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Progress Report 1- Literature Review and Detailed Study Site Descriptions:

Quantification of transmission processes along the Letaba River for improved delivery of environmental water requirements (Ecological Reserve)

T Strydom [1,2], ES Riddell [2,3], A Swemmer [4], JM Nel [5] and C Jarmain [6]

1 Scientific Services, South African National Parks

2 Centre for Water Resources Research, School of Agriculture, Earth and Environmental Science, University of KwaZulu-Natal

3 Conservation Services, South African National Parks

4 SAEON Ndlovu Node, Phalaborwa

5 GCS Consulting, Pretoria

6 Private Agrometeorologist, Stellenbosch

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1. Introduction

This deliverable report stems from the non-solicited Water Research Commission (WRC) research project K5/2338 titled:

Quantification of transmission processes along the Letaba River for improved delivery of environmental water requirements (Ecological Reserve)

This report aims to provide a comprehensive literature review on the current situation surrounding water allocation in South Africa whilst focusing on meeting environmental water requirements. Thereafter the report provides a detailed description of the study site including geophysics survey results as well as hydrocensus information. Furthermore, the project work plan is also included.

2. LITERATURE REVIEW

2.1 Introduction

The environmental laws of South Africa are world-renowned, particularly the National Water Act (NWA) 36 of 1998. The NWA is regarded as providing a platform for an innovative way of managing the country's water resources (Pollard and du Toit, 2011a). Demands on the nation's water resources are intensifying as more and more catchments are coming under increasing stress.

2.2 National Water Act (NWA) 36 of 1998

The role of law is to reflect and shape society's norms. Environmental Law is a relatively new and fast developing legal discipline that aims to control human impacts on the environment (Kidd, 2008). Since Environmental Law tries to control anthropogenic pressures on the environment, one can establish that Environmental Law provides a manner to ensure that the concerns of the environment are considered and in essence, protected.

The pioneering NWA aims to ensure that the quality of water resources is protected and that the integrated management of water resources is promoted for the benefit of all water users in the country. Furthermore, the Act promotes sustainable development by aiming to meet the basic human need of both present and future generations, while also attempting to address the legacy of past racial and gender discrimination. In the preamble of the Act, it is acknowledged that South Africa is a water-scarce country and that this limited water supply is distributed unevenly across the land.

Not only does the Act promote public participation and joint decision-making whereby water allocations are decided upon not by rights but rather through negotiations with interested parties, but it also defines the resource in its entirety as a "river ecosystem" and no longer only referring to the water in a river (Dent, 2001;

cited by van Wyk *et al.*, 2006). These other parts of the system include all aspects of the hydrological cycle, the physical environment, riparian and aquatic habitats, and biota.

2.2.1 The Reserve

One of the key reasons why the NWA is so highly-acclaimed is due to the formidable innovation of the "Reserve" (Fig. 1). The NWA defines the Reserve as:

"defining the quantity and quality of water required to –

a. to satisfy basic human needs by securing a basic human supply, as prescribed under the Water Services Act 108 of 1997 for people who are now or who will, in the reasonably near future be –
(i) relying on;
(ii) taking water from, or
(iii) being supplied from,
the relevant water resource: and

b. to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource".

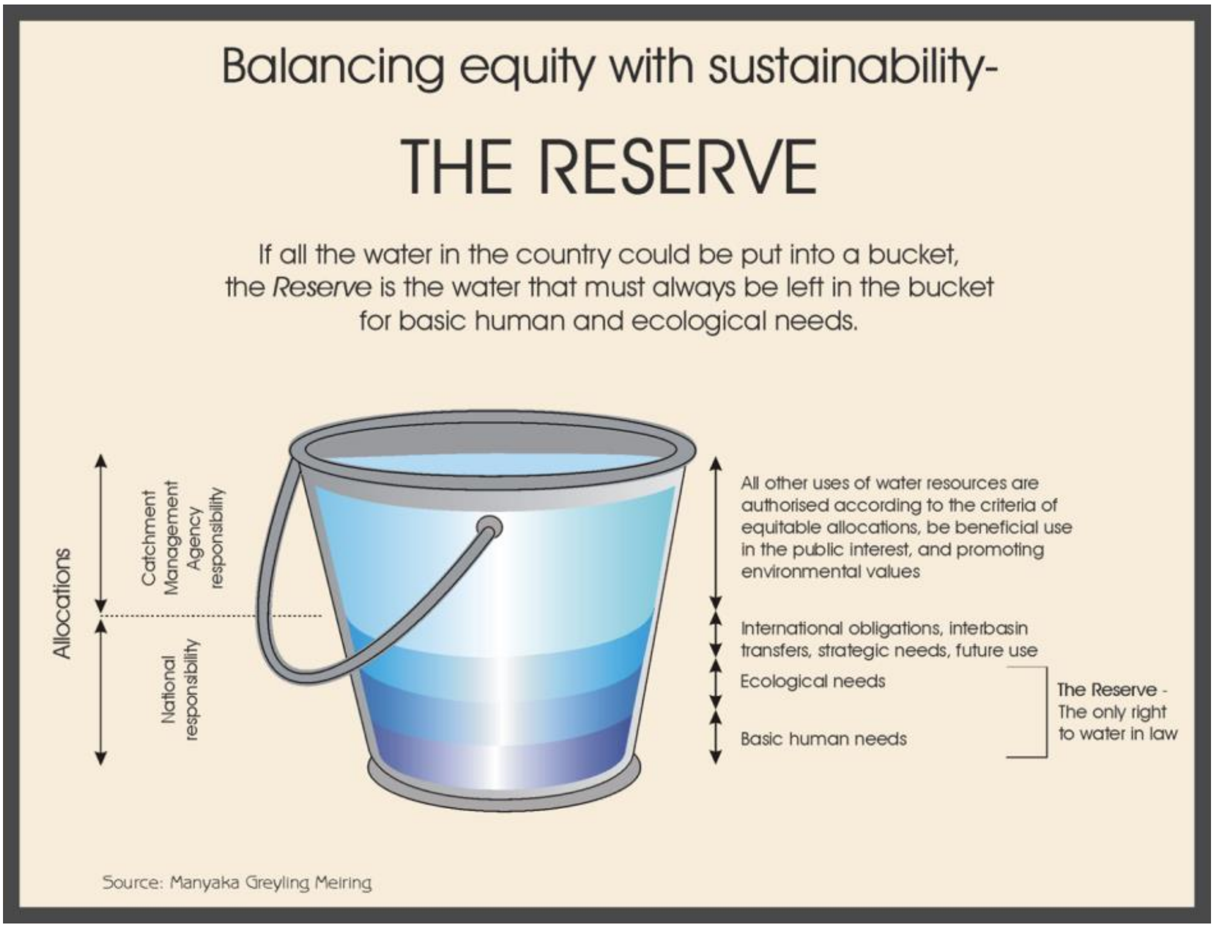


Figure 2.1. An illustration of how water is allocated according to the National Water Act 36 of 1998 (Source: Manyaka Greyling Meiring (Pty) Ltd.)

O'Keeffe and Rogers (2003) regard the NWA as an acknowledgement that if water resources are to be protected, it is critical that managing for a healthy ecosystem would be best practise. The Ecological Reserve, in particular, refers to the integrity of the aquatic ecosystems of a particular water resource. According to van Wyk *et al*. (2006), it refers to a volume of water with a specific quality which is allocated in order to protect a certain river ecosystem and is based on the river's required flow and flow duration. Previous legislation did not account for the ecological integrity of water resources and as such had no provision or emphasis on the environment.

Many would agree that the NWA may have been too ambitious in its objectives considering the challenges being faced. Even though the idea of the Reserve has a utilitarian view of ecology whereby the ecological integrity of a river ecosystem is protected for the ultimate benefit of society, many stakeholders considered the Reserve to only cater for the environment. This is illustrated in Fig. 2 where statements made by various stakeholders about the Ecological Reserve were recorded by Sherwill *et al*. (2003).

Statement	Assumptions implied or reinforced
"The Reserve is water for 'bugs' "	The ultimate purpose of the Reserve is to protect aquatic species.
"We can only use the water that is left over after we have allocated some for the ecology."	People must compete with ecological systems for water; people's needs are secondary to the requirements of natural systems.
"More water for the Reserve means less water in your stomach."	People must compete with ecological systems for water; higher levels of protection for the resource means less allocation to (and associated benefits for) people.
"How can you tell people they can't have water because the fish need it?"	People must compete with ecological systems for water; basic human need denied in favour of ecosystems.
"Ecologists keep telling us about how the river ecosystem is the resource, and not just the water it provides. But what is a river except water?"	Water is the only acknowledged component of the ecosystem; water provision is the only benefit to be had from river systems.
"The Reserve is just there to give consultants jobs"	The Reserve concept and processes to maintain it are by-products of self-serving participation by ecologists, engineers and consultants. By definition then, the purpose of the Reserve is not to serve the needs of society.
"All we really need is sustainability. Why don't we just maintain all rivers at the lowest protection level then we can get maximal use out of them while still ensuring a sustainable resource?"	The lowest levels of protection for the ecosystem translate to the provision of maximum benefits to people, i.e. protection and use are disjunctive and mutually exclusive.
"If 10% of the money already spent on Reserve determinations had been spent on supplying water to rural areas, we'd have done more good."	Reserve determinations are perceived to be technical processes that waste resources in light of more urgent basic human needs; meeting short-term goals is more important than securing long-term sustainability.
"How did ecologists in South Africa manage to negotiate so much power for protecting nature in the new water policy?"	Nature and people are perceived to be separate entities with no interdependent needs. Resource protection seen to be for protection's sake and with no intention to accommodate human needs.
"We need to rethink the Reserve. The Reserve is there to maintain the resource, which provides goods and services to people".	People depend on the resource. Resource protection enables and supports the use of resource-based benefits by people.

Figure 2.2 A copy of the table documenting perceptions of the Ecological Reserve by various stakeholders from Sherwill *et al*., 2003 (cited by van Wyk *et al*., 2006).

There are many misperceptions about the Ecological Reserve with regards to what it is and who it benefits. Clearly, the Reserve concept has not been explained or conveyed to the various stakeholders properly. Due to there being many different stakeholders who have interests in the Ecological Reserve, there are many varied views and interests, all of which needs to be satisfied. Some of the statements made are likely from stakeholders who have interests in economic development only without acknowledging that sustaining a healthy ecosystem ultimately benefits them as well. These stakeholders consider ecosystems and the environment as only being beneficial for the exploitation of the resources and regarding the Reserve as a hindrance, e.g.: "The Reserve is water for bugs". They view the ecological reserve only as a source of water and not as a resource that offers various goods and services that inevitably influence their social and personal well-being. Van Wyk *et al*. (2006) describe these statements as an overwhelming idea that there is a competition between the needs of people and the needs of river ecosystems which is supported by the Reserve validating the needs of the environment. These statements were made more than a decade ago and whether these perceptions have changed has been reviewed as part of the Shared Rivers Iniative project by Pollard and du Toit (2011a).

2.2.2 Environmental water requirements

Due to the regulation of flow by dams, excessive water abstraction, the discharge of effluent in river systems, and increasing water demands, it is critical that the Reserve and Environmental Water Requirement (EWR) be determined for all major rivers (Malan and Day, 2003) and for this EWR to be an active, rather than passive component of water resources management (Poff, 2009). EWR refers to the flow needed by a river to sustain a healthy ecosystem. Typically, this EWR is determined to mimic the components of a river's natural flow variability, taking into consideration the magnitude, frequency, timing, duration, rate of change, and predictability of flow events (Arthington *et al.* 2006). There is a global concern about the deterioration of water quality in rivers, and it has been acknowledged that the decline in river health is highly influenced by changes in river flows (O'Keeffe, 2008). EWR flows are being negatively-affected by significant changes in land-use and poor water resource governance (Pollard and du Toit, 2011b). In order to meet the determined EWR as well as to ensure that all water-users receive their allocated water supplies, dedicated flow management is required through the efficient management of water abstraction, effluent discharge and dam outflows. In South Africa this is presently being termed 'Operational Water Resources Management (OWRM)'. However for OWRM to be truly effective, it is required that the hydrological processes which affect river flows is completely quantified. Transmission processes, i.e. losses and gains of surface water from a river channel, are key knowledge gaps which currently undermine effective water allocation and management.

Until the early 2000s the EWRs of South African rivers utilised the Building Block Method (BBM; King and Louw 1998), which at that time were called 'in-stream flow requirements' (IFRs) representing the highly variable nature of the country's rivers. The BBM process defines a set of monthly (daily average) flow blocks that should be applied during 'normal/maintenance' years as well as a set that should be applied during 'drought' years (Hughes, 2001). However, Hughes (1999) also emphasized that IFRs are not sufficient for incorporating into the type of water resource systems models that are used in South Africa. The argument was that IFRs do not provide the necessary temporally dynamic information on the frequency of occurrence, or assurance levels, of the different flows. A way to overcome this was to use flow duration curves (FDCs) instead of actual flow values which display the full range of river discharges from low flows to flood events. These now form the hydrological basis of reserve determination studies, which generate FDCs as site specific flow 'assurance rules'. These assurance rules are then typically implemented/monitored at hydrometric flow gauges (typically operated by DWS) close to EWR bio-monitoring sites. Through the national Water Resources Classification System (WRCS), as mandated in the NWA, a river will be classified through public participation process, and on that basis a class of river and associated assurance rules are gazetted as the future management and operating scenario for a river system.

