by irrigation
C5H014	Riet	1938-2021	Medium	Medium	Fair gauge
C5H016	Riet	1953-1999	Fair	Fair	Fair record. No recent data
C5R001 Tierpoort	Tierpoort	1923-2021	Inaccurate	Inaccurate	Not good record
C5R002 Kalkfontein	Riet	1938-2021	Inaccurate	Good	Dam balance
C5R003 Rustfontein	Modder	1954-2021	Inaccurate	Good	Dam balance
C5R004 Krugersdrift	Modder	1970-2021	Inaccurate	Good	Dam balance

5.2 Wetlands

While there is existing information on the general extent and distribution of wetlands in the catchment, this is mostly limited to desktop studies. More detailed information is available for some key wetlands (see for example Begg, 1989), but this is not supported by available GIS-based mapping or available updated PES/EI/ES assessments. The lack of field verified ecological categorisation of most wetland systems means that there is a requirement as part of this study to derive PES and EIS scores for the Priority Wetlands using surrogate databases and information (for a desktop PES example, see Macfarlane *et al.,* 2020). As ecological categorisation derived from desktop-based surrogate information is not always an accurate representation of the wetland features on the ground, this limits the confidence in the derived categories. As there is scope for limited field verification as part of this study, it will be attempted to verify some of the desktop assessments and modelling results, categorising and refining the wetland information where possible. This will however be limited by the quality of most recent available imagery, the degree of ecosystem transformation (i.e. from natural wetland sedge-meadow to cultivation), the access to the Priority Wetlands or sections of wetlands, time available in the field, and the rapid field assessment methods used.

Similarly, the constraints related to the available, and even updated, desktop mapping do not always enable the identification of all the Hydrogeomorphic (HGM) units (as modified from Brinson, 1993, by Kotze *et al.,* 2007) applicable to a particular wetland or wetland system. This is typically the case with seepage wetlands, which are often underrepresented by the larger (national) wetland datasets. In addition, these large-scale datasets do not always provide an accurate delineation of the boundaries of the wetland systems. Also, the grouping of wetland HGM units necessary for the desktop derived ecological categorisation may over-simplify the ecological state of a particular wetland complex.

Very limited flow and water quality data (especially updated information) is available for the wetland systems in the catchment and the same is expected to be true for the Priority Wetlands. In some cases, surrogate information from the river and groundwater components/studies may be possible to use for the Priority Wetlands to indicate the health of the freshwater ecosystems associated with the wetlands. This can only be a rough indication of water quality entering these wetlands. However, the accuracy and availability of this information is expected to be limited. RQOs for the wetlands will thus at best be qualitative and confidence in these is expected to be low due to the limitations of the existing information. In addition, methods for the development and monitoring of wetland RQOs can be complex (see Bredin *et al.,* 2019) and are largely still in an early stage. This will be challenging regarding the wetland component of the overall study. It is envisaged that the integration of information between surface and groundwater components, together with the necessary support from the wetland component will, to some extent, assist with the process, although limitations to the accuracy of the data, and the applicability to wetlands is limited.

With the identification of the priority wetlands being based largely on national datasets, the majority of the prioritisation and screening process has been based on a top-down approach; discussing the various wetland features (NFEPA, NWM5, etc.) to assess the datasets/knowledge and refine the wetland sites. However, where the national datasets have gaps in attributes or have been incorrectly captured, this will directly impact on the wetlands prioritised. The top-down methodology has some limitations, and it is proposed that a bottom-up approach is also used in the prioritisation process. This will include specialist input into the evaluation of important wetlands in the broader priority areas. The bottom-up approach is expected to provide more accurate identification of wetlands with conservation importance. A combination of both approaches will assist in reducing the shortcomings associated with the top-down approach, and support identification of priority areas where specialists may provide more insight into important wetlands.

