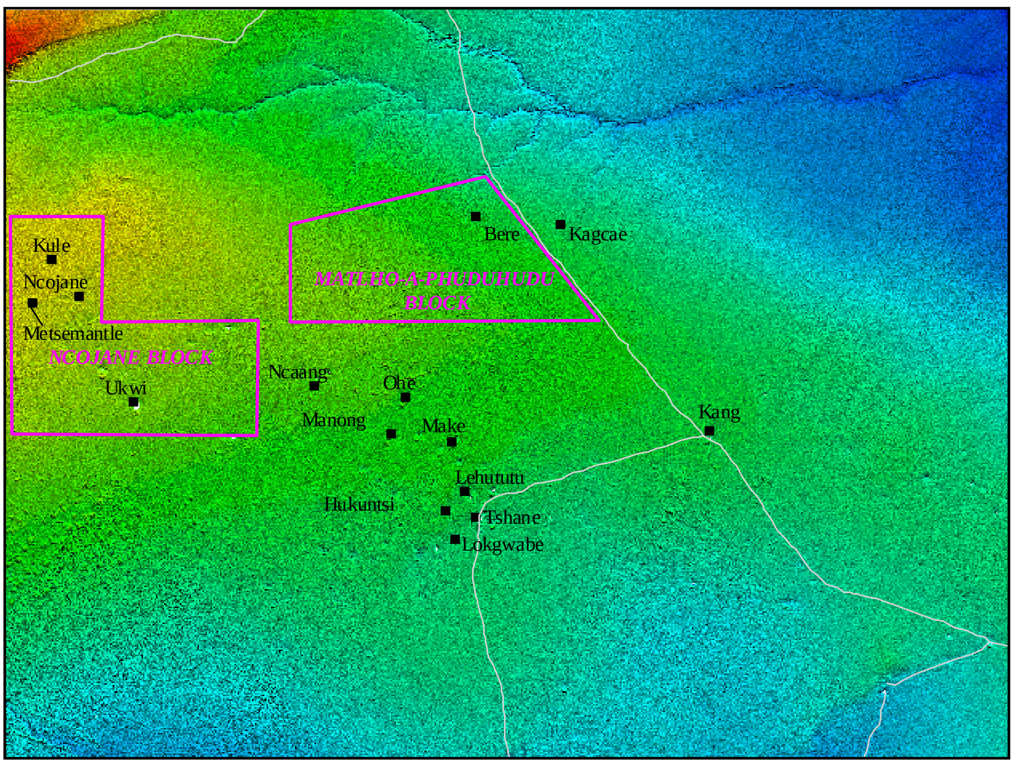
REPUBLIC OF BOTSWANA

Department of Water Affairs
Ministry of Minerals, Energy and Water Resources

Matsheng Groundwater Development Project

(TB- 10/3/93/2001-2002)



FINAL REPORT
EXECUTIVE SUMMARY

MARCH 2008

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PREFACE

This Executive Summary provides an overview of the results, conclusions and recommendations of the Matsheng Groundwater Development Project. The project was commissioned by the Department of Water Affairs and was executed by Water Resources Consultants. The project activities were commenced in August 2004 and were completed in March 2008. The main goal of the project was to locate and develop sufficient potable groundwater resources to supply the primary demand centres called as “Matsheng” Villages as well as the secondary demand centres comprising of 19 villages located in central and southern Ghanzi District up to the year 2023. The name “Matsheng” refers to a group of four villages, which are: Hukuntsi, Tshane, Lehututu and Lokgwabe. The total water demand of both primary and secondary demand centres by the year 2023 was calculated as 1, 655 cubic metres per day.

Based on results of a multi disciplinary study involving among others, use of remotely acquired data (aeromagnetic and satellite imagery), ground geophysical surveys, borehole geophysical logging, analysis of drilling, pump testing, hydrochemistry and water level monitoring data as well as numerical groundwater modelling, the Ecca aquifer was assessed to be the most potential aquifer for long term water supply to the demand centres. As a result a new wellfield with an assessed sustainable abstraction capacity of 9600 cubic meters per day was installed in the Ecca aquifer near Ncojane Village. The water quality parameters (chemical constituents) of all production boreholes in this new wellfield are within the Class II limits of the Botswana drinking water standards (BOS 32:2000).

The developed aquifer (Ecca) lies in the southwest Karoo basin which extends southwards & westwards into South Africa and Namibia respectively and hence it is a transboundary aquifer. The overall utilisation of this aquifer needs to be managed using the concepts of transboundary water management which at present are being pursued very actively by various international organizations.

Scientific and legal issues that affect the management of these shared water resources (aquifers) need intergovernmental agreements. It is recommended that the Department of Water Affairs actively participates in the on-going activities of Internationally Shared Aquifer Resource Management (ISARM) initiatives that have been commissioned by UNESCO. It will be prudent for the Department of Water Affairs to initiate collaborative arrangements with Namibia and South Africa to develop the monitoring and management programme for this transboundary aquifer.

The complete reporting of this Project has been compiled in 6 Volumes and an Executive Summary as listed below:

	Executive Summary
Volume 1	*Main Report*
Volume 2	*Hydrogeological Report*
Volume 3A	*Airborne and Ground Geophysics Report*
Volume 3B	*Transient Electromagnetic Sounding Data, Interpretation and Plots (Part 1 and 2)*
Volume 3C	*Downhole Geophysical Logging Report*
Volume 4	*Hydrochemistry and Environmental Isotopes Report*
Volume 5	*Groundwater Modelling*
Volume 6	*Preliminary Wellfield Design and Cost Estimates*

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Water Resources Consultants (WRC) would like to thank the project supervisors: Mr N. Mangisi and his predecessor Mr C. Chilume and other staff members of the Department of Water Affairs (DWA) who were generous in providing information and guidance at all stages of the Project. Their constructive views and advice were most appreciated.

WRC also wishes to express sincere thanks to Dr. A. R. Tombale, Permanent Secretary; Mr. V. Bagopi and his predecessor Mr B. Paya, the Director of the Department of Water Affairs; and Mr. I. Mannathoko, Head Groundwater Division, Department of Water Affairs for providing us with an opportunity to work on this challenging Project.

WRC is particularly thankful to the Ncojane community as a whole and to the government officials based in Ncojane, CharlesHill and Ghanzi. WRC also thanks the CharlesHill, Hukuntsi and Ghanzi Land boards who provided guidance on a number of occasions ranging from arranging meetings, obtaining data and information, clearing of the sites for drilling and other associated matters.

WRC Project Team deserves special thanks and appreciation for performing their duties with dedication, diligence and to high professional standards. The Personnel involved in the project included:

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WRC takes this opportunity to thank members of the Project Steering Committee particularly: Mr J. Ntsatsi, Mr N. Mbuli, Mr K. Setimela, Mr T. Setloboko representing the Department of Water Affairs; Mr Keakantse, from Ghanzi/CharlesHill Land Board, Dr. G. Tshoso, Mr C. Chilume, and Mr M. Keeletsang from Department of Geological Survey, Mr J. Monggae from GeoScience Consulting Services and Mr M. Madi from Hukuntsi Water Unit..

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We also take this opportunity to pay tribute to the late Mr. Flenner Linn, one of our team members, who passed away after a road accident in Zambia. May God rest his soul in peace.

Last but not least we would like to express our appreciation to the Ncojane Police, Marakanelo C. J. S. School Staff, and Ncojane Post Office Staff for giving us access to their communication devices whenever required.

Water Resources Consultants is most grateful to everyone else not mentioned here who assisted throughout the course of the project.

ACRONYMS AND ABBREVIATIONS

ACL	Analytical Compu Log
ADAS	Automated Data Acquisition System
AIDS	Acquired Immune Deficiency Syndrome
AMSL	Above Mean Sea Level
AMT	Audio Magneto-Telluric
ART	Anti-retroviral Therapy
ASTER	Advance Space-borne Thermal Emission and Reflection Radiometer
BGL	Below Ground Level
BH	Borehole
CMB	Chloride Mass Balance
CSAMT	Controlled Source Audio Magneto-Telluric
CSO	Central Statistics Office
DGS	Department of Geological Surveys
DWA	Department of Water Affairs
DTH	Down the Hole Hammer
DTM	Digital Terrain Model
EC	Electrical Conductivity
GIS	Geographical Information System
GS	Ground Surface
GCS	Geotechnical Consulting Services (Pty) Ltd.
HBC	Home Based Care
HIS	Hue- Intensity- Saturation
HLEM	Horizontal Loop Electromagnetic
Hz	Hertz (Unit of frequency)
JICA	Japan International Cooperation Agency
m	Meter
m atoc	Meter above top of casing
m bgl	Meter below ground level
$m^{3/}$day	Meter cubic per day
m^3/hr	Meter cubic per hour
mg/L	Milligram per litter
msec	Milli-seconds
MT	Magneto-Telluric
MRT	Mean Residence Time
NDVI	Normalised Difference Vegetation Index
NSAMT	Natural Source Audio Magneto-Telluric
PCIAC	Petro-Canada International Assistants Corporation
PMC	Percent Modern Carbon
PVC	Poly-Vinyl Chloride
RGB	Red- Green - Blue
PPK	Post Processing Kinematics
RTP	Reduce to Pole
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave Infra-Red
TDEM/ TEM	Time-Domain Electromagnetic/ Transient Electromagnetic
TDS	Total Dissolved Solids
TIR	Thermal Infra-red
UTM	Universal Transverse Mercator
VES	Vertical Electrical Sounding
VNIR	Visible Near Infra-Red
WCS	Wellfield Consulting Services (Pty) Ltd.
WRC	Water Resources Consultants (Pty) Ltd.
µS/cm	Micro-Siemens per centimeters (Unit of EC)
Ω-m	Ohm-meter (Unit of resistivity)

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1 INTRODUCTION AND PROJECT OBJECTIVES

1.1 INTRODUCTION

Water Resources Consultants (WRC) was contracted by the Department of Water Affairs (DWA) to execute the Matsheng Groundwater Development Project.

The goal of the Matsheng Groundwater Development Project was to locate and develop sufficient potable groundwater resources for supply to the primary and secondary demand centres of northern Kgalagadi District up to the year 2023. The primary demand centres comprise of the "Matsheng villages", which is a group of four villages, i.e. Hukuntsi, Tshane, Lehututu and Lokgwabe. The "secondary" demand centre comprise of 19 villages located in central and southern Ghanzi District. WRC estimated the water demand of both the primary and secondary demand centres by the year 2023 as 1,655 cubic metres per day. These estimates match very well with the estimates worked out by National Water Master Plan Review (2006), which has estimated the demand as 1,683 cubic metres per day. The location of the "Matsheng" villages, the secondary demand centres and the project area is shown in **Figure 1.1.**

To accomplish this goal, groundwater resources of two major aquifer systems, i.e Ntane Sandstone Aquifer and the Ecca Aquifer in the project area were investigated. The terms of reference provided by DWA had outlined two areas, i.e. Matlho-a-Phuduhudu Block and Nocojane Block for this study as previous studies had identified these areas as potential areas for further exploration, resource assessment and development. The Ntane Sandstone Aquifer present in the Matlho-a-Phuduhudu Block was investigated in detail during the Hunhukwe/Lokalane Groundwater Survey Project (WCS, 2001). As limited information was available on the Ecca Aquifer in the project area, the exploration activities of current project were focused on this aquifer.

1.2 PROJECT OBJECTIVES

The project objectives were as follows:

- Assess the current water demand and supply for the primary and secondary demand centres.
- Project water demands for next 20 years for primary and secondary demand centres and develop water supply to meet the demand.
- Project water demand for next 20 years for 8 other villages (additional demand centres) in Central Ghanzi District including Ghanzi township.
- Site, drill and test exploration, monitoring and production boreholes.
- Assess the sustainable and exploitable groundwater quantities using both analytical and numerical models and construct a wellfield in the most potential area.
- Design and install a hydrogeological monitoring network in the project area and monitor water levels for generation of input data for the numerical model and recharge assessment.
- Prepare preliminary engineering design and cost estimates for construction of water supply infrastructure system to supply the primary demand centres.
- Prepare and submit detailed technical reports providing a description of the hydrogeology of the project area in terms of aquifer geometry, aquifer characteristics, groundwater resource estimation, hydrochemistry, recharge assessment and recommendations regarding abstraction from the wellfield and its long term management.