2.3 Transmission Losses

Globally, transmission losses are also known as *channel*, *river* or *water losses*. Walters (1990) describes transmission losses as the reduction in river flow due to evaporation and infiltration to the river bed, river banks and even the adjacent floodplain. Boroto & Gorgens (2003) described transmission losses along the Limpopo River as storage recharge in alluvial channel beds or alluvial banks, and as evaporation and evapotranspiration; direct evaporation from the water body surface; deep groundwater recharge and during extreme climatic events as losses to floodplain flows. Water lost via infiltration may either percolate to recharge aquifers or will return to the river downstream and contribute to the flow (Hacker, 2005). Sharp and Saxton, 1962; cited by Hacker (2005) believes that the key factors influencing transmission losses are:

- size and sequence of floods; geology and soils of the valley;
- the gradient, depth, size, continuity, meander, and number of channels;
- riparian and phreatophytic vegetation along the channel and in the valleys;
- soil-frost conditions;
- depth to the water table;
- soil-moisture content;
- gross and gravitational pore space in the soil;
- man-made structures and alterations;
- antecedent and current rainfall; and
- the content and nature of sediment in the stream flow.

To ensure effective water management and water provision, it is critical to understand transmission losses considering that it is a key component of the water balance or hydrological budget (Gu and Deutschman, 2001). While transmission losses have yet to be properly quantified for any South African river, they are estimated to be high for perennial rivers flowing through arid and semi-arid areas, such as the Letaba system. According to Hacker (2005), transmission losses are amplified in arid or semi-arid regions where the water table is very deep and predominantly lower than the water level in a channel. Boroto & Gorgens (2003) predicted that up to 30% of the Limpopo River's mass balance may be allocated to transmission losses due to evapotranspiration and recharge to aquifer storage.. Everson *et al*. (2001) quantified losses due to evapotranspiration between two gauged sites on the Sabie River to be 0.32 m^3/s in low flow months — a significant proportion of total available flow considering that low flows range between 0-5 m^3/s (e.g. Pollard & du Toit, 2011a). In the Letaba River Reserve determination study by DWAF (2006a), transmission losses were estimated to be between 8-50% of the channel inflow. Quantitative investigations or transmission losses are necessary in order to calculate flows in a river and appropriately allocate water for different users (Gu and Deutschman, 2001).

2.4 The Letaba River System

The Letaba River situated in the north-eastern region of South Africa is a prime example of a river system where uncertainties in channel losses and gains are complicating effective water management. Water abstraction along this river is greater than the available water supply (DWAF, 2006a; Pollard and du Toit, 2011a) and water abstraction is excessive. Katambara and Ndiritu (2010) have identified that flows in the Letaba River no longer resembles natural flows due to infrastructural developments including large dams, e.g. the Magoeboeskloof, Ebenezer and Tzaneen dams. Fortunately, river operating rules for releases from the Tzaneen Dam have been developed, and downstream flows are monitored by the Kruger National Park (KNP) according to the Ecological Reserve determination for the river. Low flow concerns are communicated through the proto-CMA with the Tzaneem Dam operators via an adaptive feedback mechanism (McLoughlin *et al*., 2011). According to Pollard and du Toit (2011a), feedbacks play a critical role in resilient systems and adaptive management, and practically imply that once something is discovered, the new information is relayed to an appropriate body who takes the necessary steps to adapt to suitable management practices and it feeds back into the system.

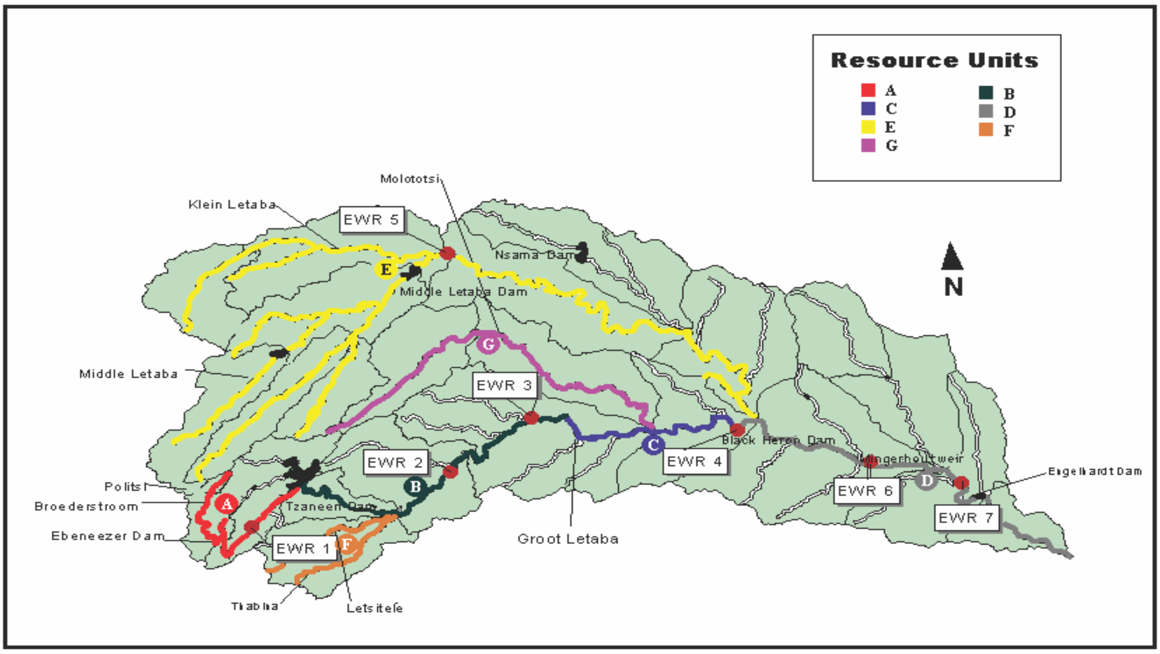


Figure 2.3 The Letaba catchment, with major dams and EWR sites (DWAF, 2006b)

2.4.1 Letaba Water Supply System – Status-quo

In terms of water resources planning, in the South Africa we often speak of catchments along with their associated infrastructure as *water supply systems*. The Letaba River is one such system which utilises water from the Groot, Middle and Klein Letaba rivers and their tributaries. In the Middle and Klein Letaba's there are a number of borehole supply schemes and water supply schemes using the Middle Letaba and Nsami dams. Whilst in the Groot Letaba water is supplied for bulk domestic use to towns such as Polokwane, Tzaneen and rural communal areas. These utilise the Dap Naude, Ebenezer, Magoebaskloof, Vergelegen, Hans Merensky, Tzaneen, Thabina and Modjadji dams. The dominant land-use in the Groot Letaba is commercial irrigated agriculture. However the surface water resources within the entire Letaba catchment are extensively developed. Faced with water shortages of increasing severity and frequency over the years, the main consumptive users of water have from time to time competed for the limited supplies and experienced significant levels of restrictions. This has resulted in the degradation of the riverine ecosystem. The water resources of the Groot Letaba are not sufficient to meet all its requirements all of the time (DWA, 2014).

The recent water resources reconciliation for the Letaba system (DWA, 2014) included amongst others the following advice to be implemented in order to achieve water resources management sustainability in this catchment up to 2040:

- Excess water from Ebenezer Dam should be allocated to users in the Groot Letaba System by augmenting the Tzaneen dam. With no further augmentation possible via inter-basin transfer to other areas (e.g. Polokwane)

– Water Conservation/Water Demand Management must be implemented in this catchment with immediate effect from both the domestic and industrial sector

- Continue with the implementation of the Groot Letaba Water Development Project (GLeWaP) which includes: raising of Tzaneen Dam by 3m to improve the assurance of supply to the users; A new major storage dam on the Groot Letaba River just downstream of the Nwanedzi River confluence, at the site known as N'wamitwa with first water to be stored by 2019; and resulting from N'wamitwa develop a bulk water supply scheme to serve rural communities without adequate water supplies;

- Importantly (and demonstrating the added value of WRC project 2338) use N'wamitwa Dam to start to deliver water according the ecological water resources requirements gazetted in the Water Resources Classification process for the Letaba.

The last point here is pertinent as the same study also noted the problem of fully understanding the large transmission losses, which were identified during the GLeWaP and other studies on the lower reaches of the Letaba. It has previously not been possible to estimate these losses because no acceptable gauging stations existed in this part of the Letaba, and because the current water resources assessment model, WRSM2000 can only specify transmission losses as a monthly value losing it from the water balance and not incorporated as an input to the groundwater module. Also the weir at Prieska Weir's (B8H017) sluice has been open since the 1996 floods due to a tree being stuck in the sluice gate. This already might account for the perceived losses on its own. The Prieska Weir issue should be resolved by either continuously measuring the flow from the leaking sluice or by destroying the Prieska Weir.

Pollard *et al.* (2012) through a historical (contextual) assessment of compliance with the ecological reserve showed that during the period of major water resource development (1960-94) in the Groot Letaba, meeting the present-day assurance rules close to the KNP at EWR 4 (using a 'C/D' class assurance determined prior to the WRCS process) that there was typically above 40% non-compliance with the ecological reserve, especially noticeable in the dry winter months (May-October). However post 1994, the situation had begun to improve where non-compliance ranged between 20-30%. It was noted in this study that this catchment had seen continuous effort to improve water resources management since 1994 and this was attributed to close interaction between the operator of Tzaneen dam and commercial agriculture through the Groot Letaba Water Users Association (GLWUA) and then more recently with the KNP monitoring flows near the western boundary, who initially started to benchmark flows at 0.6 m in the absence of a comprehensive reserve study. In 2009 a new operational system was implemented for testing using a dynamic assurance rule approach (in advance of the reserve determination from the WRCS).

2.4.2 History and Present Operating Rules

The Tzaneen dam was completed in 1976 and by 1977 the Tzaneen Dam started to fill with an annual allocation of 130 Mm^3 whilst its full supply is 156 Mm^3 and a firm yield of 50 Mm^3. History has demonstrated the stresses that the Tzaneen Dam is meant to endure. For instance the late 1980s and early 1990s droughts the Tzaneen dam capacity effectively dropped to below 5% and in 1995 it dried out completely. The short drought of 2004-2005 also saw its storage drop significantly. In general, approximately 14% of time dam is at 0-10% capacity, close to 20% of time dam is above 90% capacity.

Given that wet cycles in the Letaba region are about 20 years apart, it needed to be factored into the management of the dam and the history of constraints on the system meant that new operating practice had to be implemented for the sustainable utilization of the dam. This is in order to mainly provide the citrus orchards in Tzaneen area with a permanent supply of water (otherwise plants die and it takes 4-5 years before citrus can become productive again – so a significant risk for the local economy). Therefore from 2006 early restrictions were brought in to the operations (Water Years starts from 1 April to end of March) this allowed accrual of storage in the dam, which didn't occur previously.

The Department of Water & Sanitation operating rules for the Tzaneen dam plan for annual losses of 30% downstream, whilst 10-15% of the dam is reserved for domestic and industrial use. If the dam reaches the 15% level then there is a 100% curtailment to irrigators. Meanwhile, irrigators through the Letaba Water User Association (WUA) implement their own voluntary operating rule: 95-100% capacity - then 100% assurance of supply to irrigators, below 95% then 50% curtailment on 1 April, and for each month thereafter they add a further 5% curtailment. For example, May would be 55%, until you get to 70% curtailment. These steep restrictions allow the WUA to manage for large storage depletion in the dam.
Meanwhile it is assumed that the tributaries in the system make significant inflows that allow the reserve to be met and to meet the needs of the run-of-river users

downstream. However if the tributaries are not flowing then the Tzaneen dam needs to release on average about 6 Mm^3; if they are flowing then about 2 Mm^3 is released, in order to meet requirements at Letaba Ranch (EWR4).

At the time of writing this report, the proposed management classes for the Letaba water supply system are being gazetted and open for public comment. These will be gazetted as legally binding by end of 2014. The comprehensive reserve determination through this process has proposed the lower reaches of the lower Groot Letaba to be a Management Class II with a C class reserve. The implication of this is high assurance rule flows that must be implemented than the present day operating scenario, although it is acknowledged that this will only be achievable following the construction of N'wamitwa dam.

2.4.3 The SPATSIM Model

In 2006, the Department of Water Affairs (DWA) developed operating rules for the Letaba River, and commissioned the development of a real-time ecological reserve implementation model known as SPATSIM (Spatial and Times Series Information Modelling) (Hughes *et al.*, 2008; Sawunyama & Hughes, 2010). During the development of the model, it was identified that when implementing the Ecological Reserve, that methods must take in account varied water resource developments and supply scenarios. It was agreed that the first step in implementing the SPATSIM modelling system and associated feedbacks (within an adaptive management framework) would be to implement the relevant operating rules and initiate communication feedback between the KNP and the dam operators (McLoughlin *et al*, 2011). The system operated between 2009 and 2012 before problems were identified relating to that of channel losses, which include alluvial channel, riparian and/or floodplain recharge as well as evapotranspiration. SPATSIM acknowledges these uncertainties in natural transmission losses along the Letaba River. Significant transmission losses are likely as flows at the Letaba Ranch (B8H008) monitoring weir, where the river enters the KNP are often lower than those predicted by SPATSIM for a known release from Tzaneen Dam (e.g. DWAF 2010).

