

# **GEOHYDROLOGICAL CHARACTERISTICS OF THE MSIKABA, DWYKA AND ECCA GROUPS IN THE LUSIKISIKI AREA, EASTERN CAPE**

by

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Appendix 4	Pumping tests, water quality results and management recommendations

## List of Abbreviations

DEM	Digital Elevation Model
DEV	development
DWAF	Department of Water Affairs and Forestry
Dwyka	Dwyka Formation
Ecca	Ecca Group
EP	Exploitation Potential
GDP	Groundwater development potential
GEP	Groundwater exploitation potential
GEXP	Groundwater exploration potential
GIS	Geographical Information Systems
GMU	Groundwater Management Unit
GRIP	Groundwater Resource Information Programme
GW	ground water
inv	investigation
K	Hydraulic conductivity
LGFS	Lusikisiki Groundwater Feasibility Study
LRWSS	Lusikisiki rural water supply study
l/s	litres per second (discharge) - $1000 \text{ l/s} = 1 \text{ m}^3/\text{s}$
m	metre
MAP	Mean Annual Precipitation
Mbgl	metres below ground level
NGDB	National Groundwater Data Bank
NGS	Natal Group Sandstone
RWSS	Rural water supply study
SRK	SRK Consulting (South Africa) Pty Ltd
TOR	Terms of reference
WL	water level (groundwater - usually measured as depth from surface)
w/s	water Supply
w/supply	water supply
T	Transmissivity

## List of definitions

**Airlift yield:** Refers to the yield as measured during drilling by means of air pressure induced by the drilling action.

**Aquifer:** An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials.

**Borehole development:** After drilling a new borehole, the borehole is developed by a flushing the inside of the borehole using the air pressure from a compressor.

**Desk study:** Study done mainly in the office and without visiting the project area. The desk study is usually used to collect and evaluate existing information that is relevant to the project.

**Hydrocensus:** Field survey of existing boreholes and springs where all relevant and available information is gathered.

**Outcrop:** Visible rock on the surface.

**Pump testing:** Technique used to determine the sustainable yield of a borehole and to determine aquifer parameters such as Transmissivity (T).

**Study area:** Refers to the area included under the Lusikisiki Groundwater Feasibility project.

**Transmissivity (T or KD):** The product of the average hydraulic conductivity K and the saturated thickness of the aquifer D and is expressed as  $\text{m}^2/\text{day}$ .

**Vadose zone:** The vadose zone, also termed the unsaturated zone, is the portion of earth between the land surface and the zone of saturation (water).

## FOREWORD

Rural water supply has changed dramatically over the past 10 years, especially in the Eastern Cape since it is considered one of the poorest provinces in South Africa. The role of geohydrology and the understanding of groundwater have also increased to a degree where groundwater is considered first, before bulk water from rivers and dams. The approach to using groundwater as a source of drinking water also changed from individual village water supply to supplying regional schemes. In the past, groundwater (boreholes) were considered as an emergency, short term solution to water needs and boreholes were mainly drilled close to the point where water was needed. A typical example would be where the water reticulation system is put in place first and then the hydrogeologist is tasked to find water near the reservoir. The results were often low yielding boreholes with little or no recharge (catchment) and boreholes dried up, resulting in groundwater getting a bad name.

Fortunately the approach changed a few years ago and engineering companies and authorities working with water supply realised that high-yielding groundwater sources can be developed with success if the hydrogeologists are given the freedom and the budget apply available scientific techniques such as lineament mapping and geophysical exploration. The availability of Landsat Imagery boosted the successes of finding high yielding boreholes tremendously. However, even with the latest technology available, the necessity of proper geological field investigations and geophysical interpretation cannot be neglected.

This study has shown that preconceived ideas such as drilling inside dolerite dykes or drilling the contact between sedimentary rock and a dolerite dyke, are not always the best options and drilling a distance away from the dyke (especially in quartzitic sandstone) can produce significant water strikes. The study also proved that geophysical methods can produce contradicting results and that non-magnetic / non-electromagnetic methods should be considered in areas underlain by dolerite sheets such is the case in the Ecca Group.

Acknowledgement is given to the following people for providing valuable input to the project:

- Alan Woodford and Mildred Fortuin for the finer lineament mapping, GIS support and GRID based recharge calculations that were used for the groundwater feasibility maps (e.g. exploitation potential map).
- Jaco Pretorius (geophysical traverses and borehole logging) and Mfundo Mari (hydrocensus) for their field support.
- Professor van Tonder for the pre-evaluation of the thesis and input regarding the recharge calculations.

## 1. INTRODUCTION

The town of Lusikisiki in the Eastern Cape and the surrounding villages are currently supplied with bulk water, pumped from a weir in the Xura River. The water from the river is pumped to a water treatment works from where it is reticulated to the town of Lusikisiki and to surrounding villages. The volume of water is however not sufficient to meet the overall demand of the town and of the villages situated along the reticulation network.

The Department of Water Affairs and Forestry (DWAF) subsequently requested that a groundwater feasibility study be conducted in the area of Lusikisiki to determine the potential of groundwater for the augmentation of the bulk water supply scheme. The study included the Natal Group (also called the **Msikaba Sandstone**), **Ecca Group** and **Dwyka Formation**. The study was undertaken by Gert Nel as the project manager and lead hydrogeologist. The main purpose of the study was to define areas where groundwater could be targeted for drilling, to drill these areas and to make recommendations pertaining to future drilling programs. Thirty boreholes were drilled and pumping tests were conducted on selected boreholes. Although one of the deliverables of the study was to determine aquifer parameters such as Transmissivity, no packer tests were conducted.

The information resulting from the investigation was used to conduct further research into the geohydrological characteristics of the Msikaba Sandstone and Ecca Group, as well as the Dwyka Formation, as part of the Master's thesis.

## 2. OBJECTIVES

The objectives of the research included the following:

- To investigate and compare the groundwater characteristics of the three geological units, namely the Msikaba Sandstone, Ecca Group and Dwyka Formation;
- To evaluate the effectiveness of the groundwater exploration techniques that were used, i.e. Landsat mapping and geophysical exploration and
- To estimate recharge from available information.

Although recharge was calculated using a standard GRID-based GIS modelling technique (Woodford & Fortuin) and compared against the Chloride method, the recharge for the study area is seen as complex and therefore does not form the focus of this thesis.

### 3. BACKGROUND

The study area was originally chosen to include an area that stretches from Port St Johns inland to Mabalulu ( $\pm 15$  km west of the town of Lusikisiki), down towards Mkambati at the coast (See Figure 3.1). It therefore included an area of approximately 100 km<sup>2</sup>. Since the primary aim of the project was to investigate the groundwater potential in the vicinity of the existing reticulation network, it was however decided to decrease the study area to only include the areas within approximately 15 km of the existing reticulation network. Although the Mkambati area is situated far from the existing reticulation network, a special request was put forward from the Oliver Tambo District Municipality (OR Tambo) to investigate the potential of finding sufficient groundwater near the Mkambati Nature Reserve to enable the future development of tourism. The Mkambati area was therefore included in the LRWSS and added valuable information on the Msikaba Sandstone. Refer to Figure 3.1 for the locality of the project area (study area).

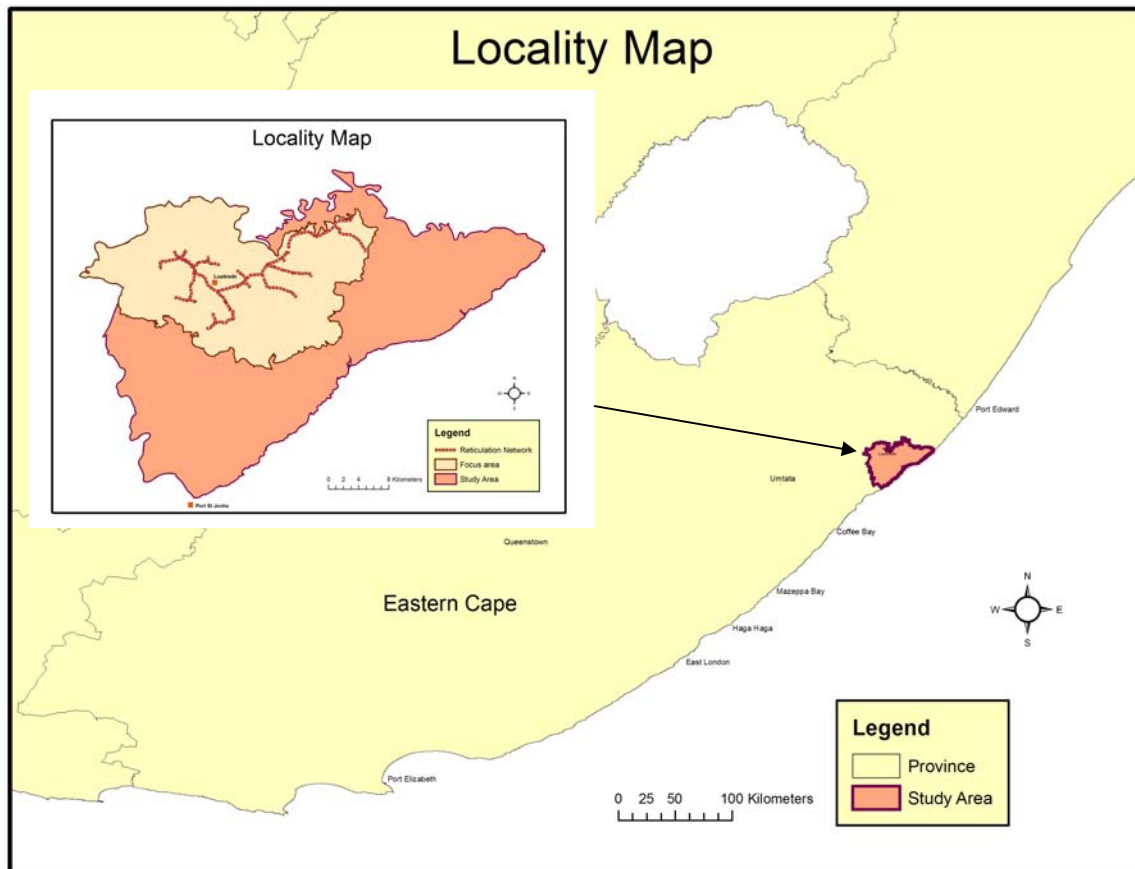


Figure 3.1: Locality of the study area



### 3.1 Previous studies

A previous study done by Woodford and Chevalier (1999), where the groundwater resources of the T60 Drainage Region (Eastern Pondoland) were investigated, included Landsat lineament mapping and desktop target identification. During a data search on the GRIP database<sup>1</sup> the following reports (Table 3.1) were listed by the Department of Water Affairs and Forestry as containing key words that relates to the study area. Most of the reports could however not be sourced and are therefore not referenced in this study.

**Table 3.1: List of reports obtained from the GRIP database - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

Number	Date	Project Name	Author	Client
174392/1	Nov-89	Northern Zone Village w/s study	C.J. Taylor	Transkei DAF.
174392	Jul-91	Northern Zone Village w/s study	C.J. Taylor	Transkei DAF.
174392	Jul-91	Northern Zone Village w/s study	C.J. Taylor	Transkei DAF.
174392	Jul-91	Libode rural w/supply scheme	C.J. Taylor	Camdekon
174392	Jul-91	Northern Zone Village w/s study	C.J. Taylor	Transkei DAF.
174392		Drawings - Borehole Maps	C.J. Taylor	Transkei DAF.
174392		Transkei Pump Test Results		
174392		Missing Pump Test Data		
174392		Pump Test Date		
174392		Transkei Northern Zone Borehole Siting		
149105(1A)	Mar-92	Central Zone, Borehole Reports:	C.J. Taylor	Transkei DAF.
149105(4F)	Feb-92	Hydrocom: Northern Zone Status	C.J. Taylor	Transkei DAF.
149105(5B)	Jul-91	Transkei Agricultural	L.M. Mbana	Transkei DAF.
149105	Jul-91	Transkei national GW		Transkei DAF.
149105	Mar-92	Hydrocom Central Zone		Transkei DAF.
149105	Mar-93	Transkei national GW	SRK,DEV,BANK	Transkei DAF.
149105/5	Mar-93	Natal group sandstones hydrogeological inv. Phase 3		DWAF
149105/4	Mar-93	Central and Southern Zones Hydrocensus Phase 2		DWAF
149105	Feb-92	Hydrocom Data Dictionary of Northern Zone		DWAF
149105/3	Mar-93	Overview Report		DWAF
149105	Jul-91	Transkei National GW Progress Report	N Lachovitzki	DWAF
149105	Jul-91	Northern Zone Village Water Supply Studies	C.J. Taylor	DWAF
173823	Apr-88	Proposal to Investigate GW Supply in Tabankulu District, Transkei		DWAF
	Feb-03	G/W source development for Lusikisiki	J.A MYBURG	UWP Engineers
	Feb-03	G/W source development for Lusikisiki	J.A MYBURG	UWP Engineers

In addition to the GRIP database, background groundwater information on the study area was obtained from the following sources:

- National Groundwater Database (NGDB); GIS Division, The Department of Water Affairs and Forestry, Regional Branch, Port Elizabeth;
- UWP Consulting who previously designed the current Qaukeni Bulk Water Scheme.

<sup>1</sup> GRIP : Groundwater Resource Information Programme, an initiative launched by DWAF to collect and table all reports on groundwater. Coordinates and key words are used for search functions.

## 4. METHODOLOGY

The approach to the study was twofold, namely (1) conducting a general geohydrological investigation and (2) further research of the results obtained.

The general geohydrological investigation comprised the following:

- **Desk study:** Information was collected from various data sources such as the NGDB and existing reports (work done previously in the area) and reviewed. As part of the desk study the topography, geology and general topography is discussed.
- **Hydrocensus:** The desk study was followed by a hydrocensus whereby field surveys were conducted and borehole and other groundwater information collected.
- **Target selection:** The information from the desk study (which included the evaluation of work previously done in the project area) and the hydrocensus was then used in conjunction with further research such as lineament mapping to define target areas for groundwater drilling.
- **Geophysical exploration:** With the use of geophysical instruments and field-geological mapping, the selected targets were then further investigated and drilling positions determined.
- **Drilling:** Boreholes were drilled on the selected targets by means of rotary air percussion drilling.
- **Borehole testing (pump testing):** The successful boreholes drilled (those that yielded water) were then pump tested to determine their sustainable yield and also their water quality.

The research part of the investigation focussed on defining the geohydrological characteristics of the three major units, namely the Msikaba, Dwyka and Ecca and concentrated on:

- Comparison of the drilling results between the three geological units;
- Comparing the pump testing results, including changes in water quality and
- Focussing on the different geophysical anomalies obtained in each of the three geological units.

The above information was then used to define the groundwater potential of the area which can further be described in terms of the groundwater exploration potential (GEP - refers to the ease of drilling a successful borehole) and the groundwater development potential (GDP - refers to the possibility of finding a sustainable groundwater source). The GEP focuses on the available structures and geological targets, while the latter also takes into account aspects such as average recharge (calculated from rainfall and topography).

## 5. RESULTS

### 5.1 Hydrocensus

The information that was gathered included the following:

- borehole coordinates;
- existing equipment;
- borehole identification numbers;
- borehole use;
- current water source of community, including springs;
- borehole information (measured where possible) such as depth, water level, etc. and
- basic sanitation information.

The information gathered is presented in Appendix 1.

Figure 5.1 indicates the positions of the boreholes that were detected during the hydrocensus and their respective airlift yields indicated by classes. The yield information was obtained from the NGDB (where available) and is presented in litres per second (l/s).

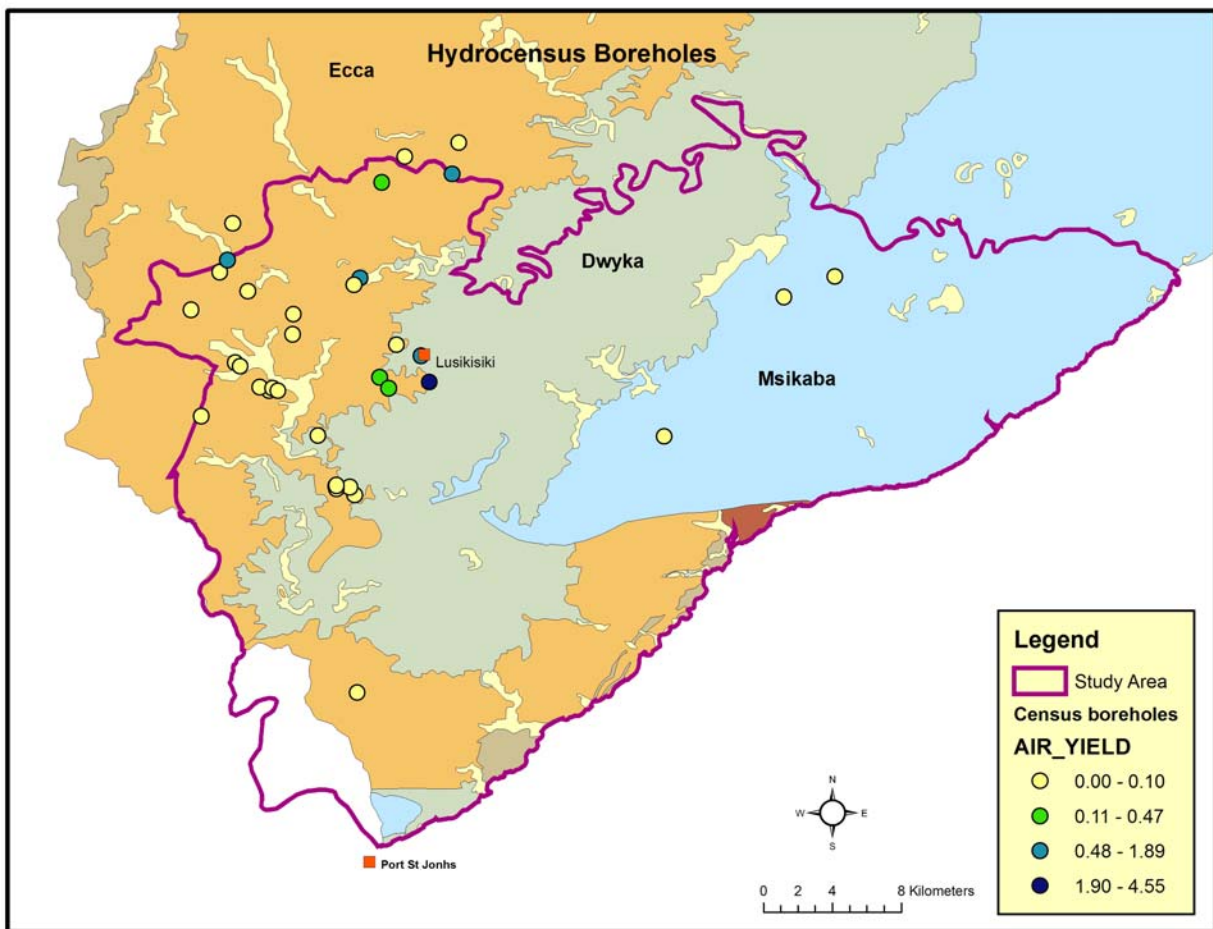
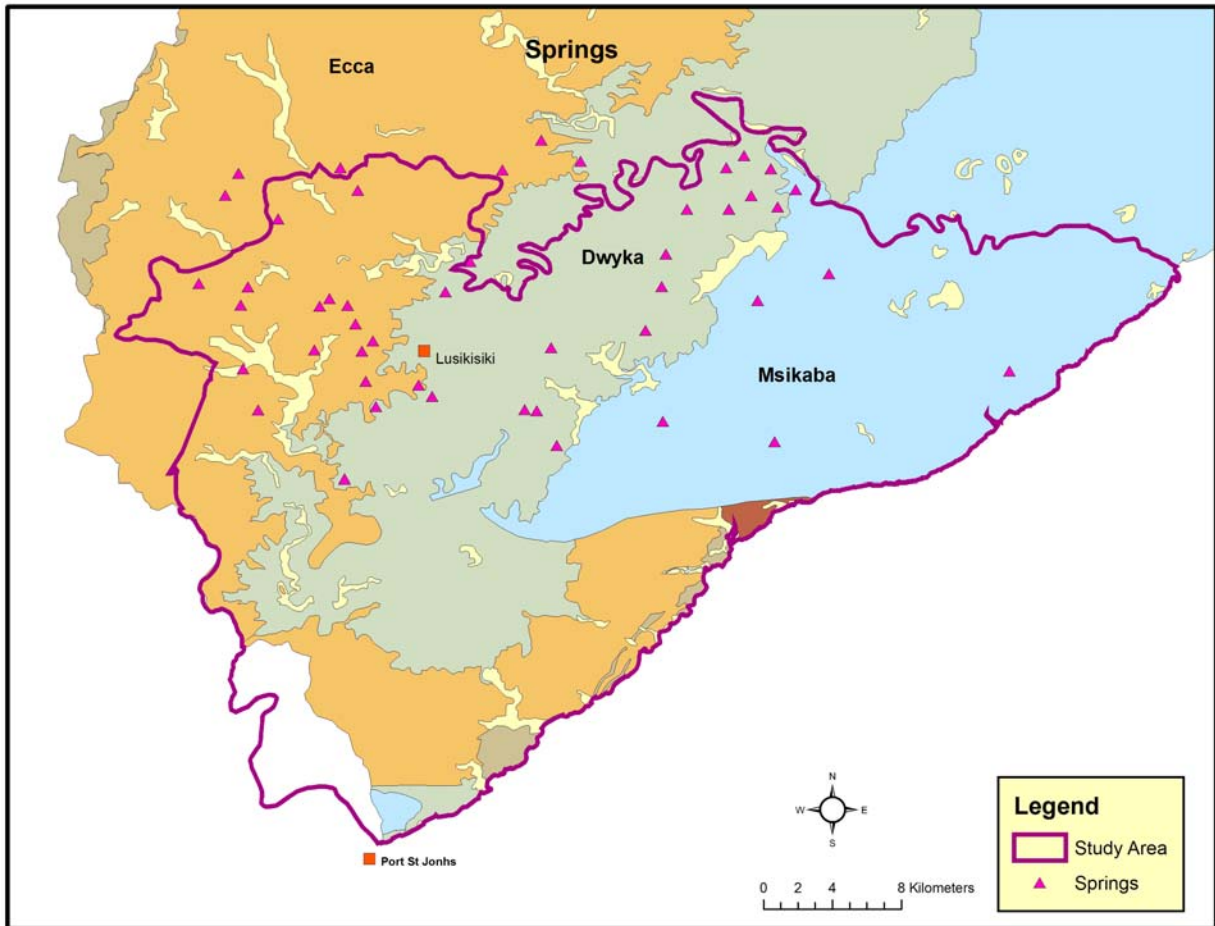


Figure 5.1: Existing boreholes and respective yields

During the hydrocensus the current water sources of the communities were also noted. They mostly consist of springs as indicated in Figure 5.1a.

The springs were mostly seepages and from varying origin and no spring flow measurements could be taken. Electrical conductivity (EC) was however measured and values were all below 70 mS/m which classifies the water quality as Ideal.



**Figure 5.1a: Positions of springs**

Although springs are still widely used by the communities as water supply sources, those communities that were interviewed do not consider the springs as sustainable water sources as they are mostly seasonal. The springs are not protected (see photos in Figure 5.1b) and livestock get water from the same springs. In some cases, an effort was made by the community to isolate or protect the eye of the spring, but due to lack of proper construction and knowledge of spring protection measures, it failed.