Figure 1.1 Project Area Location Map

2 PROJECT AREA OVERVIEW, WATER DEMAND AND SUPPLY

2.1 PHYSICAL SETTING

2.1.1 LOCATION

The project area consists of two blocks, the Ncojane and the Matlho-a-Phuduhudu Blocks and is located in the western part of Botswana and falls within two administrative districts of Kgalagadi and Ghanzi districts. The Matlho-a-Phuduhudu Block falls within the Ghanzi District while the Ncojane Block straddles both the Kgalagadi and Ghanzi Districts. Both blocks are located southwest of Ghanzi Township, west of the Trans-Kalahari Highway, and east of the Namibian Border. The Trans-Kalahari Highway is the main access road into the project area. Bere, Hunhukwe, Lokalane, Ncaang and Monong villages/settlements are located within and in the vicinity of the Matlho-a-Phuduhudu Block, while Kule, Ncojane, Metsimantle, Metsimantsho, Ukwi and Ngwatle villages/settlements are located within the Ncojane Block. The Matsheng villages, comprising of Hukuntsi, Tshane, Lehututu and Lokgwabe and associated localities, are located approximately 120 to 150 km south of the Matlho-a-Phuduhudu Block and 150 to 200 km southeast of the Ncojane Block (**Figure 1.1**).

2.1.2 PHYSIOGRAPHY

Gently undulating topography in which fossil vegetated dunes, pans and dry river valleys occur are the principal geomorphologic features of the project area. A topographic map of the project area, generated using 5 metre interval DTM data obtained from the Department of Surveys and Mapping is given in **Figure 2.1**. In general, the area slopes from west to east with a surface divide oriented NW-SE running through the area. To the north of this divide, the general slope is toward the northeast whilst to the south the overall slope is to the southwest (**Figure 2.1**) .The highest elevation in the project area of about 1285 m above mean sea level (amsl) occurs near Kule village in the northern part of the Ncojane Block while the lowest elevation of about 1030 m is present south east of Tshane Village. The numerous pans and depressions are also clearly visible in the contour map, particularly in the southern parts of both the Ncojane and Matlho-a-Phuduhudu blocks. Some of the pans follow a linear pattern aligned northwest to southeast along major structural lineament directions identified from satellite imagery interpretation.

2.1.3 CLIMATE

In terms of climate, the study area is arid to semi-arid (WCS, 2001; Bhalotra, 1987). Rainfall data from four locations (Kang, Tshane, Ncojane and Ghanzi) in and around the project area indicate that rainfall mainly occurs during the warm to hot summer months of November to March. Most of the rain fall occurs between the months of November to March, with the peak rainy months being January and February. The highest annual rainfall recorded in the area was 858 mm in 1974 in Ghanzi while the lowest annual rainfall on record is 99 mm recorded in Ncojane in 1995. Mean annual rainfall amounts range from 250 mm in Ncojane in the west to 456 mm in Ghanzi in the northeast. Tshane has a mean annual rainfall of 350 mm. The average potential evapotranspiration calculated from data obtained from the ADAS station in Matlho-a-Phuduhudu is 1700 mm/annum (Chilume, 2001). Overall, the area is characterised by low rainfall and high potential evapotranspiration resulting in soil moisture deficits, hence, very low potential for annual groundwater recharge under normal rainfall conditions.

2.1.4 SURFACE WATER

There are no permanent surface water bodies in the project area because of its semi-arid to arid climatic conditions, high evaporation rates and the high infiltration rate capacity of its sandy soils. However after heavy rainfall events, surface water accumulates in the numerous pans found throughout the project area for relatively long periods of time, and thus pans constitute an important source of drinking water for both wildlife and livestock in the area for certain months of the year during the rainy season.

Figure 2.1 Topographic Map of the Study Area

2.2 GEOLOGICAL FRAMEWORK

2.2.1 GEOLOGICAL FRAMEWORK

The project area lies within the Southwest Botswana Karoo Basin, which constitutes one of the seven Karoo basins recognised in Botswana (Smith, 1984; WCS, 2001). This basin is bound in the east by the north-south trending Kalahari Line (approximately west of 22^{O} E), which is an ancient fault system intruded by basic igneous rocks (Smith 1984). In the north, the basin is bound by the northeast-southwest trending Tsau Fault and emergent Proterozoic units of the Ghanzi Group. The Southwest Botswana Karoo basin extents southwards and westwards into South Africa and Namibia respectively. Most of the bedrock geology within the project area is obscured by unconsolidated Kalahari Beds sediments of variable thickness and lithologies.

The Proterozoic Okwa Basement Complex is the oldest bedrock unit in the project area, while the Karoo Supergroup constitutes the most important geologic unit in terms of groundwater resources potential in the project area. The bedrock geology of the project area is illustrated in **Figure 2.2 and** the regional stratigraphy is summarised in **Table 2.1** whilst the Karoo stratigraphy of Botswana and Namibia is given **Table 2.2**.

Table 2.1 Regional Stratigraphy *(after Carney, et al, 1994)*

Age	Supergroup	Group/Formation	Description
Cretaceous to Recent	Kalahari Beds		Unconsolidated sand, clay, and duricrusts
Cretaceous	Dolerite intrusions and dykes		Dolerite Dykes and sills
Carboniferous to Cretaceous	Karoo	Stormberg Lava	Basalt
		Lebung	Sandstone , minor conglomerates and mudstone
		Ecca	Interlayered sandstone, siltstone, mudstone with carbonaceous mudstones and thin coals seams
		Dwyka	Tillite, mudstone and siltstone
Late Proterozoic		Nama	Conglomerate, sandstones and siltstones
Mid - Late Proterozoic	Damara	Ghanzi	Quartzites, arkoses and shales
		Kgwebe	Volcano-sedimentary units
		Okwa	Felsites and clastic sedimentary units
Early Proterozoic	Okwa Basement Complex		Granite, gneiss and felsite

Table 2.2 Karoo Stratigraphy of the Project Area *(Modified from Smith, 1984; JICA, 2002)*

Group	Eastern Namibia	Botswana		Lithology	Age
		West of 22° E Longitude (SW Karoo Basin)	East of 22° E Longitude (Central Kalahari Karoo Basin)		
Stormberg Lava	Kalkrand Basalt	Stormberg Lava	Stormberg Lava		Triassic to Lower Cretaceous
Lebung	*absent*	Nakalatlou	Ntane Sandstone	Reddish to pink fine to medium grained sandstone	Permian to Triassic
		Dondong	Mosolotsane	Basal conglomeratic sandstone, greenish-yellow sandstone interbedded with red-brown siltstones, red-brown mudstone	
	Upper Reitmond		*absent*		
Beaufort	Lower Reitmond	Kule	Kwetla	Basal fine grained sandstone (thin), dark grey mudstone/siltstone/shale purple grey reddish fine to medium sandstone (thin), grey, none carbonaceous purple-brown mudstone (main)	
Ecca	Auob	Otshe	Boritse	Coarsening upwards grey-brown to orange sandstone, micaceous at base and carbonaceous mudstone/siltstone and coal towards top	
				Thin fine grained dark grey sandstone, interbedded dark-grey siltstones/silty mudstone	
				Fine to medium grained sandstone (occasionally micaceous), overlain by occasionally micaceous dark grey/black mudstone with bands of dull coal	
				Interbedded light grey micaceous siltstone and dark grey mudstone with bright coal bands near top	
			Kweneng	Sequence of fine to medium grained sandstone interbedded with dark grey siltstone/mudstone, silty mudstone and occasionally pyrite reach at top	
				Coarsening upwards sequence of micaceous yellow, grey and brown sandstones, with micaceous siltstone, coarse grained pale grey arkosic sandstone near top	
	Mukorob	Upper Kobe	Bori	Dark grey silty mudstone with thin sandstone, grey micaceous siltstone with very thin coal bands at top	
	Nossob	Lower Kobe (Ncojane Sandstone)		From bottom dark grey siltstone, grey fining upwards sandstone, dark grey siltstone/carbonaceous mudstone	
Dwyka	Dwyka Group	Malogong Formation	Dukwi Formation	Predominantly Tillite with quartzite/granite clasts in sandstone matrix.	Carboniferous to Permian
		Khuis Formation		Purple mudstone rythmites/varvites with dropstones	
		Middlepits Formation		Purple siltstone and very fine sandstone	

Figure 2.2 Geological Map of the Project Area

2.2.2 Regional Structural Setting

The project area is located within a regional sedimentary basin, the South West Botswana Karoo Basin which contains mid-Proterozoic and Paleozoic sedimentary rocks. This basin is bounded by the Damara Orogenic Belt, which includes the Ghanzi Ridge, just to the north of the project area. To the west, the basin extends more than 200 kilometres into Namibia where it is bounded by emergent early Proterozoic basement. The southern margin of the basin is less well defined but extends well beyond the project area into northern South Africa and to the east the basin joins the Central Kalahari Sub-basin (Carney et al, 1994; Smith, 1984). In the project area, the Karoo formations dip gently to the east, with Karoo thickness increasing similarly to the east. The pre-Kalahari bedrock surface also slopes generally to the east again with thickness of Kalahari cover increasing to the east.

The dominant regional structural features in the project area are two major cratonic discontinuities, the north-south trending Kalahari Line and the northeast-southwest Makgadikgadi Line. The Kalahari Line is identified in regional aeromagnetic surveys and represents a broad and co-linear series of deep seated faults and coincident mafic intrusions. It is believed to represent the edge of a continental craton of mid-Proterozoic age (WCS, 2001). The Makgadikgadi Line coincides with a zone of increased seismicity which separates regions of strongly contrasting magnetic and gravity signatures (Carney et al, 1994).

The northeast trending Tsau Fault is a major fault in the project area, located along the southern edge of the Ghanzi-Chobe Fold Belt and bounding much of the Karoo formations to the north (**Figure 2.3**). The Tsau Fault, includes a series of thrust faults and forms the stratigraphic boundary between the Karoo to the south and the Ghanzi Group to the north.

Significant lineaments identified from Satellite Imagery interpretation evident in the areas underlain by the Karoo Supergroup may reflect structures, and are oriented NE and ENE sub-parallel to the Tsau Fault. Other lineaments are oriented in a N-S direction and are most probably associated with re-activation of much earlier fractures associated with the Kalahari Line. Some of these structures exert significant control on the depth to the top of the different geological units, groundwater quality and groundwater flow directions in the project area.

A series of NW-SE trending faults/lineaments transect the project area and parallel the direction of the post-Karoo dolerite dyke swarm in north eastern Botswana.

Figure 2.3 Lithostructural Map of the Project Area

2.3 WATER DEMAND AND SUPPLY

2.3.1 OVERVIEW

The Matsheng villages, comprising of Hukuntsi, Tshane, Lehututu and Lokgwabe are located within a 10 km radius from each other and are connected by tarred roads. Prior to the year 2000, when an integrated water supply scheme interconnecting the four villages was commissioned, each of the four Matsheng villages had its own independent water supply scheme that sourced water from boreholes tapping shallow perched aquifers in Kalahari Beds (DWA, 2003). Some of these production boreholes have since been decommissioned due to factors such as increasing salinity, nitrate pollution, ecoli contamination, and declining yields. These factors, together with the realisation that the perched Kalahari Beds aquifers supplying the Matsheng villages are not sustainable, prompted the Department of Water Affairs to seek alternative sources of water in the area, leading to the present project.

The terms of reference had provided a list of villages in the area whose water supply needs required review to meet the 2023 year demands. These villages were categorised into groups and were designated as primary, Secondary and additional demand centres. These demand centres are as follows:

- The four Matsheng Villages - Hukuntsi, Lehututu, Lokgwabe and Tshane were regarded as the '***Primary Demand Centres***' and the project was principally focused on meeting their water demand.

- Nineteen villages and settlements located in Northern Kgalagadi and Western/Southern Ghanzi Districts around the Ncojane Block. These were termed as '***Secondary Demand Centres***' and in addition to meeting the demand of the primary demand centres, the project also catered for their water demand.

- Eight villages and settlements in the Ghanzi District including Ghanzi Township. These were referred to as '***Additional Demand Centres'*** and were not considered for supply by the project.

The Location of these demand centres is shown in **Figure 2.4** and the details of the Population and water demand of each village and its associated locality is provided in **Appendix 1**.