2.5 Methodology Overview

The primary aims of this research project are to quantify natural hydrological processes along a stretch of the Letaba River, and update the SPATSIM model. It is critical that the most efficient, reliable and reasonable methods are applied in order to address the abovementioned concern in an appropriate manner.

Geophysical survey techniques will be applied in order to obtain valuable information of the subsurface geology. Electrical Resistivity Tomography (ERT) is a common geophysics technique used in water resource and geomorphological studies (Robinson *et al.*, 2008). According to Loke (1999), this technique provides a reliable account of the bedrock and lithological distribution within catchments since detailed measurements of the subsurface resistivity distribution is obtained based on known geological resistivity ranges. Resistivity values are influenced by soil/ rock properties, water content and salinity. Studies by Uhlenbrook *et al.* (2005), Kongo *et al.* (2007), Wenninger *et al.* (2008) and Riddell *et al.* (2010) have shown how the ERT method could be successfully applied in hydrological investigations in southern Africa. In this particular study, ERT will be used to extensively survey the subsurface resistivity distribution along the river and to identify ideal locations for drilling boreholes required for monitoring groundwater-surface water interaction.

These boreholes will be drilled in a nested, multi-piezometer network comprising of both shallow and deep boreholes into weathered material and hard rock formations by the Department of Water and Sanitation (DWS) - Limpopo Office. Aquifer properties such as transmissivity rates will be determined using typical pump tests such as constant discharge and slug tests. Fluid logging techniques will be used to identify borehole fractures using a multi-parameter YSI Sonde.

In order to measure groundwater-surface water interaction, stable isotopes and other hydrochemical constituents will be used as a tracer technique. Tracer-based hydrograph separation techniques provide valuable information on the spatial and temporal origin of streamflow components (Kalbus *et al*., 2006). Furthermore, end member mixing analysis serves as an indication of the connectivity between streamflow and local/ regional groundwater. Riddell *et al.* (2013) and Petersen (2012) have conducted groundwater-surface water interaction studies in the Lowveld by successfully applying tracer techniques using stable isotopes and hydrochemistry. Differences in concentrations of environmental tracers between groundwater and surface water allows for the identification of groundwater discharge and recharge zones, particularly if differences are sufficiently large (Kalbus *et al*., 2006).

Actual evapotranspiration (aET) along the river channel and riparian zone will be quantified using direct measurement of latent heat flux. A Surface Layer Scintillometer (SLS), which functions optimally within a 50-500m range, will be installed perpendicular to the river to measure aET from the river channel and riparian zone. The Large Aperture Scintillometer (LAS), which can be used over large distances ranging 500-5000m, will measure aET of riparian vegetation parallel to the river. Since these instruments allows for extensive spatial coverage, are highly sensitive to small temperature and wind fluctuations, and are regarded as quite reliable, this method should be suitable for the Letaba River. Recent studies by Jarmain *et al.* (2008), Clulow *et al.* (2012) and Riddell *et al.* (2013) have successfully applied scintillometry methods elsewhere in South Africa.

A mass balance approach will be used for direct measurement of transmission losses. This involves measuring the streamflow at two gauging stations along the river. Walters (1990) and Costas *et al.* (2013) applied this technique to identify controls influencing transmission gains and losses along different river reaches. Everson *et al.* (2001) coupled this technique with aET determination through energy balance methods along another Lowveld river, as will be in this study. A hydrocensus will be required to compliment the mass balance along different river reaches. This hydrocensus will aim to account for all sources of water whether for domestic, agricultural or natural use (watering holes for wildlife). A survey of the properties within the study site will identify each borehole on the property and record data relating to location, borehole depth, water level, and hydrochemical signatures. In addition, the hydrocensus will take cognisance of direct water abstraction from the river.

3. DETAILED SITE DESCRIPTIONS

The Letaba River catchment is located in the Limpopo Province of South Africa and extends over an area of roughly 13 400 km^2 (Moon and Heritage, 2001). It is delineated by the Drakensberg Escarpment in the west extending into the low-lying Lowveld in the east (Fig.3.1). The catchment can be divided into the Klein Letaba sub-catchment in the north and the Groot Letaba sub-catchment in the south (Pollard and du Toit, 2011a). Downstream of the Middle Letaba Dam, the Middle Letaba River flows into the Klein Letaba which drains into the Groot Letaba River at the KNP boundary. According to Heritage *et al.* (2001), nearly three-quarters of the catchment is underlain by granitic and gneiss geological formations whereas the east is dominated by volcanic formations derived from the Karoo sequence, i.e. basalts. Due to the presence of granites, weathered zones are shallow and soils have a sandy soil texture (Pollard and du Toit, 2011a). There are numerous diabase dykes across the catchment (Pollard and du Toit, 2011a), with many intercepting the Letaba river upstream of KNP.

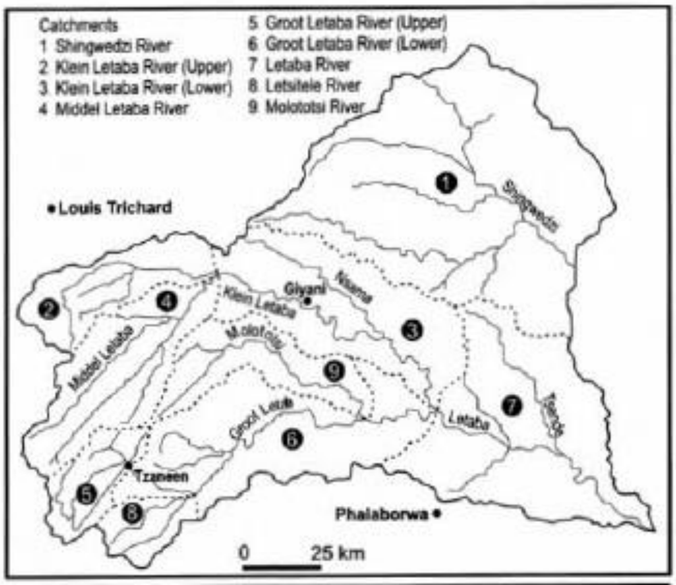


Figure 3.1 The Letaba Catchment (after Moon and Heritage, 2001)

3.1 Climate

The climate across the catchment is considered semi-arid and varies since it extends across high altitude, mountainous areas in the west and low-lying areas of the Lowveld in the east. Generally, summers could be classified as wet and hot whereas winter conditions are dry and mild. The mean annual precipitation (MAP) in the catchment is approximately 612 mm, of which more than 60% is captured in only 6% of the total area, i.e. the mountainous region in the west (WRC, 2001). In particular, 500-1800 mm of rainfall falls in the western mountainous areas whereas the east receives 450-700 mm (Moon and Heritage, 2001). According to the WRC (2001), mean annual evaporation is estimated to be 1669 mm. Since evaporation rates are greater than annual rainfall, most agricultural practises require additional irrigation. This emphasizes how stressed and vulnerable the catchment is with regards to water security (Pollard and du Toit, 2011a).

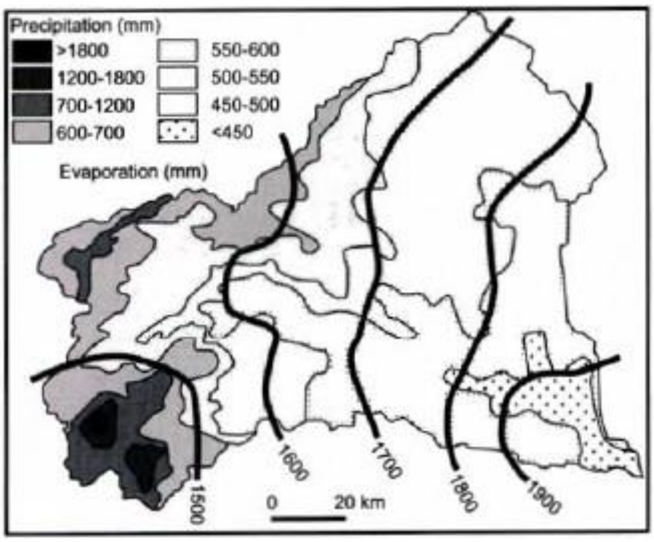


Figure 3.2 Precipitation and evaporation rates for the Letaba Catchment (after Moon and Heritage, 2001)

3.2 Hydrology and Geomorphology

There are more than 20 major dams located in the Letaba Catchment (WRC, 2001). The Letaba River is one of the few major rivers flowing through KNP before joining the Olifants River just upstream of the Mozambican border. The Molototsi River and Klein Letaba are the major tributaries contributing to the Letaba River. The macro-channel of the river may be described as bedrock-bounded (van Niekerk *et al.*, 1995; cited by Heritage *et al.*, 2001). The channel is further characterized by steep bedrock including cascading boulder rapids with sporadic waterfalls (State of the Rivers Report, 2001). Further downstream in sections with gentler gradients, cobble riffles occur before changing to an alluvial channel type as it approaches KNP (WRC, 2001). Deep pools may be found all along the Letaba River.

There are a number of different morphological units due to varying sediment distribution along the Letaba River (Heritage *et al.*, 2001). Sediment yield ranges between 150 and 400 km^2/a with the greatest yields generated in densely populated rural areas (Moon and Heritage, 2001). Sediment yields are expected to increase as agricultural activities intensify across the catchment.

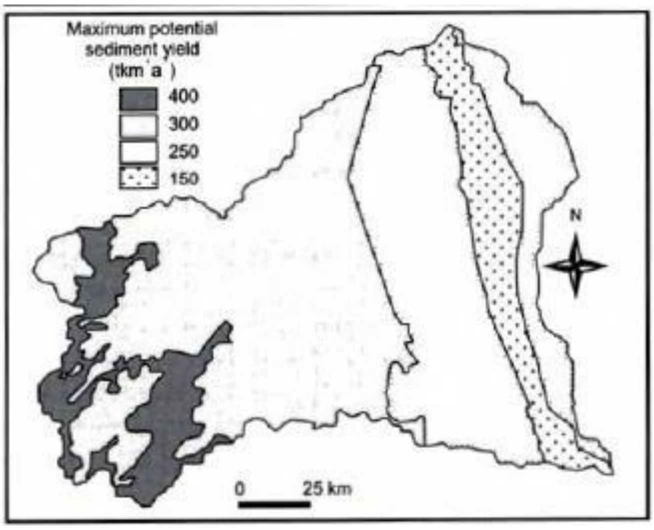


Figure 3.3 Sediment yield estimates for the Letaba Catchment (after Moon and Heritage, 2001)

3.3 Land-use Activities

Throughout the Letaba catchment, land-use is dominated by commercial agriculture, afforestation, densely-populated rural communities with informal, rain-fed agriculture and protected areas in the eastern section of the catchment (Pollard and du Toit, 2011a). The Letaba catchment is home to intense, commercial agricultural activities where citrus, tropical fruits and vegetables are the most commonly farmed produce (Pollard and du Toit, 2011a). Since the headwaters in the western section of the catchment are under commercial forestry, water resources are already under stress due to the additional demand of water supply for irrigators downstream. The upper reaches of the catchment is generally regarded as being in a good condition but it deteriorates further downstream due to natural salinization and nutrient enrichment by anthropogenic influences (Pollard and du Toit, 2011a).

The water supply schemes in the catchment currently consists of numerous small to major dams for storage, bulk water pipelines as well as extensive canal networks (Pollard and du Toit, 2011a). More than a decade ago, Vlok and Engelbrecht (2000) noted that the Tzaneen Dam allocated 103.9 million m3/a to irrigators, 8.4 million m3/a to households and industry and 14.7 million m3/a for environmental flows. However, the water which was allocated exceeded available supply because Tzaneen

Dam could only yield 98 million m3/a (Vlok and Engelbrecht, 2000). Situations such as these highlight the magnitude of poor water management strategies in a stressed catchment such as the Letaba.

3.4 Project Study Site

3.4.1 Desktop Investigation

The following site description maps were derived from desktop analysis and are focused on the immediate study site only. These maps provide information on the local lithology, soils, stream networks, topography and topocadastral features. Figure 3.4 delineates the study site, where Point A represents the first weir and B8H008 is the second weir at Letaba Ranch. Due to poor construction, the weir at Point A is no longer actively measuring flow data for the Department of Water and Sanitation (DWS). B8H008 is currently under construction to repair the weir and ensure that flow data is downloaded automatically to the DWS hydrology website.