It is likely that the identification of Priority Wetlands and the development of an integrated Priority Wetland GIS layer, combined with updated desktop delineations and categorisations will be an important supplement to the study results. However, in a wetland study of this nature there are limitations and risks related to the lack of comprehensive field-verified information.

The gap analysis based on the information assessment for the wetland's component (Section 4) is illustrated in Table 5-4.

Table 5-4: Evaluation of information available and identification of gaps for wetlands

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
Wetland mapping, identification and delineation	National Wetland Map 5 (SANBI) NFEPA GroundTruth database (Working for Wetlands information)	Yes. All three datasets provide an overview of the general wetland presence/absence. NWM5 and NEFPA are both national coverages, with the accuracy likely to be rough; whilst the GroundTruth wetland coverages will be slightly more detailed, with higher confidence. All datasets provide a good indication of wetland areas, however the gaps in all datasets are acknowledged, as well as the accuracy of the national datasets is recognised	A noticeable gap in the wetland coverage was identified within the middle to southern reaches of the Free State. Both national coverages had very few wetlands in this specific area. These gaps were noted by GroundTruth when undertaking the WfWetlands strategy.	Without running additional wetland ID models, the most accurate and time-sensitive means to fill in these wetland gaps is to contact wetland specialists that have worked in the areas. This was undertaken by GroundTruth previously during the Free State strategic planning, whereby specialists and datasets from the WfWetlands team were reviewed and additional wetlands not originally included in the shapefile were added where relevant. Specialist wetland workshop being held with SANBI, DWS, Northern Cape Wetland Forum, Working for Wetlands representatives and various other wetland specialists on 9 December 2021 for further

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
				input/support to address these gaps.
Wetland typing	National Wetland Map 5 (SANBI) NFEPA	Yes. The wetland type (HGM Unit) has been determined in the national wetland datasets, with NWM5 being an update of the NFEPA coverage. The Majority of these HGM units are derived through large-scale modelling, taking into account topographic setting, etc. Since different wetland types provide different services at varying levels, this classification can be used to prioritise wetlands based on the services that are required (e.g. unchannelled valley-bottom wetlands prioritised below WWTW – water quality improvements)	Those wetlands not identified by the national databases will not have been assigned an HGM unit.	Where a priority wetland has not been assigned an HGM unit classification, a review of the wetland characteristics and topographical setting may allow for a low-confidence HGM unit classification. This can be reviewed infield during the site visit.
Wetland categorisation (PES/EI/ES)	National Wetland Map 5 (SANBI)	Yes	Those wetlands not identified by the national databases will not	Where a priority wetland has not been assigned a PES/EI/ES score, a review of the wetland

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
	NFEPA	When prioritising wetlands, the integrity of the system is a key factor to consider. The more intact the wetland, the better the wetland functions and the better the provision of ecosystem services.	have any PES scores assigned to the systems.	characteristics may allow for a low-confidence PES/EI/ES score to be determined. This can be reviewed infield during the site visit.
Priority Wetland identification	WfWetlands strategic plans (Eastern Cape, Northern Cape & Free State) Wetlands upstream of priority dam sites, as identified through the river and groundwater prioritisation Location of Ramsar sites. Consideration of the EWT crane sites database Wetlands within protected areas Wetlands categorised with PES of A/B and identified as critically endangered or endangered and occur within a high priority catchment (strategy plan)	Yes. Through a review of the relevant wetland prioritisation layers, the important wetlands can be identified from the thousands listed with the national datasets. Refining the prioritised systems will assist in identifying those important areas to be visited infield and reviewed further.	As described above, the gaps in the wetland coverage are one of the limiting factors for the wetland component. Also, although there are not necessarily gaps in all the datasets, with the national datasets being compiled at a national scale, it is likely that some of the information may not accurately reflect actual site conditions to be considered during review of the prioritised systems and infield. Upper reaches of Kraai (Strategic Water Area) – unavailable wetland data for this key priority wetland area.	A more intensive review of the characteristics of the prioritised wetland systems will be undertaken, which can be further refined during the fieldwork component of the project. Phase 1 survey / modelling and student refinements at desktop level / SANBI support.