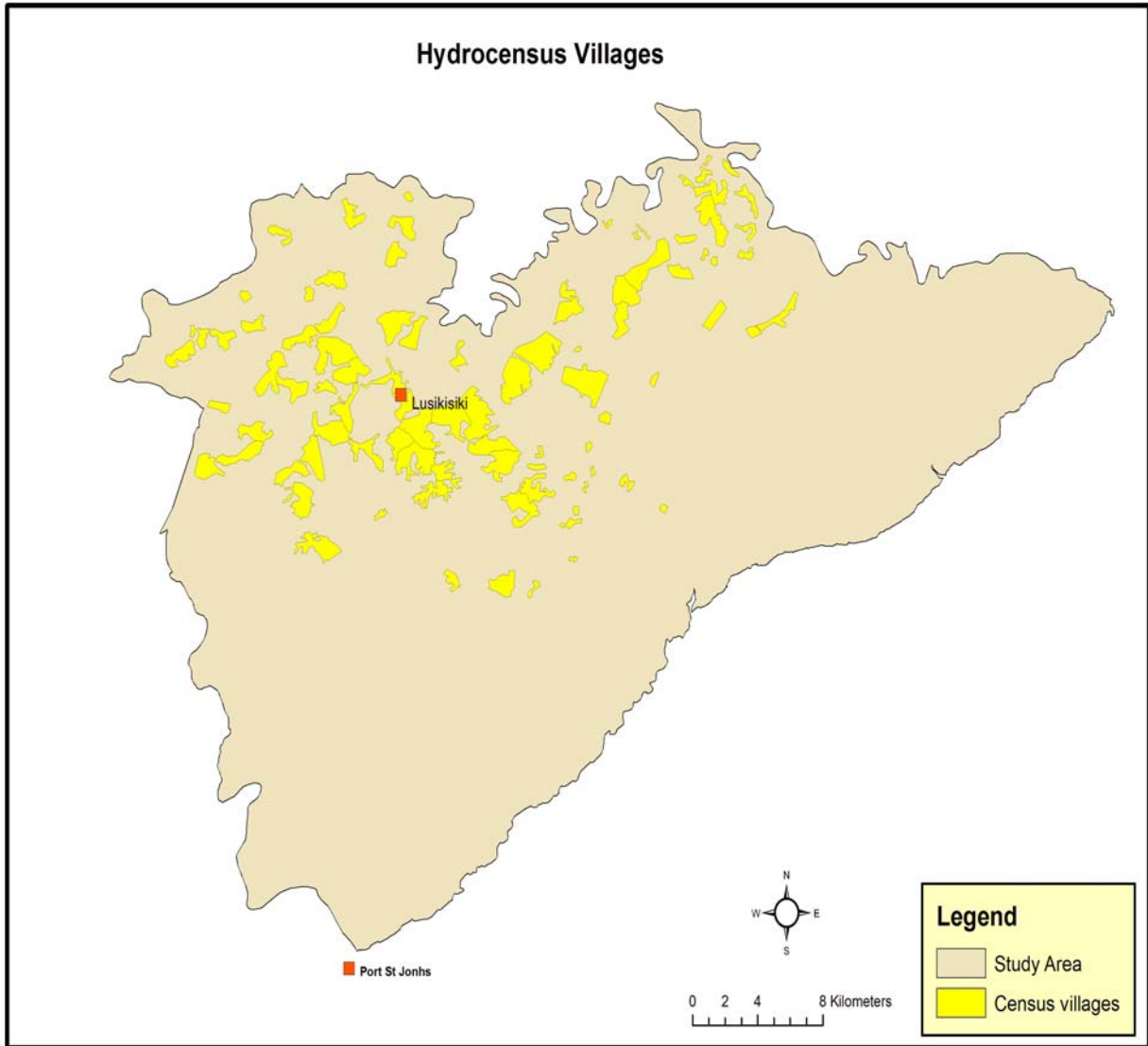


**Figure 5.1b: Photos showing springs - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**



Approximately 90 villages were selected for the hydrocensus to include villages that fall within the areas earmarked for the feasibility drilling programme.

Figure 5.1c indicates the positions of the villages that formed part of the hydrocensus. Only the villages that are situated near the existing reticulation network were included in the hydrocensus.



**Figure 5.1c: Villages included in the census**

## 5.2 Evaluation of historical information

The desk study and hydrocensus were essentially done to collect and review previous work done in and around the Lusikisiki study area. The two main sources of existing information that were consulted, namely the NGDB and GRIP, are discussed below together with a statistical analysis.

### 5.2.1 NGDB

Groundwater information from the NGDB was obtained from DWAF in Pretoria. The following conclusions were made from the NGDB data:

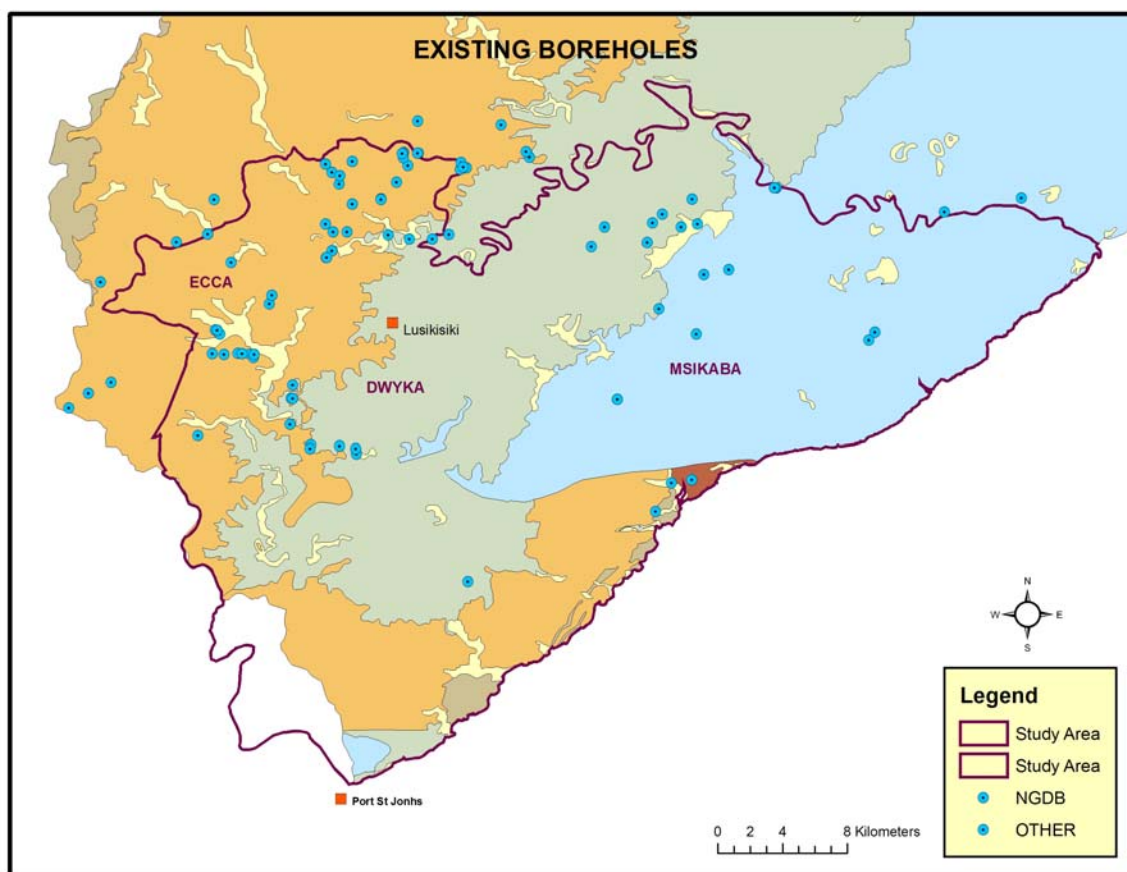
- coordinate accuracies of the borehole data are generally low;
- the average discharge yield of the successful boreholes are 1.36 l/s and
- discharge yields ranges between 0.1 l/s and 5 l/s with the lower yields typical of the Msikaba (Natal Group) Sandstone and the moderate and higher yields typically in the Ecca and Dwyka Groups. Discharge rates vary between 3 hrs and 9 hrs pumping schedules.

After evaluating the results from the historical reports it was clear that not all the data from the reports have been captured into the NGDB. The comment on the discharge yields are based on the NGDB data only and do not include the data from the reports (which suggests otherwise).

### 5.2.2 Groundwater Resource Information Programme (GRIP)

Information on the GRIP was obtained from DWAF's Port Elizabeth Office. The reports are listed in Table 3.1 (under section 3.1). The majority of the reports cover areas outside the Lusikisiki study area, but some of their findings are relevant because of similar geological setting.

Figure 5.2.2 indicates the positions of existing boreholes, combined from the various information sources.



**Figure 5.2.2: Existing boreholes as per census**

### 5.2.3 Evaluation of the historical reports and existing information

The conclusions below are based on the information as obtained in the reports, many of which dealt with areas outside the LGFS area since very little historical work was done in the LGFS area. Information was found to be contradictory, especially on the potential yield of the Natal Group Sandstone (NGS) and Dwyka Diamictite. The discussions below also focus on the geophysical methods used in the siting of the targets, the types of geological structures targeted and other geohydrological information. Where mention is made of the yield of a borehole, it is the airlift yield unless stated otherwise.

#### 5.2.3.1 *Msikaba Sandstone (NGS / Natal Group Sandstone)*

- The Magnetic method proved inadequate in the detection of lineaments and/or faults in the Natal Group Sandstones (NGS) whereas the Electromagnetic (EM-34) method produced better anomalies, especially in detecting fracture zones. A combination of aerial photography and satellite images should be used together with geophysical techniques. (SRK, Report 149105/5, 1993).



- Boreholes drilled on linear features produced low yields ranging between 0.1 l/s and 0.7 l/s.
- Water strikes and geological logging information indicated that insignificant yields have been encountered in horizontal bedding planes and that they are considered largely closed.
- Although the dolerite dykes produced variable results, higher yielding boreholes are associated with dykes (up to 5 l/s). Deeper water strikes produced less water than shallower water strikes. Dykes are normally thicker than 10 m and concave sills are between 30 to 50 m thick.
- Pumping tests indicated rapid dewatering as the recharge is fracture controlled.
- The most likely aquifers are fracture zones associated with dykes, faults and lithological boundaries.
- Extended constant discharge tests (up to 3 days) were recommended in cases of high-yielding boreholes for large scale supply.

#### 5.2.3.2 *Dwyka and Dwyka / NGS contact*

- The Dwyka Tillite Formation adjacent to the Msikaba (NGS) appears to have good groundwater potential (SRK, Report 149105/5, 1993).
- Boreholes drilled in the Dwyka shale and Diamictite produced good yields (up to 5 l/s).
- Some boreholes however recovered poorly after pumping tests and their recommended yields were in the order of 20% of airlift yield;
- A borehole drilled through the Dwyka to intersect the NGS at depth of 90m did not produce significant yields at the contact.

#### 5.2.3.3 *Ecca Group*

- Boreholes in the Ecca Group can be ranked as having medium to high groundwater potential with expected yields in the order of 1.4 l/s to 2.8 l/s.
- Dolerite sheets provided inconsistent groundwater targets with yields ranging from dry to > 2 l/s. Shallow water strikes are common where the boreholes are drilled in well-developed drainages. Higher yields were obtained where the sheets were intersected at depths exceeding 40m. In some cases the pumping tests indicated sustainable yields greater than the airlift yield.
- Bottom contacts of dolerite sheets generally proved unsuccessful (data limited).
- High airlift yields were obtained in fractured shale (~ 4 l/s). Tested yields proved good (80 – 100% of airlift yield). Lineament plots indicate an east-west fracture system.
- Yields of up to 2 l/s have been obtained in bedding planes and associated fractures within mudstone.

### 5.3 Groundwater Potential of the study area

#### 5.3.1 Groundwater Resource Potential

Groundwater resource potential is of particular concern to the planner, developer and groundwater user. Groundwater resource potential normally embraces the following key parameters:

- Access to the site and depth of drilling.
- Yield and pumping height.
- Resource and recharge.
- Water quality and pollution risk.
- Sustainability.

The calculation of the groundwater potential requires a multidisciplinary approach covering hydrogeological, geological, GIS, hydrological and project management components at regional scale. This chapter deals with the regional groundwater resources of the Lusikisiki district in terms of the potential volumes of water available and the potential to abstract this water via boreholes. The groundwater resource assessment is presented per Groundwater Management Unit (GMU).

#### 5.3.2 Aquifer Recharge

Sustainable groundwater abstraction depends on adequate recharge to replace the water being removed from the aquifer system by pumping. Historically, estimated recharge rates for most aquifer systems in South Africa range between 5% and 10% of the annual precipitation. For the purposes of this study, aquifer recharge refers to the amount of rainwater that infiltrates into the vadose zone and then actually passes into the main underlying aquifer system, i.e. effective recharge (Nel 2005, Lusikisiki Groundwater Feasibility Study). The calculated mean annual recharge (MAR) is shown in Fig 5.3.2. The calculated mean annual precipitation (MAP) is given in Figure 5.3.2a.

If the three main geological units are taken, the average rainfall in each would be approximately:

- Msikaba        1400 - 1600 mm/a
- Dwyka         1200 - 1400 mm/a
- Ecca            1000 - 1200 mm/a

Two methods of calculation will be used, namely:

- GRID-based GIS modelling technique using estimated percentage recharge values (based on geology) – referred to as GGT (GRID-based GIS modelling technique)
- Chloride method using a comparison between the Chloride in the rainwater and the Chloride in the groundwater – referred to as Chloride Method.

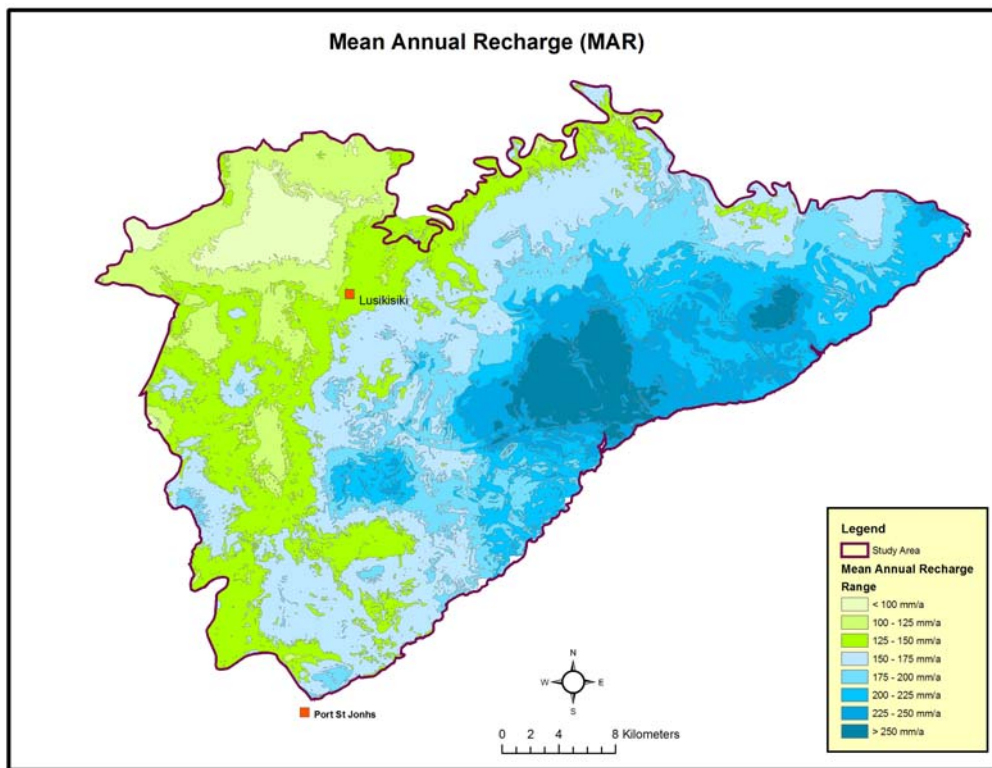


Figure 5.3.2: Mean annual recharge (Nel 2005, Lusikisiki Groundwater Feasibility Study)

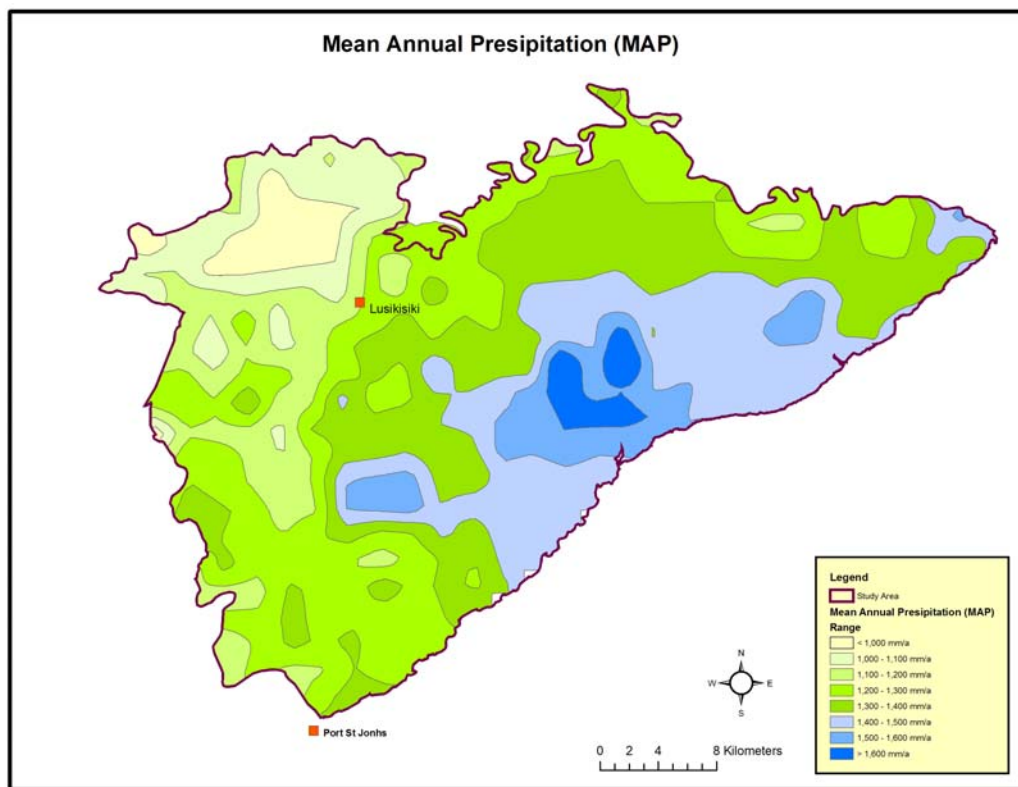


Figure 5.3.2a: Mean annual precipitation (MAP) - (Nel 2005, Lusikisiki Groundwater Feasibility Study)

### **GRID-based GIS modelling technique (GGT):**

The mean annual effective recharge ( $R_e$ ) from rainfall to the study area was estimated using the following GRID-based GIS modelling technique:

- A 30x30m grid of variable recharge rate or factor ( $R_f$ ) was derived from the mean annual precipitation (MAP) dataset, after Schultze, 1997), as follows:

$$R_f = [\text{MAP (mm)} / 10\,000]$$

- A 30x30m runoff factor ( $S_f$ ) grid was derived from a percentage slope grid (calculated from 30x30m digital terrain model), as follows:

$$S_f = [100 - \text{Slope\%}] / 100$$

- A 30x30m lithology factor ( $L_f$ ) was derived to take into account the variable recharge rates with the various lithological units as follows:

The Lithological factor for recharge estimates is given in Table 5.3.2.

**Table 5.3.2: Lithological factor for recharge estimates - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

Code	Lithological Unit	Recharge Factor ( $L_f$ )
Qa	Alluvium.	0.87
Qs	Dune and beach sand.	1.00
Jd	Karoo Dolerite.	0.95
Pa	Mudrock, subordinate sandstone.	1.05
Pe	Shale with sandstone-rich units present toward basin margins in south, west and northeast. Coal seams in northeast.	0.90
C-Pd	Diamictite (polymictic clasts set in poorly sorted, fine-grained matrix) with varved shale, mudstone with dropstones and fluvioglacial gravel common in north.	0.75
TRb	Red and greenish-grey mudstone, subordinate sandstone.	0.95
TRk	Sandstone (pebbly in places), mudrock.	1.10
Kmb	Breccia/conglomerate, greenish sandstone.	1.10
On	White, siliceous quartz arenite, locally feldspathic and conglomeratic.	1.15

- The rivers in the study area were buffered by 150m and a recharge factor ( $R_{iv_f}$ ) of 1.10 was applied to these areas.
- A 30x30m mean annual effective recharge or  $R_e$  (mm) grid was derived for the study area as follows:  
$$R_e \text{ (mm)} = \text{MAP} \times R_f \times S_f \times L_f \times R_{iv_f}$$
- The Lower and Upper Limits of  $R_e$  were estimated from Schultze *et al* (1997) Coefficient of Variation (%) of Annual Precipitation, which they refer to as an 'index of climatic risk'.

The mean annual effective recharge from rainfall for the study area is estimated at  $194 \times 10^6 \text{ m}^3$ , which equates to an average recharge rate of 12.9% of the mean annual precipitation.

The mean annual groundwater recharge from rainfall within each management unit is presented in Table 5.3.2a. The recharge rate as a percentage of MAP is consistent across the study area, with a minimum of 10.5% and a maximum of 15.4% between the management units. This is to be expected given uniform rainfall and topography in the study area. The groundwater management units that are part of the reduced area of investigation (area surrounding the existing reticulation network) are given in Figure 5.3.2b.

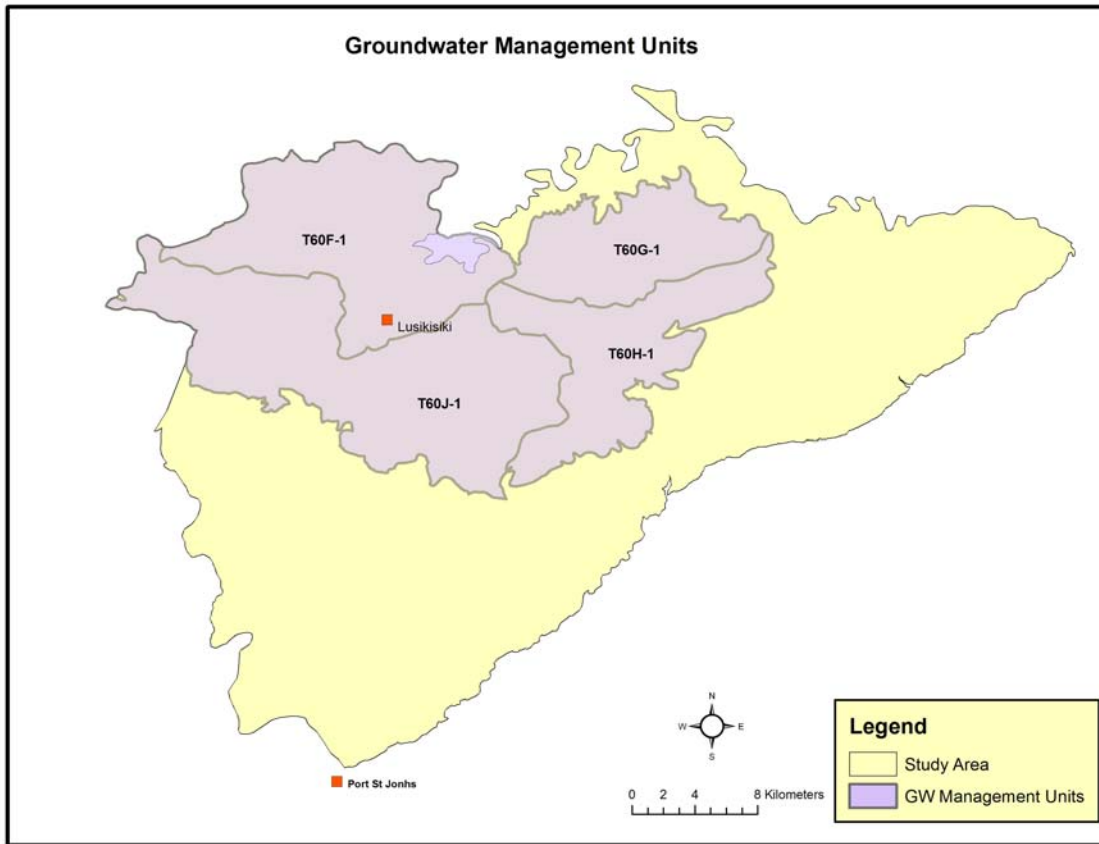


Figure 5.3.2b: Groundwater management units - (Nel 2005, Lusikisiki Groundwater Feasibility Study)

Table 5.3.2a: Mean annual effective recharge from rainfall - (Nel 2005, Lusikisiki Groundwater Feasibility Study)

GW Man Unit	Area (km <sup>2</sup> )	MAP (mm/a)	MAR X10 <sup>6</sup> m <sup>3</sup> /a	MAR (mm/a)	Recharge Factor (%)	Upper Recharge (mm/a)	Upper Recharge (X10 <sup>6</sup> m <sup>3</sup> /a)	Lower Recharge (mm/a)	Lower Recharge X10 <sup>6</sup> m <sup>3</sup> /a	Hi-Low Range X10 <sup>6</sup> m <sup>3</sup> /a
T60F-1	132.2	1,088.2	15.1	114.5	10.5%	137.7	18.2	91.3	12.1	6.1
T60G-1	71.6	1,337.8	12.4	172.9	12.9%	200.1	14.3	145.7	10.4	3.9
T60H-1	92.1	1,464.4	20.8	225.6	15.4%	260.0	23.9	191.2	17.6	6.3
T60J-1	184.2	1,231.8	27.2	147.9	12.0%	173.8	32.0	122.1	22.5	9.5
Other	657.3	1,340.3	118.4	180.1	13.4%	208.6	137.1	150.7	99.1	38.0
<b>TOTAL</b>	<b>1,137</b>		<b>193.9</b>				<b>225.6</b>		<b>161.7</b>	<b>63.9</b>
<b>AVG</b>		<b>1,292.5</b>			<b>12.9%</b>					

- MAR = Mean Annual Recharge      MAP = Mean Annual Precipitation

### **Chloride Method:**

If the Chloride profile method is applied and the average rainfall is used for each of the three geological units, the following formula would apply:

$$RE = [C_{input}/C_{gw}] \cdot R_f \quad \text{[From Bredenkamp et al, 1995]}$$

Where:         $C_{input}$  = chloride from rainfall  
                  $C_{gw}$  = chloride in the groundwater  
                  $R_f$  = rainfall

A rainfall sample taken near the town of Lusikisiki, on the Ecca Group, contained a chloride concentration of **13 mg/l**. If applied into the above formula, the recharge calculation of the **Ecca Group** would be as follows;

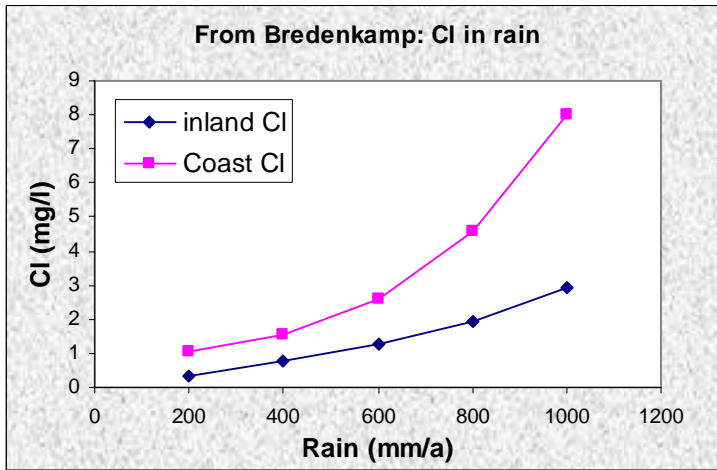
- 1)         $RE = [13 / 248] * 1000 = 52 \text{ mm/a (5.2\%)}$
- 2)         $RE = [13 / 59] * 1000 = 220 \text{ mm/a (22\%)}$

based on the following average chloride concentrations of the groundwater in the three geological units and on the average rainfall for each unit:

Msikaba Sandstone	=	27 mg/l	(7 samples, ignoring EC/T60/080)
Dwyka	=	22 mg/l	( 1 sample, ignoring dykes)
Ecca	=	248 mg/l	( 2 samples)
	=	59 mg/l	( 2 samples)

If assumed that the chloride concentration in the rainfall remains constant over the entire area, the groundwater recharge in the Msikaba and Dwyka would be 48% and 59% respectively, which is too high considering the density and composition of the Dwyka and Msikaba. In order to apply the Chloride method to all three geological units, more rainwater samples will have to be taken across the entire area.