Figure 3.4 A delineation of the study site

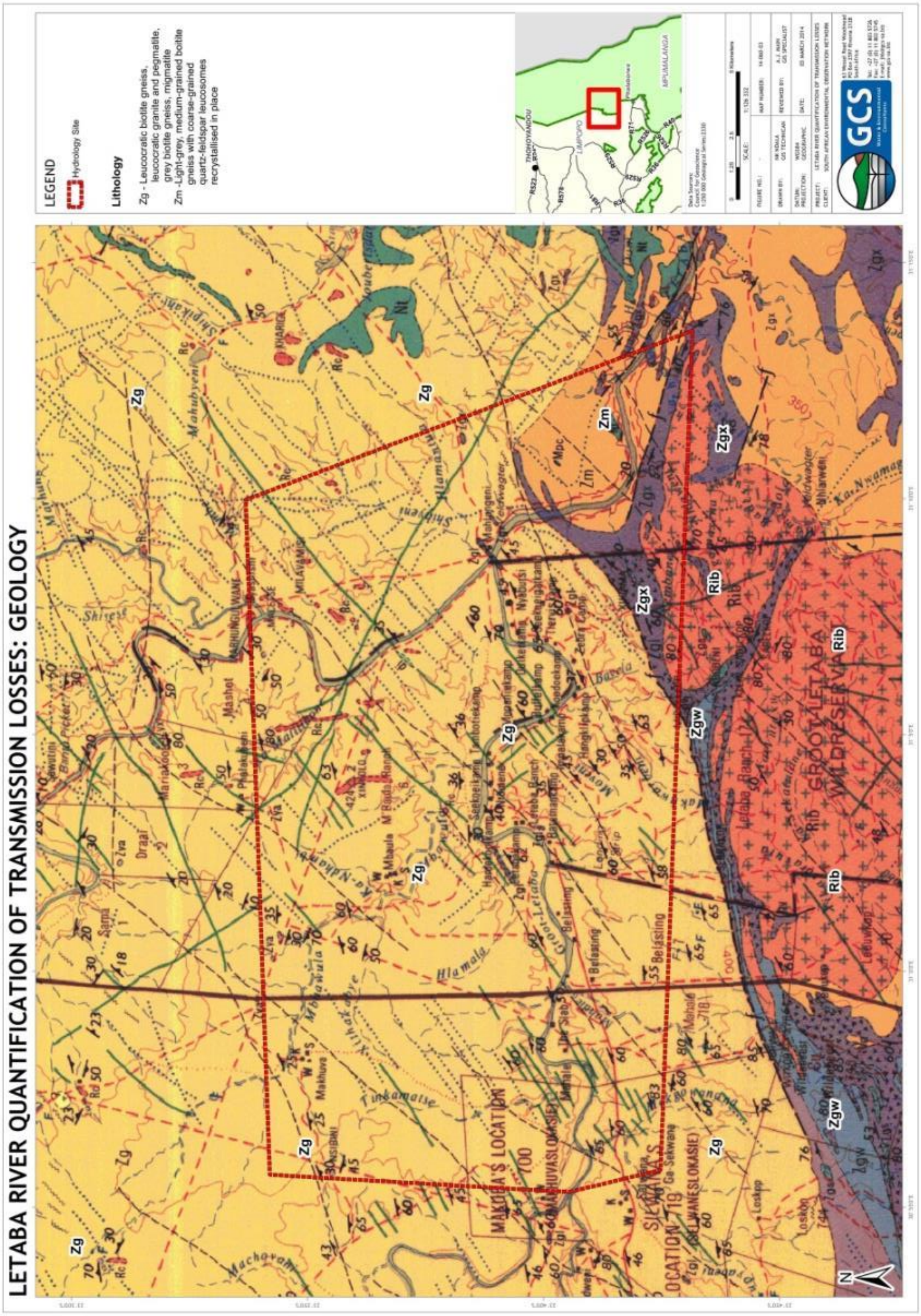


Figure 3.5 Geology of the site illustrating the dominant geology and dykes

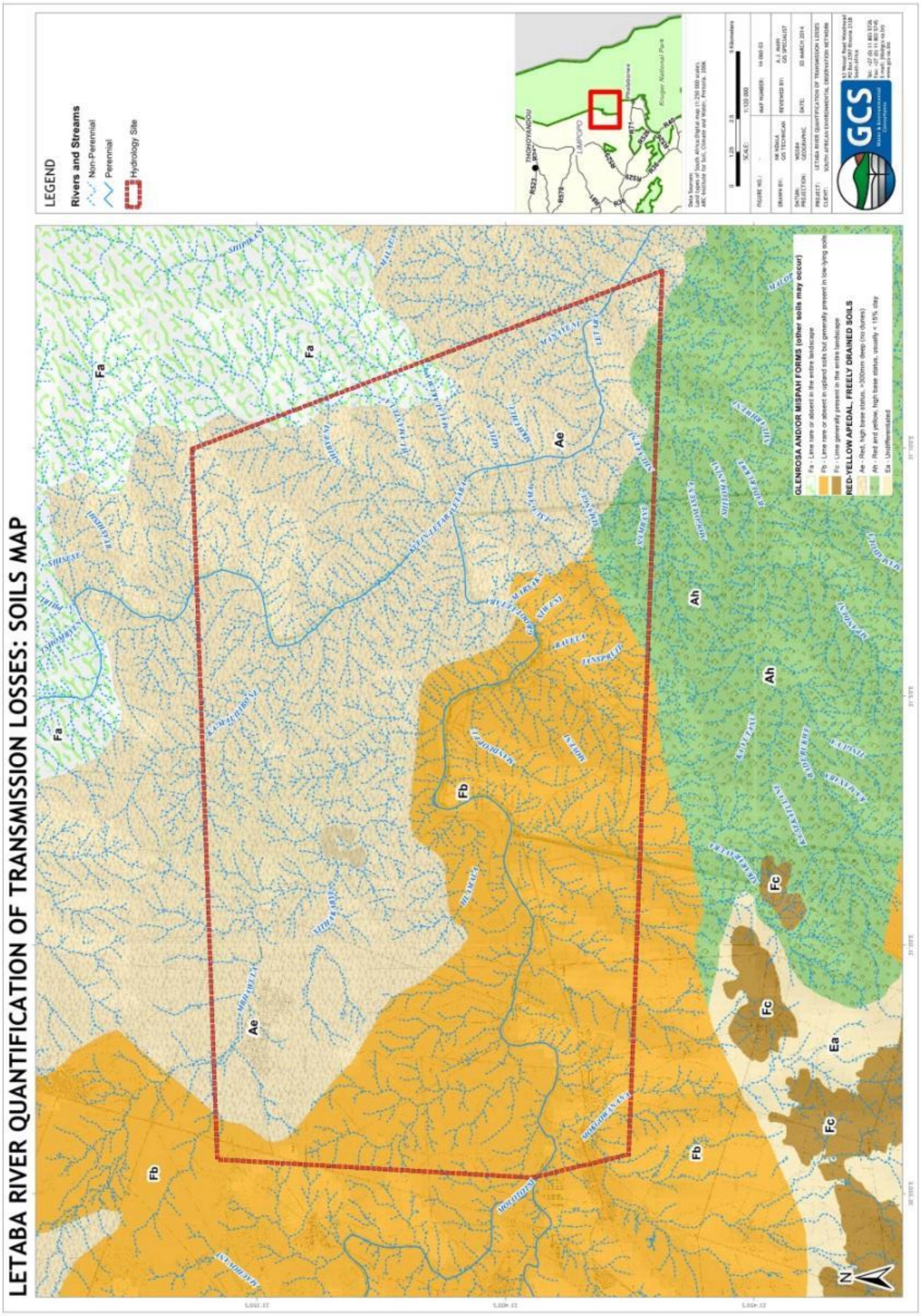


Figure 3.6 The dominant soil types and perennial/ non perennial streams

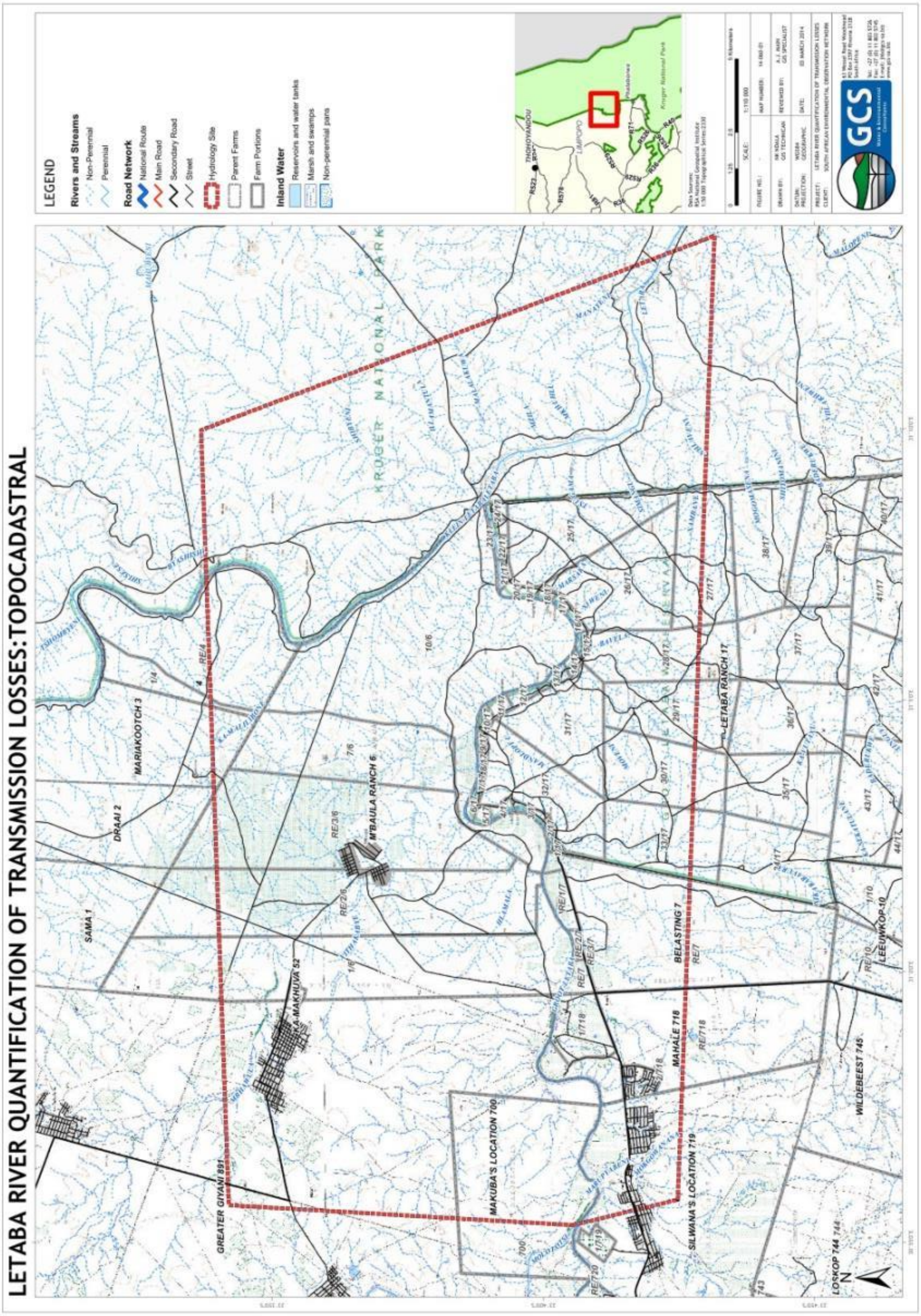


Figure 3.7 A topocadastral map of the study site delineating farms, ranches and rural communities.