Figure 2.4 Location of the Demand Centres

2.3.2 WATER SUPPLY AND DEMAND

2.3.2.1 OVERVIEW OF WATER SUPPLY

Based on a review of existing information in the project area, the following conclusions were reached regarding the water supply status:

1. According to the records provided by the Water and Wastewater Department in Hukuntsi, the September 2004 supply for the Matsheng Villages was 912 m^3/d. However data from the Regional Master Plan for the Western Region (July 2004) indicates that the available supply was 510 m^3/day. During the field visits to the project area, an acute shortage of water was observed for all the four Matsheng villages. It is therefore likely that the reported supply rate of 912 m^3/day was overestimated. The exact abstraction rates for Matsheng Villages is not easy to verify due to un-availability of reliable abstraction data since 1998 when DWA closed their offices in Hukuntsi.

2. Only a handful of the original production boreholes in the Matsheng villages are operational mainly due to water quality deterioration associated with nitrate and ecoli contamination as well as due to declining yields. This highlights the need for effective aquifer management including source protection, particularly in areas with such limited potable water resources.

3. In order to alleviate the acute water shortage for the Matsheng villages, a DWA commissioned project to interconnect the four villages was completed in 2005. The source for this project is four boreholes (BH8570, BH8571, BH7854 and BH7856) located in Lokgwabe and Lehututu Villages**.** According to information supplied by the Hukuntsi Water Unit on 14th April 2008, the daily abstraction rate from these boreholes is 700 m^3/d (**Table 2.3)**. Although the reported abstraction rate is more than the estimated daily water demand for the Matsheng Villages (2004 to 2010), acute water shortages are still common place probably indicating that, the supply infrastructure is inefficient (leakage or wastage) or that the supply is overestimated. In view of the fact that the interconnection project was a temporary measure designed to cater for the Matsheng Villages supply up to 2009, estimates for new supplies were made assuming that all the supply has to come from new sources after 2009. This is because the current supply is from perched Kalahari Beds aquifers which are not sustainable for long term water supply and are vulnerable to pollution.

Table 2.3 Status of Water Supply Boreholes in Matsheng (*April 2008)

Location	BH No	TDS (mg/L)	Static Water Level (m)	Pump Intake (m)	Recommended Hrs of Operation	Recommended Yield (m^3/hr)	Daily Yield at Recommended Hrs of Operation (m3/d)
Lokgwabe	8570	284	19.50	29	10	10	100
	8571	348	14.31	25	10	33	330
Lehututu	7854	371	18.23	36	10	12	120
	7856	399	18.10	37	10	15	150
Total							**700**

(* April) – information provided by the Hukuntsi Water Unit on 14 April 2008.

4. For the Secondary Demand Centres, existing records and field observations indicate that there is currently no major supply shortfall in most of these villages. However, the settlements of Ngwatle, Ncaang, and Monong have very serious water shortages and the water is being supplied through water bowsers. Additional water resources to cater for the needs of the Secondary Demand Centres were developed during this project.

5. Existing records seem to indicate that there is no water shortage in the villages classified as Additional Demand Centres with the exception of Ghanzi Township. However as per the Regional Master Water Plan for the Western Region (2004), there is shortage of water in these villages. It has to be noted that these villages were not considered as the main demand centres and their supply was not considered when developing the new wellfields.

2.3.2.2 *WATER DEMAND*

Based on the projected populations and the per capita water consumption assessed during the project, water demand projections for the project area's demand centres are given in **Table 2.4** and their location is shown in **Figure 2.4.**:

Table 2.4 Population and Water Demand of the Demand Centres

Demand Centre	Year 2001	Year 2006		Year 2010		Year 2023	
	Census Population	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)
Primary Demand Centre Matsheng Villages	8,202	8,668	597	9,540	659	12,507	863
Secondary Demand Centre	13,641	11,227	625	12,111	676	14,183	792
Additional Demand Centre	15,973	16,782	936	18,785	1048	23,618	1319

The main observations are as follows

1. The 2006 water demand for the Matsheng Villages (Primary Demand Centres) is 597 m^3/d and is estimated to increase to 863 m^3/d by the year 2023. This figure (863 m^3/d, for 2023) is very comparable with the National Water Master Plan Review (NWMPR, 2006) figure of 888 m^3/d.

2. For the secondary demand centres, the 2006 and 2023 water demands were calculated as 625 m^3/d and 792 m^3/d respectively. The relatively low increase in the water demand for the secondary demand centres is attributed to low increases in the population of these centres, which among other factors can be attributed to the impacts of HIV/AIDS (CSO, 2001). Again the year 2023 water demand estimate by WRC is very close to the figure of 795 m^3/d contained in the NWMPR.

3. For the "Additional Demand" centres, the water demand is estimated as 936 m^3/d for 2006 whilst for the year 2023 the demand is estimated as 1319 m^3/d. The NWMPR gives an estimated demand for 2023 of 3019 m^3/d for these centres which is ~2.4 times the WRC estimate. It has to be noted that the demand for the "Additional Demand Centres" was not considered during the project execution following discussions with Client.

The total combined water demand for the Primary and Secondary Demand Centres for 2023 based on WRC estimates is 1655 m^3/d (~0.604 million cubic metres/year).

The population and water demand of each village in the Primary, Secondary and additional demand centres is provided in **Appendix 1.**

3 PROJECT ACTIVITIES AND PROGRAMME

WRC's overall approach to the execution of the Matsheng Groundwater Development Project, was based on a phased sequence of activities aimed at ultimately achieving the project goal of locating a wellfield capable of meeting the water demand for the Matsheng Villages and the Secondary Demand Centres up to the year 2023. The programme was divided into three main Phases of activities which constituted a logical breakdown of the overall project schedule as follows:

Phase 1: Inception Phase
Phase 2: Exploration Phase
Phase 3: Production and Resource Evaluation Phase

This approach allowed for integration and evaluation of results from the various activities resulting in making judicious decisions that ultimately resulted in developing the water supply wellfield. The conclusion of all phases of the project culminated with preparation and submission of the **Final Report Volume 1** (Main Report), Six Technical Reports and an Executive summary.

The major activities undertaken in each phase are summarised below.

3.1 PHASE 1; INCEPTION PHASE

The main activities undertaken during the ***Inception Phase*** included the following;

- Review and Interpretation of existing data sets in the Project Area
- Integration of the different data sets to Develop a Conceptual Hydrogeological Model
- Assessment of the water demand for the project area's demand centres which were designated as Primary, Secondary and Additional Demand Centres
- Evaluation of suitable geophysical techniques to be deployed during the Exploration Phase
- Review of Existing Numerical Models in the Project - Matlho-a-Phuduhudu Area
- Development of a work plan and time schedule for the Exploration Phase
- Preparation of the Terms of Reference for the Environmental Impact Assessment Study
- Preparation of the Terms of Reference for Drilling and Test Pumping of Exploration Boreholes

The findings of the Inception Phase Activities were summarised in an Inception Report which was submitted to DWA on 22 November 2004.

3.2 PHASE 2; EXPLORATION PHASE

The ***Exploration Phase*** (***Phase 2***) was started in mid May 2005 and was completed in April 2006.

The main activities included:

- Rainfall and Groundwater Level Monitoring
- Ground Geophysical Surveys for Exploration Borehole Siting
- High Precision GPS Surveys

- Drilling of Exploration and Monitoring Boreholes
- Borehole Geophysical Logging
- Pump Testing of Exploration Boreholes
- Numerical Groundwater Modelling

The findings of the exploration Phase were summarised in a Project Review Report which was submitted to the client in April 2006.

3.3 PHASE 3; PRODUCTION AND RESOURCE EVALUATION PHASE

Phase 3, the Production and Resource Evaluation Phase, was started in May 2006 and completed in October 2007. The final reporting was carried out over the period November 2007 to March 2008. It involved among others the following activities:

- Ground Geophysical Surveys for Production Borehole Siting
- Drilling of Production Boreholes
- Test pumping of Production Boreholes,
- Updating of the Numerical Groundwater Model and Simulation of Wellfield Abstraction
- Borehole Geophysical Logging
- Resource Evaluation
- High Precision GPS Survey of Production Boreholes

Summaries of the project results, conclusions and recommendations are presented in the following chapters.

4 SUMMARY OF PROJECT RESULTS

The potential of the two main aquifers in the study area i.e. the Ntane Sandstone and Ecca (Otshe) to meet the long term water demand (2023) of the project area's primary demand centres (Matsheng Villages) and the secondary demand centres was assessed during the study.

A multi disciplinary approach involving review of previous groundwater studies in the area, aeromagnetic data interpretation, ASTER satellite imagery analysis, ground geophysical surveys, borehole geophysical logging, drilling, pump testing, hydrochemistry analysis, water level monitoring, numerical groundwater modelling and recharge assessment based on environmental isotopes was used to assess the groundwater potential of the two principal aquifers in the project area. Based on an integrated assessment of the study results, the following conclusions have been reached.

4.1 HYDROGEOLOGICAL

The main hydrogeologic units of the project area are aquifer systems developed in Karoo Supergroup sandstones (Ntane and Otshe Formations), with minor aquifers developed in unconsolidated Kalahari Beds, Mosolotsane/Kule Formations and Dwyka Group. The current assessment was focused on the two main aquifers of the project area i.e. the Ntane and Otshe aquifers. A summary of the main hydrogeological characteristics of two main aquifer units of the project area is given below.

4.1.1 NTANE SANDSTONE AQUIFER

The Ntane Sandstone which constitutes the main aquifer unit of the Lebung Group is only well developed in the Matlho-a-Phuduhudu Block, in what was termed the 'Lebung/Ntane Sub-Basin' by WCS, (2001). The southern boundary of the Ntane aquifer occurs about 70 km north of the Matsheng villages, where only the lower argillaceous Mosolotsane Formation was intercepted during drilling (DGS, 1996). West of the Matlho-a-Phuduhudu Block, the Ntane Sandstone becomes unsaturated and the formation wedges off against Ecca Group just east of the Ncojane ranches (**Figure 2.2**). It is overlain by Kalahari Beds for most of its extent. No water strikes were recorded in the Kalahari Beds while only minor water strikes were recorded in the overlying Stormberg Lava where present. Water strike depths range from 140 to 230 meters, while water levels range from 113 to 156 meters.

Groundwater levels of the Ntane Sandstone, where saturated often rise above the first reported water strikes suggesting that the aquifer is semi-confined in some areas of the Matlho-a-Phuduhudu Block, however for practical purposes it can be considered to be fully unconfined (WCS, 2001). The aquifer has variable yields, ranging from 3 to 54 m^3/hr. Transmissivity values of between 7 to 88 m^2/d were obtained. In terms of storativity, values of 6.70×10^{-4} and 2.20×10^{-3} were obtained from two boreholes with observation wells, which indicate semi-confined to unconfined conditions.

The general direction of ground flow for the Ntane aquifer is predominantly from west to east, with a north-easterly component in the central portion of the Matlho-a-Phuduhudu Block. Local flow variations occur in the southern part of this block with the flow patterns tending to a south-easterly direction. The general direction of groundwater flow follows the alignment of (W-E, NW-SE and NE-SW) lineament directions obtained from ASTER imagery interpretation (**Figure 4.1**). In terms of seasonal groundwater level fluctuations, the water levels in this aquifer are very flat to declining indicating that there is probably very negligible recharge to this aquifer.

Figure 4.1 Piezometric Map, Ntane Sandstone Aquifer

4.1.2 ECCA (OTSHE) SANDSTONE AQUIFERS

Sandstones of the Otshe Formation, which underlie an extensive portion of the project area, constitute the main aquifer unit within the Ecca Group. The Otshe aquifer consists of an alternating sequence of fine to coarse, clean sandstones separated by coals, carbonaceous mudstones, mudstones, shales and siltstones. On average, water strike depths range between 350 and 380 meters (bgl) in the central, eastern and southern parts of the Matlho-a-Phuduhudu Block. In the Ncojane Block and northwestern parts of Matlho-a-Phuduhudu Block, where the Ecca occurs beneath relatively thin Kalahari Beds and Lebung/Beaufort Group rocks, water strikes are generally between 145 to 290 meters below ground level. Rest water levels in the Otshe Sandstone aquifer range from 77 m to 153 m. In the majority of cases, the interpreted aquifer response from test pumping data is confined. Borehole yields are variable and range between 20 to over 100 m^3/hr. Transmissivity and storativity values respectively ranging between 4 to 431 m^2/d and $1.00x10^{-4}$ to $4.05x10^{-6}$ were obtained for this aquifer.

Existing data together with data collected during the current project also indicates that there is salinity stratification within the Ecca aquifer where both decreases and increases in salinity with depth were observed. Data collected during the current project indicates that the basal sandstones of the Kule and Mosolotsane Formations are often saturated with poor quality groundwater and might pollute the Otshe aquifer if boreholes are not properly constructed.