Based on a different method of calculation, namely the linear relationship between annual precipitation and the total chloride input is taken (Bredenkamp, et al 1995), formulas are derived (see below) and the percentage recharge can be calculated.



Bredenkamp, *et al*, 1995

Borehole EC/T60/080 is situated less than 900 m from the coastline and had a chloride value of 80 mg/l in comparison to the average of 27 mg/l of the rest of the Msikaba boreholes. Two of the Dwyka boreholes (non dyke related) had chloride values of 32 mg/l and 12 mg/l (average 22 mg/l), while those associated with dykes had an average of 216 mg/l. Two distinct chloride groups were observed in the Ecca, ranging from 248 mg/l (average) and 59 mg/l (average). The reason for the large difference is not certain as dolerite was encountered in all the Ecca boreholes. Using Bredenkamp's linear graph and standard values for (1) Cl inland and (2) coastal, the percentage recharge for each of the three geological units calculates as follows:

For example, Msikaba

### MSIKABA (inland)

Van Tonder

0		
Average annual rainfall (mm)=	1500	
Cl in rain (mg/l) =	0.2207	If Cl rain unknown use = 0.2207 for inland 1.8448 for coast
Dry deposition Cl (mg/l) =	0.1	
Cl in gw or unsat. zone (mg/l) =	27	if dry depo Cl unknown Use: 0.1*(Cl of rain) for inland if no forest exist 2.5*(Cl of rain) if forest exist 0.8*(Cl of rain) if spray of mist/dust is a factor at coast
Average annual recharge (mm) =	18	
Percentage recharge =	1.2	

### MSIKABA (Coast)

Van Tonder

Average annual rainfall (mm)=	1500	
Cl in rain (mg/l) =	1.8448	If Cl rain unknown use = 0.2207 for inland 1.8448 for coast
Dry deposition Cl (mg/l) =	0.8	
Cl in gw or unsat. zone (mg/l) =	27	if dry depo Cl unknown Use: 0.1*(Cl of rain) for inland if no forest exist 2.5*(Cl of rain) if forest exist 0.8*(Cl of rain) if spray of mist/dust is a factor at coast
Average annual recharge (mm) =	147	
Percentage recharge =	9.8	

Following the same calculation method for the **Dwyka and Eccca**, the percentage recharge is as follows:

- Dwyka            12 % (coast)                    1.5 % (inland)
- Eccca            4.5 and 1.1 % (coast)            0.5 and 0.1 % (inland)

Parts of the Msikaba and the Dwyka can be considered coastal, as the Msikaba borders the coast and the Dwyka receives a fair contribution of mist from the sea. The Eccca is however far removed from the coast (> 25 km) and hence the influence of the coastal conditions should be minimal.

If the recharge calculation from the rainwater sample in the Eccca is considered (and if a groundwater concentration of 248 mg/l is taken), together with Breckenkamp & Van Tonder method, the percentage recharge estimates based on the Chloride method is in the same magnitude (5%) under **coastal conditions**.

If a groundwater chloride value of 59 mg/l is however taken, the percentage recharge plots more towards what was calculated in the GRID based GIS modelling technique with the build-in Lithological recharge factor.

### 5.3.3 Groundwater Exploitation Potential

Woodford and Chevalier *et al* (1999) describes the '*Exploitation Potential*' (EP) as the maximum volume of groundwater that can be abstracted per unit area per annum without causing any long-term 'mining' of the aquifer (i.e. without continued long-term declining water levels).

The EP was estimated for the Lusikisiki district using a raster-based GIS modelling and uses mean annual effective recharge from rainfall as its basis. Woodford also determined the so-called 'Exploration Potential' based on the probability of drilling high-yielding production boreholes with a high success rate. The EP essentially considers the resource potential in terms of recharge, whilst the Exploration Potential assesses the accessibility for drilling and success thereof (Fortuin *et al*, 2004). The geo-spatial intersection of these two datasets was used to produce a 'Development Potential' (DP) map. The DP indicates areas where large-scale abstraction of groundwater should receive high priority considering the exploitation and exploration potential (Fortuin *et al*, 2004).

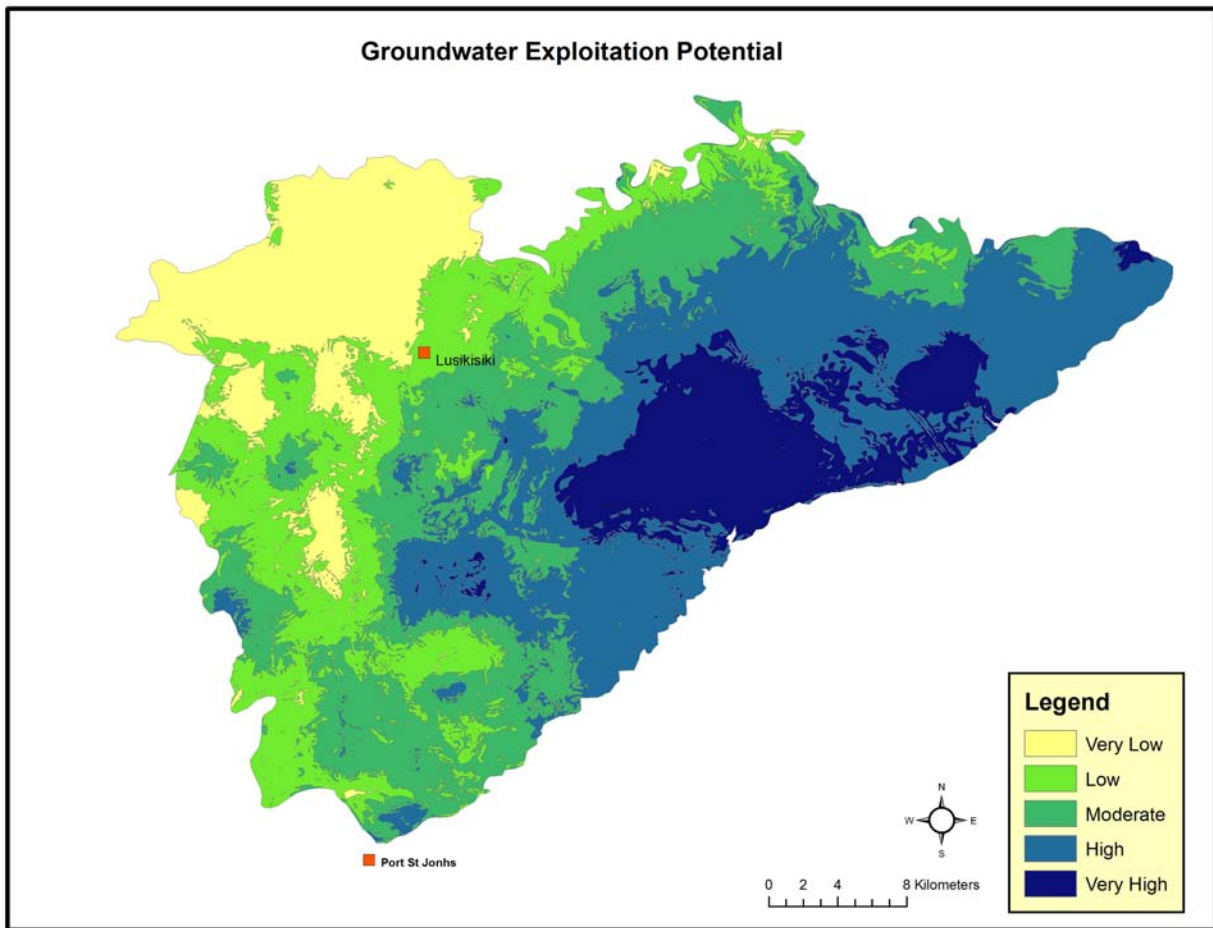
A grid-based ranking and modeling process within the GIS, was used to qualitatively rank the recharge as follows (Table 5.3.3):



**Table 5.3.3: Groundwater exploitation potential - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

Mean Annual Effective Recharge (mm/a) from Rainfall	Qualitative Ranking
> 225	Very High
175 - 225	High
150 - 175	Moderate
125 - 150	Low
< 125	Very Low

The Groundwater Exploitation Potential is presented in Figure 5.3.3



**Figure 5.3.3: Groundwater exploitation potential - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

#### 5.3.4 Groundwater Exploration Potential (GEXP)

The groundwater exploration potential of the study area provides a qualitative indication of the potential for siting and drilling successful boreholes. Also, the higher the rating of an area the higher the anticipated yield of the borehole. The groundwater exploration potential of the study

area was qualitatively estimated using a grid-based ranking and modeling process within the GIS, where the following parameters were considered;

**Lithology:** the physical and chemical character (permeability, grain size, mineralogy, etc.) of the aquifer material both directly and indirectly controls the regional and local occurrence of the groundwater, as well as the groundwater quality. Woodford et al (1999) studied the effects of lithology on borehole productivity in the Lusikisiki district and surrounding areas. Borehole yields in the Beaufort rocks were found to be marginally higher than those drilled in the Ecca Group, although they both exhibit a similar borehole failure rate of 12% i.e. dry boreholes. Boreholes drilled into the Dwyka Group were significantly lower and a greater percentage (29%) of these boreholes was dry. Lithology of the study area was subdivided into three categories in terms of anticipated borehole productivity. A factor was applied to each of the Lithological units and is presented in Table 5.3.4.

**Table 5.3.4: Lithological factors for recharge estimates - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

Code	Lithological Unit	Recharge Factor ( $L_f$ )
Qa	Alluvium.	1.10
Qs	Dune and beach sand.	1.10
Jd	Karoo Dolerite.	1.50
Pa	Mudrock, subordinate sandstone.	1.20
Pe	Shale with sandstone-rich units present toward basin margins in south, west and northeast. Coal seams in northeast.	0.80
C-Pd	Diamictite (polymictic clasts set in poorly sorted, fine-grained matrix) with varved shale, mudstone with dropstones and fluvio-glacial gravel common in north.	0.70
TRb	Red and greenish-grey mudstone, subordinate sandstone.	1.30
TRk	Sandstone (pebbly in places), mudrock.	1.40
Kmb	Breccia/conglomerate, greenish sandstone.	1.00
On	White, siliceous quartz arenite, locally feldspathic and conglomeratic.	1.80

Geological Lineaments: Numerous detailed studies have shown that boreholes drilled in the vicinity of the lineaments (<250m) are higher yielding than those drilled away from such structures ( Woodford and Chevalier, 2001; Gustafsson, 1983; Bobba et al, 1982; Water et al (1990); Rauch et al; 1984; Schowengerd et al, 1979; Latmman and Parizek, 1964). Woodford et al (1999) found that the palaeo-extensional NE and ENE-trending lineaments were more favourable for obtaining higher yielding boreholes in the region. They also found that the palaeo-extensional WNW-trending structures may also have been recently reactivated within a NW-SE to E-W orientated extensional stress regime and should therefore favour the development of high yielding boreholes.

The mapped dolerite dykes and faults as well as the aerial photograph and satellite lineaments were subdivided into four categories in terms of anticipated borehole productivity:

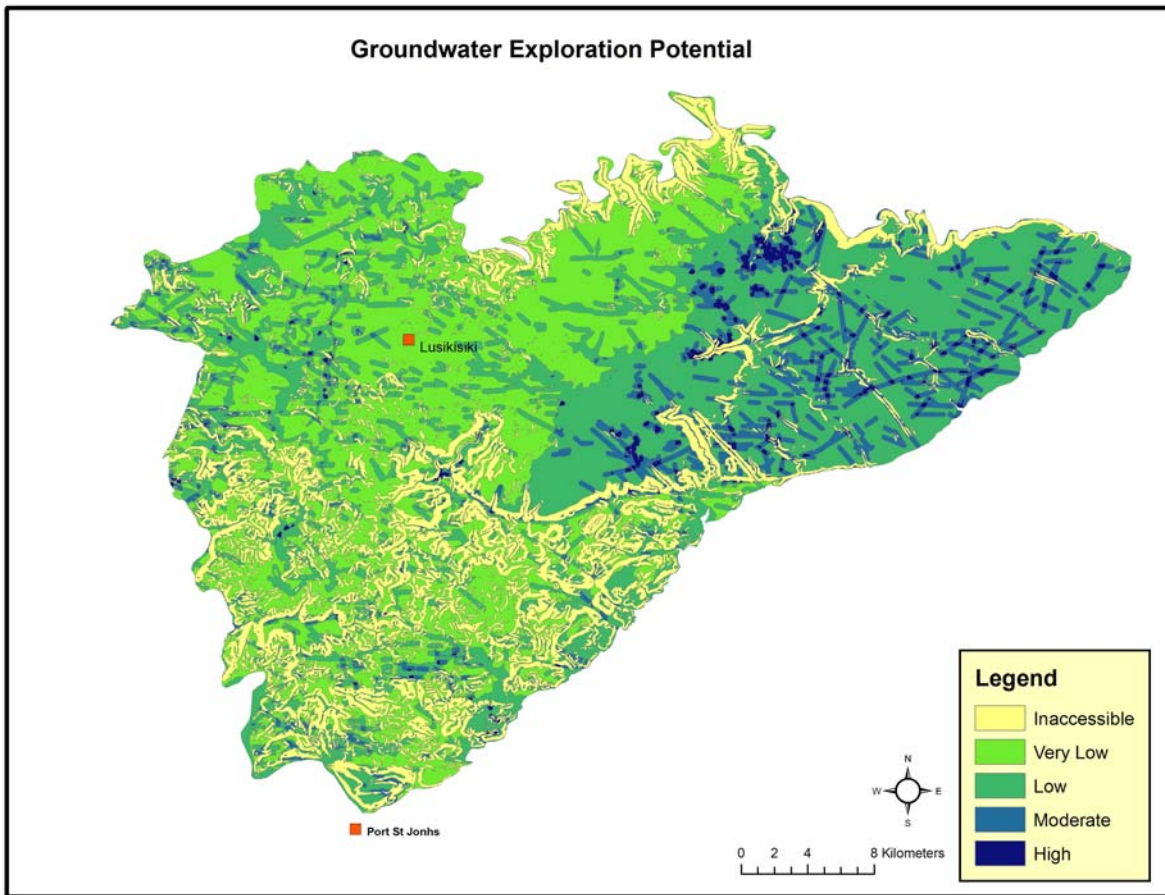
- Very high – all dolerite dykes and faults and lineaments that may have been subjected to extension under both palaeo- and neo-extensional stress regimes;
- High – all lineaments that may have been subjected to extension with recent times;
- Moderate – all lineaments that may have been subjected to extension under palaeo stress regimes; and
- Low – all unclassified aerial photograph and satellite lineaments.

In the GIS modeling process the geological lineaments were ‘buffered’ by 150m in order to take into account the anticipated zone of influence of these structures.

Terrain Accessibility: The percentage slope of the terrain was derived from the DTM and any areas with a percentage slope in excess of 15% were regarded as inaccessible to drilling rigs and therefore excluded from the analysis process regardless of their borehole productivity ranking. A grid-based ranking and modeling process within the GIS, where the above parameters were considered, produced the Groundwater Exploration Potential map which is presented in Figure 5.3.4. Table 5.3.4a below summarises the aerial extent of the categories of exploration potential.

**Table 5.3.4a: Qualitative groundwater exploration potential - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

Qualitative Groundwater Exploration Potential	% of Total Area
Very High	1.35%
High	0.09%
Moderate	8.47%
Low	35.88%
Very Low	31.86%
Inaccessible	22.35%



**Figure 5.3.4: Groundwater exploration potential map - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

### 5.3.5 Groundwater Development Potential

The development potential map was generated by 'geospatially' intersecting the exploitation and exploration potential maps. The map as indicated in Figure 5.3.5 was reclassified to qualitatively rank the potential of an area to sustain large-scale abstraction as follows:

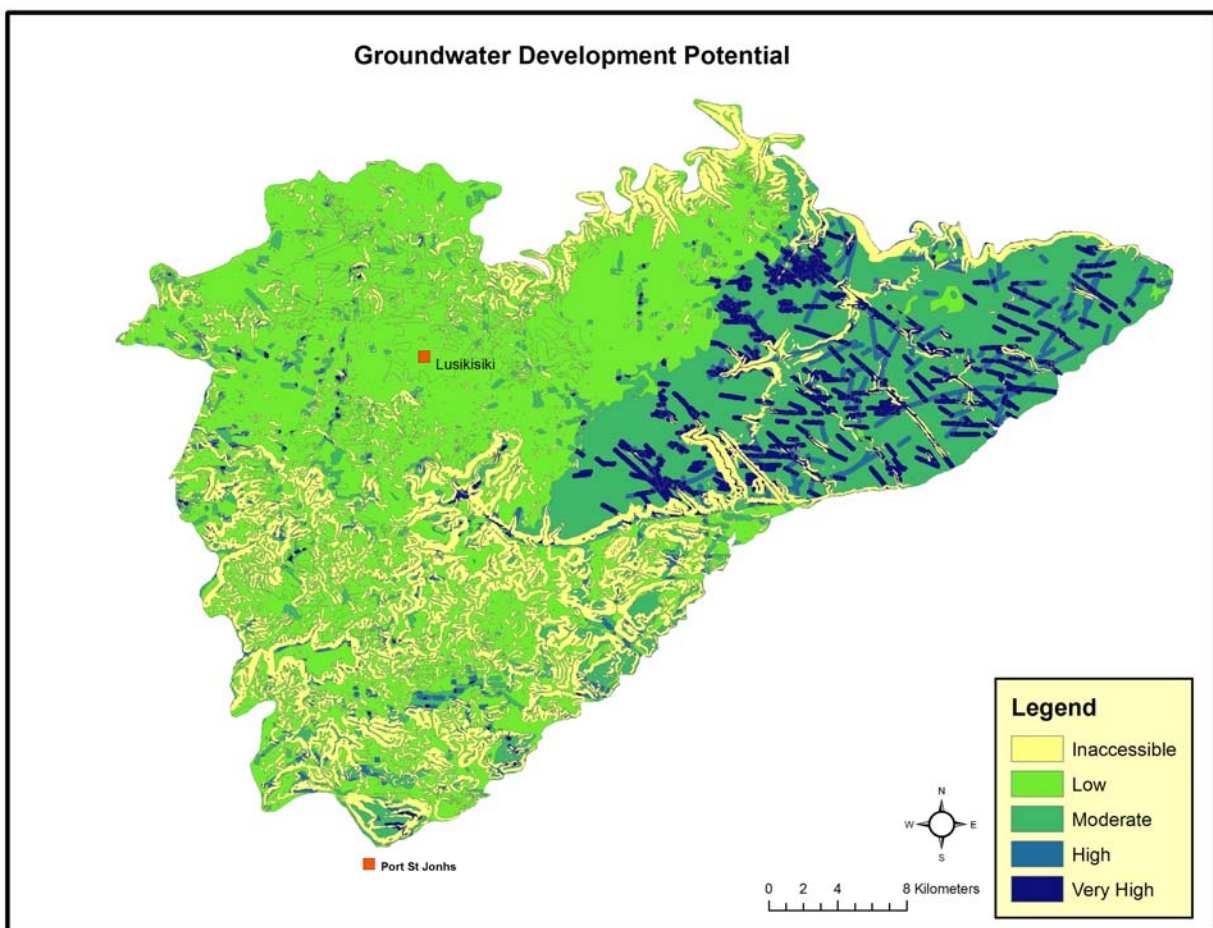
- Excellent
- Very High
- High
- Moderate
- Low
- Very Low
- Inaccessible

It is evident that high to excellent development potential exists along the regional dykes and faults in the Natal Group Sandstone Formation, whereas the Natal Group Sandstone Formation itself is

of moderate development potential. The development potential in the Dwyka Formation is low to very low as well as the Ecca Group and the Adelaide Subgroup. The aerial extent of the qualitative development potential is summarized in Table 5.3.5 below.

**Table 5.3.5: Qualitative groundwater development potential - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

Qualitative Groundwater Development Potential	% of Total Area
Excellent	1.34%
Very High	4.73%
High	3.40%
Moderate	23.02%
Low	37.39%
Very Low	7.76%
Inaccessible	22.35%



**Figure 5.3.5: Groundwater development potential - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

## 5.4 Target selection

### 5.4.1 Lineament mapping

#### 5.4.1.1 Remote-Sensing Study and GIS-based Exploration Target Identification

The aim of this component of the study was to locate target areas with the highest potential for the establishment of high-yielding boreholes for further field investigation (i.e. structural mapping and geophysical profiling). ESRI's ArcGIS 9 (ArcView) software was used to develop a GIS database to aid with the task of selecting areas with high groundwater yield potential.

The GIS database included the following coverages:

- borehole and spring information from the NGDB, as well as from the hydrocensus carried out during this study;
- 1 : 250 000 scale geology (Umtata 3128 - Council for Geoscience);
- DWAF's 20x20m resolution digital elevation model (DEM) and
- 1 : 50 000 scale drainage features.

A remote-sensing study was conducted with the prime objective of mapping geological lineaments such as dolerite dykes, faults and fracture zones using the following three types of digital imagery:

1. LANDSAT ETM7
2. ASTER
3. Panchromatic, 10 000 scale ortho-photographs .

ERDAS Imagine was used to process and digitally enhance the satellite imagery (i.e. LANDSAT and ASTER) with the aim of assisting in the detection of geological lineaments. The three forms of imagery used compliment one another in such a study as they provide a broad range of spatial and spectral resolutions. The more regional lineaments were more easily mapped using the coarser scale LANDSAT and ASTER imagery, whilst the ortho-photography was more suited to the mapping of fracture zones, dolerite sheets and lithological contacts. Figure 5.4.1.1 provides an indication of the extent of the mapped lineaments. When selecting target exploration areas, consideration was given to proximity to the existing pipeline for the bulk surface water supply scheme and to the geohydrological assessment of the various lithological units and structural settings. The Dwyka Formation underlies most of the area in close proximity to the infra-structure of the Lusikisiki Bulk Water Supply Scheme. In the area, the Natal Group Sandstone (Msikaba) dips beneath the Dwyka rocks at a low angle of  $\pm 2^\circ$  and can thus be intercepted at depths of up to 200m below the Dwyka Formation at distances of up to 6 km from the contact between the two Formations as indicated in Figure 5.4.1.2.