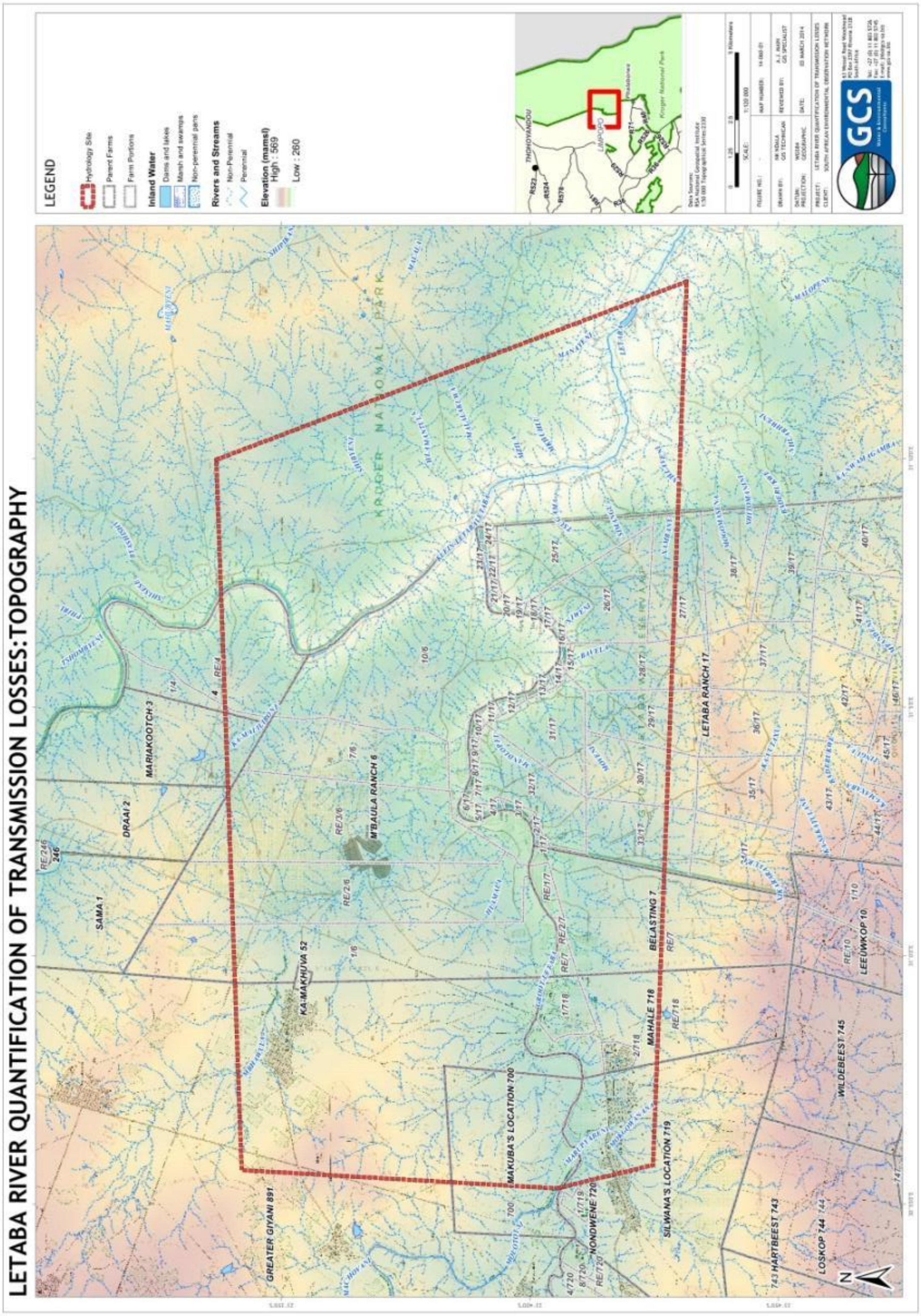


Figure 3.8 A topographical map of the study site

3.4.2 Geological Substrate Investigation

Geophysical techniques, specifically Electrical Resistivity Tomography (ERT) surveys, were used to investigate the geological substrate in order to identify ideal borehole drilling locations along the Letaba River. Along all these transects, the Schlumberger Protocol was applied. These surveys were conducted over two different land-uses, i.e. farming areas and protected areas (Fig. 3.9).

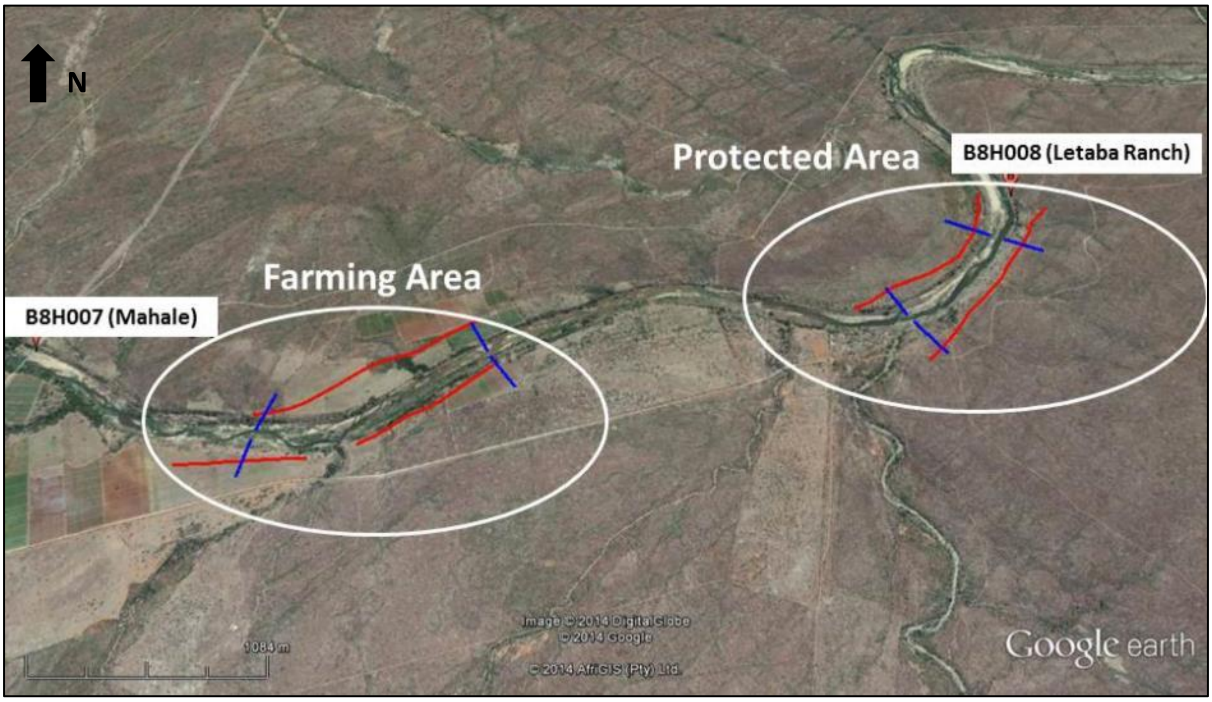


Figure 3.9 The location of the geophysics transects over two different land-uses.

(i) Farming Area

Two geophysics transects were surveyed on both sides of the river running in parallel, from east to west (red lines). These surveys used a minimum electrode spacing of 5m using the Schlumberger array in order to measure deep resistivity profiles (~ 70m). The blue transects represent surveys which ran perpendicular across the river. These surveys also utilsed a Schlumberger array with minimum electrode spacing of 2.5m for shallower resistivity profiles (~35m). Ideally, these perpendicular transects would have ran from one bank to the opposite bank but due to accessibility constraints, surveys had to split with each transect beginning in the river bed progressing upwards towards the river bank.

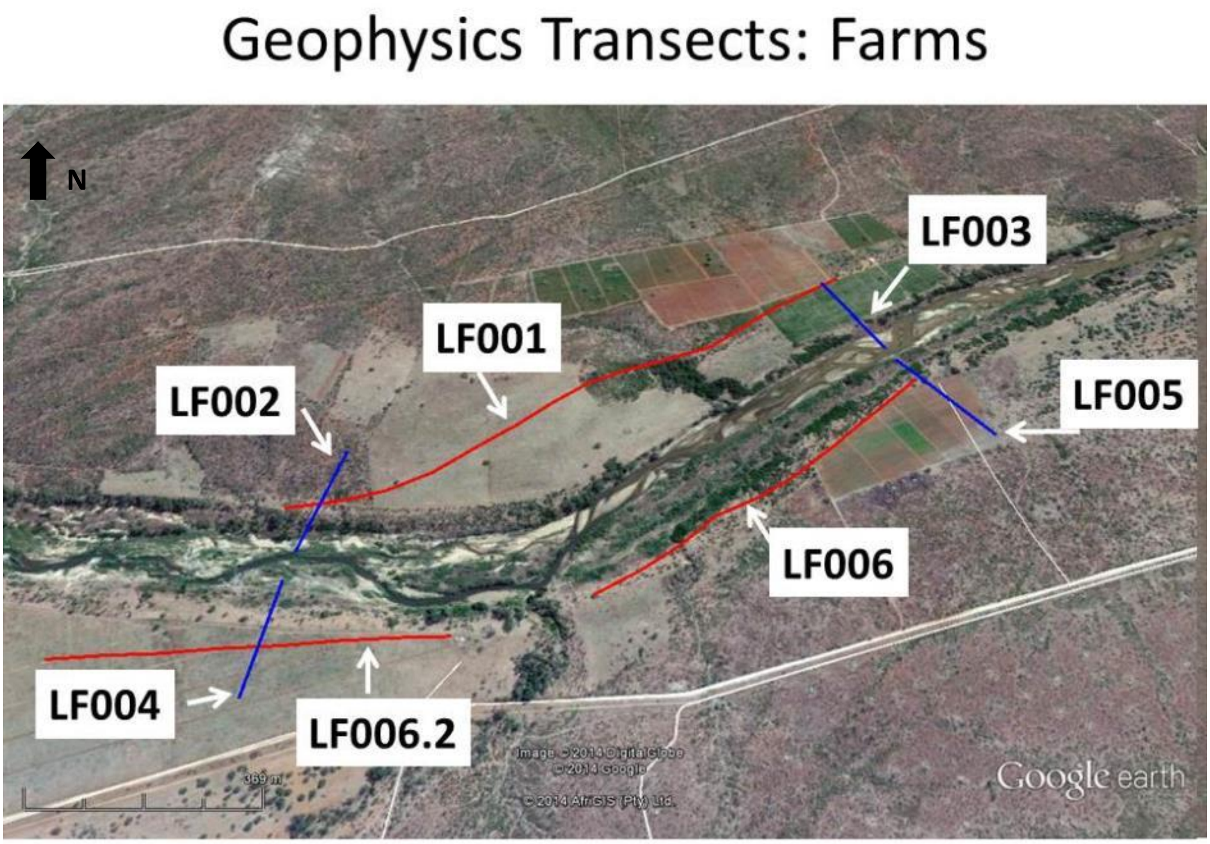
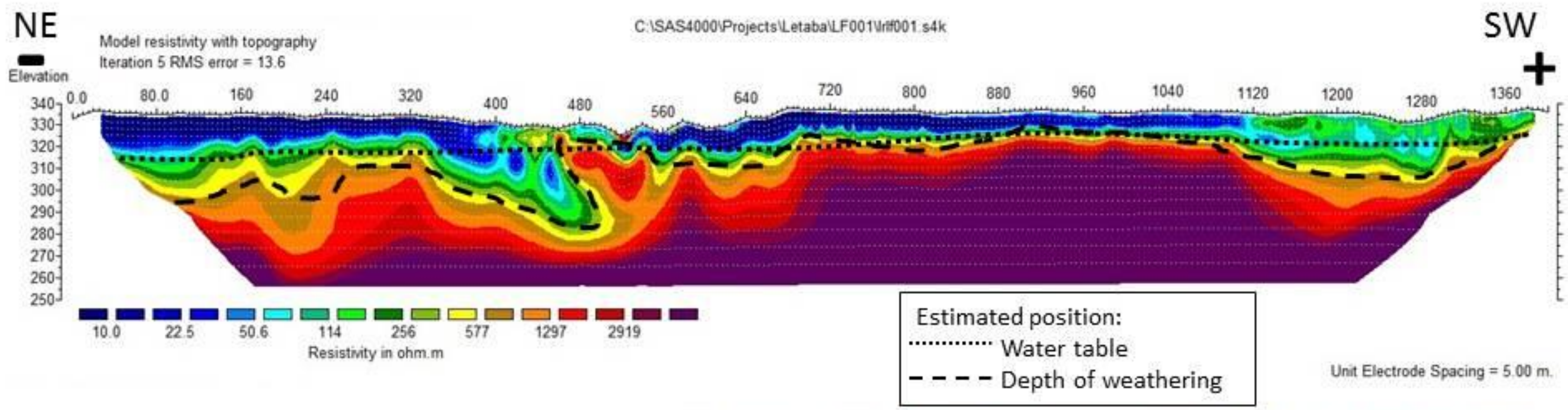


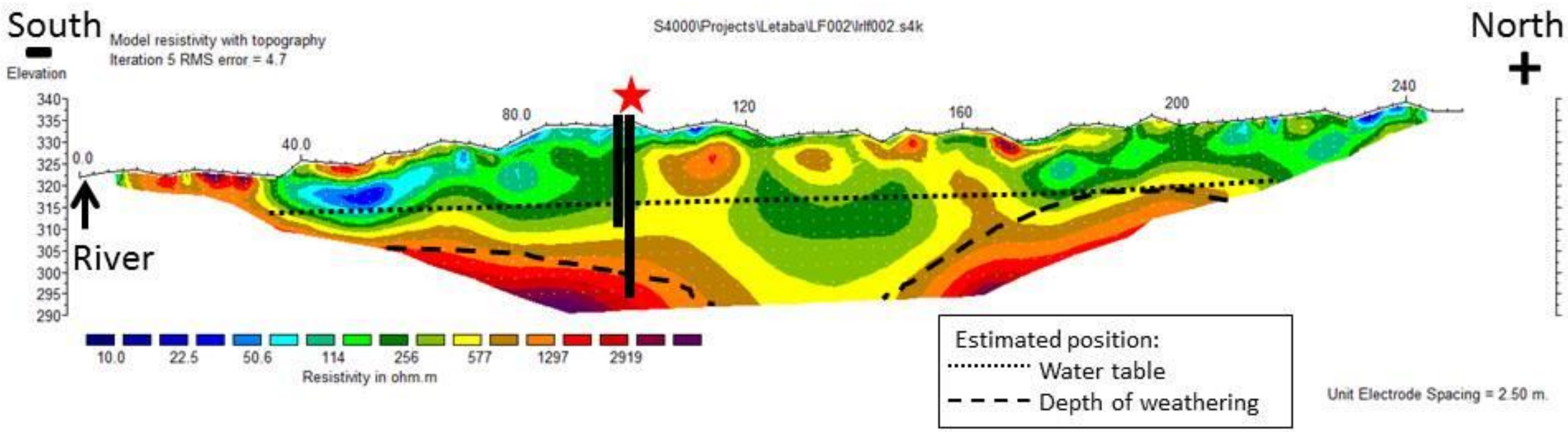
Figure 3.10 An illustration of the locations of geophysics transects across the farms