The primary direction of groundwater flow for the Ecca (Otshe aquifer) is from west to east with a northwest to southeast component in the southern part of the Ncojane Block (**Figure 4.2**). Several faults and lineaments were inferred from aeromagnetic and remote sensing data interpretation during the study and were referred to as F4, F5, F6, and F7. Faults **F6** and **F7**, although having a significant impact on the depth to the top of the Otshe Formation (dip slip faults), seem to have very limited impact if any on the groundwater flow direction. On the other hand faults, **F4** and **F5** have little impact on the depth to the top of Ecca (strike slip faults), but have a significant impact on the direction of groundwater flow as the groundwater flow direction runs parallel to their orientation (**Figure 4.2**). Regionally, the Ecca aquifer system is laterally continuous and groundwater inflow is from Namibia, where reported sub-cropping conditions and saturated Kalahari Beds result in enhanced recharge potential.

Figure 4.2 Piezometric Map, Ecca (Otshe) Aquifer

4.2 HYDROCHEMISTRY

4.2.1 NTANE SANDSTONE AQUIFER

Hydrochemical data for the Ntane aquifer is relatively sparse, with only 15 boreholes having reliable analytical data. However the available data was used to determine whether any noteworthy trends could be observed in the Ntane aquifer.

The salinity distribution trend for this aquifer is illustrated in **Figure 4.3** in the form of a TDS contour map. From this figure it is observed that groundwater in the central and western parts the Ntane Sub-basin is fresh with TDS values of between 200 and 600 mg/L with the lowest TDS found in the west associated with thin Kalahari cover (near BH9045). Towards the margins of the basin, particularly in the basalt sub-crop area in the north and the southern part of the Matlho-a-Phuduhudu Block, groundwater with relatively elevated TDS values (600 to 1000 mg/L) occurs. This trend was also observed in the sodium (Na) and chloride (Cl) distribution patterns, suggesting that recharge to the Ntane aquifer if any occurs mainly in the west in areas with thinner Kalahari cover. The TDS distribution pattern shows that in terms of groundwater development only the central portion of the Ntane Sub-basin has the potential for long term abstraction as the areas towards the basin margins already have water quality which is close to and above the Class II limits for drinking water for TDS (1000 mg/L). Significant exploitable saturated thickness for this aquifer is also limited to a small area in the central portion of the basin. Groundwater quality analysis results also supports the findings from groundwater flow data, that the aquifer may be compartmentalised into at least two flow systems, one in the north and one in the central part of the basin.

Figure 4.3 TDS Contour Map, Ntane Sandstone Aquifer

4.2.2 ECCA (OTSHE) AQUIFER

The Otshe aquifer is well represented with regard to boreholes with analytical data, particularly in the Ncojane Block, with a total of 40 exploration and 6 production boreholes in the study area. This means that hydrochemical trends in the Otshe aquifer can be identified with a high degree of confidence. Furthermore, as set out in the description of the hydrogeologic framework, the Otshe is essentially a confined aquifer. Hence a consistent hydrochemical evolution is expected along the flow path in the aquifer from recharge areas to discharge areas except for faults that may affect the groundwater flow in the aquifer by connecting it with either overlying or underlying aquifers.

In general, the groundwater flow is primarily from the west to east with a northwest to southeast component in the southern part of the Ncojane Block which means that the hydrochemical evolution in the aquifer should take place in an eastward or south-easterly direction.

Overall, the total dissolved solids (TDS) values for groundwater from the Ecca (Otshe Sandstones 1 and 2) aquifer are less than 1000 mg/L except in the extreme south of the Ncojane Block (Ngwatle area) and the southern parts of the Matlho-a-Phuduhudu Block. Salinity in the overlying Mosolotsane/Kule basal aquifers, where present, is consistently high and these aquifers could act as sources of contamination for the underlying Otshe aquifers. Most boreholes which had water strikes in the basal sandstone units of the Kule Formation have elevated fluoride and sodium concentrations.

Regionally, the salinity increases from the west to east and northwest to the southeast following the regional flow directions interpreted from the piezometric head of the Ecca aquifer. A relatively sharp increase in salinity (TDS) southeast of faults **F6** and **F7** indicates that these structures play an important role in the salinity distribution of the Ecca (**Figure 4.4**), by either connecting it with overlying or underlying poor quality aquifers. Also noticeable in this figure, is the distinctively low salinity region in the west and northwestern portions of the area (TDS less 1000 mg/L), suggesting that these areas are actively recharging or receiving active inflow from recharge areas to the west. The possibility of active recharge to the Ecca in western parts is also indicated by water level monitoring data.

Chemical analysis results from project boreholes tapping the Otshe aquifer indicate that most of the measured parameters in the Ecca (Otshe) aquifer are within the Class II limits of the BOS32:2000 standards with the exception of sodium, fluoride, TDS, and chloride in a few exploration boreholes. All boreholes with parameters exceeding the limits for drinking water standards are located to the southeast of fault **F6** which is an area not targeted for wellfield development.

For the six production boreholes in the Ncojane Wellfield, the groundwater is of very good quality with only the hardness exceeding BOS 32:2000 Class I limit in all boreholes (**Table 4.1**). However for three boreholes BH10404, BH10407 and BH10410 sodium and the TDS (salinity) slightly exceeds the Class I specification while chloride marginally exceeds the Class I specification in BH10404 and BH10407. One borehole, BH10402 has a fluoride value which is slightly above the Class I limit.

However, all parameters in the production boreholes are well within the Class II specification which is a very rare case for groundwater in Botswana.

Table 4.1 Chemical Analysis Results of the Production Boreholes

Macro Constituents

BH No	Sample Date	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Nitrite as NO_2 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Nitrate as NO_3 mg/L	F (mg/L)	EC (µS/cm)	TDS (mg/L)	Hardness as $CaCO_3$ mg/L
BH10402	23/9/07	7.3	88.2	25.9	19.3	<0.2	18.8	67.9	204	17.1	0.72	690	442	144
BH 10404	05/8/07	7.8	135.5	21.4	19.0	<0.05	33.0	112.5	208	17.1	0.59	840	538	132
BH10405	24/8/07	6.5	85.8	26.5	16.9	2.90	17.2	67.9	188	13.9	0.64	650	416	136
BH10407	05/9/07	8.3	139.5	22.7	19.7	<0.2	31.3	116.1	219	17.7	0.64	860	550	138
BH10410	16/9/07	7.5	112.0	21.8	16.3	<0.2	21.1	77.8	235	<0.2	0.69	720	461	122
BH10411	17/10/07	7.5	90.9	26.7	19.9	<0.2	19.5	62.5	215	17.6	0.6	690	442	148
Class I		25	100	80	30	3	200	100		45	0.70	700	450	20
Class II		50	200	150	70	3	250	200		45	1.00	1500	1000	200
Class III		100	400	200	100	3	400	600		45	1.5	3100	2000	500

Note Parameters Highlighted in grey exceeds the BOS 32:2000 Class I Limit

Micro Constituents

BH No	Sample Date	Al (mg/L)	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Ni (mg/L)	Zn (mg/L)	Cyanide as CN mg/L	pH (Lab) (20°C)
BH10402	23/09/2007	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.80
BH10404	05/08/2007	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.80
BH10405	24/08/2007	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.60
BH10407	05/09/2007	<0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.70
BH10410	16/09/2007	0.1	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6.90
BH10411	17/10/2007	0.3	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	7.60
Class I		0.1	0.01	0.003	0.05	0.25	1	0.03	0.01	0.05	0.020	3	0.070	6.5-8.5
Class II		0.2	0.01	0.003	0.05	0.50	1	0.3	0.01	0.1	0.020	5	0.070	5.5 - 9.5
Class III		0.2	0.01	0.003	0.05	1	1	2	0.01	0.5	0.020	10	0.070	5.0 - 10

Figure 4.4 TDS Contour Map, ECCA (Otshe) Aquifer

4.3 GROUNDWATER EXPLORATION AND DEVELOPMENT METHODOLOGY

Ground geophysical surveys comprising of TEM soundings magnetic profiling, and HLEM profiling were used to site exploration and production boreholes during the project with the following conclusions:

- Magnetic profiling assisted in locating aeromagnetic and remote sensing data interpreted lineaments and faults, some of which were proven to have major control on the aquifer geometry, groundwater flow and water quality. Magnetic profiling was also very instrumental in locating some dolerite sills, though not always due the horizontal and weathered nature of these dolerites.

- TEM soundings together with magnetic profiling were found to be the most effective methods for hydrogeological investigations in the project area and should constitute the main ground geophysical techniques employed for siting water supply boreholes in the area

- HLEM profiling was found to be ineffective because a large portion of the project area is underlain by thick conductive units overlying the target aquifer, except near Ncojane and Kule villages where Kalahari Beds, Mosolotsane and Kule Mudstones are thinner and more resistive.

- The DTH drilling technique was found to be an effective method for borehole construction in the project area. However, tricone bits have to be used to overcome backpressure problems associated with high yielding deep water strikes in the Otshe Sandstone aquifers.

- Down Geophysical logging comprising of a combination of electrical parameters, natural gamma and neutron logs was found to provide the best information to delineate geological contacts/formations.

- Water inflow zones were generally not recognised from temperature logs, probably because of the primary nature of the aquifers (not fractured). However, there were a few boreholes where water inflow zones were inferred from temperature logs.

4.4 RESOURCE ASSESSMENT

- The comparative analysis of the two main aquifers indicates that the Ecca aquifer has the highest potential in terms of groundwater development and a wellfield was constructed in this aquifer as shown in **Figure 4.5**.

- Numerical groundwater modelling indicates that the wellfield can sustain abstraction rates of approximately 10,000 m^3/d for a period of up to 30 years.

- The recommended daily abstraction rates for the new wellfield are given in **Table 4.2**.

- The potable exploitable groundwater reserves were calculated as 32 MCM and 8 MCM for the Ecca and the Ntane aquifers respectively (**Table 4.3**)

- For the Ntane aquifer, numerical groundwater modelling indicates that a wellfield in this aquifer pumping at 5000 m^3/day would dry up in less than 20 years. The potential for the Ntane aquifer to sustain large scale wellfield abstraction is therefore evaluated as low and it is not considered as viable long term solution for sustainable water supply to the major demand centres of the project area. However it is a viable source for local (village scale) water supply.

- Water level trends indicate that the Ecca aquifer, particularly in the Ncojane block is recharging probably through both regional inflow and local rainfall events.

- In general, water level trends in the Ntane Sandstone aquifer are flat to declining with very small magnitudes of water level fluctuations probably because of its unconfined nature or possibly because it is the least actively recharging aquifer in the project area.

- Recharge estimates based numerical modelling and isotope studies indicate that recharge rates for both aquifers are low with values of 0.15 to < 6 mm per annum obtained.

- Carbon 14 dating indicates that the groundwater in both aquifers is very old with indicative ages of between 6,400 and 11,600 years for the Ntane and between 11,400 to 33,400 years for the Ecca aquifer.

Table 4.2 Summary of the Production Boreholes

BH No.	East	North	Screen (m)	Rec. Pump Intake (m)	SWL (m)	Rec. drawdown (m)	*T (m^2/d)	S	Tested yield (m^3/hr)	Rec . Yield (m^3/hr)	Daily Abstraction 24 hrs pumping (m^3/d)
10402	441130	7435358	189 to 248	180	106.4	74	45	1.31E-04	70	64	1 542
10404	445760	7438700	205 to 226 & 236 to 245	180	108.3	72	94	1.31E-04	65	65	1 560
10405	442666	7436299	190 to 195 & 200 to 250	180	106.2	74	55	1.31E-04	75	75	1 800
10407	440170	7432108	198 to 243	180	103.6	76	46	1.31E-04	65	65	1 560
10410	442253	7428629	213 to 258	180	101.5	78	43	1.31E-04	70	66	1 574
10411	438645	7431005	211 to 261	180	103.6	76	45	1.31E-04	70	67	1 601
									Total	**402**	**9 637**

*T Later time transmissivity was used to allow for negative boundary effects

Table 4.3 Summary of Groundwater Resources Assessment

Aquifer	Surface Area m^2	Aquifer Thickness (m)	Saturated Matrix Volume (m^3)	Average Storage coefficient (S)	Water Reserves (m^3)	Exploitable Reserves, MCM	Average Q (m^3/hr)	Average Q/s (m^2/hr)	Average T (m^2/d)
Ecca Aquifer (Otshe), Ncojane Block	4,391,115,829	81	307,378,108,012	4.43E-04	157,566,409	31.5 MCM	54	5	137
Ntane Aquifer	1,126,898,090	25	28,172,452,251	1.44E-03	40,427,469	8.1 MCM	33	3	52

Figure 4.5 Location of the Ncojane Wellfield and Other Potential Wellfield Areas

5 CONCLUSIONS AND RECOMMENDATIONS

- The Ncojane wellfield comprising of 6 production boreholes has the capacity of providing supply of 9,600 cubic meters per day. This supply is more than adequate to cater for the total demand of 1,655 cubic metres per day of primary and secondary demand centres.