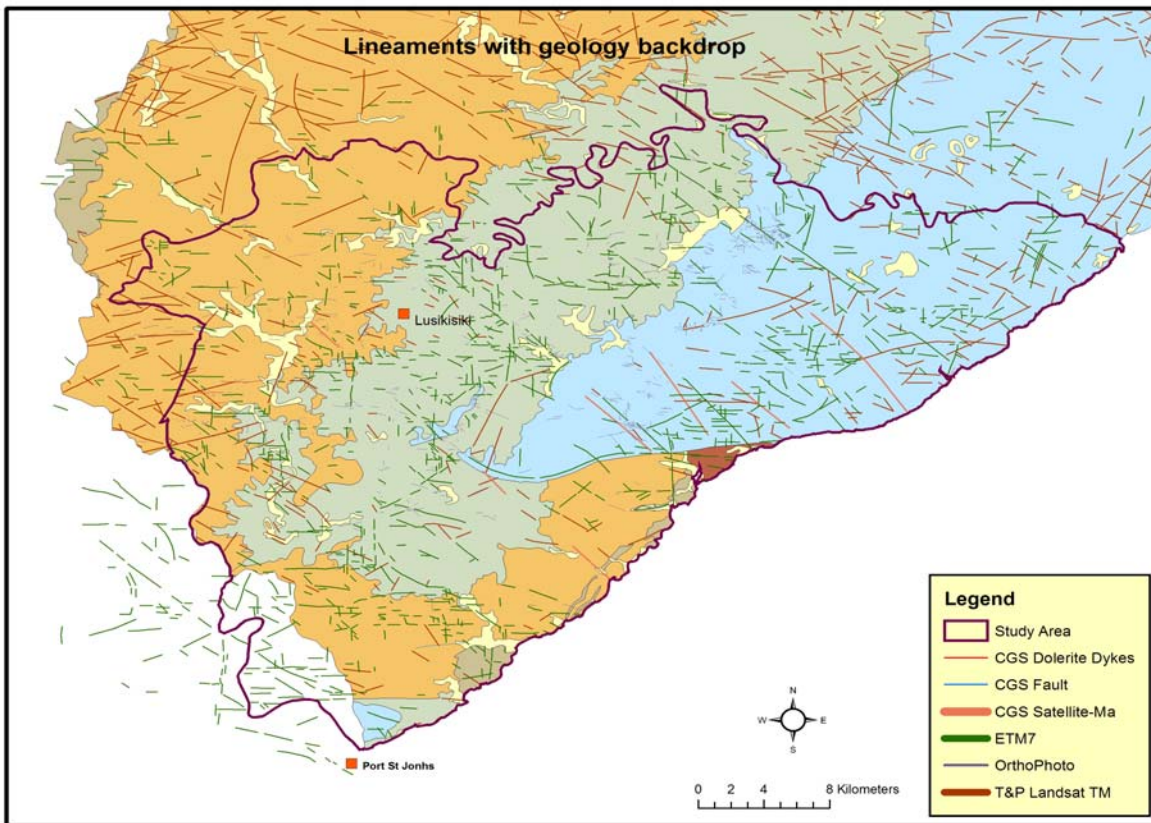
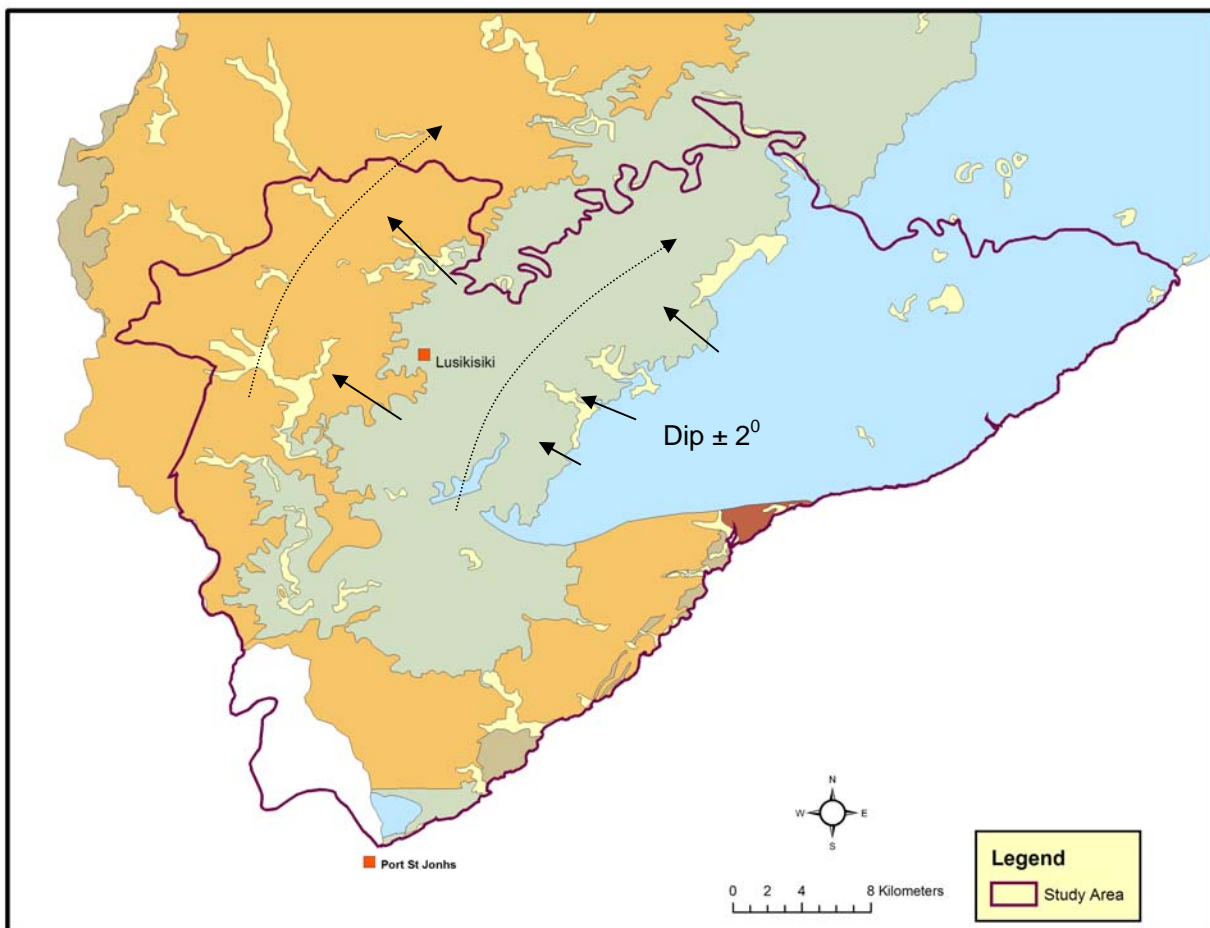


Figure 5.4.1.1: Lineaments as mapped



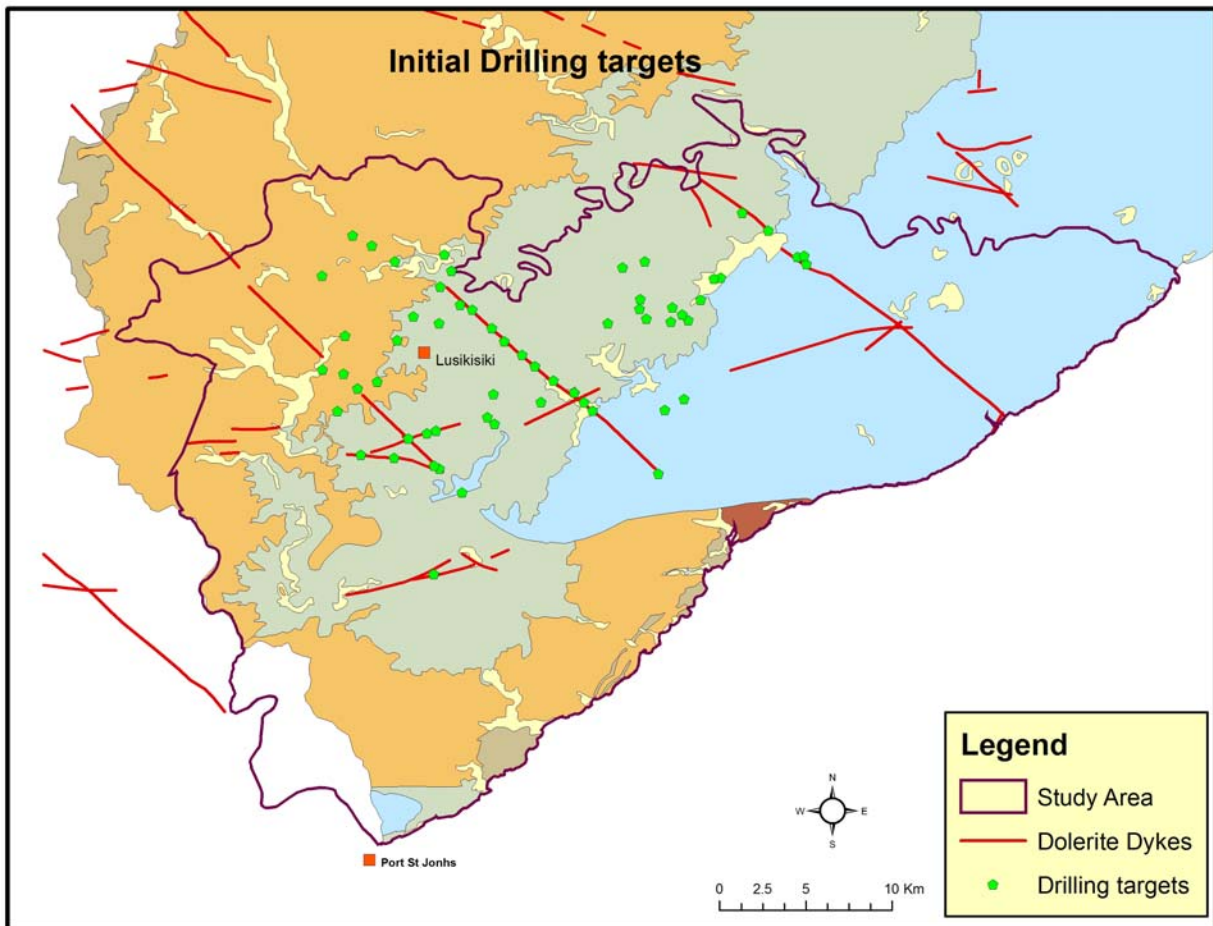
**Figure 5.4.1.2: Dip of Msikaba underneath Dwyka**

#### 5.4.2. Geophysical exploration

The Geotron G5 Proton Magnetometer and Geonics EM-34 were used for the geophysical exploration and were supplemented with the Electrical Resistivity method where necessary. The geophysical graphs are attached in Appendix 2.

As can be seen from the targets drawn from the Landsat and geological mapping (refer to Figure 5.4.2), the main emphasis was placed on locating the dolerite dykes, but lineaments, faults and geological contact zones were also targeted.





**Figure 5.4.2: Positions of drilling targets relative to dolerite dykes**

In most of the areas where geophysical work was done, outcrop was not visible and the targets were searched with reconnaissance traverses (mostly magnetic) and when found, electromagnetic traversing was done across the magnetic anomalies.

Geophysical exploration proved very difficult in the Ecca Group because of the abundance of dolerite sheets and the resistivity method was used in conjunction with the magnetic and electromagnetic to verify targets.

## 5.5 Drilling and testing of exploration boreholes

### 5.5.1 Drilling and testing results

The geophysical exploration was followed by the drilling of the identified targets. The drilling focussed on a number of sites throughout the area to first establish the expected yields in each of the three geological areas, namely the Ecca Group, Dwyka and Natal Group Sandstone. Table 5.5.1 lists the drilling and pump testing results. The borehole logs are attached in Appendix 3 and the results of the pumping tests and water quality tests in Appendix 4.

**Table 5.5.1: Drilling and pump testing results**

BH No	Latitude	Longitude	Airlift yield (l/s)	12-hr yield (l/s)	24-hr yield (l/s)	BH depth (m)	** Water Quality
EC/T60/051	31.30908000	29.75960000	22	4.6	3.2	110	M - Iron
EC/T60/052	31.30313000	29.75283000	2.75	1.26	0.89	100	M - Bacteria
EC/T60/053	31.34855000	29.70891000	11	1.24	0.87	146	M - Bacteria
EC/T60/054	31.39673000	29.66307000	85	10.5	7.5	100	Good
EC/T60/055	31.39117000	29.65699000	1.1	1.1	0.75	98	Good
EC/T60/056	31.35509000	29.61120000	0.1	Not tested		120	No sample
EC/T60/057	31.31655000	29.48660000	1.6	0.5	0.34	86	M - Iron & chloride
EC/T60/058	31.31135000	29.47263000	1.05	0.2	0.1	98	M - Iron
EC/T60/059	31.31152000	29.47281000	0.4	Not tested		70	U - Iron
EC/T60/060	31.35744000	29.53353000	0	Not tested		110	No sample
EC/T60/061	31.37449000	29.52324000	22	3.3	2.3	120	M - Chloride & Bacteria & Iron
EC/T60/062	31.37458000	29.52327000	5	Not tested		60	No sample
EC/T60/063	31.30420000	29.53667000	0	Not tested		128	No sample
EC/T60/064	31.33744000	29.59236000	2.2	0.84	0.6	86	U - Iron & Bacteria
EC/T60/065	31.42056000	29.54342000	0.1	Not tested		80	No sample
EC/T60/066	31.31145000	29.91935000	0	Not tested		80	No sample
EC/T60/067	31.31104000	29.91933000	0	Not tested		80	No sample
EC/T60/068	31.33211000	29.92446000	0	Not tested		80	No sample
EC/T60/069	31.34969000	29.50047000	0.85	0.2	0.13	80	P-Coliforms
EC/T60/070	31.34958000	29.50069000	0	Not tested		100	No sample
EC/T60/071	31.34960000	29.68408000	0	Not tested		35	No sample
EC/T60/072	31.38769000	29.65072000	5	2.1	1.5	150	U-Coliforms
EC/T60/073	31.39144000	29.65567000	0.3	Not tested		33	No sample
EC/T60/074	31.39164000	29.65579000	0.6	0.48	0.34	120	P - Bacteria
EC/T60/075	31.35328000	29.8214000	0.2	Not tested		74	No sample
EC/T60/076	31.35342000	29.82075000	1.0	0.57	0.4	80	U - Iron, Bac
EC/T60/077	31.31741000	29.77086000	0	Not tested		32	No sample
EC/T60/078	31.31758000	29.7708000	15	1.33	0.94	105	GOOD
EC/T60/079	31.33893000	29.92912000	0.3	Not Tested		80	No sample
EC/T60/080	31.33175000	29.95383000	2.5	0.72	0.51	80	M - Iron

\* **P = Poor, M = Marginal, U = Unacceptable**

## 6. EVALUATION OF THE RESULTS

### 6.1 Drilling

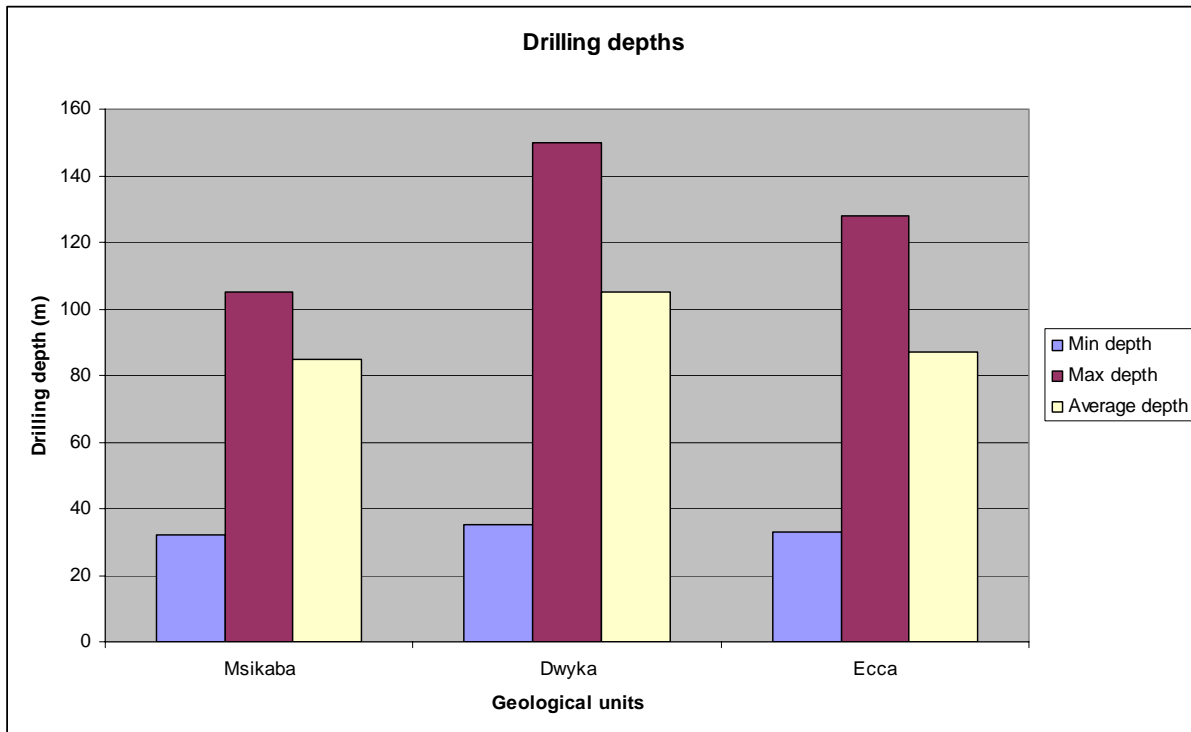
A comparison was done on the results of the drilling in terms of the feature or structure drilled and the results. This comparison is shown in Table 6.1. Following Table 6.1 are comparisons between the water strike depth and yields of the three major geological units and the average depth drilled per unit.

**Table 6.1: List of main targets and drilling results**

Feature	Details	Drilled (Yes / No) - Comments
<b>DOLERITE:</b> (ECCA, DWYKA, NGS)	Top contact of dolerite sheet / sill	Yes, no significant water strikes in Dwyka, Eccca. Not drilled in NGS
	Bottom contact of sheet / sill	Yes, no significant water strikes in Dwyka, Eccca. Not drilled in NGS.
	Inside sheet / sill	Yes, no significant water strikes
	Dyke contact	Yes, significant water strikes > 5 l/s in NGS, but not significant in Dwyka when dyke is thin. Thicker dykes yielded 5 l/s shallow strikes. Low yields also when dyke in situated in the Eccca.
	Inside dyke	Yes, but less water than next to dyke (2-3 l/s) - NGS. Low yields where dyke occurs in Dwyka (< 1 l/s)
<b>LINEAMENTS</b>	East west trending lineaments	Yes, significant strikes in Dwyka; none in NGS
	South east trending lineaments	Yes, no strikes in NGS (not drilled in Eccca / Dwyka)
	East north east trending lineaments	Yes, no strikes in NGS (not drilled in Eccca / Dwyka)
<b>FRACTURING / WEATHERING</b>	In Dwyka	Yes, significant strike where associated with EW lineament
	In thick dolerite sheets	Not targeted, will require resistivity work
	Associated with Dykes (near dykes)	Yes, high yields of up to 85 l/s in NGS in fracturing within 2-20 m from regional dykes.
<b>GEOLOGICAL CONTACTS</b>	Between Eccca / Dwyka	Yes, no significant strikes
	Between Dwyka / NGS	Yes, significant strike but little fracturing. Strikes de-watered.
<p><b>Notes:</b></p> <ul style="list-style-type: none"> <li>• Significant yields are considered &gt; <b>1.5 l/s airlift yield</b> for the purpose of the above table.</li> <li>• Lineaments not extensively drilled where they occurred on their own. Those drilled near Mkambati were dry.</li> </ul>		

The **depth of the drilling** was primarily controlled by the type of target drilled and also the capacity of the drilling rig. In the cases of the very high yielding boreholes (EC/T60/051 and 054) the drilling could not progress passed the last water strike as the back pressure of the water was too great. In general, drilling targets were chosen where they occurred 40 – 60 metres below the static water level as the weathering and fracturing were believed to be well developed at such depth and sufficient drawdown could be obtained during abstraction.

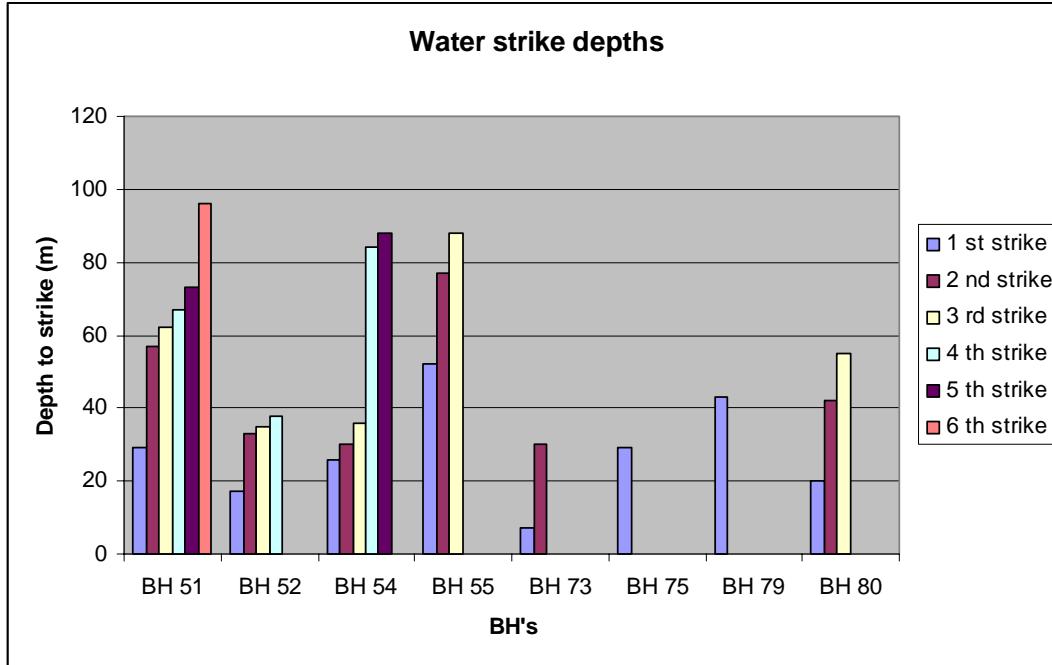
Figure 6.1a portrays the drilling depths per geological unit as achieved in the study.



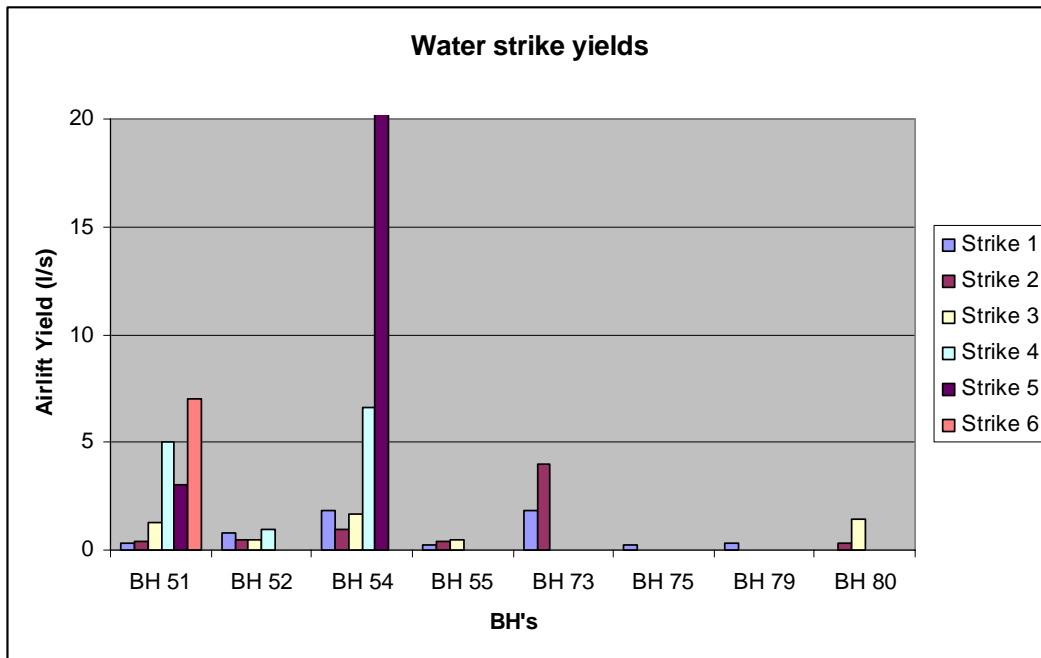
**Figure 6.1a: Drilling depths**

Figures 6.1b – 6.1g portrays the water strike depths and strike yields of each of the three geological units.