Letaba Farms: LF001



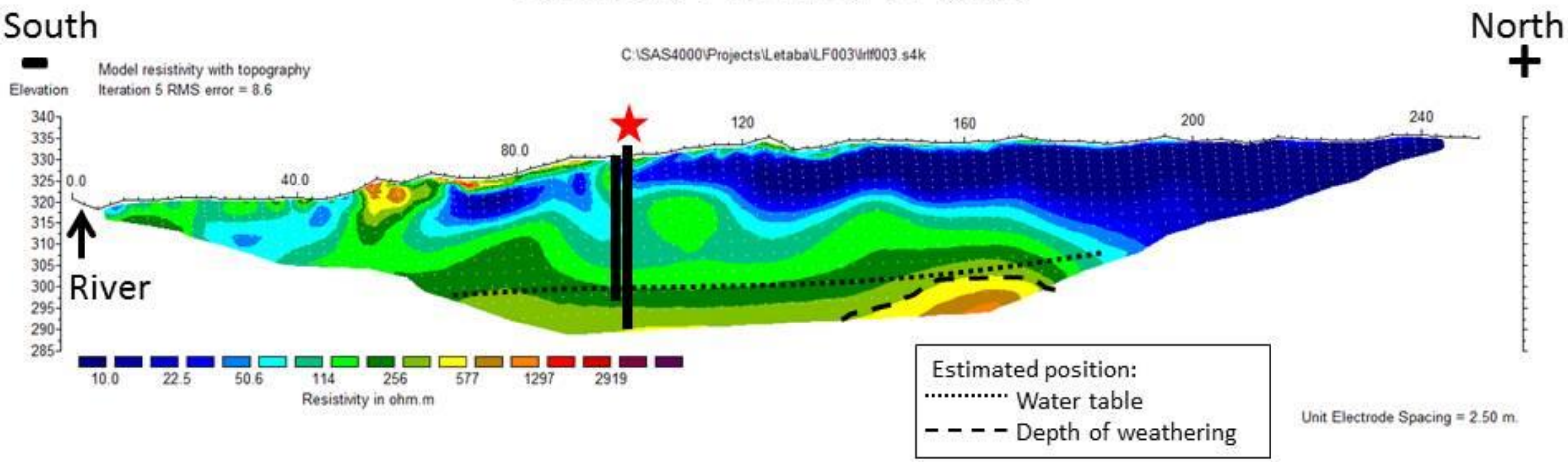
- Runs parallel to river channel (in a south-west direction)
- Evidence of tributary between 400m and 550m ~ negative weathering
- Shallow weathering 500-1100m

Letaba Farms: LF002



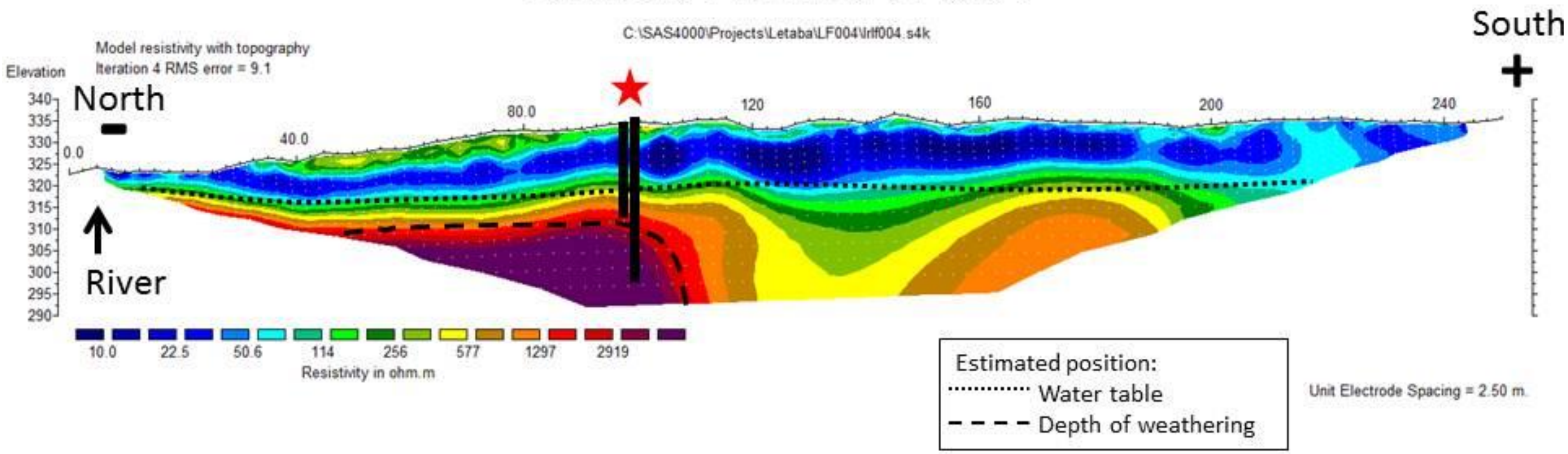
- Runs perpendicular to river channel
- A relatively flat water table
- Proposed borehole drilling location at ± 100m.

Letaba Farms: LF003



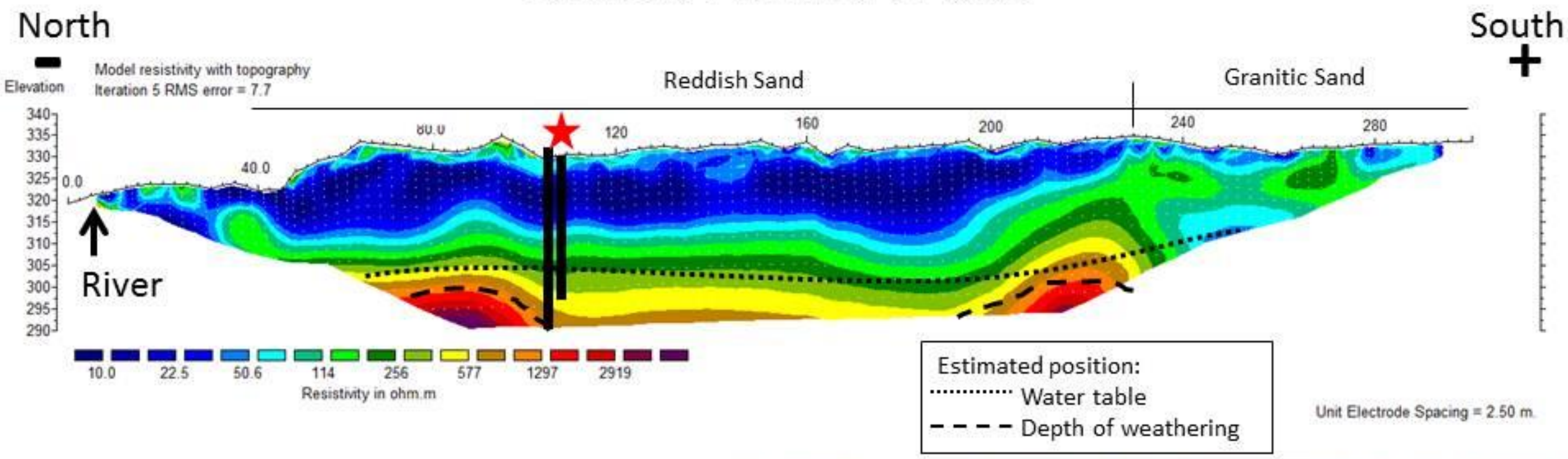
- Runs perpendicular to river channel
- Deep weathering (>25m)
- Proposed borehole drilling location at ± 100m (at edge of farm).

Letaba Farms: LF004



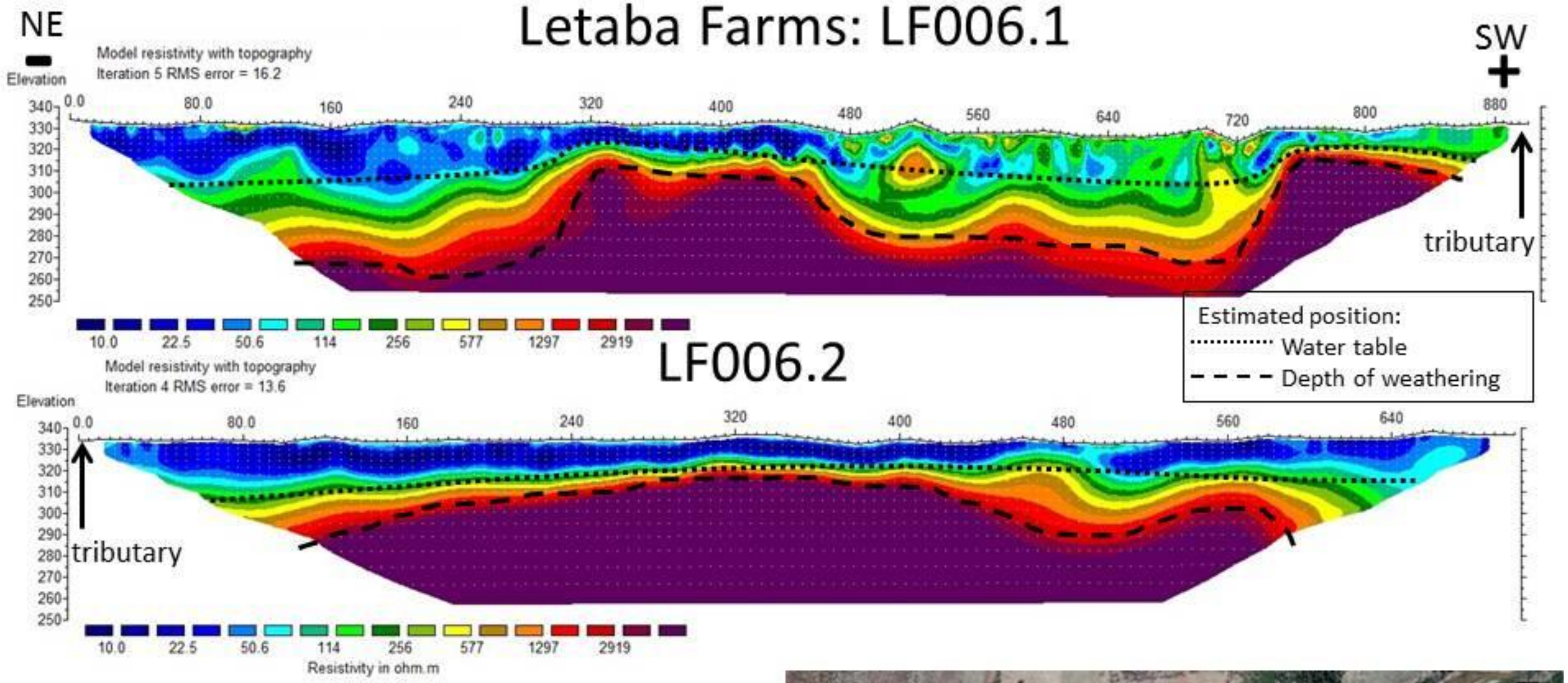
- Runs perpendicular to river channel (from north to south)
- Shallow weathering (± 10m) closer to river
- Proposed borehole drilling location at ± 100m.

Letaba Farms: LF005



- Runs perpendicular to river channel (north to south)
- Groundwater flow direction towards the river
- Red sands up to roughly 230m; likely river deposition on floodplains.
- Typical granitic soils from 240m onwards.
- Proposed borehole drilling location at ± 110m (at edge of farm)

Letaba Farms: LF006.1



- Runs parallel to river channel (in a south-west direction)
- LF006.1- Deep sands at 0-280m and 470-750m
- LF006.2 – similar floodplain sediment with no distinct structures
- Large tributary to the Letaba intercepts between LF006.1 and LF006.2 at ± 900m

(ii) Protected Areas

Downstream of the farming area, geophysics surveys were set up in an identical design in the protected area. Two transects were surveyed on both sides of the river running in parallel, from east to west (red lines). The transect on the northern bank was spaced 2.5m short and 5m long whereas the southern bank transect was spaced 5m short and 10m long. The blue transects represent surveys which ran perpendicular to the river. These surveys were spaced 2.5m short and 5m long for shallower resistivity profiles (~35m).