5.3 Groundwater

The relevant RDM attributes assessed and subsequently calculated during the DWAF 2009 High-Level Assessment of the Groundwater Reserve Determination forms a sound baseline for addressing only specific time-related variables for this study. It is, therefore, foreseen that in certain cases, “hotspot” RUs or parts thereof identified in 2009, might have changed significantly and these will need to be re-assessed. As per the 2009 study, only eight (8) quaternary catchments representing two (2) RUs need to be re-assessed. It is expected that the surpluses identified in the remaining 80 quaternary catchments during the 2009 Reserve study will still be classified as being in an unstressed condition. However, desktop screening of the remaining quaternary catchments will be conducted using the latest WARMS dataset.

In terms of the groundwater component, the information produced for the 2009 Reserve Determination study requires limited updates to bridge the information gap between 2009 and 2021. Assuming that the WARMS information is accurately updated, and information from local groundwater sites, i.e. water use license audits, specific (recent) groundwater resources studies and long-term regional monitoring data, are available, this “time-lapse” can be successfully addressed and a 2021 version of the required RDM attributes produced.

The gap analysis based on the information assessment for the groundwater component (Section 4) is illustrated in Table 5-5.

Table 5-5: Evaluation of information available and identification of gaps for groundwater

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
Groundwater recharge	WR2012	Suitable for high-level investigations; not suitable for more detailed investigations	Local databases and reports	Engage with local stakeholders, water use associations Propose a technical task group meeting with DWS and key Project Steering Committee/ Water User Association members Collect new data in focused areas (priority quaternary catchments / where linkages occur between groundwater, wetlands and rivers
Basic Human Needs	WR2012; Census 2011	Adequate	None	Linking with socio-economics team members to ensure the use of the same data.
Groundwater quality	WR2012; WMS	Suitable for high-level investigations; not suitable for more detailed investigations	Municipal databases; WUA databases	Engage with local stakeholders, water use associations Propose a technical task group meeting with DWS and key Project Steering Committee/

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
				Water User Association members Collect new data in focused areas (priority quaternary catchments / where linkages occur between groundwater, wetlands and rivers
Water level depths	WR2012; NGA	Suitable for high-level investigations; not suitable for more detailed investigations	Municipal databases; WUA databases	Engage with local stakeholders, water use associations Propose a technical task group meeting with DWS and key Project Steering Committee/ Water User Association members Collect new data in focused areas (priority quaternary catchments / where linkages occur between groundwater, wetlands and rivers Cross-link with wetlands component

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
Contribution to baseflows	No, but this is related to groundwater level depths near streams, GDEs, wetlands etc.		Identify strategic sites for the setup of monitoring networks	Collect new data in focused areas (priority quaternary catchments / where linkages occur between groundwater, wetlands and rivers Cross-link with wetlands component
Groundwater use	WR2012; WARMS	Suitable for high-level investigations; not suitable for more detailed investigations	Municipal databases; WUA databases	Engage with local stakeholders, water use associations Propose a technical task group meeting with DWS and key Project Steering Committee/ Water User Association members Collect new data in focused areas (priority quaternary catchments / where linkages occur between groundwater, wetlands and rivers

Criteria	Data available	Suitability for use	Gaps identified	Proposed solutions/mitigation to address gap
Stress index	WR2012	Suitable for high-level investigations and planning purposes	Revise if needed based on new data on recharge, baseflow and groundwater use	Collect new data in focused areas (priority quaternary catchments / where linkages occur between groundwater, wetlands and rivers

6. SUMMARY OF KEY GAPS

Based on (i) the assessment of information and review of data availability and (ii) an internal specialists workshop held on 18 November 2021, the identified gaps were discussed and collated as well as how these will be addressed during this study to ensure high confidence Reserve results. The key gaps that will impact the confidence of the final results that won't be or only be partially addressed during this study are listed below in Table 6-1.