**NATAL GROUP SANDSTONE (MSIKABA)**



**Figure 6.1b: Water strikes in the Msikaba Sandstone (BH 51 = EC/T60/051, etc.)**



**Figure 6.1c: Water strike yields (airlift) in the Msikaba Sandstone**

Multiple water strikes are observed in most of the boreholes with the yield generally increasing in depth.

## DWYKA FORMATION

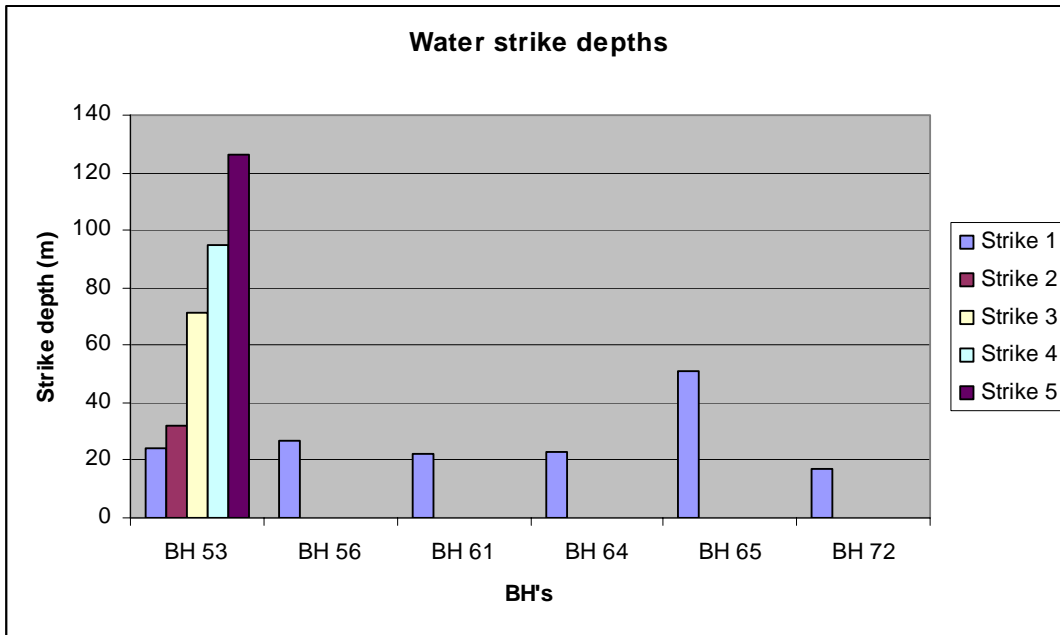


Figure 6.1d: Water strike depths of boreholes drilled in the Dwyka

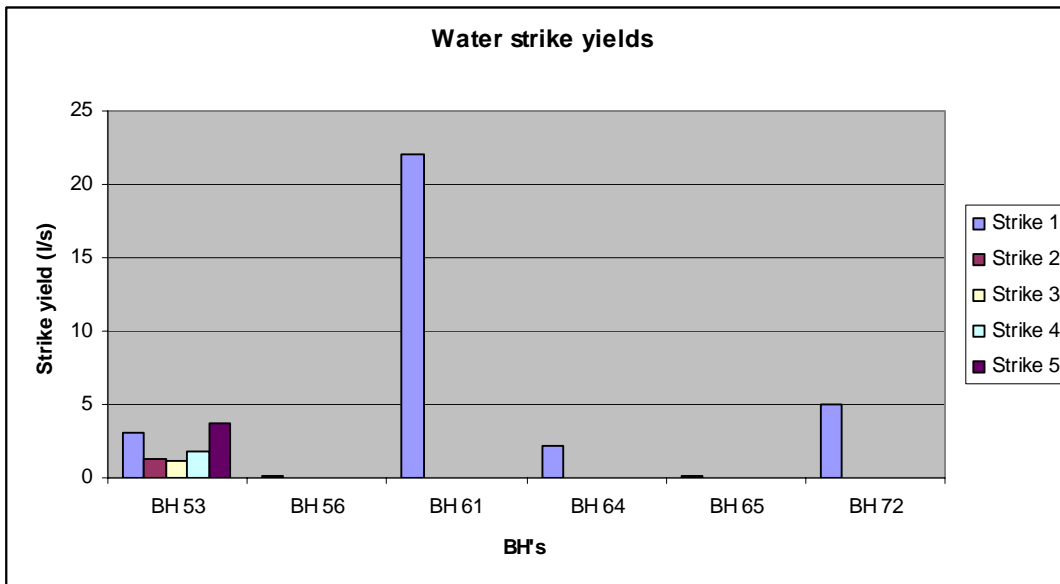


Figure 6.1e: Water strike yields (airlift) of boreholes drilled in the Dwyka

With the exception of borehole 53 (EC/T60/053), single water strikes are observed and the depth to water strike are generally within the first 60 m.

## ECCA GROUP

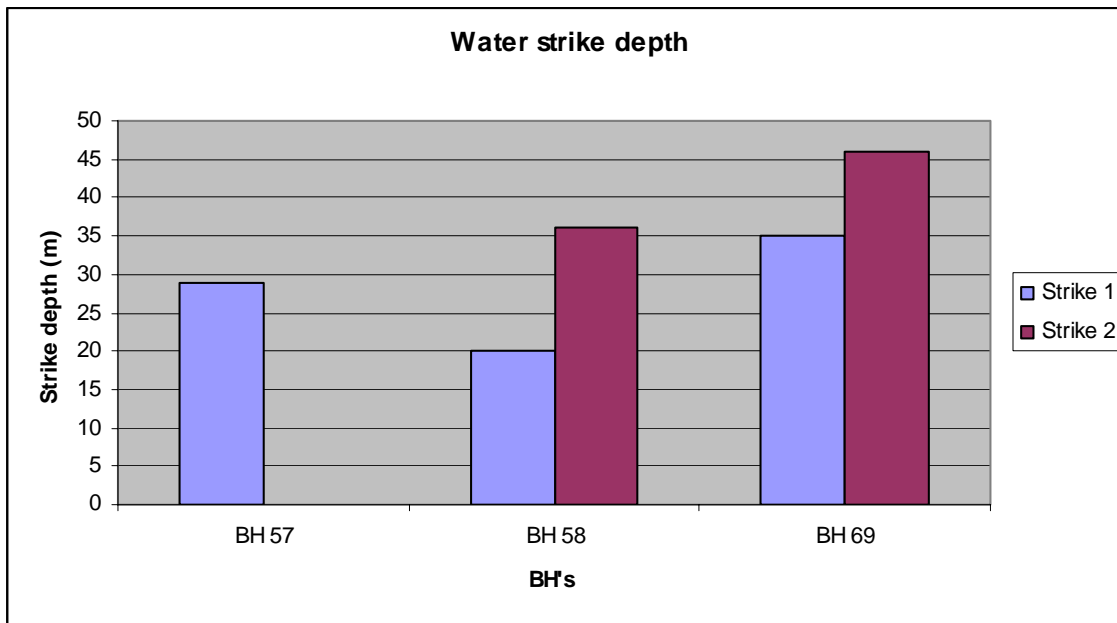


Figure 6.1f: Water strike depths of boreholes drilled in the Ecca

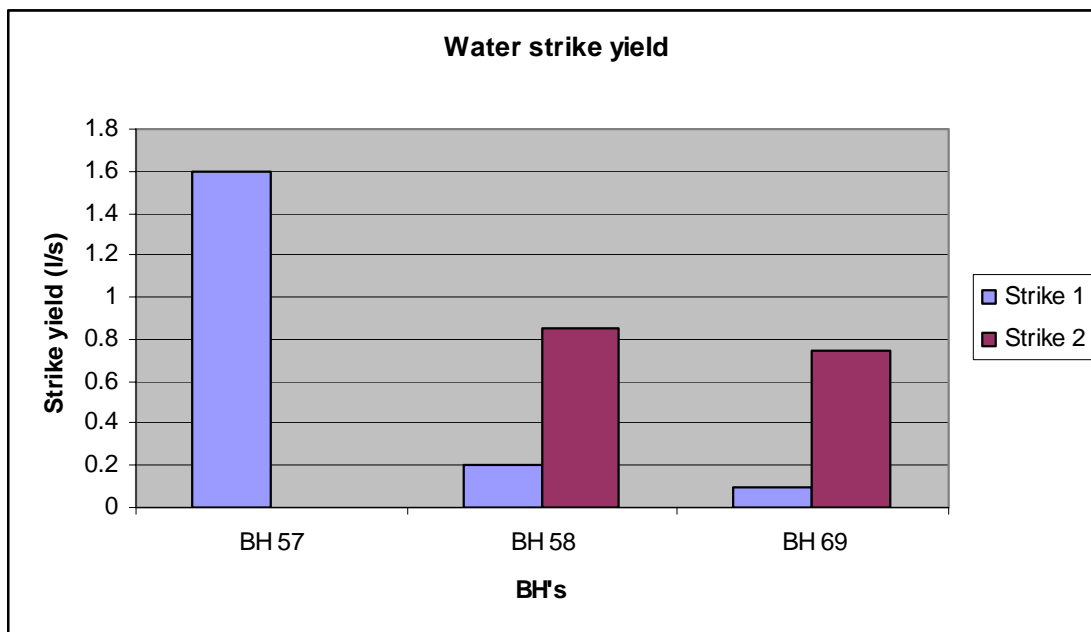


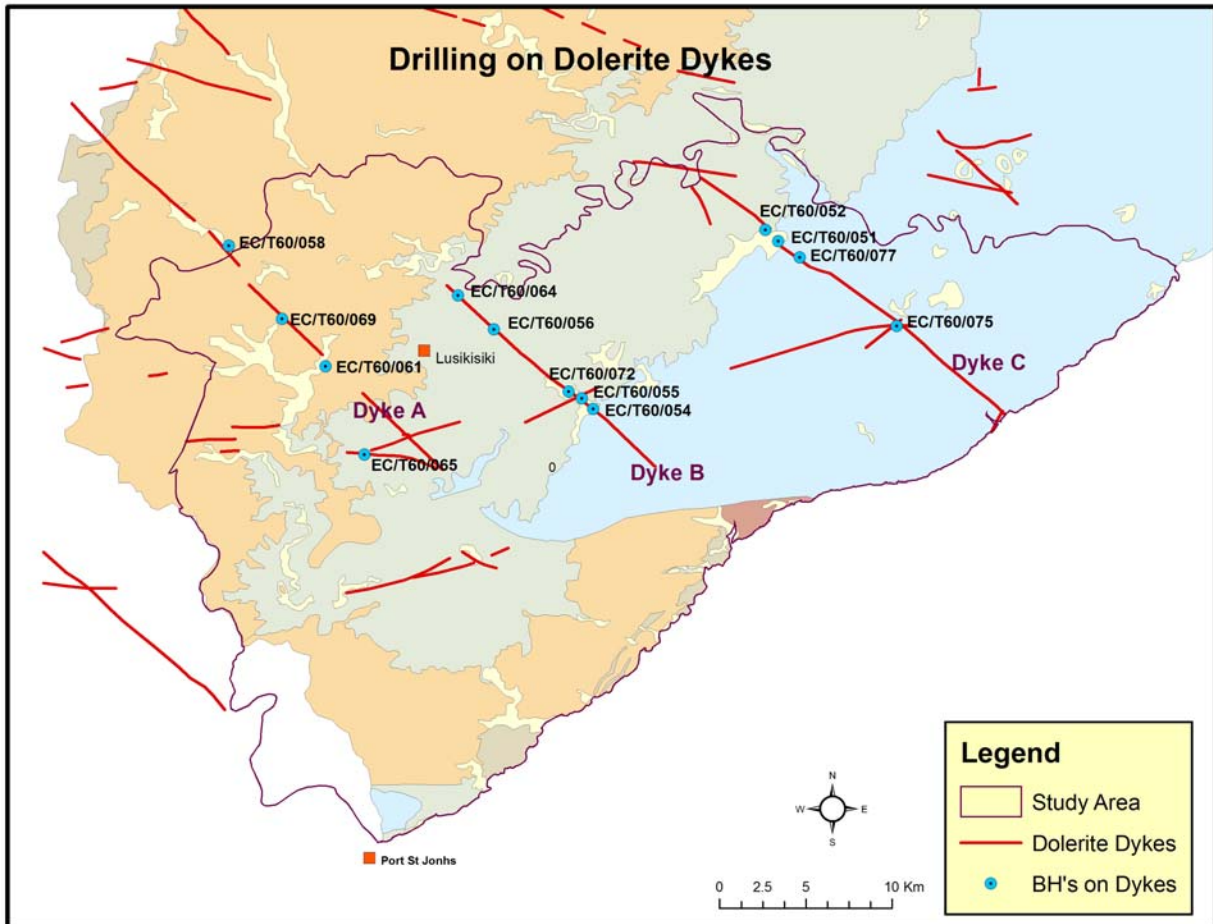
Figure 6.1g: Water strike yields of boreholes drilled in the Ecca

The water strike depths were generally within 50 m with the strike yields showing a tendency of increasing towards depth (BH's 58 and 69)

The drilling results are also evaluated against the structures or features targeted such as dolerite dykes, geological contact zones and lineaments and also against the geophysical anomalies describing these targets.

### 6.1.1 Targeting dolerite dykes

Figure 6.1.1 shows the positions of major dykes and the boreholes drilled on the dykes.



**Figure 6.1.1: Boreholes drilled on dykes**

#### Boreholes EC/T60/051 and 052 targeting dykes in the NGS:

The first target was aimed at a near-vertical dolerite dyke near the contact between the Dwyka diamictite and the Natal Group Sandstone as is shown in Figure 6.1.1, Dyke C. The geophysical graph of borehole EC/T60/051 is shown in Figure 6.1.1b. Although the dyke was not visible on the surface, the geophysical graph defined the position of the dyke clearly and also indicated fracturing & weathering on both sides of the dyke (EM-34 graph). The dyke dipped north-east and because the surface drainage was from the south-west, it was decided to start the borehole drilling

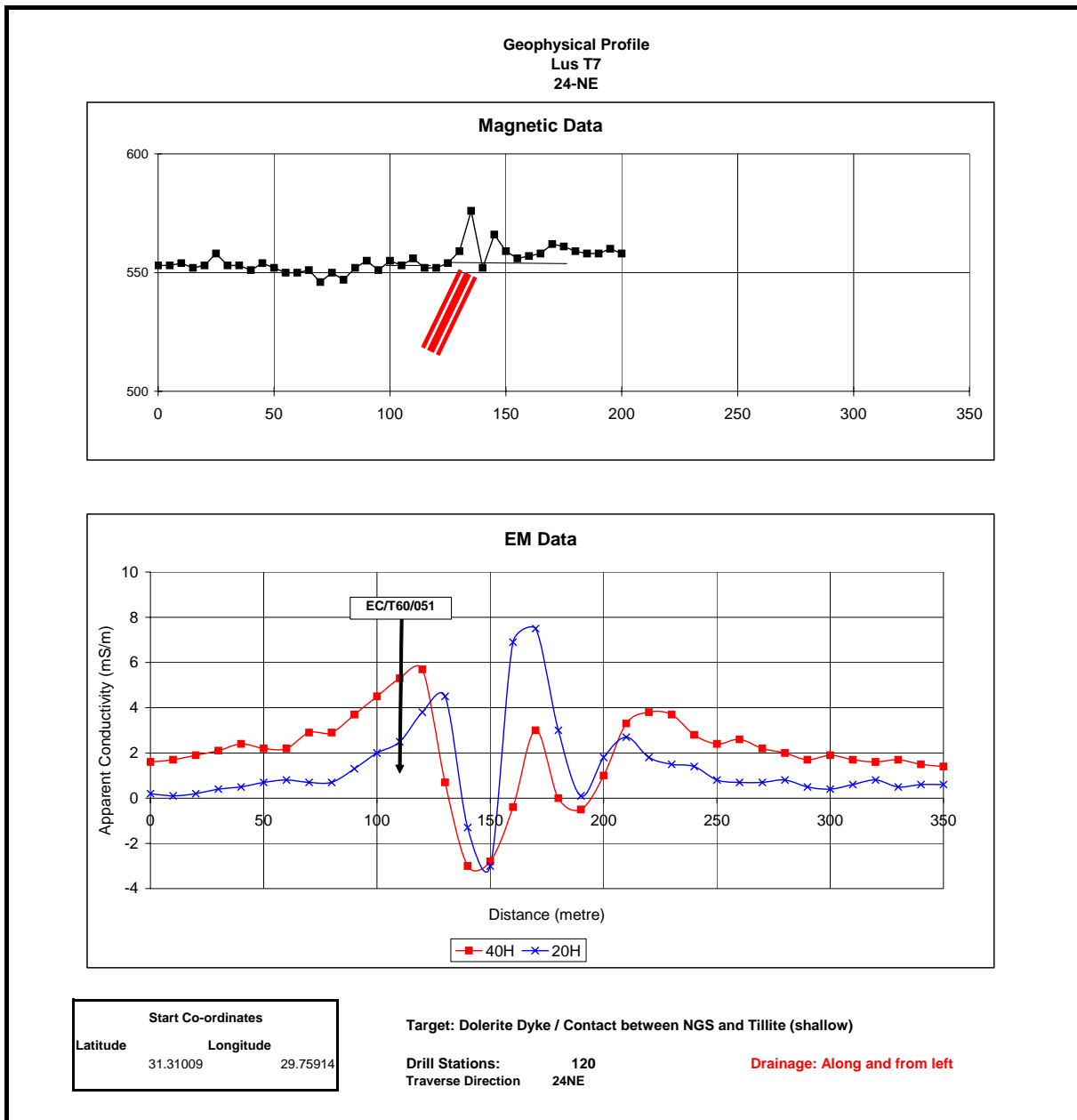


approximately 10 m to the south-east of the dyke contact. The hole would therefore start in the sandstone, penetrate the fractured zone and eventually hit the dolerite dyke.

As predicted, sandstone was encountered at the start of the drilling and then progressed through highly fractured sandstone producing chunks of sandstone of up to 5 cm in size as shown in Figure 6.1.1a. Water strikes were encountered from a depth of 50 m and onwards until clay was encountered at a depth of 78 m. Drilling through the clay proved difficult and although dolerite were struck below the clay and drilling continued to 110 m, the clay could not be contained as it proved to be too active (swelling and pushing up the borehole). After several unsuccessful attempts were made by the drilling contractor to secure the borehole, coarse gravel was inserted down the hole as a last attempt to contain the clay at depth 82 m. The airlift yield was measured with a V-Notch at **22 l/s** during drilling.



**Figure 6.1.1a: Photos showing yield measurement and drilling residue - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

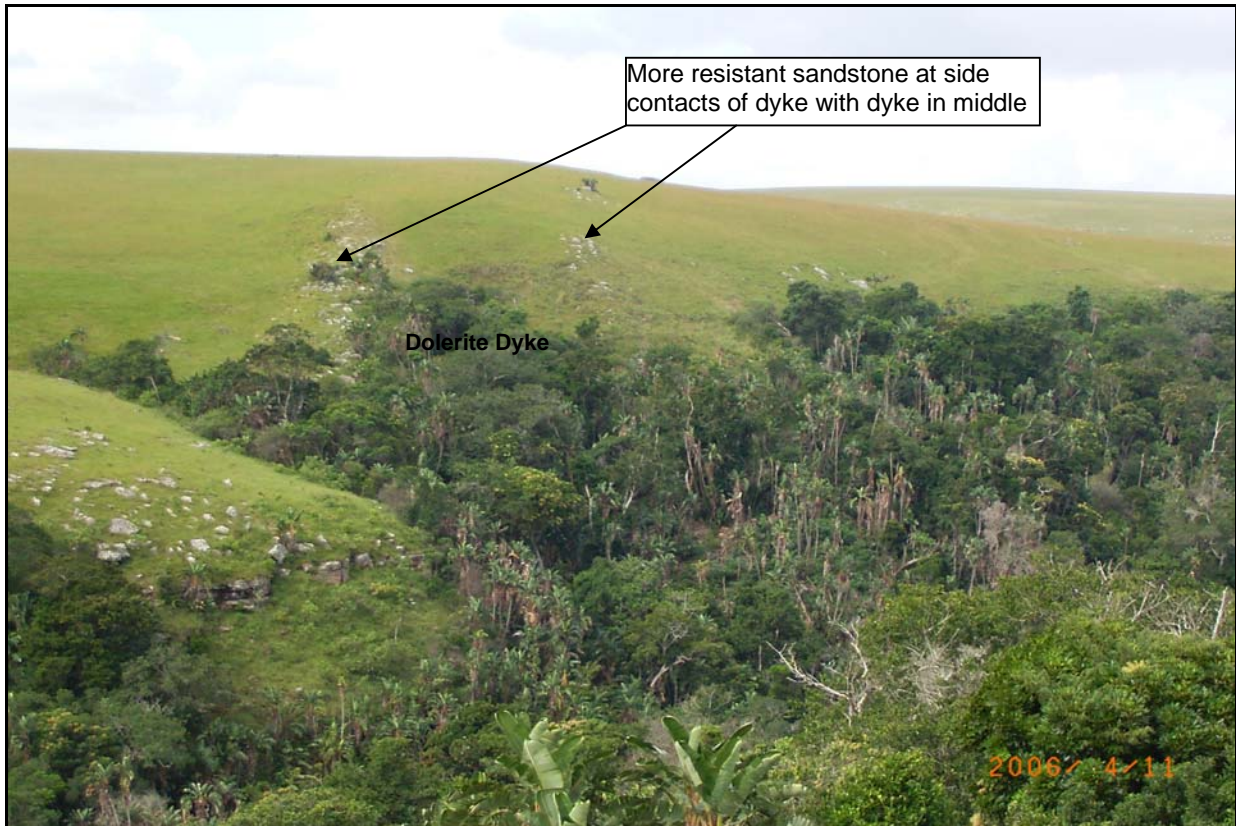


**Figure 6.1.1b: Geophysical graph of borehole EC/T60/051**

As this was the first borehole drilled on the project and the different types of targets were being investigated, another borehole was drilled on the same dyke approximately 500m away, but this time targeting the inside of the dyke to compare the results with drilling the fractured sandstone away from the dyke. Borehole EC/T60/052 was subsequently drilled into the dyke and yielded 2.8 l/s.

From the drilling of borehole EC/T60/051 it was clear that large fractures develop at a distance away from the side of the dyke, probably because of the heating and cooling effect associated with the intrusion of the dyke into the sandstone. Drilling into these fractures proved more successful than drilling into the dyke. Examples found in similar conditions, for example a near vertical dyke

occurring in Natal Group Sandstone as indicated in Figure 6.1.1c, have shown that the sandstone (quartzitic of nature) are melted near the dyke because of the intense heat at the time of the intrusion and as the heat decreases with distance from the centre of the dyke, the sandstone is fractured, giving rise to a frequency of dyke, melted sandstone (hard) and then fractured sandstone. The melted sandstone is more resistant than the surrounding sandstone and forms a prominent ridge at the side of the dyke. The distance from the dyke to this melted zone would probably depend on the thickness of the dyke. If however, the dyke intruded into a previously formed fault, the melting of the sandstone could also have been caused by the fault and the heat and pressures from the dyke then induced further fracturing.



**Figure 6.1.1c: Photo indicating the harder "sandstone shoulders" - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

Borehole EC/T60/054 also targeting a dyke in NGS:

Another borehole, EC/T60/054 was drilled in a similar geological setting, namely a near-vertical dolerite dyke in the Natal Group Sandstone near the contact with the Dwyka Diamictite as shown in Figure 6.1.1, Dyke B. As shown in Figure 6.1.1d, a very similar geophysical graph was obtained and drilling again was focused on the fractured zone away from the dyke.

Several water strikes were again encountered with similar large chunks of sandstone airlifted from the fractured water strike areas. From approximately a depth of 50 m, the yield increased

gradually and when a depth of 80 m was reached, the airlift yield was already 85 l/s. Drilling progressed slowly and a second compressor had to be used as a booster to equalise the back pressure of the water.

Immediately after the drilling stopped, the borehole flowed artesian at 20 l/s for a few minutes and then decreased to a steady 2 l/s. The photos in Figure 6.1.1e show the artesian yield and airlift yield respectively. Note the water gushing out of the borehole during the borehole development process.