- It is recommended that once the production boreholes are brought into operation, regular water level and water quality monitoring is carried out to establish the sustainable yield of each borehole.

- Longer term monitoring of the groundwater level, groundwater quality and abstraction volumes is essential to assess the long term sustainable yields of the aquifer as well as to protect the groundwater quality. The monitoring network initiated during the project was handed over to DWA in January 2008 and DWA is encouraged to continue with manual and as well as transducer monitoring to ensure availability of data for updating of the numerical model in future.

- Pumping of the production boreholes should be in accordance with the recommended pump installation depths and pumping rates. Pumping rates and schedule can be adjusted once long term trends are established through water level, water quality and abstraction volume monitoring.

- Minimum standards for borehole construction should be followed e.g. grouting/sealing of the upper saline aquifers and use of corrosion resistant casings. The risk for pollution exists not only from faulty borehole construction, e.g. inadequate sealing of saline aquifers or incorrect placement of screens, but also from corrosion, and seepage from surface pollution points.

- Adequate protection zones should be maintained around the wellfields to prevent any pollution from surface to reach the aquifer. In particular sealing of the brackish /saline aquifers, overlying freshwater Ecca (Otshe) aquifer is paramount to protecting this aquifer.

- Drilling of new private boreholes within the wellfield area and future potential wellfield expansion areas should be prohibited. If this is not possible then drilling of these boreholes should be fully controlled and supervised by DWA to ensure standard construction procedures are followed in order to minimize the risk of direct connection between the saline aquifer and the freshwater aquifer.

- The possibility of anthropogenic pollution at BH8346, Ncojane needs to be established through re-sampling and analysis, as well as inspection of BH8346 by borehole camera and hydrochemical logging. It could be complemented by ^{15}N isotope investigations in order to identify the likely sources of nitrogen. This is essential for developing a protection plan to safeguard the aquifer against pollution.

- The numerical groundwater model for the project area was developed based on relatively short duration water level monitoring data and is considered reliable within the limits imposed by the available data. It is therefore recommended that, the groundwater model should be updated by DWA on a regular basis and should be used as a groundwater management tool.

- Groundwater "ages" determined through isotope measurements indicate that the water body is very old and has very low replenishment rates necessitating great caution in its exploitation.

- Future recharge investigations should be directed to mapping the area of low chloride water, investigating its flow pattern and its isotopic content. The question of lateral inflow from the west (Namibia) and north needs detailed investigation.

- The developed aquifer within the Karoo basin which extends southwards & westwards into South Africa and Namibia respectively and hence it is a transboundary aquifer. The overall management of this aquifer needs to be managed utilizing the concepts of transboundary water management which are at present being pursued very actively by various international organizations. Scientific and legal issues that affect the management of these shared water resources (aquifers) need intergovernmental agreements.

- It is recommended that the Department of Water Affairs initiates collaborative arrangements with Namibia and South Africa to develop the monitoring and management programme for this transboundary aquifer.

APPENDIX 1

Table A 1 Population of the Demand Centres

District	Village	No. of Associated Localities	Population 1971	1981	1991	2001	Associated Localities	Total Population (2001)
Primary Demand Centres (4): Matsheng Villages								
Kgalagadi N.	Hukuntsi	7	1160	2009	2562	3807	324	4131
Kgalagadi N.	Lehututu	1	448	713	1304	1719	59	1778
Kgalagadi N.	Lokgwabe	5	300	866	1037	1304	131	1435
Kgalagadi N.	Tshane	0	604	637	706	858	0	858
Total								**8202**
Secondary Demand Centres (19) :Northern Kgalagadi and Western /Southern Ghanzi District								
Ghanzi	Charles Hill	4			996	1819	192	2051
Ghanzi	Ncojane	25	921	945	1448	1185	591	2030
Ghanzi	Tsootsha (Kalkfontein)	11	1155	978		1397	249	1646
Ghanzi	Karakobis	18	658	573	562	785	328	1113
Ghanzi	Mamuno				65	40	-	
Ghanzi	Makunda	19			200	331	990	1321
Ghanzi	New Xanagas	13			149	540	242	782
Ghanzi	Bere	12				385	313	698
Ghanzi	Kacgae	3				282	184	466
Ghanzi	Kule	16	540	637	656	741	283	1024
Ghanzi	Metsimantle					160		160
Kgalagadi	Monong				232	172		172
Kgalagadi	Ncaang					175		175
Kgalagadi	Hunhukwe				356	431	148	579
Kgalagadi	Ngwatle				92	206	0	206
Kgalagadi	Make				182	366	0	366
Kgalagadi	Ukwi				313	453	1	454
Ghanzi	Metsimantsho	-	-	-	144	152	152	304
Ghanzi	Ranyane	-	-	-	39	94		94
Total								**13,641**
Additional Demand Centres (8) : Central Ghanzi								
Ghanzi	Ghanzi Township	15	1198	3281	5550	9934	861	10795
Ghanzi	Chobokwane	21	-	-	192	484	477	961
Ghanzi	Qabo	0	-	-	-	401	0	401
Ghanzi	East Hanahai	1			373	405	20	425
Ghanzi	West Hanahai	7				560	182	742
Ghanzi	New Xade	6			528	930	164	1094
Ghanzi	Groote Laagte	2			278	483	129	612
Ghanzi	Dekar	0			627	943	0	943
Total								**15,973**

Sources: CSO 1971,1981,1991,2001 Population and Housing Census

Notes:

1. Mamuno is an associated locality of Charles Hill
2. Metsimantle and Ranyane are associated localities of Ncojane
3. Kalkfontein is also known as Tsootsha
4. Metsimantsho farm is a locality with no affiliation
5. Spellings for the Village Names are based on CSO 2001 Population and Housing Census

Table A 2 Projected Water Demand for the Primary Demand Centres (Matsheng Villages)

Village	Year 2004		Year 2006		Year 2010		Year 2020		Year 2023	
	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)
Hukuntsi	4093	282	4295	296	4729	326	6331	437	6733	465
Lehututu	1858	128	1957	135	2171	150	2235	154	2195	151
Lokgwabe	1440	99	1440	99	1558	108	1809	125	1863	129
Tshane	976	67	976	67	1082	75	1519	105	1716	118
Total	**8367**	**576**	**8668**	**597**	**9540**	**659**	**11894**	**821**	**12507**	**863**

Table A 3 Projected Water Demand for the Secondary Demand Centres (19 Villages)

Village	Year 2004		Year 2006		Year 2010		Year 2020		Year 2023	
	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)
Charles Hill	2142	120	2326	130	2682	150	3067	171	3551	198
Ncojane	1437	80	1436	80	1434	80	1432	80	1429	80
Kalkfontein	1459	81	1496	83	1562	87	1678	94	1701	95
Karakubis	847	47	885	49	954	53	1081	60	1107	62
Mamuno	79	4	90	5	106	6	137	8	137	8
Makunda	371	21	397	22	445	25	537	30	557	31
Bere	413	23	430	24	462	26	519	29	530	30
Kacgae	301	17	313	17	335	19	374	21	382	21
Kule	762	43	774	43	796	44	832	46	840	47
Metsimantle	161	9	166	9	175	10	193	11	203	11
Monong	161	9	155	9	145	8	130	7	127	7
Ncaang	189	11	197	11	213	12	242	14	247	14
Hunhukwe	450	25	461	26	482	27	517	29	524	29
Ngwatle	247	14	275	15	331	18	449	25	447	25
Make	429	24	471	26	552	31	718	40	756	42
Ukwi	492	27	517	29	562	31	646	36	663	37
New Xaanagas	561	31	573	32	595	33	633	35	641	36
Metsimantsho	159	9	164	9	173	10	202	11	211	12
Ranyane	98	5	101	6	107	6	125	7	130	7
Total	**10758**	**600**	**11227**	**625**	**12111**	**676**	**13512**	**754**	**14183**	**792**

Table A 4 Projected Water Demand for the Additional Demand Centres

Village	Year 2004		Year 2006		Year 2010		Year 2020		Year 2023	
	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)	Projected Population	Water Demand (m^3/d)
Gantsi	11335	632	12244	683	13981	780	15840	884	18154	1013
East Hanahai	413	23	417	23	425	24	438	24	441	25
West Hanahai	638	36	689	38	786	44	977	55	1019	57
Chobokwane	513	29	530	30	562	31	618	34	629	35
Qabo	420	23	432	24	453	25	490	27	498	28
New Xade	839	47	790	44	713	40	603	34	584	33
Groote Laagte	547	31	589	33	668	37	822	46	856	48
Dekar	1034	58	1091	61	1197	67	1377	77	1437	80
Total	**15739**	**879**	**16782**	**936**	**18785**	**1048**	**21165**	**1181**	**23618**	**1319**

Table A 5 Comparison of WRC and NWMPR (2006) Water Demand Estimates

Primary Demand Centres (Matsheng Villages)

Year	Water Demand (m^3/d) WRC	Water Demand (m^3/d) NWMPR
2006	597	648
2010	659	676
2020	821	835
2023	**863**	**888**

Secondary Demand Centres

Year	Water Demand (m^3/d) WRC	Water Demand (m^3/d) NWMPR
2006	644	531
2010	676	592
2020	754	757
2023	**792**	**795**

Additional Demand Centres

Year	Water Demand (m^3/d) WRC	Water Demand (m^3/d) NWMPR
2006	936	1910
2010	1048	2137
2020	1181	2867
2023	**1319**	**3073**