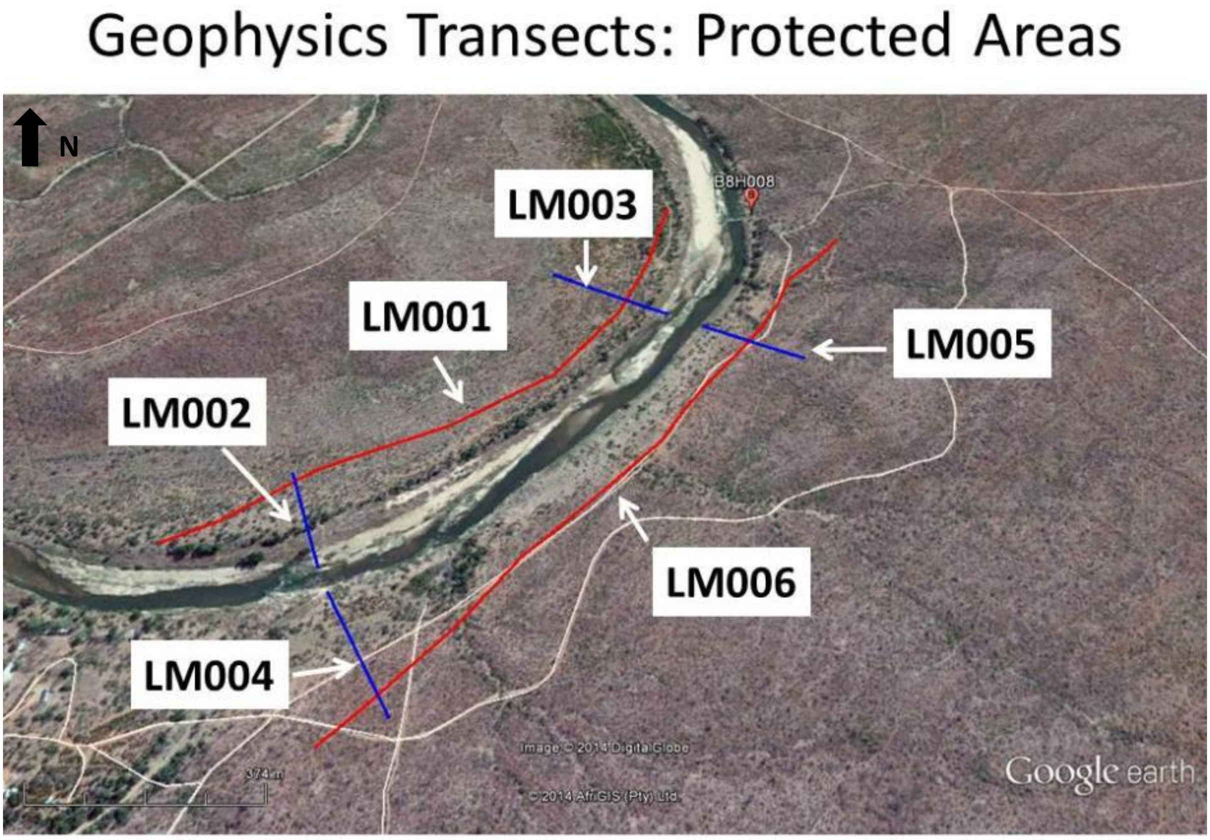
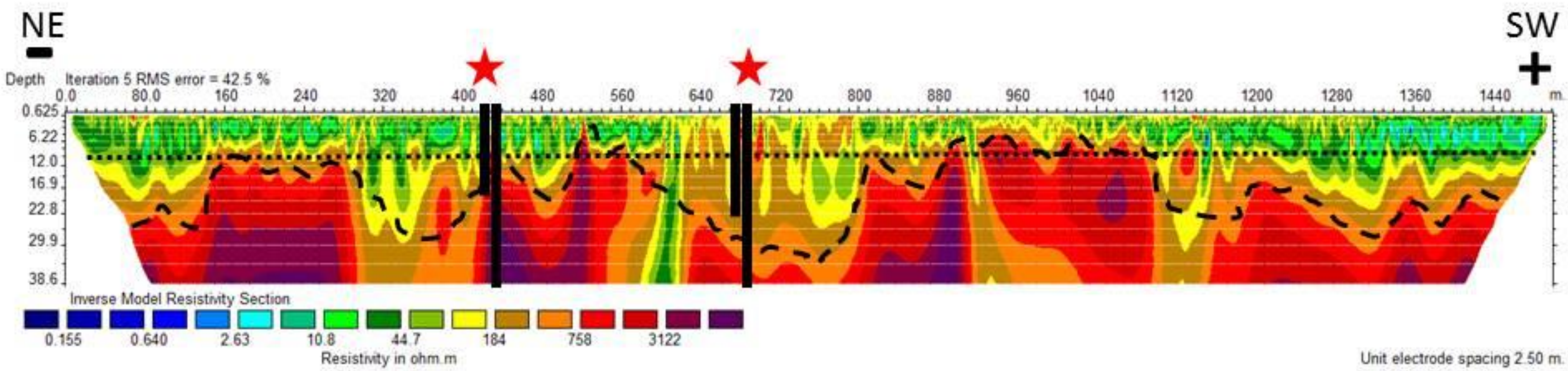


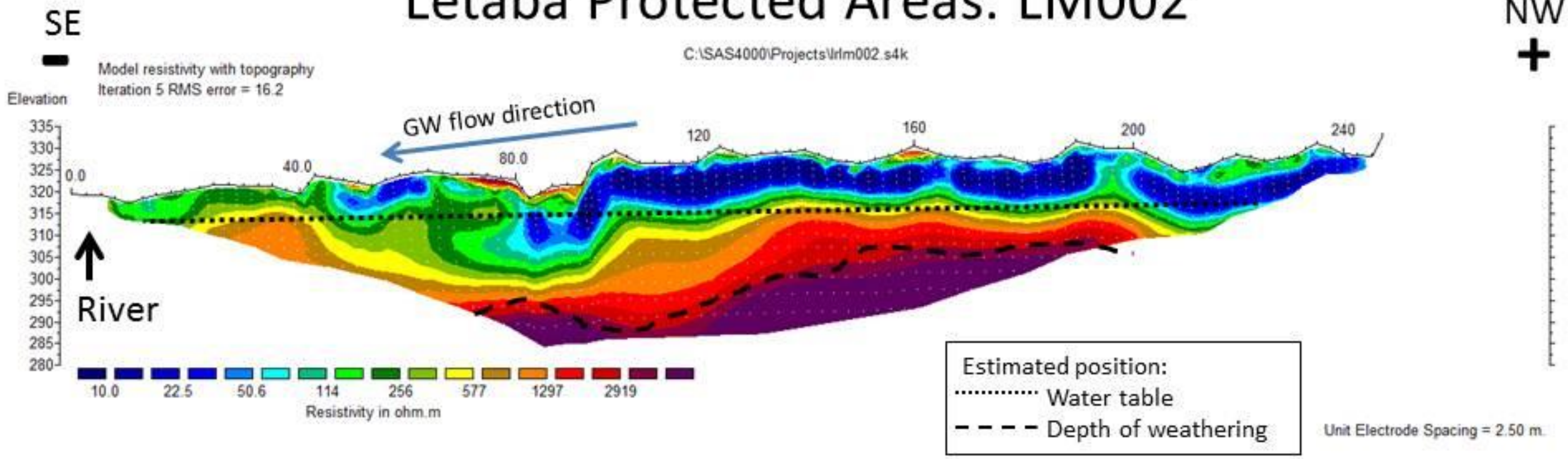
Figure 3.11 The locality of the geophysics surveys in the protected areas along the Groot Letaba.

Letaba Protected Areas: LM001



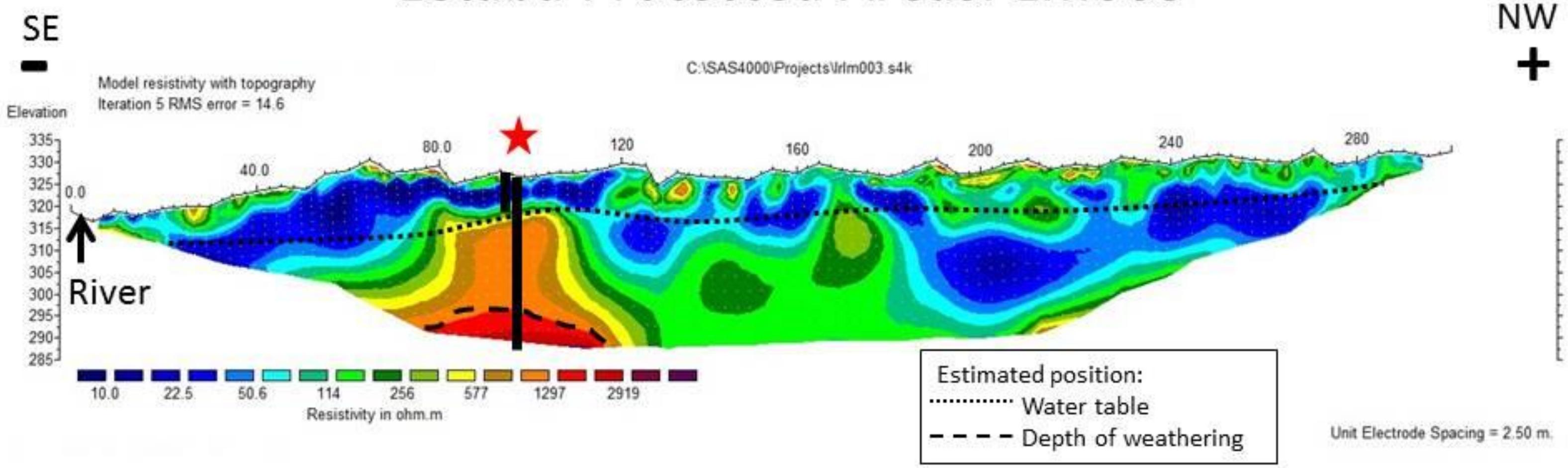
- Runs parallel to river channel (from NE to SW)
- A number of structures (dykes) possibly intercepting; i.e. 320-400m, 580-620m, ± 910m and 1100-1160m.
- Proposed boreholes drilled at 420m and 670m.
- No differential correction

Letaba Protected Areas: LM002



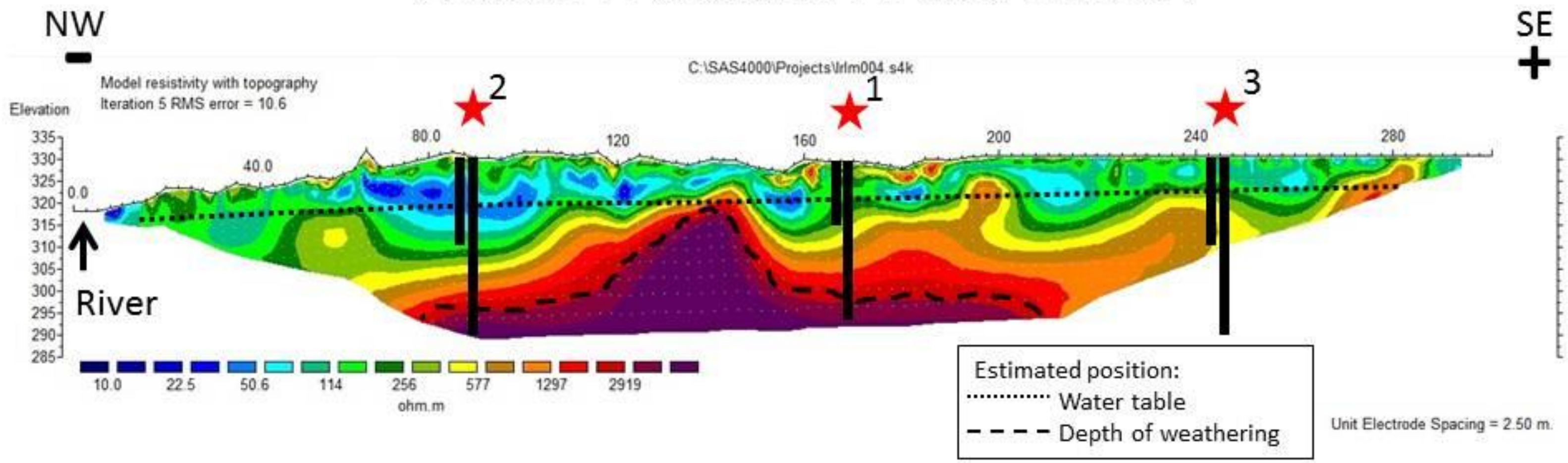
- Runs perpendicular to river channel
- Possible groundwater contribution to streamflow from bank.