Table 6-1: Summary of key gaps

Criteria	Key gap	Interventions
Hydrology		
Gauged daily data	Limited gauging stations in catchment area. Old/unreliable/poor quality of flow data. Dam balances but unreliable due to environmental factors namely rainfall/evaporation.	Monitoring of long-term flow data falls outside the scope of this study. Will use where available and indicate confidence in results.
Water quality		
Current water quality data	Indications are that much of this monitoring stopped in early 2018.	Information from other sources (JBS3 – Upper Orange catchment) will be utilised to assess the current state of water quality in the study area.
Wetlands		
Wetland identification	Gaps in the national wetland coverage for the middle to southern reaches of the Free State. Upper reaches of Kraai (Strategic Water Source Area)	Combine all existing and relevant wetland shapefiles into a consolidated and updated wetland shapefile. Specialist wetland workshop being held with SANBI, DWS, Northern Cape Wetland Forum, Working for Wetlands representatives and various other wetland specialists on 9 December 2021 for further input/support to address these gaps. Focused areas to be identified to ensure the cross-linkage between wetland, groundwater and rivers.

Criteria	Key gap	Interventions
Groundwater		
Groundwater information	Local databases (WARMS, etc.) and reports	Propose a technical task group meeting with DWS and key Project Steering Committee/ Water User Association members Collect new data in focused areas i.e. priority quaternary catchments where linkages occur between groundwater, wetlands and rivers.
Integration		
Integration between components	No existing information or processed data available for the integration of the various components. Some partial integration between components has been undertaken as part of previous Reserve studies	A specific area will be selected where the integration of rivers, wetlands and groundwater components will be undertaken. It is proposed that the Kraai River catchment is used as it also forms part of the SWSA

A challenge for data acquisition is accessibility constraint in parts of the study area, especially in the upper reaches of the Seekoei, Kraai, Caledon and tributaries and along the main stem Orange River due to fenced-off areas. This can severely compromise the site selection process. Liaison with stakeholders (especially farmers through irrigation boards and/ or Water User Associations) will be key to ensure contact details are available to arrange site access before the surveys.

7. INTEGRATION BETWEEN SURFACE WATER, GROUNDWATER AND WETLANDS

The integration between surface water, groundwater and wetlands will be considered and evaluated with the use of available data. Knowledge of these interactions will be essential in addressing these key gaps identified in Chapter 6. Further integrations for this study will include:

- Using the Kraai System for the integration between wetlands, groundwater and surface water;
- Current assessments will provide an opportunity to integrate geomorphology data and sediment with riparian vegetation, macroinvertebrate and fish information; and
- Integrate data between diatoms results and water quality.

8. CONCLUSIONS

Several studies have been undertaken for the Upper Orange Catchment, although most have been on a basin-scale and not focussed on the study area. However, information from these studies will be useful and will be used as a basis, to collect additional data during the surveys to ensure high confidence results in this study.

Based on the review and analysis of the available datasets, GIS layers, information from previous studies, the project team has a better understanding of the availability, accessibility and usefulness of the information and data sources. However, various gaps do exist, of which some of these will be addressed during the study, through the collection of additional data during the seasonal field surveys.

The major gaps that will not be addressed during this study, as long-term monitoring is required are:

- Lack of adequate gauging weirs in the study area and the consequent lack of long-term flow data, especially daily data that is invaluable for the setting of EWRs; and
- Recent water quality data to determine the present state. However, data available from the 2021 JBS3 study, coupled with the planned surveys forming part of this study, will assist with mitigating this gap.

Accessibility to the rivers may further be problematic, as experienced during the JBS3 and recon surveys in October 2021. Specific attention will be given to contacting stakeholders/ farmers/ landowners before the surveys, to ensure accessibility to their properties.

Thus, the best available, sensible data and information sources will be used to meet the objectives of this study, with guidance from the DWS where specific project direction is required.

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