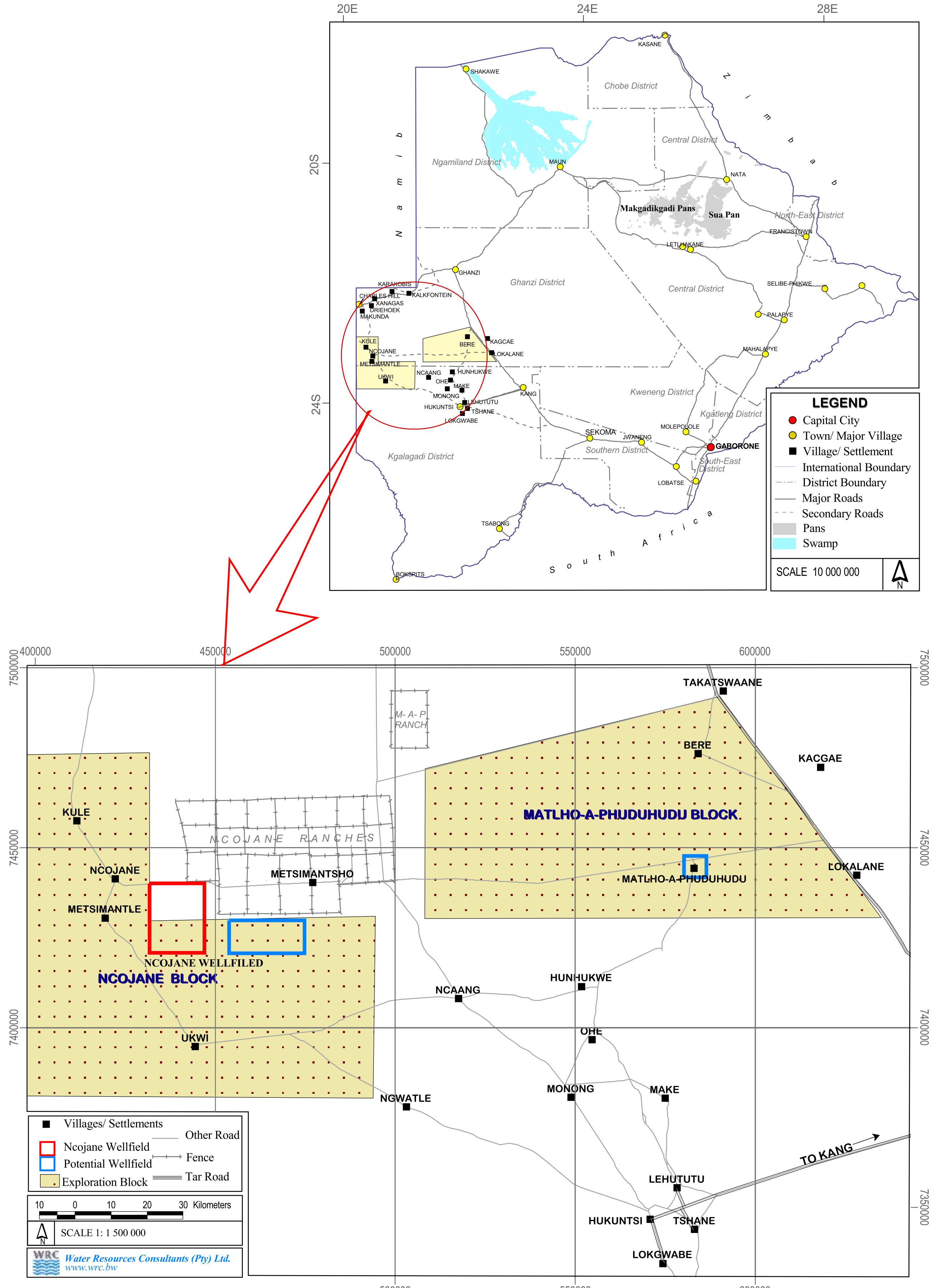

Figure 2.1 : Project Area Location Map

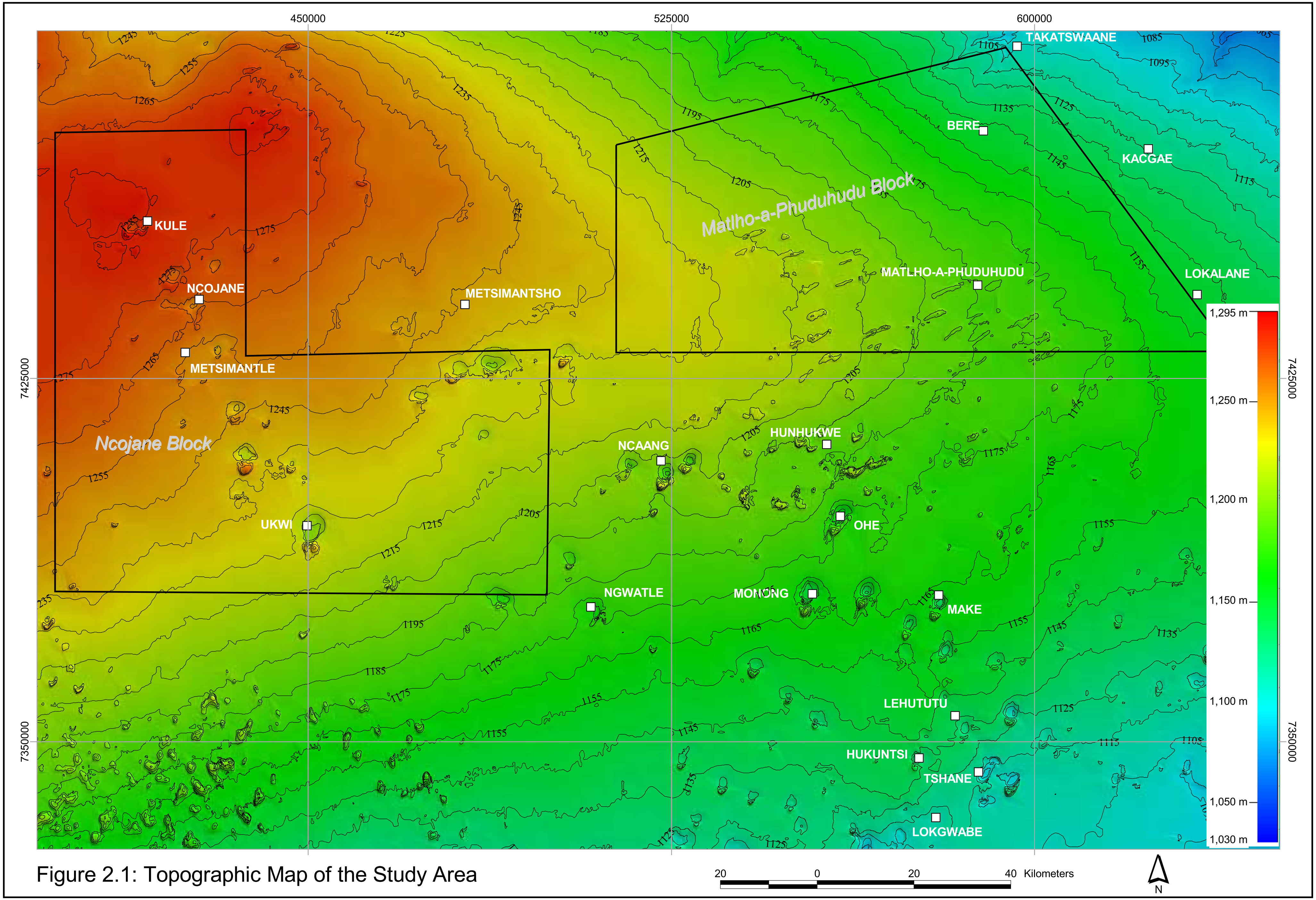

Figure 2.1: Topographic Map of the Study Area

(DEM generated from 5m interval digital contour data obtained from Department of Surveys & Mapping, Govt. of Botswana)

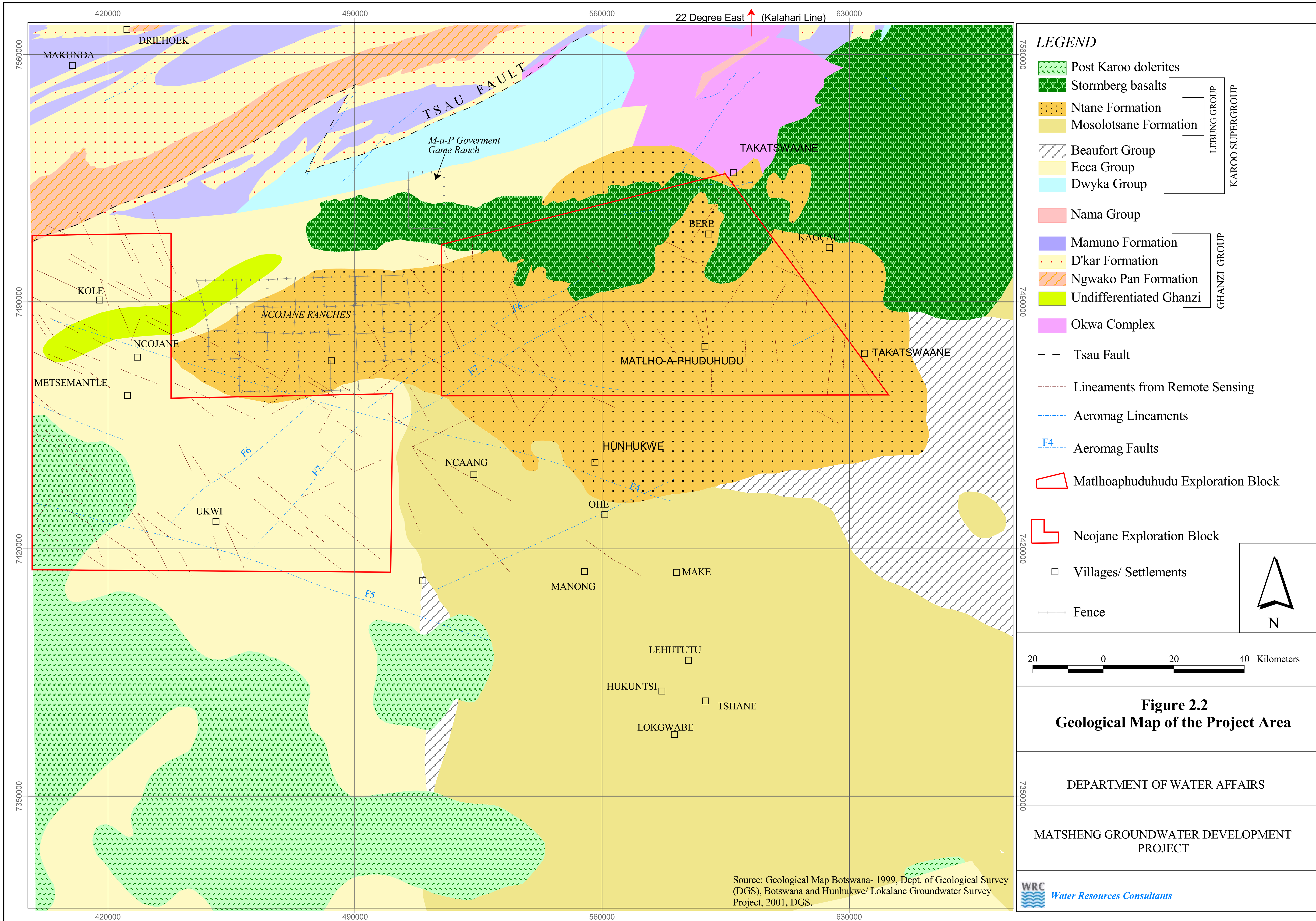

Figure 2.2
Geological Map of the Project Area

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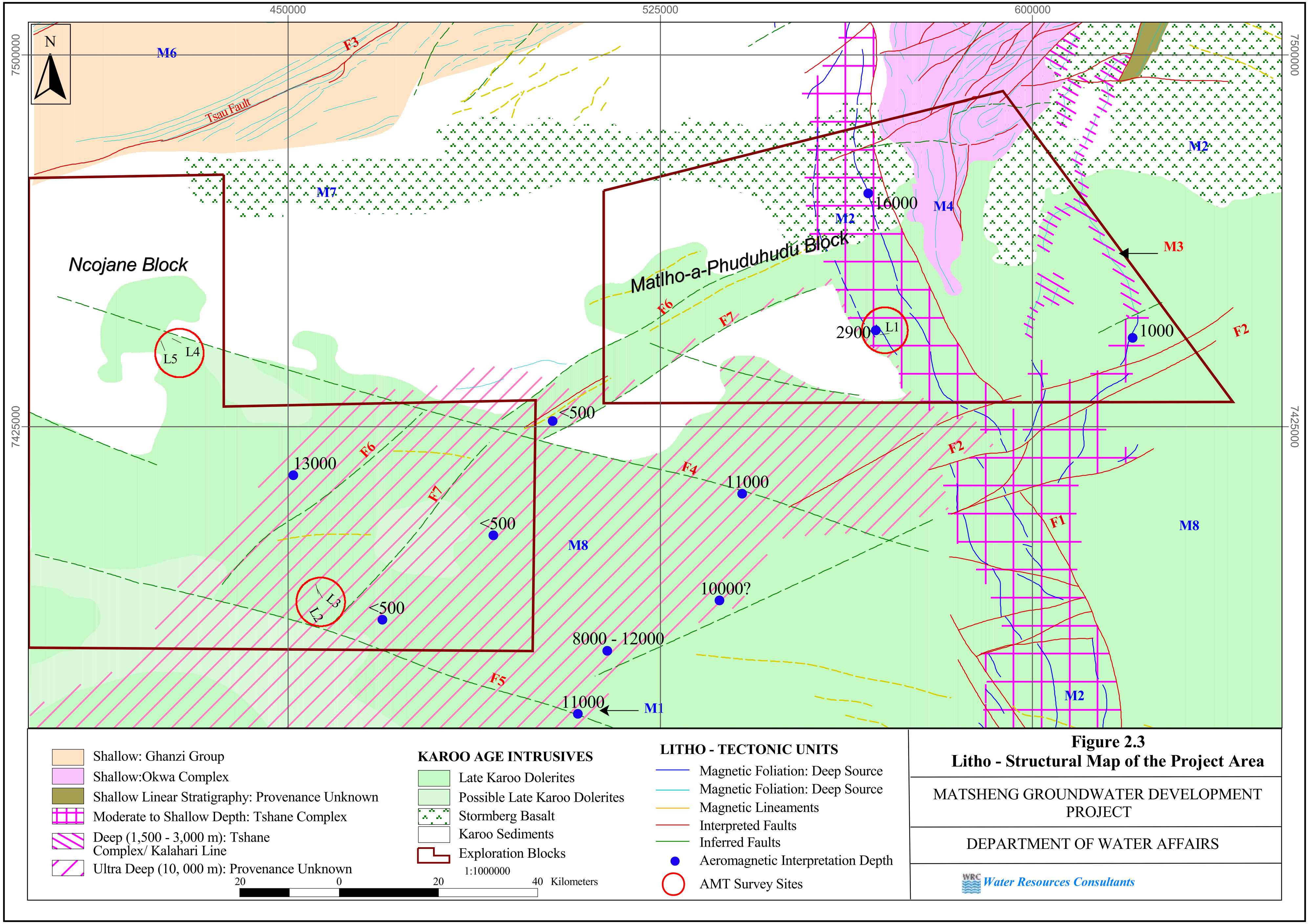