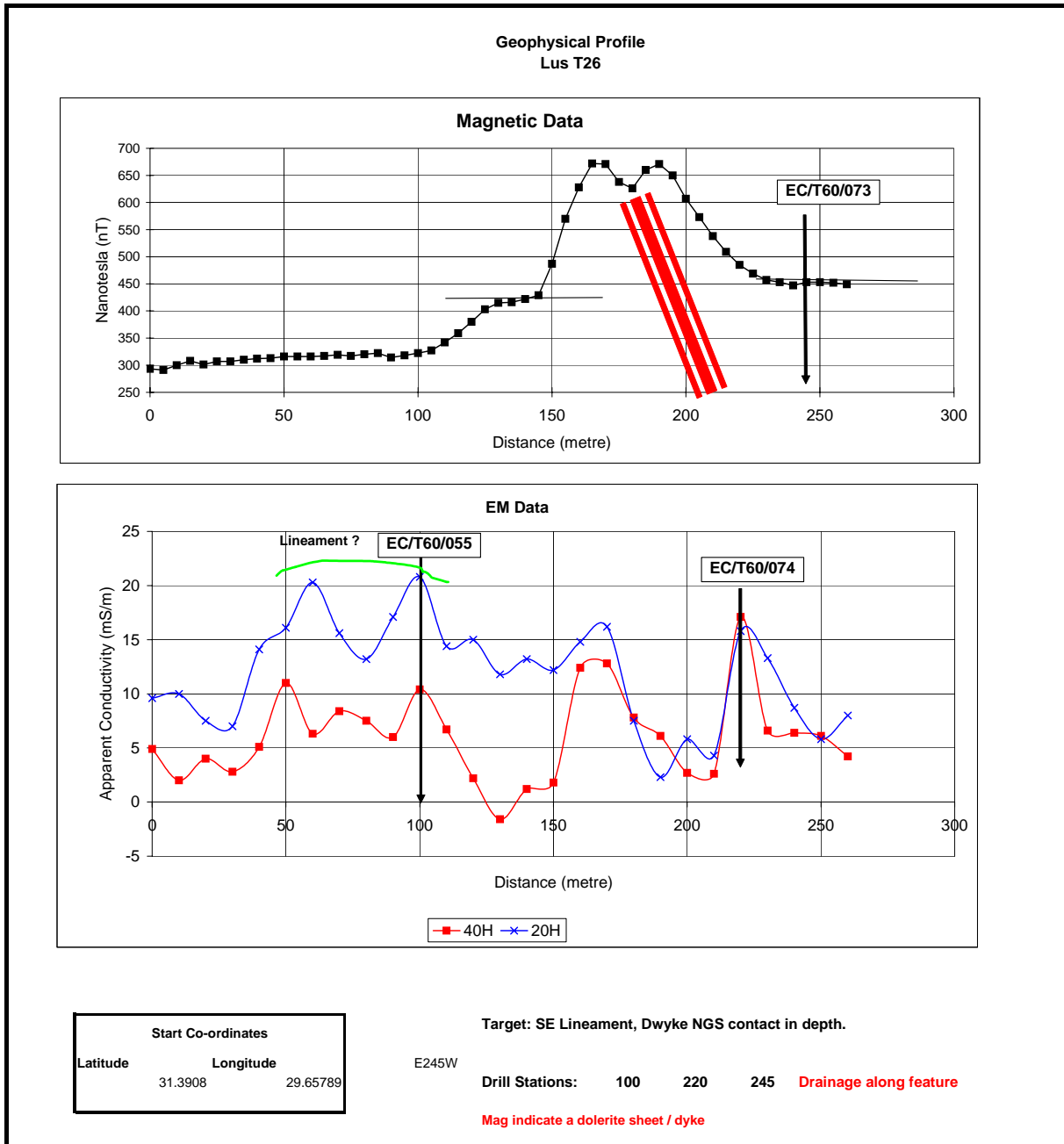


Figure 6.1.1d: Geophysical graph of borehole EC/T60/054



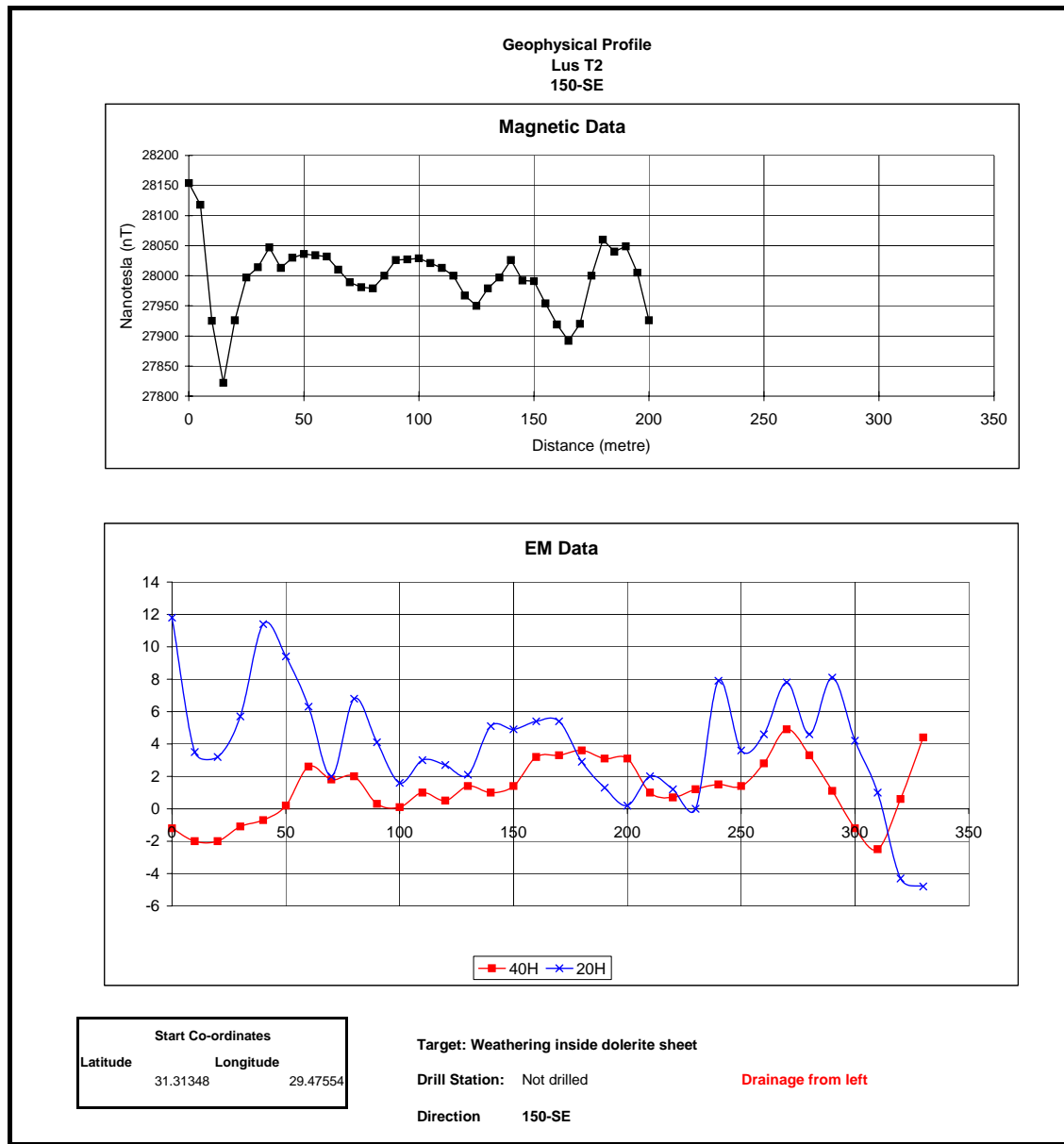
Figure 6.1.1e: Photos of EC/T60/054 (above and below)



Boreholes EC/T60/058 and 059 targeting dykes in the Ecça

Both boreholes were drilled on one geophysical traverse in the Ecça, targeting the regional dolerite dyke as indicated in Figure 6.1.1, Dyke A. Because of the dense vegetation and lack of outcrop, finding the exact location of the dyke by means of field geological inspection, was difficult.

The magnetic and electro magnetic methods (EM-34) were used and anomalies were found as can be seen in Figure 6.1.1f, but the drilling contradicted the results of the EM-34. For example, on the positions where the EM indicated high conductivity and hence where high weathering and fracturing could be expected, the drilling penetration rates however showed harder, more solid rock and *visa versa*. Two boreholes were drilled on this graph, namely EC/T60/058 (drilled on station 50) and 059 (drilled on station 100). They yielded 1.1 l/s and 0.4 l/s respectively.

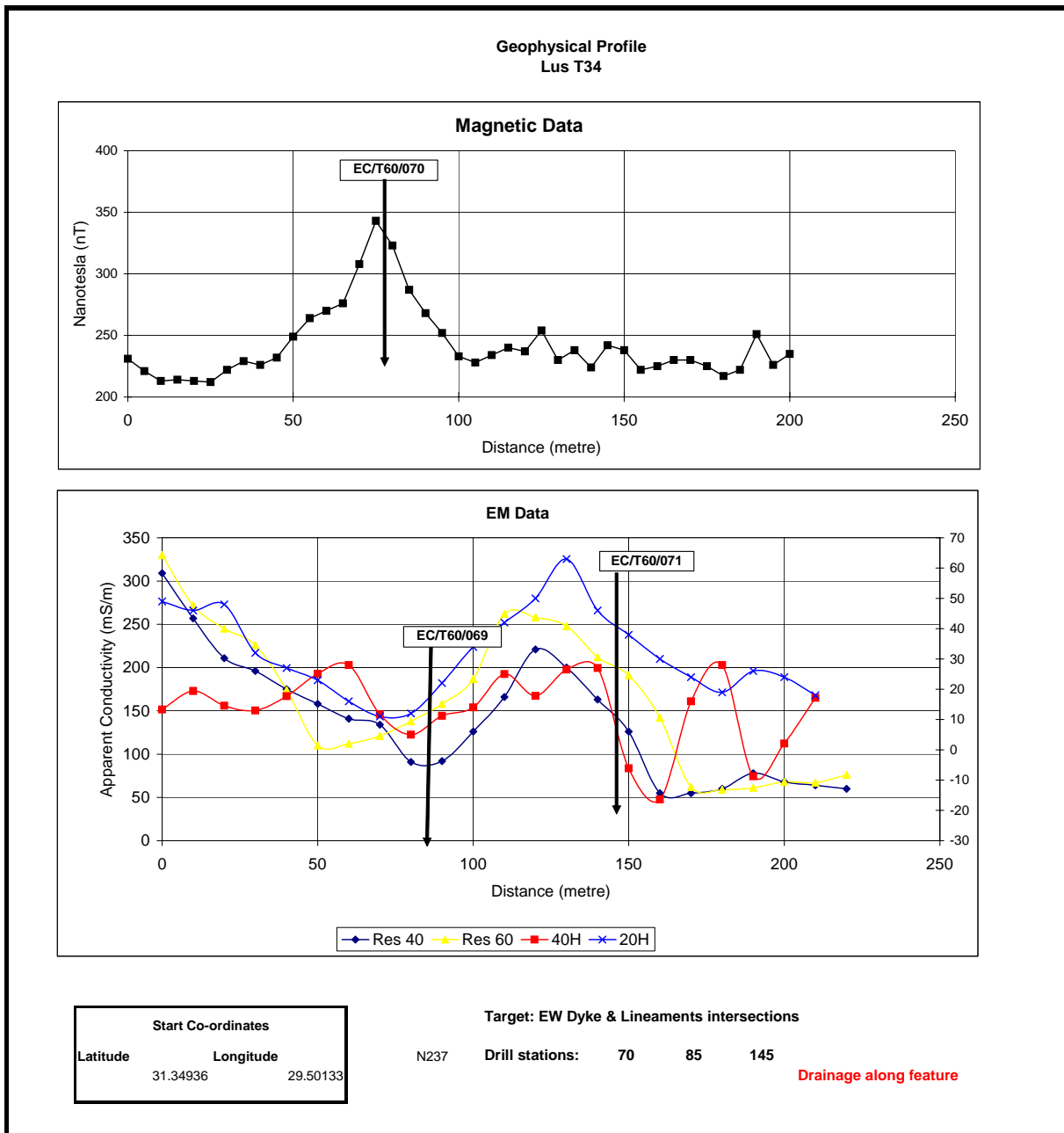


**Figure 6.1.1f: Geophysical graph of EC/T60/059**

In comparing the anomaly of the magnetic graph as seen in Figure 6.1.1g with the anomalies of the EM-34 data it is evident that the positions of the anomalies in terms of the station numbers (where readings were taken) do not correspond. For example, note the change in position of the anomaly on the magnetic graph (magnetic peak on station 85 m - horizontal axis - top graph), compared with a dyke-like anomaly between stations 20 m and 80 m on the EM-34 (lower graph). Drilling was done on the anomalies of the EM-34 and two boreholes were drilled, one at station 20 (positive anomaly) and one on the negative anomaly (station 50). Despite minor changes in topsoil structure, the composition of the dolerite was mostly the same and the conclusion was made that the target (regional dolerite dyke) was not present at the position where the geophysical line was conducted and drilling took place on a thick (> 70 m) inclined dolerite sheet.

#### Boreholes EC/T60/069, 070 and 071

In another effort to try and locate Dyke A (refer to Fig 6.1.1), geophysical surveys were done around the area where boreholes EC/T60/069 to 071 were eventually drilled. Again the magnetic graph did not correspond with the EM-34 graph as can be seen in Figure 6.1.1g. Because it is less susceptible to magnetic influences, the electrical resistivity method was then applied on the same traverse and indicated a solid, resistant feature where the EM-34 indicated a highly weathered feature. The results from the three different types of geophysical methods therefore did not correspond.



**Figure 6.1.1g: Geophysical graphs of EC/T60/069 to 071**

Although the different geophysical methods yielded different graphs with each indicating a different position of the possible dyke, the drilling logs of the three boreholes drilled were much the same with dolerite being encountered and penetrated in each of the boreholes, hence suggesting an inclined dolerite sheet with varying degrees of weathering and fracturing. The best yield obtained was 1.2 l/s with poor water quality. Still the regional dyke was not encountered, suggesting that the position as indicated by the 1:250 000 geological series is incorrect by some margin.



Boreholes EC/T60/064, 056 and 072 targeting dykes in the Dwyka Formation

The following graphs as represented by Figures 6.1.1h, 6.1.1i and 6.1.1j all represent the geophysical graphs of dykes cutting through Dwyka diamictite. If compared with the geophysical graphs of the dykes in the Natal Group Sandstone, it is clear that the diamictite is not so susceptible to the influence of the dyke (heating & cooling effects) and produces far less weathering and fracturing on the side contacts. Borehole EC/T60/056 targeted fracturing and weathering on the side of a dyke and only yielded 0.1 l/s, while a water strike of 2.2 l/s was achieved inside the dyke with borehole EC/T60/064 and 5 l/s on the contact of the dyke in EC/T60/072.

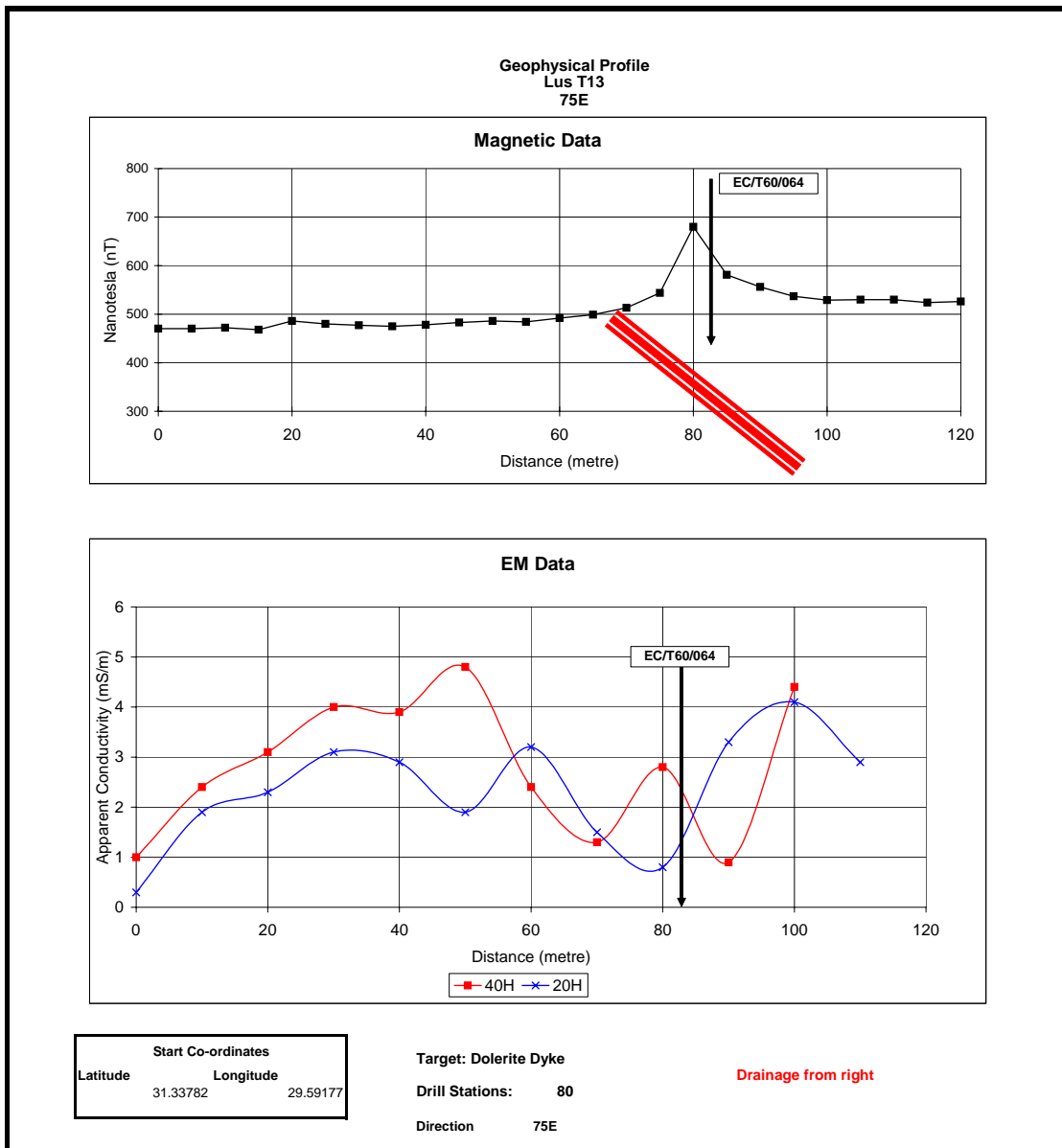


Figure 6.1.1h: Geophysical graph of EC/T60/064

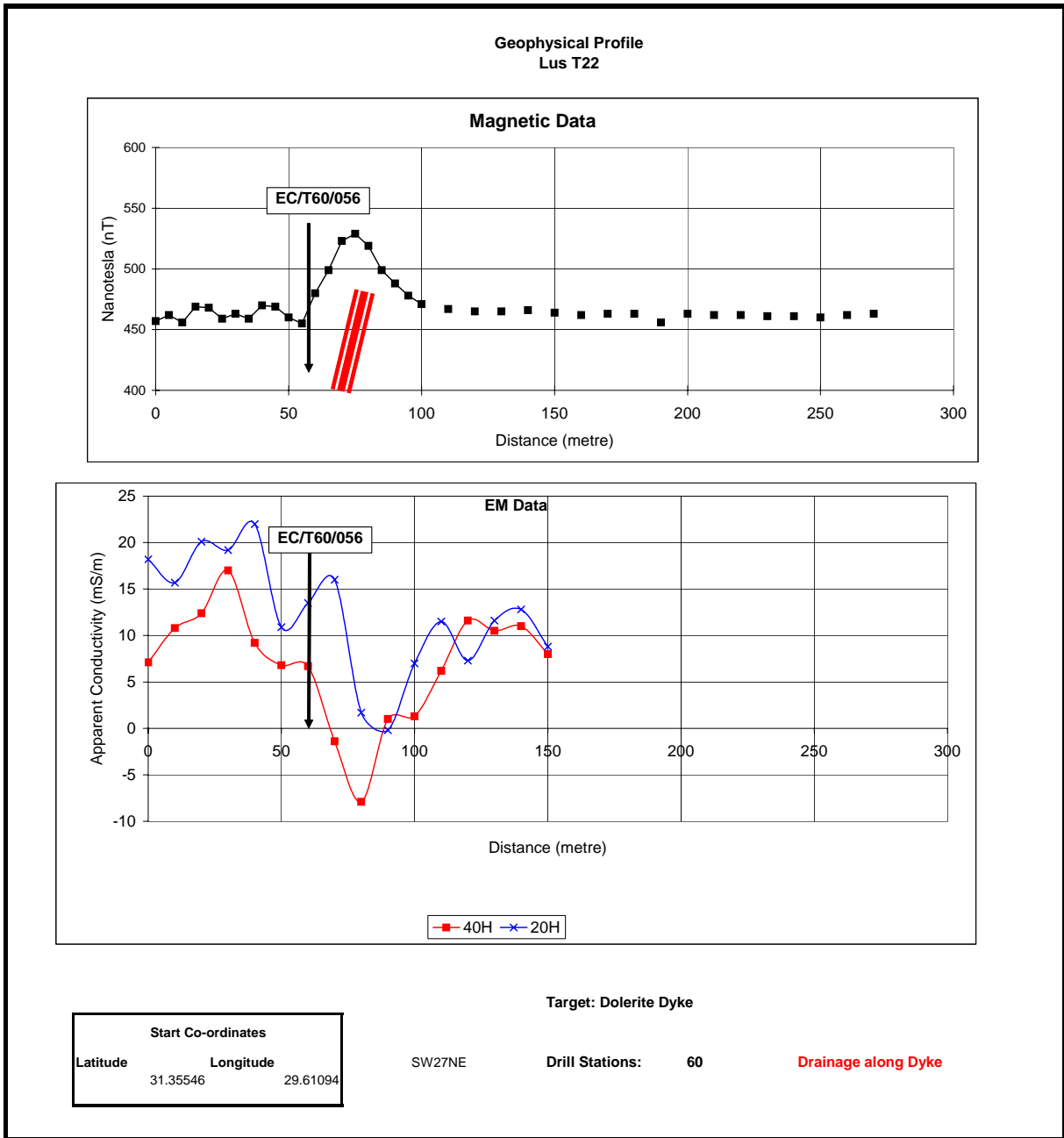
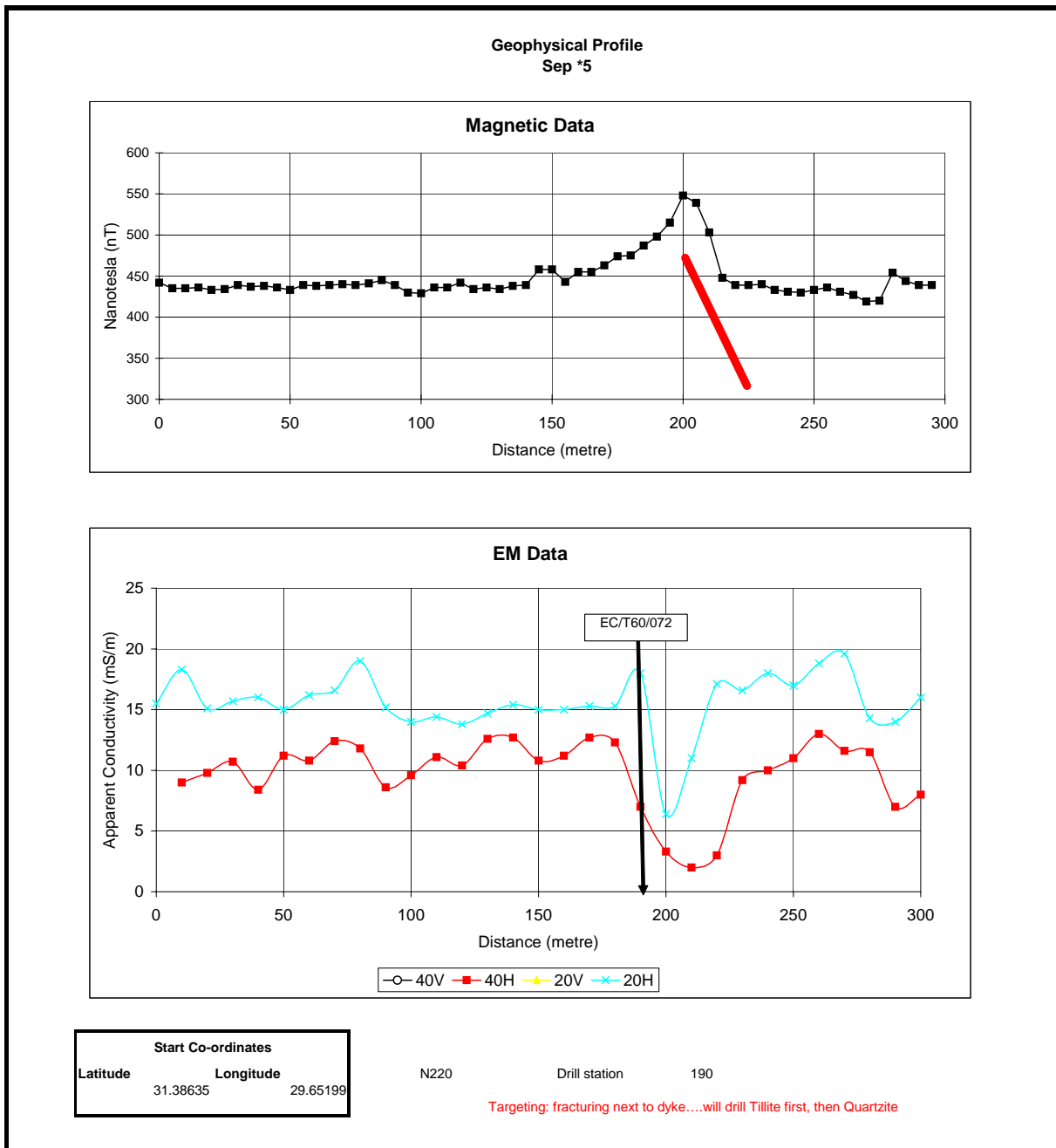


Figure 6.1.1i: Geophysical graph of EC/T60/056



**Figure 6.1.1j: Geophysical graph of EC/T60/072**

## 6.1.2 Geological contacts

### 6.1.2.1 Contact between the Natal Group Sandstone and Dwyka

The NGS dips in a north westerly direction underneath the Dwyka Formation at an angle of 2-3 degrees. The Dwyka again dips underneath the Eccca at similar angle and direction. Boreholes were targeted to intersect the geological contact between these units to investigate the degree of fracturing and weathering on the contact zones.