Letaba Protected Areas: LM003



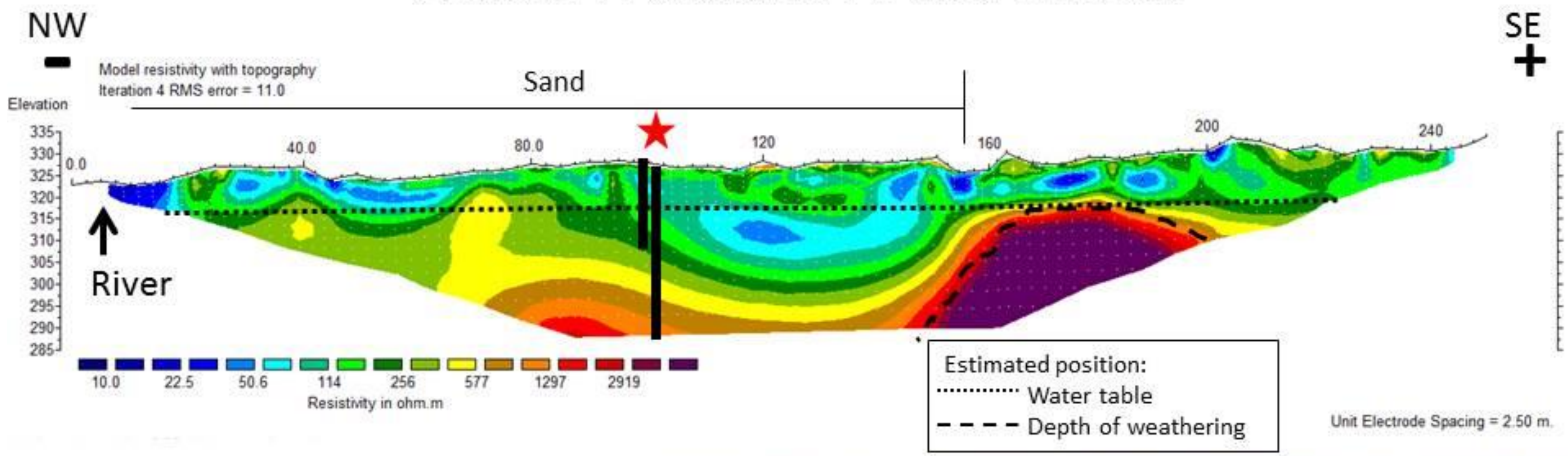
- Runs perpendicular to river channel starting in river channel
- Deep weathering after 120m to depths up (>35m)
- Proposed borehole drilling location at ± 100m

Letaba Protected Areas: LM004



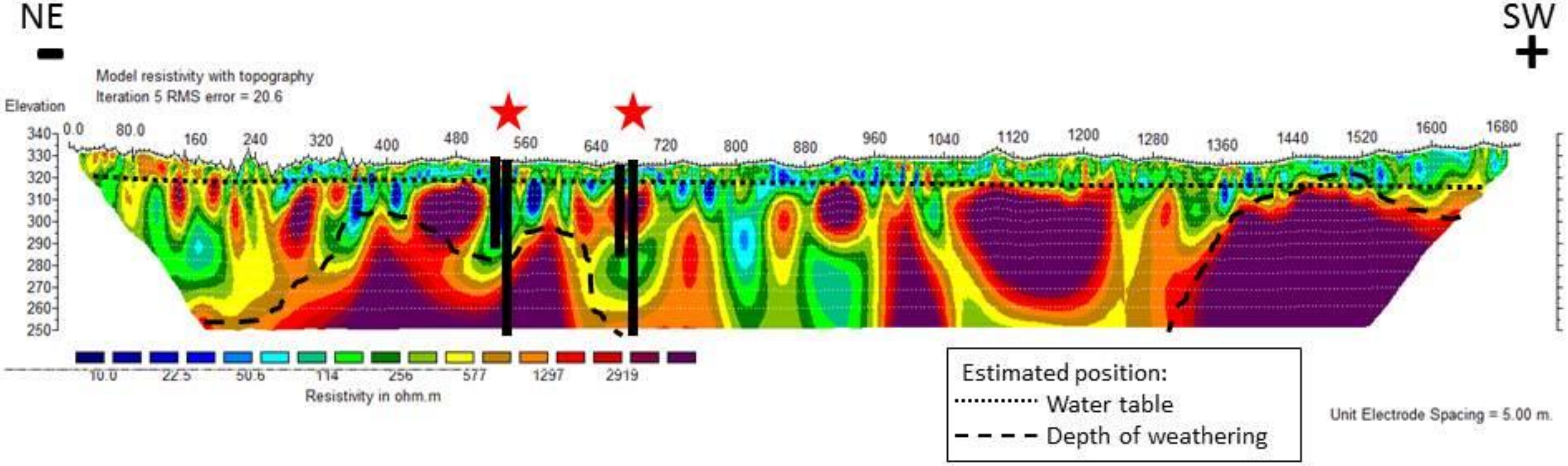
- Runs perpendicular to river channel (from north to south)
- Structure identified at ± 150m possibly having a damming effect on groundwater flow from the south towards the river.
- Proposed borehole drilling locations at ± 170m, 90m and 250m (in order of priority)

Letaba Protected Areas: LM005



- Runs perpendicular to river channel from river in a SE direction
- Deep sands closer to river; possibly part of alluvial aquifer
- Proposed borehole drilling location at ± 100m

Letaba Protected Areas: LM006



- Runs parallel to river channel in a South-westerly direction
- Shallow water table estimated
- A number of structures identified; i.e. 240m, 550m, 670m, 800m and between 1270-1350m.
- Both geophysics and aerial imagery suggests presence of more dykes on the southern side of Letaba River (i.e. Letaba Ranch).
- Proposed boreholes to be drilled at 550m and 670m.

3.4.3 Hydrocensus

An initial hydrocensus was performed during May 2014 in a local community just north of the study site. The hydrocensus was conducted in order to provide some indication of the local hydrochemistry in the surrounding area as well as how dependent local communities are on groundwater for domestic and small-scale irrigation supply. The data provided below stems from an initial hydrocensus conducted north in Mbaula and on a local reserve, Mthimkhulu (Fig. 3.12).

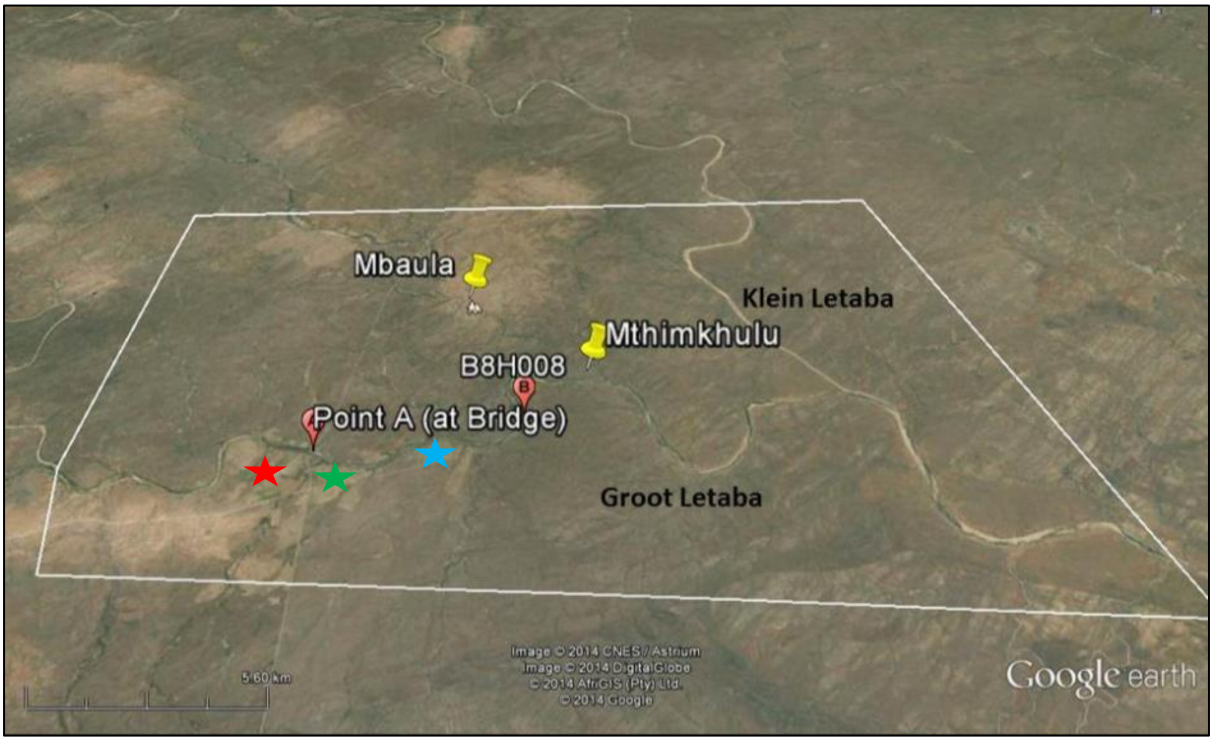


Figure 3.12 Mbaula Village and Mthimkhulu Reserve in relation to the study site

(i) Mbaula

A total of 37 boreholes were identified in Mbaula. However, hydrochemistry variables were only measured in 32 of these due to owners / operators not being available to switch on the pumps to obtain a water sample. Boreholes in Mbaula were drilled to an average depth of 50m. Of the 32 boreholes, the pH in Mbaula averaged at 7.19 while groundwater temperatures averaged at 24.44 °C. Groundwater measured in nine of these boreholes was extremely saline resulting in instruments unable to measure electrical conductivity (EC) because it was out of range. In 16 of these boreholes, EC ranged between 12-19 mS/cm. In less than 22% of the boreholes measured (i.e. only 7 boreholes), groundwater was very fresh with a low EC ranging between 1-2 mS/cm. It is likely that these boreholes were drilled along dykes where preferential pathways act as conduits for fresh surface water to recharge aquifers. When aquifers have longer residence times, water reacts with the chemistry of the subsurface geology and influencing the chemical signature of the groundwater.

(ii) Mthimkhulu

There is a total of six boreholes located throughout the Mthimkhulu Reserve, of which only five could be accessed for recording (Table 3.1). Not all of these boreholes are actively pumped. At these inactive boreholes, a baler was submerged in order to collect a water sample for hydrochemistry measurements.

Table 3.1 Details of boreholes located on Mthimkhulu Reserve.

Borehole ID	**Status**	**Activity (eg. Domestic, farming)**	**Borehole Depth (m)**	**Water Level (m)**	**pH**	**EC (mS/cm)**	**Temp (°C)**	**TDS (ppt)**
WP 019	Active	Domestic	?	Covered				
WP 020	Not always	Domestic, Watering Hole	50	10.21	6.9	14.75	26.2	7.36
WP 021	Not active	Domestic	100	21.96	6.26	0.5	27.6	0.25
WP 022	Not active	Domestic, Watering Hole	30	2.32	6.9	13.33	25.6	6.71
WP 023	Active	Domestic, Lodge	60	10.97	7	15.5	20.2	7.64

In general, the groundwater observed on Mthimkhulu is similar to that measured around Mbaula thus providing a decent indication of the local hydrochemistry in the area. Borehole WP021, which was drilled up to 100m to supply water for a guest lodge along the Groot Letaba (just upstream of the Groot and Klein Letaba confluence), has good quality water with regards to the low EC measured. A hydrocensus is still to be completed south of the Groot Letaba in the Selwane area and on Letaba Ranch.

(iii) Additional Hydrocensus Information

Although no formal hydrocensus has been completed on these farms as yet, correspondence with the farmers provided additional hydrocensus information. The farm represented by the red star in Figure 3.12 has a total of seven boreholes on the property but only one of these are actively used to supply water for household use. Crops are irrigated directly from the Groot Letaba River. The farm represented by the green star irrigates using both groundwater as well as direct supply from the river. The exact amount of boreholes on this property is still uncertain. The farm represented by a blue star (as well as the farm directly opposite the river) does not have any boreholes drilled on the property since it irrigates daily using water directly from the Groot Letaba. A more detailed hydrocensus will be conducted to verify the water resources being used by these farmers.

4. WORK PLAN

- Over the next few months, focus will be on borehole drilling, installation of equipment and monitoring.
- Boreholes will be drilled along the Groot Letaba which will be characterised using pump tests and equipped with instrumentation to monitor water level fluctuations.
- Hydrochemistry and isotopic signatures of the river and surrounding groundwater will be monitored as well.
- Once procured, scintillometers will be installed along the river to measure evapotranspiration rates by riparian vegetation.

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6. APPENDIX

Below are photos taken at the study site during the geophysics survey and hydrocensus.

Figure 6.1 The ABEM Terrameter used to measure resistivity of subsurface geology.

Figure 6.2 Resistivity survey across a farm along the southern bank of the Groot Letaba River (LF006).

Figure 6.3 Low flows along the Groot Letaba during August 2014.

Figure 6.4 Students during a geophysics survey on a farm on the northern bank (LF003).

Figure 6.5 Using a baler to obtain a water sample for hydrochemistry during a hydrocensus (A) while (B) depicts a dyke intercepting the river bed along the Groot Letaba.

Figure 6.6 Community boreholes enclosed and locked away in order to prevent vandalism and misuse of the resource.

Figure 6.7 The LF002 survey conducted on the northern bank running from the river bed up along the bank perpendicular to the river.

Figure 6.8 The start of a transect of one of the surveys which ran from the river bed towards the bank.

Figure 6.9 Low flows along the Groot Letaba at Letaba Ranch during August 2014.

Figure 6.10 One of the communal boreholes to supply water for Mbaula.

Figure 6.11 Transect LF003 running from the river bed up along the northern bank for roughly 250m.