Figure 2.3
Litho - Structural Map of the Project Area

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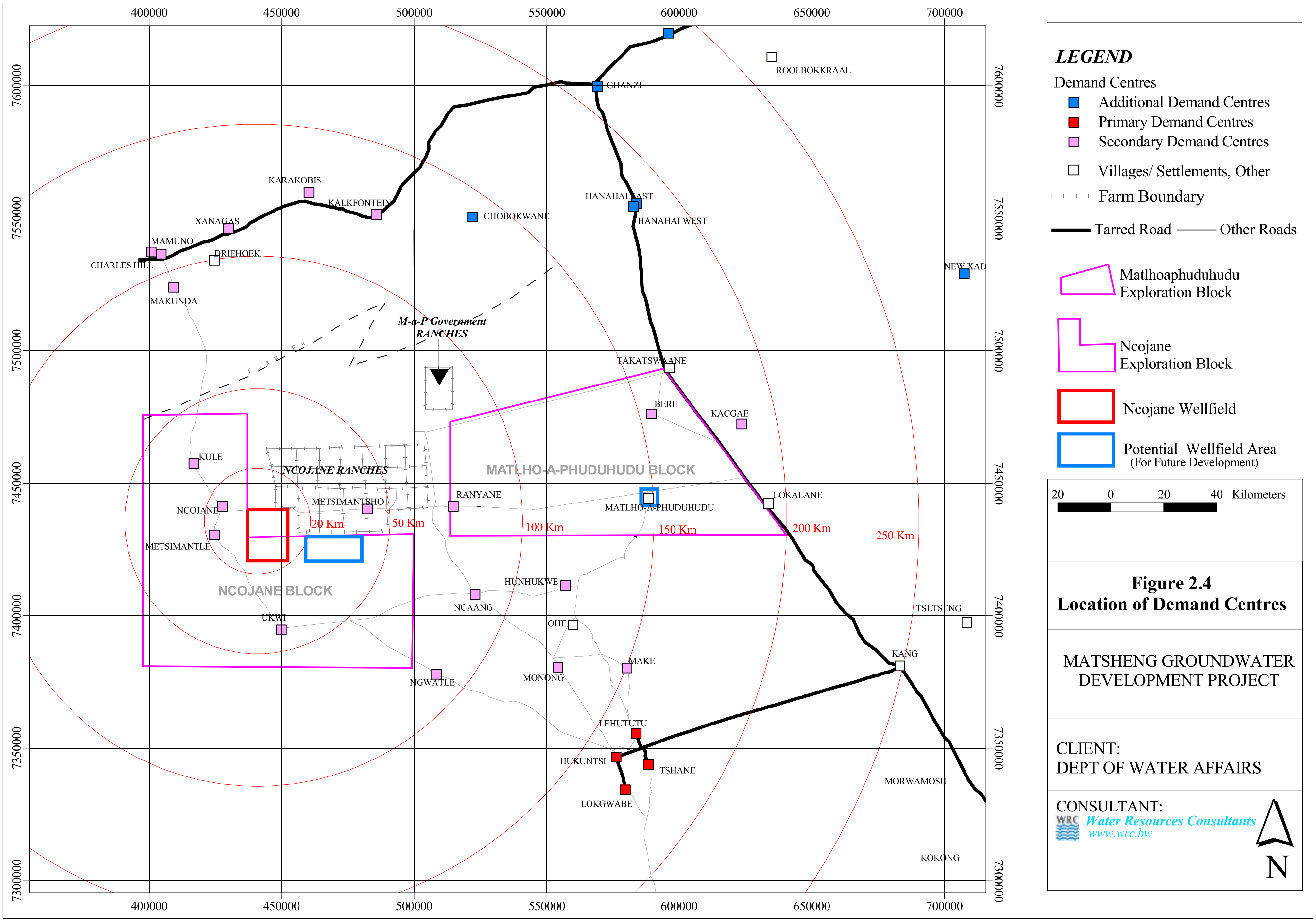
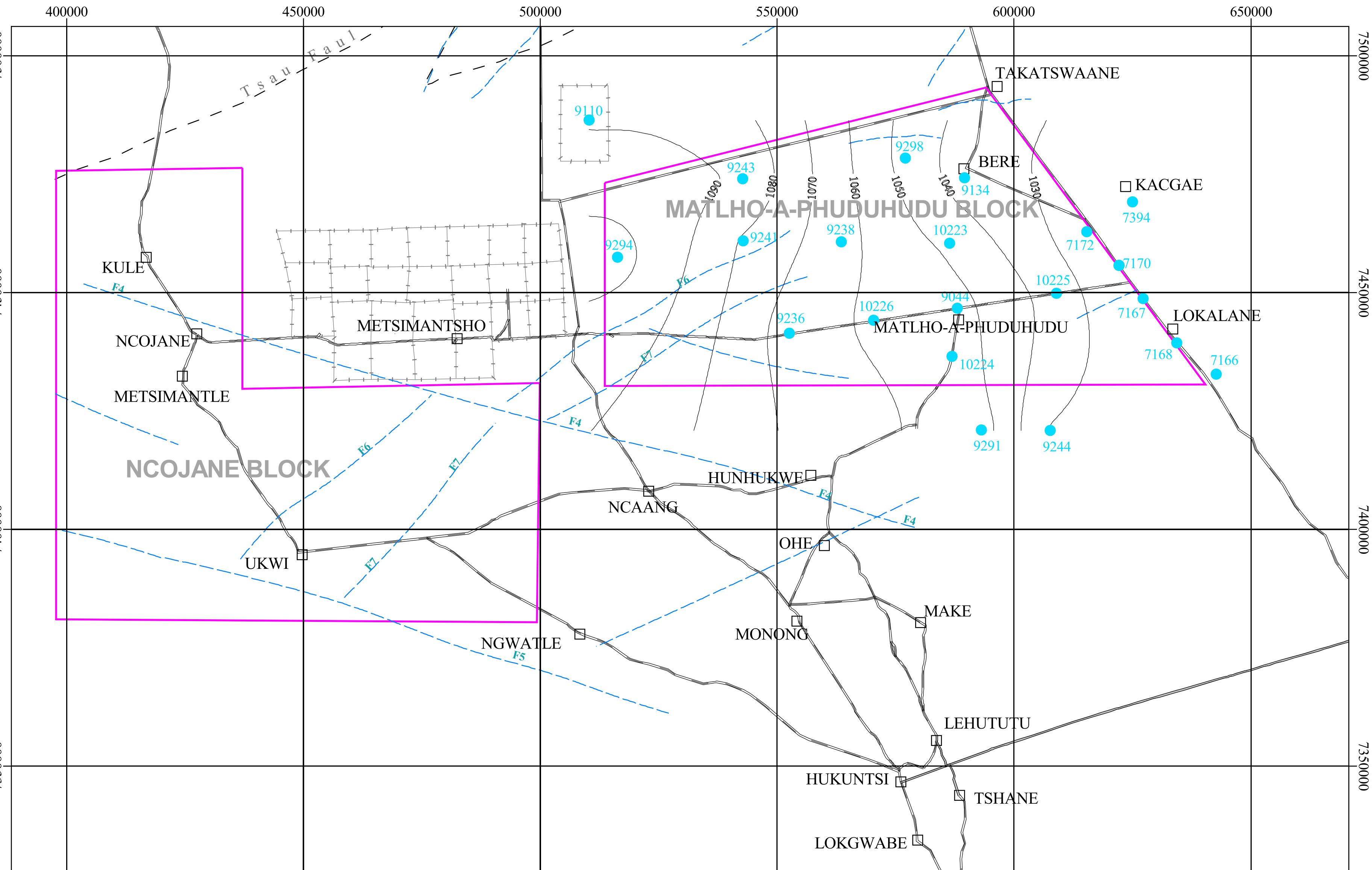


Figure 2.4
Location of Demand Centres



LEGEND

Lineaments from Aeromag — F6 Aeromag Fualt

Exploration Block — Villages/ Settlements — Tsau Fault

Farm Boundary — 9110 Boreholes used for contouring

1090 Saturated Thickness(m) — Tarred Road — Other Roads

Figure 4.1
Piezometric Head Ntane Sandstone Aquifer

20 0 20 40 Kilometers

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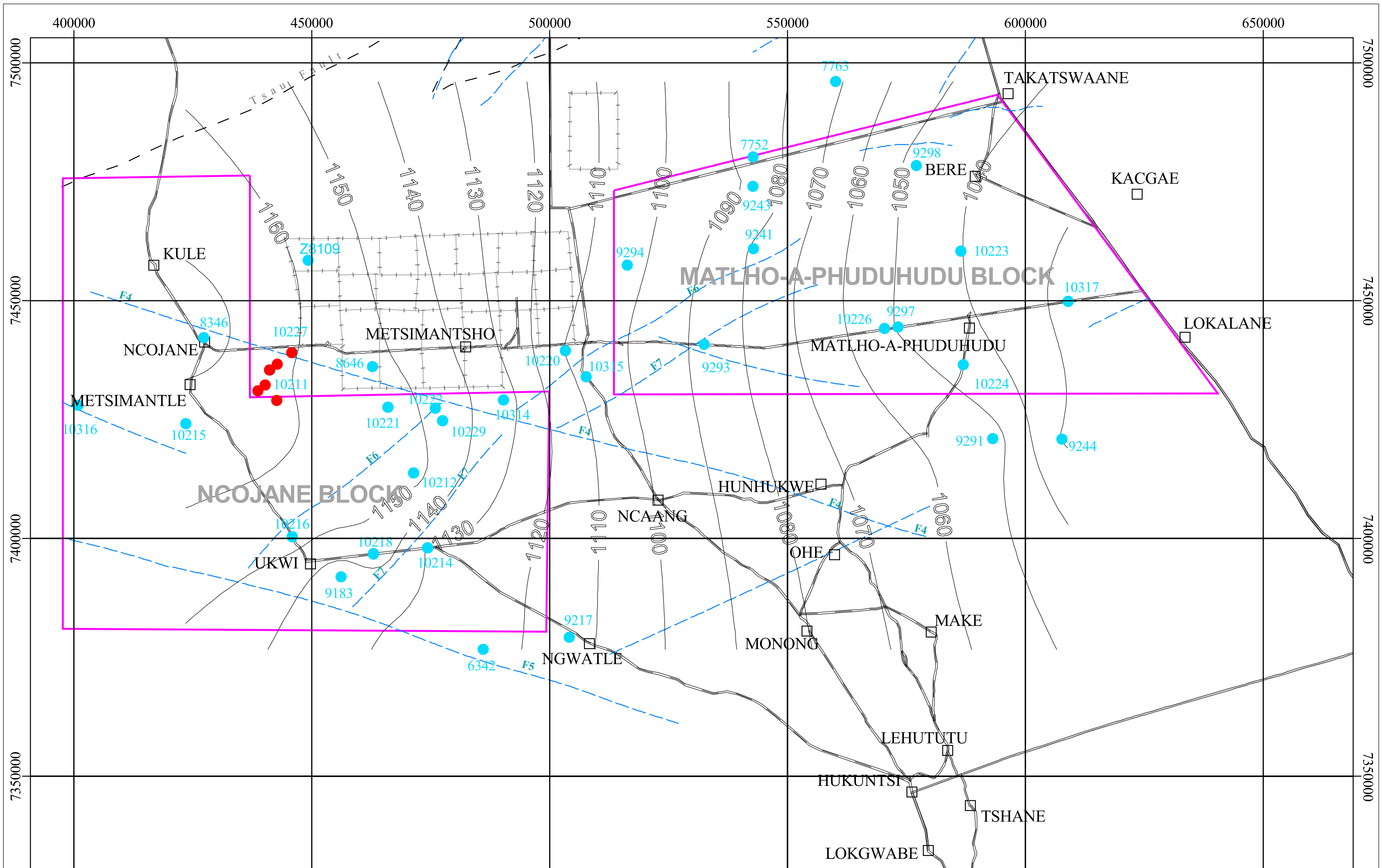