Boreholes **EC/T60/051 and 052** were drilled on the contact between the Natal Group Sandstone and Dwyka diamictite, but the diamictite was less than 1 metre thick where drilling took place and cannot be considered as drilling the contact.

Borehole **EC/T60/053** targeted a lineament in the Dwyka, but was also aimed at penetrating the Dwyka and finding the contact between the Dwyka and the NGS which was calculated to be at a depth of approximately 70 m (based on a 2% dip and 2 km from contact). Water was struck in the diamictite (4.4 l/s), on the contact with the sandstone (1.1 l/s) and again inside the sandstone (5.5 l/s), resulting in a combined airlift yield of 11 l/s with the majority of the water coming from both the diamictite and sandstone and not from the contact between them.

Borehole **EC/T60/060** was drilled to intersect the contact between the Eccca and the Dwyka, but also to penetrate a thin dolerite sheet at shallow depth. Drilling started in Eccca shale, intersecting dolerite at 41 m and again intersecting shale at 56 m. Dwyka diamictite was struck at 77 m and drilling continued to 110 m. The borehole was therefore drilled through the top contact of the dolerite sheet, into the sheet, through the sheet and into the contact between the Eccca and the Dwyka. Although this borehole was drilled in a well-developed drainage area, no water was encountered at any of the contacts and the borehole was dry. No further contacts were drilled.

Figure 6.1.2.1 shows the positions of the above boreholes relative to the geological contacts.

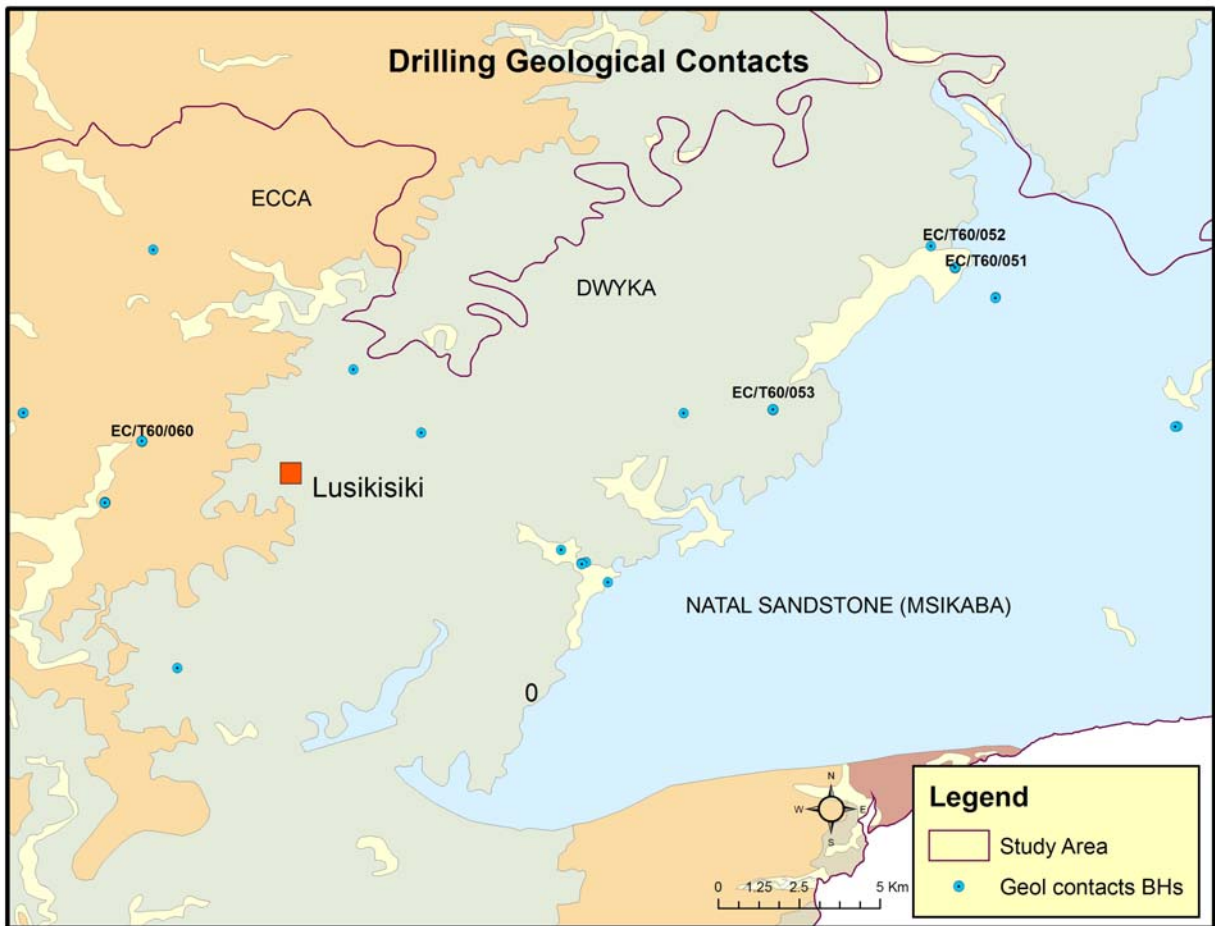


Figure 6.1.2.1: Drilling geological contacts

### 6.1.3 Lineaments

Lineaments cannot usually be seen in the outcrop and geophysical surveys are required to locate them in the field. Of great importance therefore is the accuracy of the lineament mapping. Figure 6.1.3 shows the lineaments that were mapped for the study area and also shows the boreholes drilled on the lineaments.

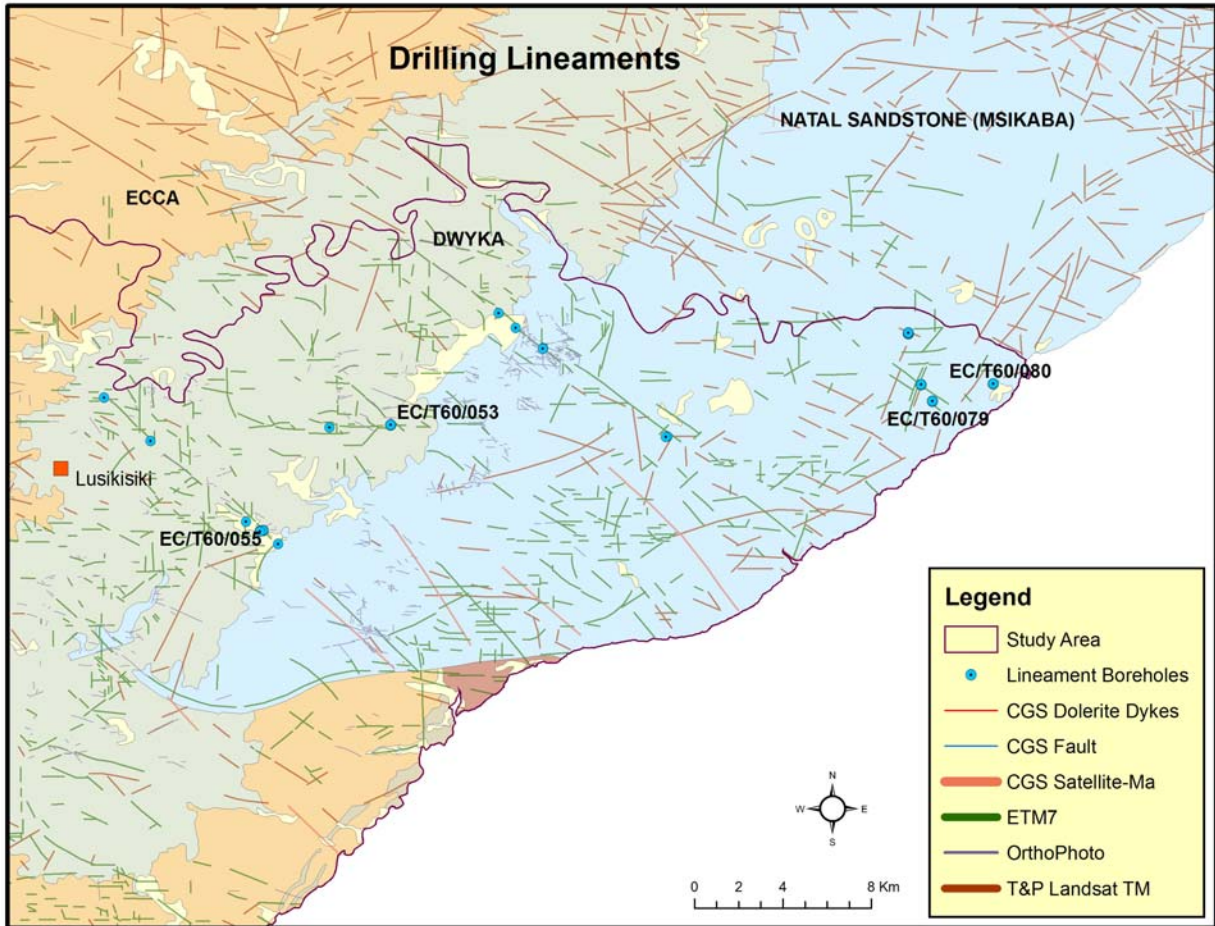
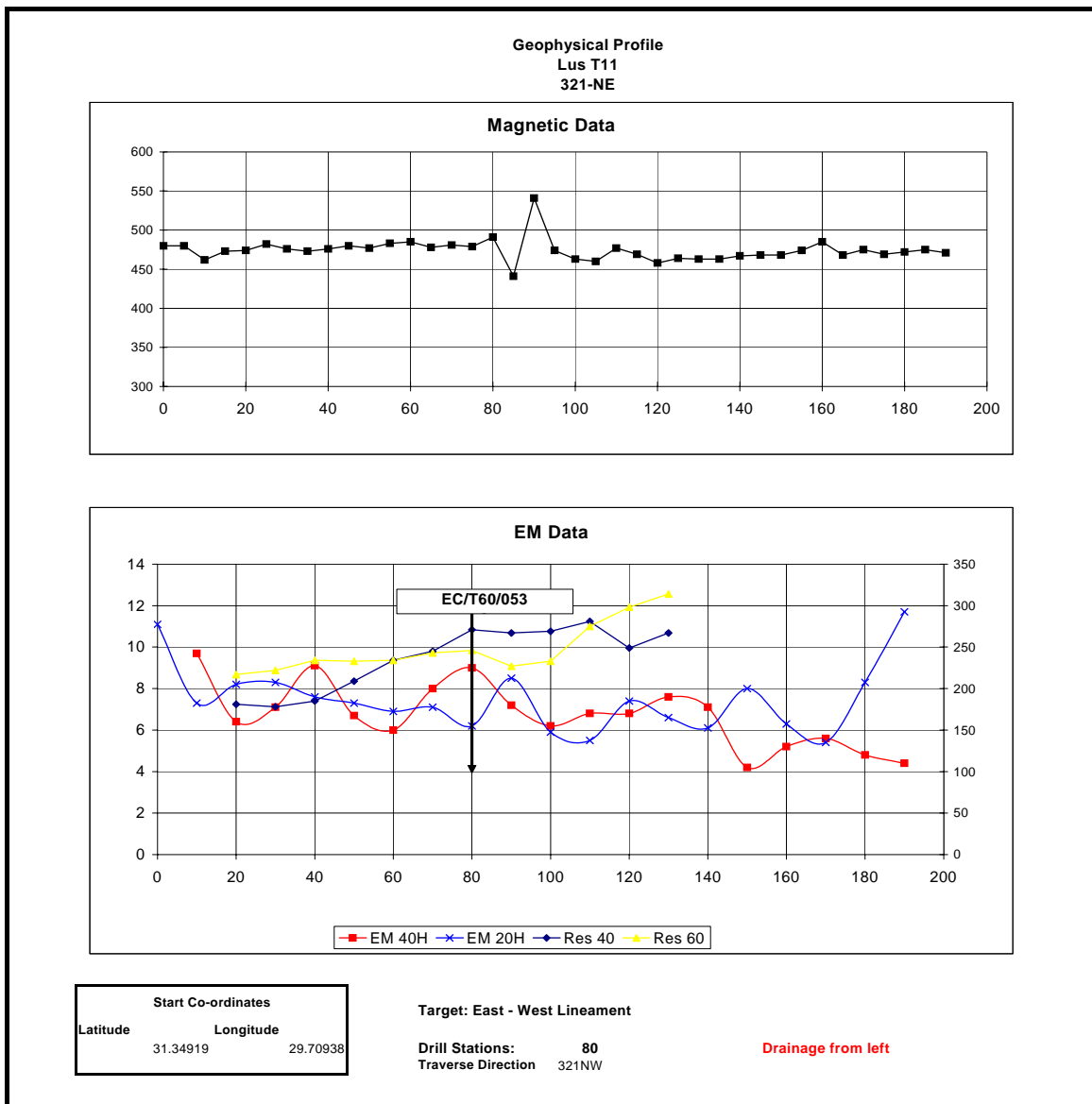


Figure 6.1.3: Positions of boreholes relative to lineaments

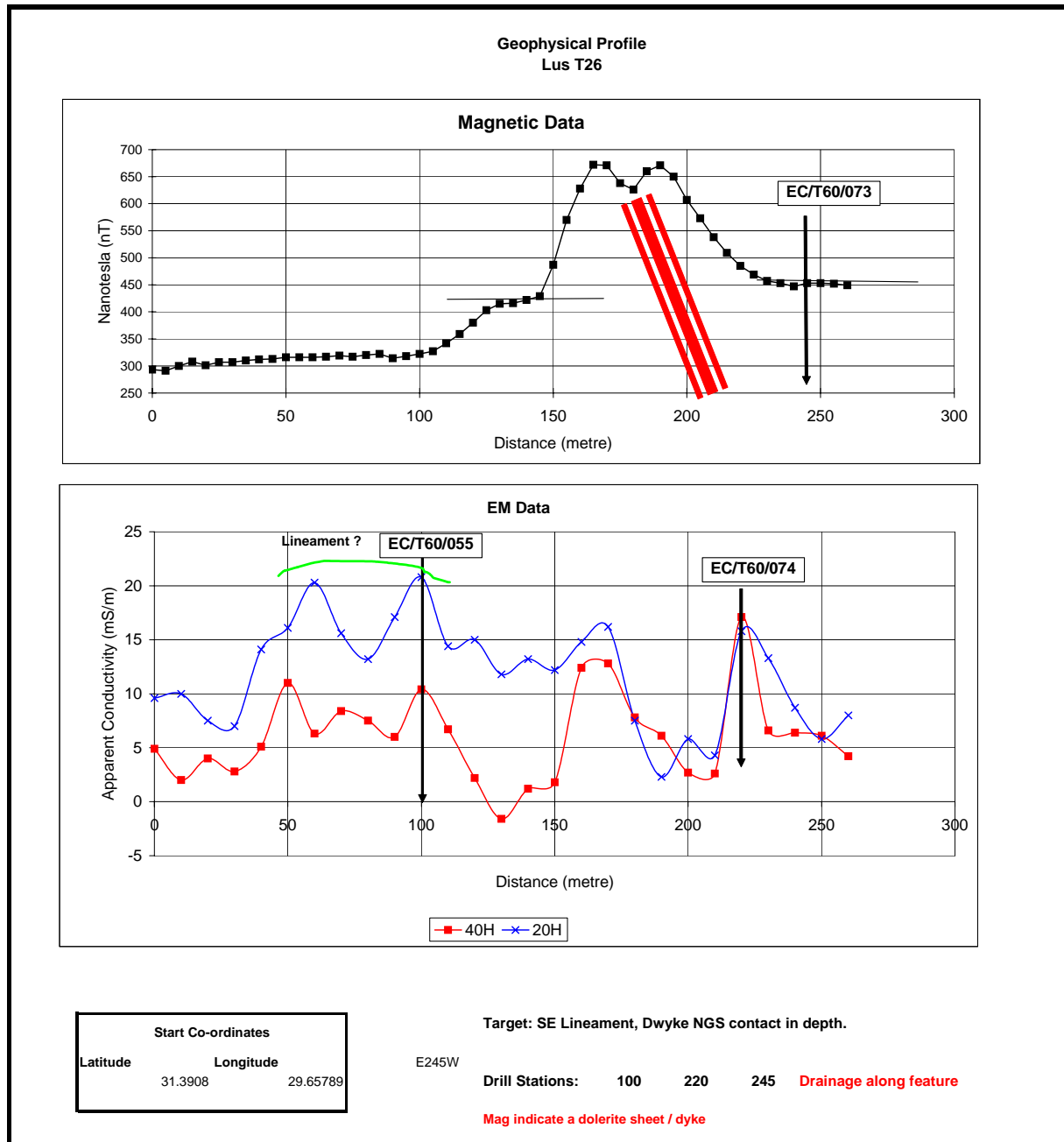
**Borehole EC/T60/053** was drilled targeting an east west lineament in a well-developed drainage area. Although the Landsat image clearly indicated the lineament, the geophysical graphs were not very conclusive as seen in Figure 6.1.3a.

The magnetic anomaly indicated a single anomaly, similar to what can be expected from a thin dyke or transported magnetic material (as found in streams), while the EM-34 indicated no specific anomaly, but rather areas of high and low conductivity. Water was struck in the Dwyka as per the target according to the magnetic graph, but then also on the contact between Dwyka and NGS and inside the NGS. The combined yield of the water strikes related to the targeted lineament was approximately 4 l/s.



**Figure 6.1.3a: Geophysical graph of EC/T60/053**

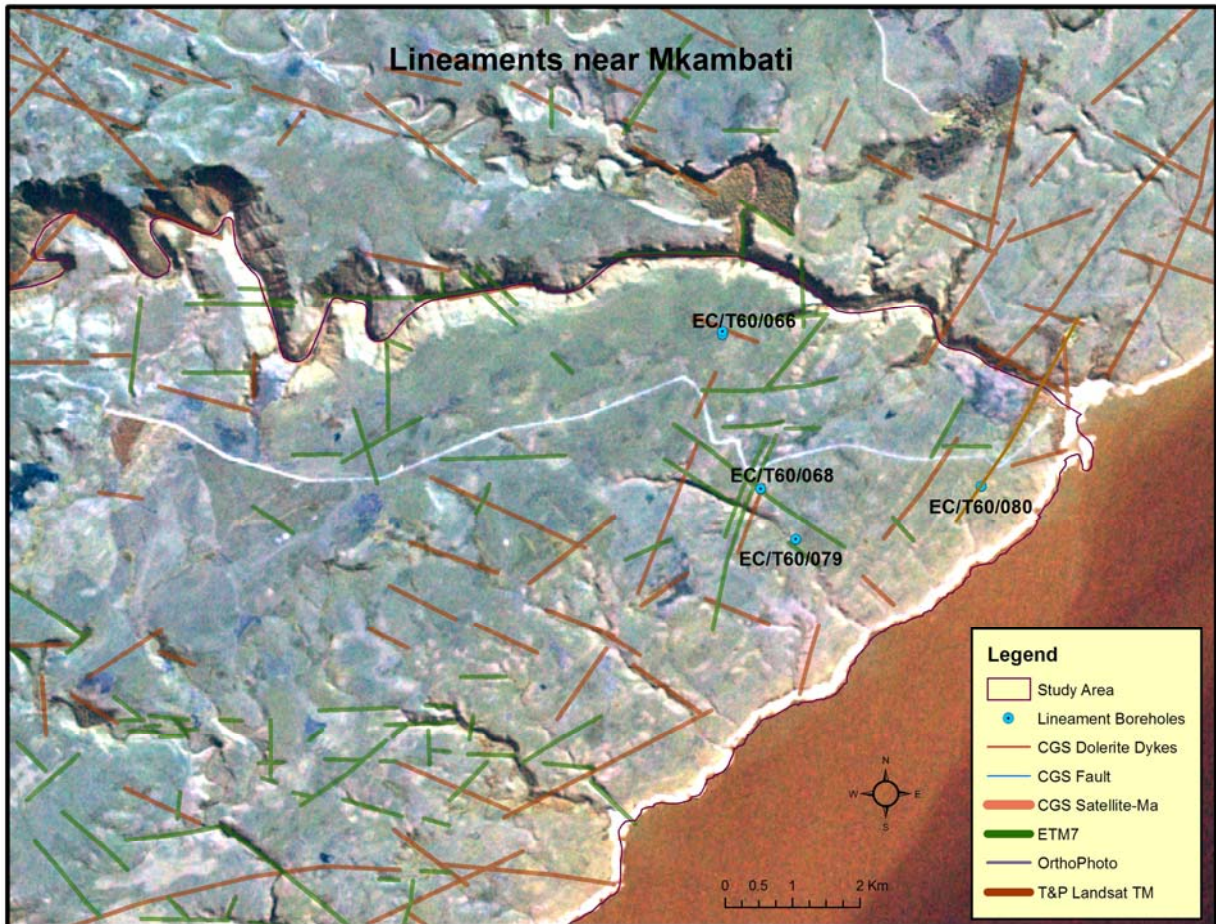
**Borehole EC/T60/055** was drilled on a lineament that is situated perpendicular to the dyke targeted in borehole EC/T60/053 and was purposefully drilled away from the dyke. The geophysical anomaly was very promising and from Figure 6.1.3b it can be seen that the anomaly was very similar to that of borehole EC/T60/053, but drilling confirmed a thick layer of saturated, sub-surface clay, which probably caused the anomaly. The borehole yielded a disappointing 1.1 l/s, but was artesian at the time of drilling.



**Figure 6.1.3b: Geophysical graph of EC/T60/055**



There are no dolerite dykes in the vicinity of Mkambati and lineaments had therefore to be targeted for drilling in order to invest the groundwater potential near Mkambati. Figure 6.1.3c shows the positions of the lineaments in the vicinity of Mkambati. Also shown are the positions of the boreholes drilled.



**Figure 6.1.3c: Lineaments near Mkambati**

Topographically, the main lineaments are situated along drainage features and cannot be reached for drilling as they form valleys with dense vegetation as seen in Figure 6.1.3d, which shows the lineament where borehole **EC/T60/080** was drilled. The borehole could however not be drilled in the valley due to the dense vegetation and had to be drilled lower down towards the coast (second photo). The lineament had to be extended graphically and the geophysical surveys were done on the graphical extensions of the lineament was accessible.

Although this was not ideal, it was the only way possible without extensive earthworks for road construction.