LEGEND

Lineaments from Aeromag

F6 Aeromag Fualt

Exploration Block

Villages/ Settlements

Tsau Fault

Farm Boundary

9217 Boreholes used for contouring

1130 Piezometric Head (masl)

masl - Meters above sea level

Production Boreholes

Tarred Road

Other Roads

Figure 4.2
Piezometric Head Ecca Aquifer

20 0 20 40 Kilometers

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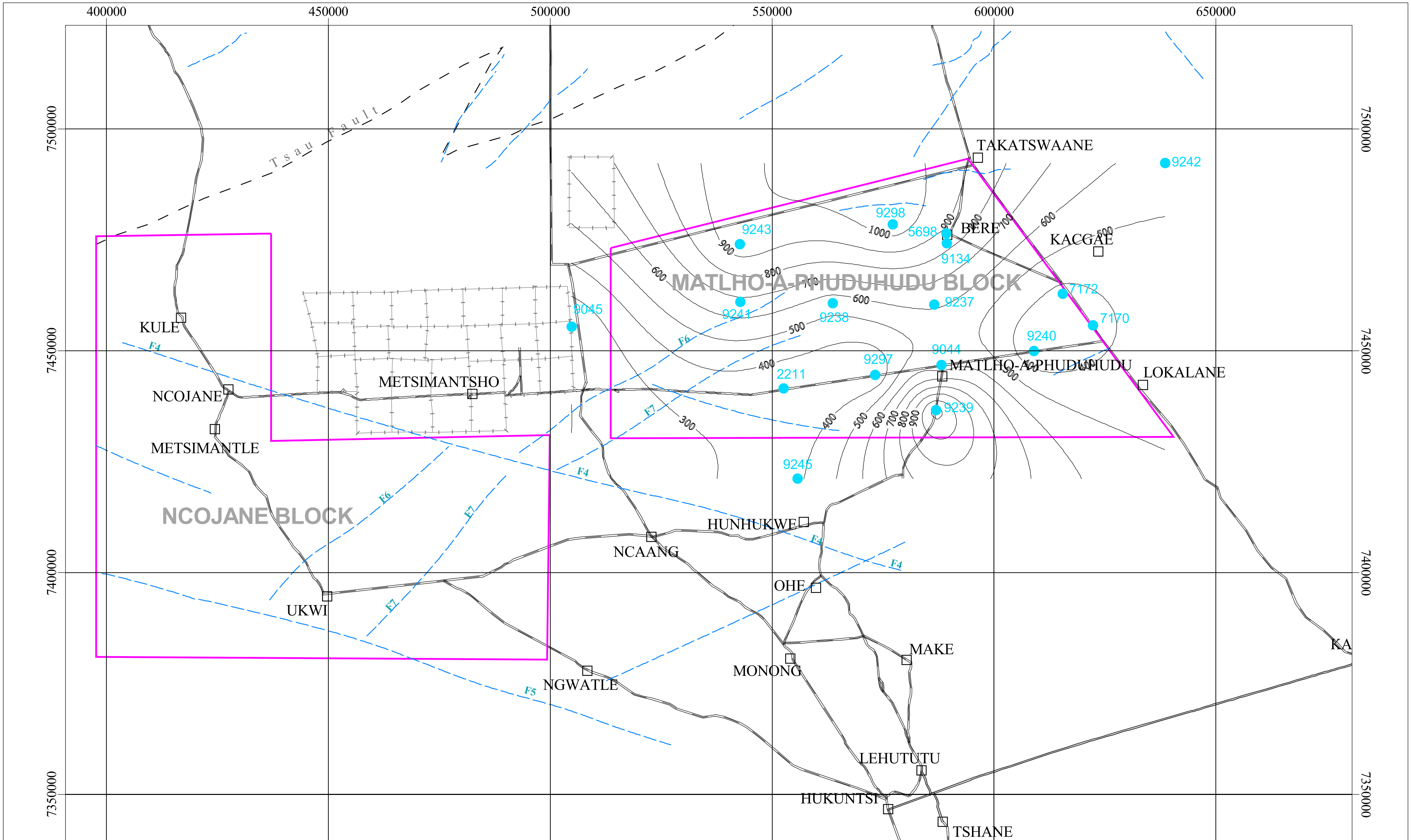

LEGEND

Lineaments from Aeromag

F6 Aeromag Fualt

Exploration Block

Villages/ Settlements

Tsau Fault

Farm Boundary

9243 Boreholes used for contouring

300 Saturated Thickness(m)

Tarred Road

Other Roads

Figure 4.3
TDS Distribution Ntane Sandstone

Scale 1:1 200 000

20 0 20 40 Kilometers

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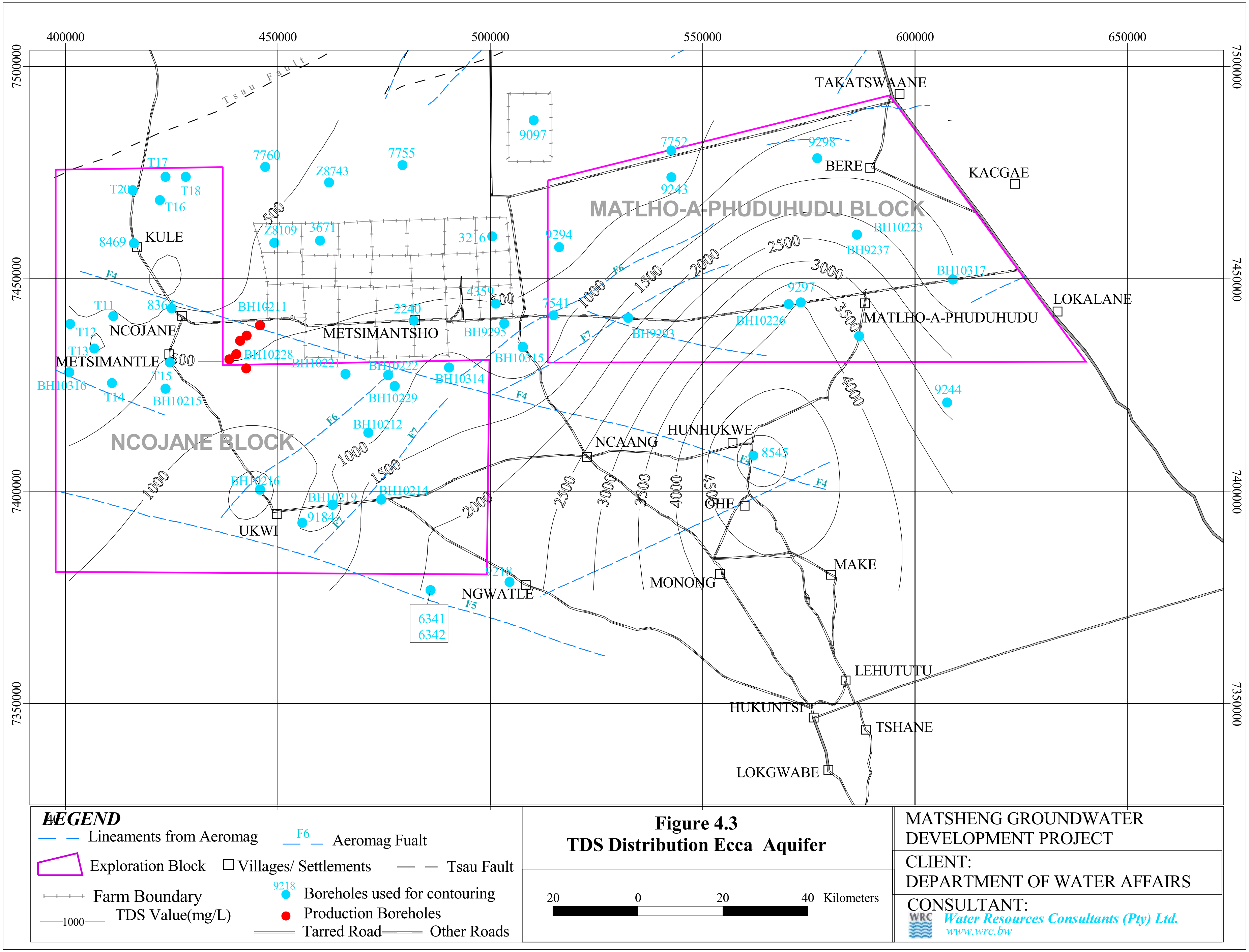

Figure 4.3
TDS Distribution Ecca Aquifer

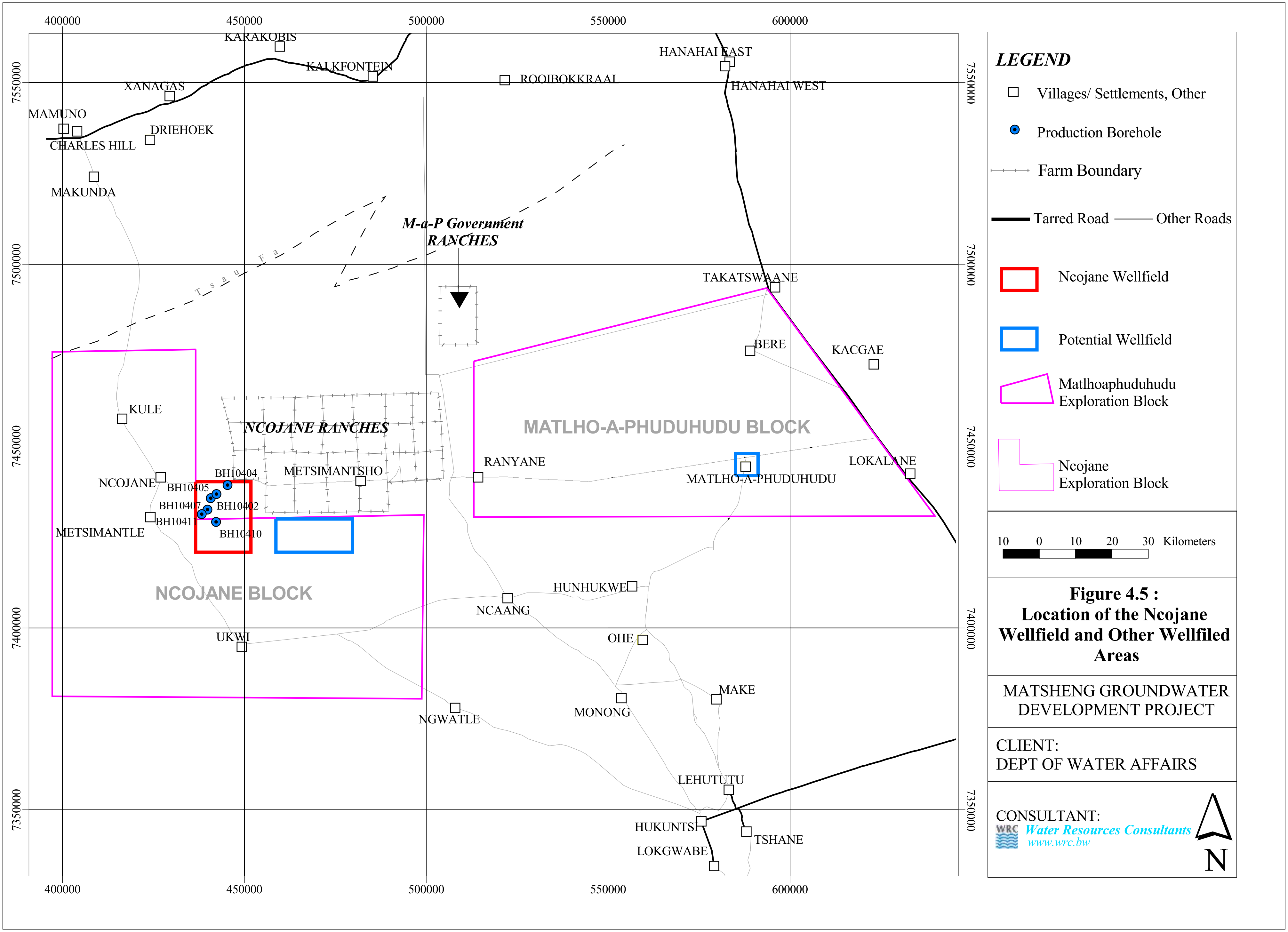

Figure 4.5 : Location of the Ncojane Wellfield and Other Wellfiled Areas

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