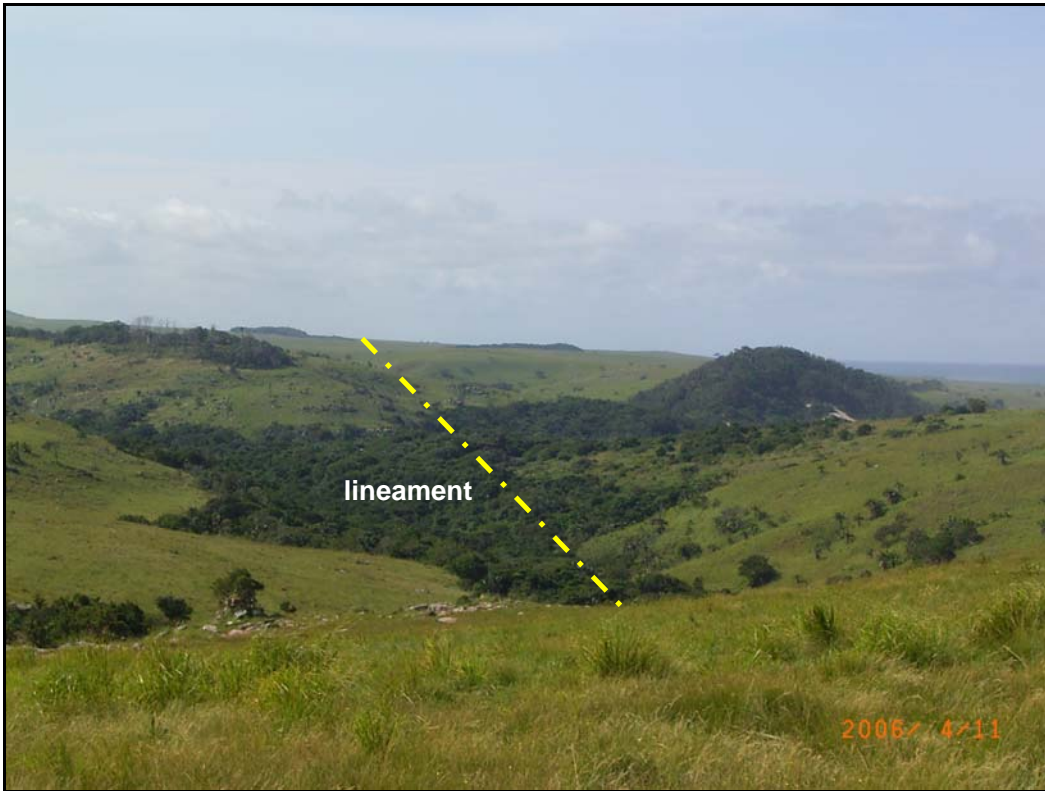


Figure 6.1.3d: Photos showing lineament (above and below) - (Nel 2005, Lusikisiki Groundwater Feasibility Study)



Various geophysical traverses were done on the lineaments and yielded promising electromagnetic (EM-34) results, such as can be seen in the geophysical graph displayed in Figure 6.1.3e.

Two boreholes were drilled on what seemed to be different weathered and fractured patterns in the sandstone, but turned out to be variations in the depth of subsurface clay. The sandstone underneath the clay was fractured, but did not contain any water. Both boreholes drilled were dry. The magnetic method did not yield any anomalies.

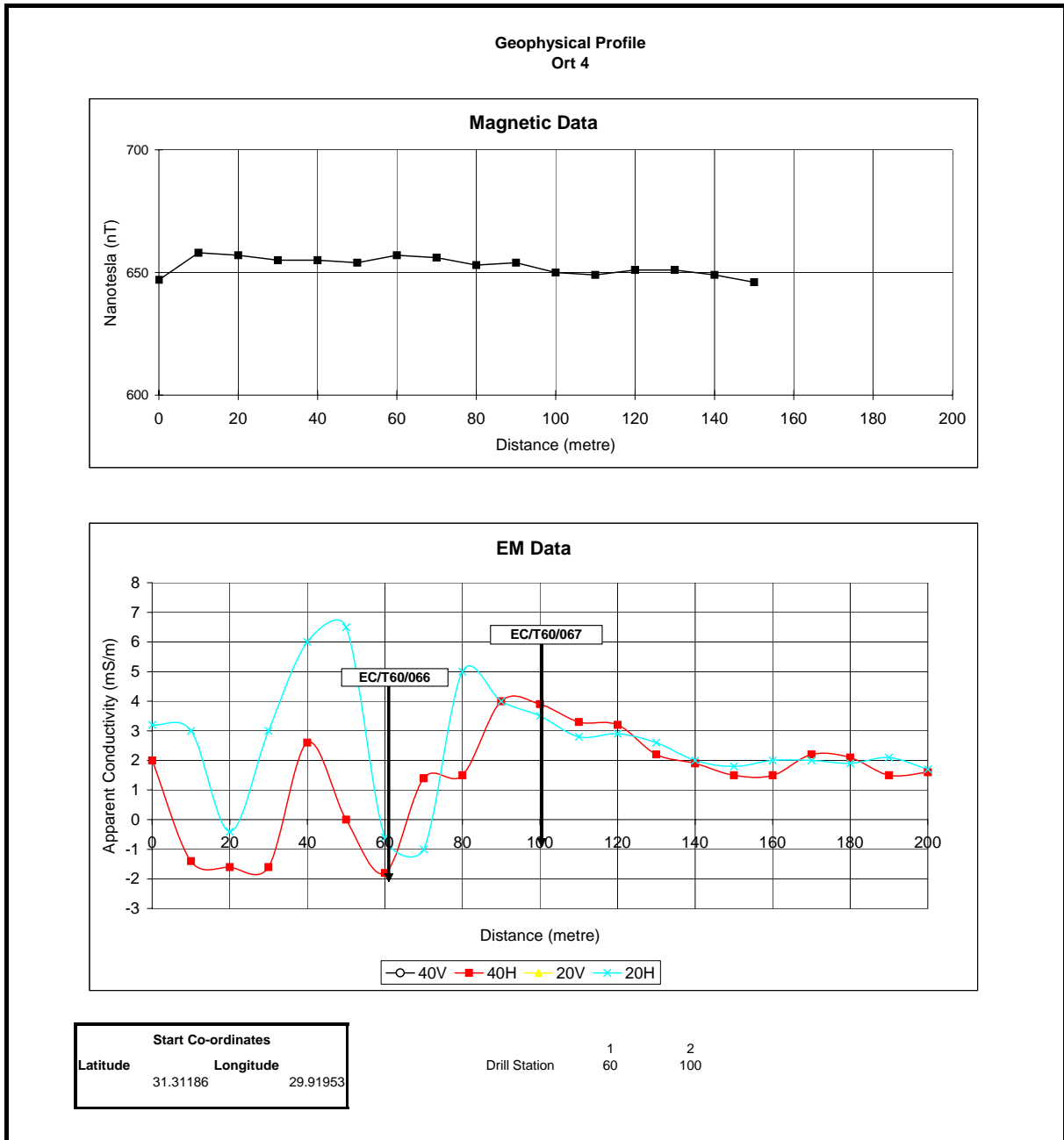
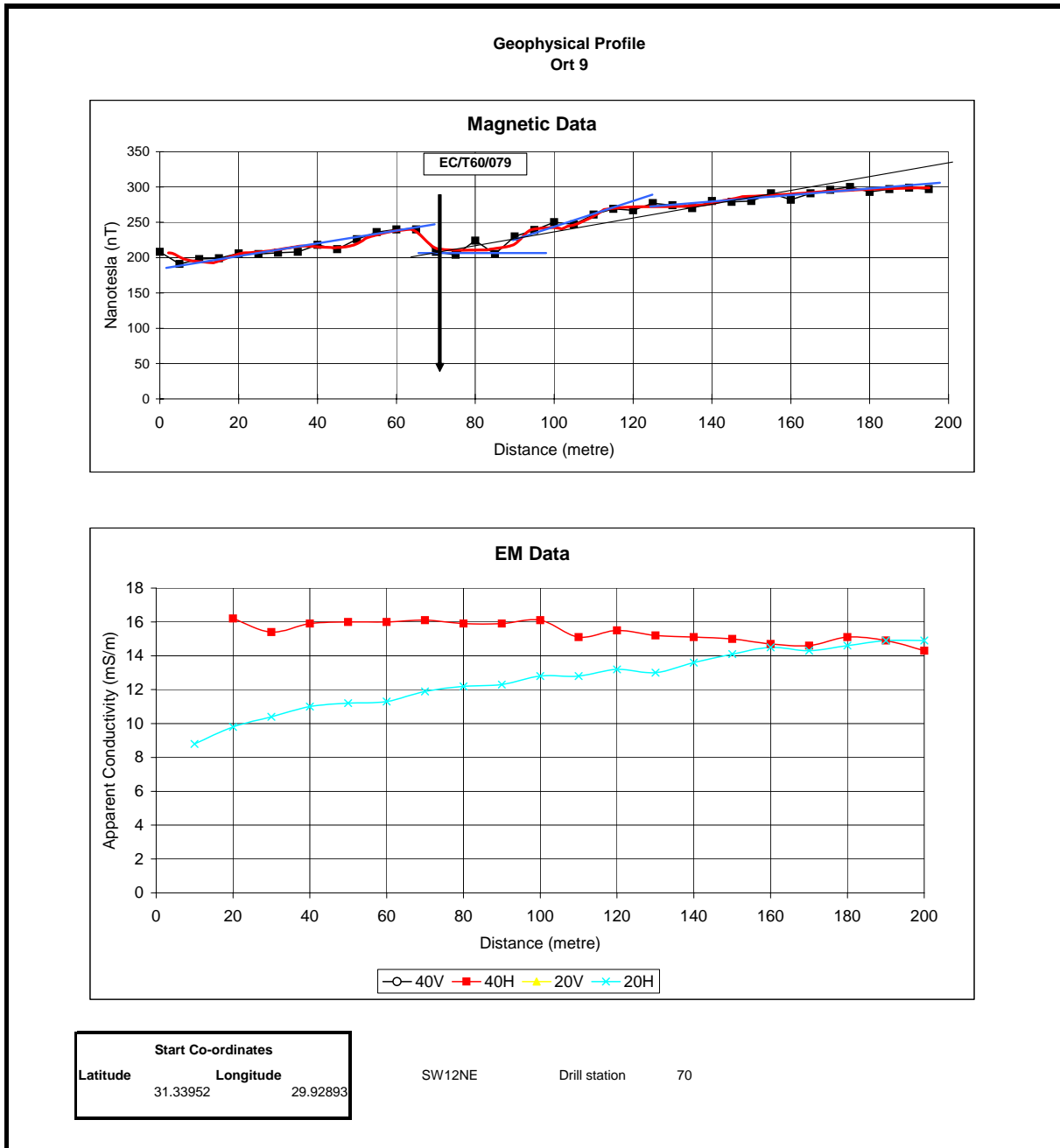


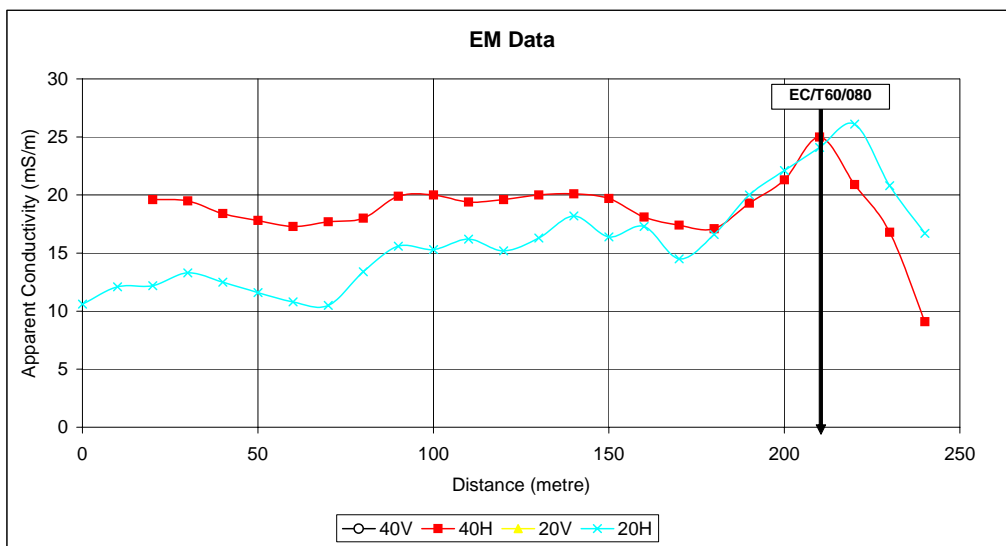
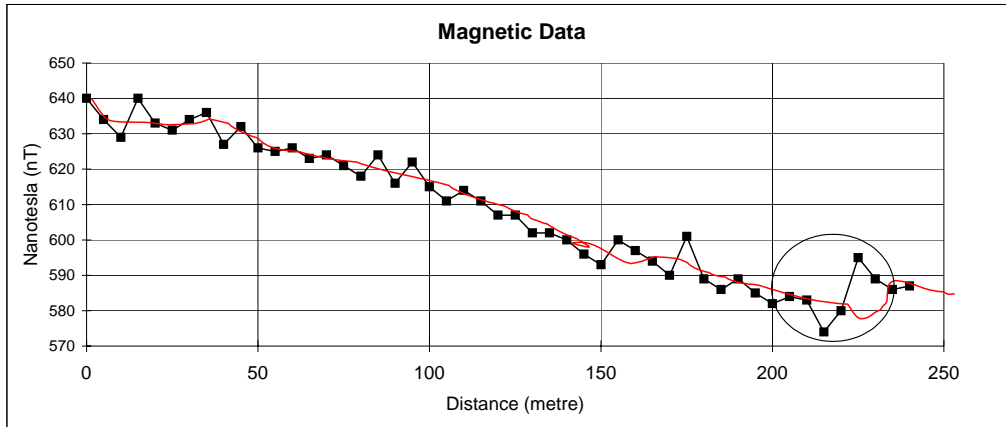
Figure 6.1.3e: Geophysical graph of EC/T60/066 and 067

Borehole **EC/T60/079** was drilled on a prominent NW-SE lineament and borehole **EC/T60/080** on a NE-SW lineament. Although the magnetic method indicated a step-like anomaly in borehole 079, the EM-34 were non-conclusive, whereas both the EM-34 and magnetometer showed anomalies on the same position where borehole 080 was drilled (See Figures 6.1.3f and 6.1.3g). Borehole 080 yielded 2.5 l/s and 079 yielded 0.3 l/s (airlift yields).



**Figure 6.1.3f: Geophysical graph of EC/T60/079**

Geophysical Profile  
Ort 7



Start Co-ordinates	
Latitude	Longitude
31.33029	29.95242

NW 150 SE      Drill station      210

Figure 6.1.3g: Geophysical graph of EC/T60/080

## 6.2 Testing

The following evaluation includes a comparison between airlift yield and the calculated 24-hr yield, discussions on the water quality and calculations of the aquifer parameters. Each of the three geological units (Ecca, Dwyka and Natal Group Sandstone) that are found in the project area is discussed individually. The borehole testing results, management recommendations and water quality results are attached in Appendices 4. In the calculation of the estimated yield of the boreholes, Storativity (S) was taken as an estimated constant of  $3.0 \times 10^{-3}$  and transmissivity (T) was calculated based on conventional methods as proposed in Kruseman & de Ridder (Analysis and Evaluation of Pumping Test Data - Second Edition, Single Well Tests, Cooper Jacob method). In some cases, for example borehole EC/T60/054, the FC - Program developed by Van Tonder, Kunstmann & Xu - Institute of Groundwater Studies, University of the Free State, version 3, 2001, was also used.

### 6.2.1 Natal Group Sandstone (NGS)

Table 6.2.1 lists the boreholes that were drilled in the Natal Group Sandstone. Two of the boreholes will be discussed, namely borehole EC/T60/054 which was drilled next to a dolerite dyke and borehole EC/T60/080 which targeted a lineament in an area with no dolerite.

**Table 6.2.1: Boreholes drilled in the NGS**

BH No	Latitude	Longitude	Water strike(m) and Strike Yield (l/s)	Airlift yield l/s)	24hr yield (l/s)	BH depth (m)	Water Quality*
EC/T60/051	31.30908000	29.75960000	29(0.34), 57(0.36), 62(1.3), 67(5), 73(3), 96(7)	22	3.41	110	M - Iron
EC/T60/052	31.30313000	29.75283000	17(0.8), 33(0.5), 35(0.5), 38(0.95)	2.75	0.89	100	M - Bacteria
EC/T60/054	31.39673000	29.66307000	26(1.8), 30(0.95), 36(1.65), 84(6.6), 88(74)	85	7.5	100	Good
EC/T60/055	31.39117000	29.65699000	52(0.2), 77(0.4), 88(0.5)	1.1	0.72	98	Good
EC/T60/066	31.31145000	29.91935000	Dry	0		80	Not tested
EC/T60/067	31.31104000	29.91933000	Dry	0		80	Not tested
EC/T60/068	31.33211000	29.92446000	Dry	0		80	Not tested
EC/T60/075	31.35328000	29.82140000	29(0.2)	0.2		74	Not tested
EC/T60/077	31.31741000	29.77086000	Dry	0		32	Not tested
EC/T60/079	31.33893000	29.92912000	43(0.3)	0.3		80	Not tested
EC/T60/080	31.33175000	29.95383000	20(0.1), 42(0.3), 55(1.4)	2.5	0.51	80	M-Iron

\***Note:** M = Marginal; P = Poor; U = Unacceptable; G = Good

The following statistics can be derived from the testing data:

- Ratio of airlift yield to recommended 24-hr yield: 15 - 65%
- Average (airlift yield to 24-hr recommendation): 28%
- Percentage recovery after testing: 54 - 98% (majority = 90%)
- Highest airlift yield 85 l/s
- Lowest airlift yield 0 l/s

The percentage recovery figures can however be misleading as they are dependant on the drawdown that was achieved during the constant discharge test. For example if a borehole recovered to within 4 m of the starting water level after a drawdown of 8 m was achieved, the percentage recovery is only 50 %, while the recovery could measure as 80 % on a borehole where the drawdown was 40 m and the recovery was back to 8 m.

Borehole EC/T60/054 (dyke in NGS)

The highest yielding borehole drilled in the Natal Group Sandstone was EC/T60/054 which measured 85 l/s airlift yield and 7-8 l/s sustainable yield (24-hr pumping). The constant discharge test (CD test) was done at a yield of 25 l/s for a period of 72 hrs. The flow was measured with a calibrated U-Notch as shown in Figure 6.2.1

A steady drawdown was achieved during the constant discharge test and the percentage recovery as measured equal to the pumping time (72 hours) was 45 % at the time, but when visited in February 2006, it was again flowing artesian. The aquifer parameters as derived from the FC Program are presented below.

Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m <sup>2</sup> /d)	Late T (m <sup>2</sup> /d)	S	AD used
<input checked="" type="checkbox"/>	Basic FC	7.84	4.23	32	15.7	2.20E-03	68.2
<input type="checkbox"/>	Advanced FC			32	15.7	1.00E-03	68.2
<input checked="" type="checkbox"/>	FC inflection point	6.74	3.70				66.3
<input checked="" type="checkbox"/>	Cooper-Jacob	7.17	4.64		15.8	3.01E-03	68.2
<input type="checkbox"/>	FC Non-Linear						68.2
<input checked="" type="checkbox"/>	Barker	7.73	4.09	K <sub>f</sub> = 79		S <sub>s</sub> = 6.20E-04	68.2
	Average Q <sub>sust</sub> (l/s)	7.37	0.52	b = 0.20	Fractal dimension n =	2.00	
	Recommended abstraction rate (L/s)	7.50	for 24 hours per day				
	Hours per day of pumping	12	10.61	L/s for 12	hours per day		
	Amount of water allowed to be abstracted per month	19440 m <sup>3</sup>					
	Borehole could satisfy the basic human need of	25920 persons					
	Is the water suitable for domestic use (Yes/No)						



**Figure 6.2.1: Borehole EC/T60/054 measured with U-Notch - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

During the pump test of borehole EC/T60/054, borehole EC/T60/055 was used as observation borehole to determine whether the pumping of 054 would have any effect on 055, which at the time was also flowing artesian. Throughout the 72 hours of pumping, no effect was observed on borehole 055 and the flow remained artesian and at a steady rate of approximately 1 l/s.

This led to the conclusion that borehole EC/T60/054 sources its water within the confines of the contact zone between the sandstone and the dolerite dyke and very little water (if anything) was drawn from the sandstone host rock adjacent (>20 m) to the dyke. As the dyke is considered near-impermeable, very little recharge (if any) occurred along the south-western side (opposite contact) of the dyke. The contact zone is considered to be of thickness 5 - 20 m on either side of the dyke and is defined as the zone where the intrusion of the dyke had a direct or indirect effect (heating, cooling, pressure fracturing, etc.) on the quartzitic sandstone host rock. The slow recharge is further proof of the long lateral distance along the north-eastern side of the dyke where the borehole must source water to replace the water that was abstracted. The majority of recharge is therefore not emanating from the adjacent host rock, but mostly along the dyke and the hydraulic water pressure along the contact zone needs to restore itself before the water level rises.



Figure 6.2.1a shows the position of borehole EC/T60/055 relative to borehole EC/T60/054 and also shows the position of the dolerite dyke. Unfortunately the other boreholes indicated on figure 37 were drilled after 054 was pump tested and could not be used as observation points at the time of the pumping test.

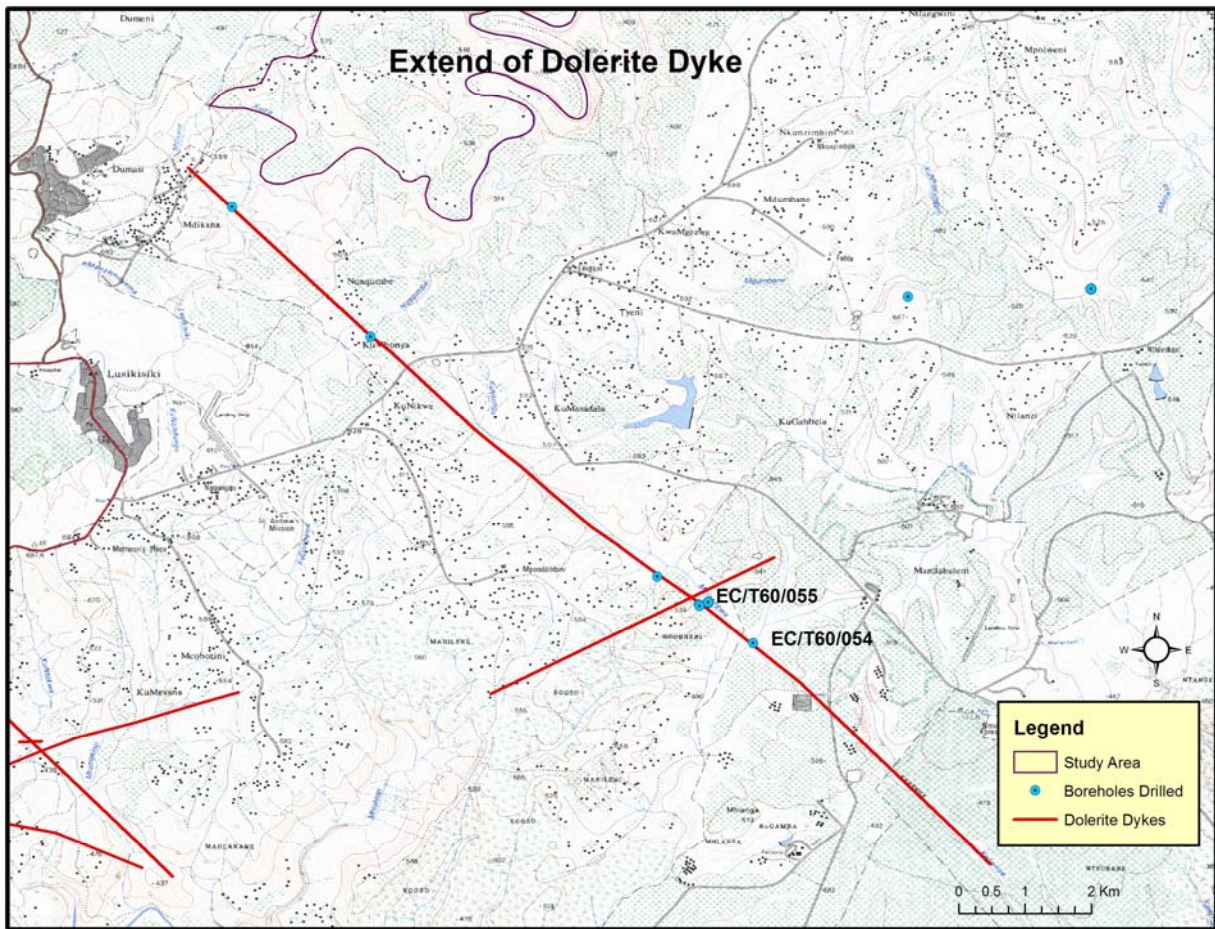


Figure 6.2.1a: Positions of EC/T60/054 and 055

The water quality tested good and although reddish deposits is prominent around the top of the casing of the borehole, as seen in Figure 6.2.1b, it can be ascribed to the low Ph of the water (pH = 6.16) which reacts with the upper steel casing that had to be placed around the inner PVC casing for maximum borehole protection.



**Figure 6.2.1b: Photo showing oxidation around EC/T60/054 - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

Borehole EC/T60/080 (borehole in lineament / fracturing in NGS - near Mkambati)

This borehole was drilled near Mkambati on a north-west south-east striking lineament. The last recorded water strike was at 55 m (1.4 l/s), but the yield increased as drilling progressed to 80 m. The final airlift yield was measured as 2.5 l/s. The Constant Discharge Test (CD test) was done at a yield of 1.3 l/s for a planned period of 24 hrs, but the water level in the borehole reached pump intake after 12 hrs and the test was ended and recovery measurements taken.

The early- T calculated at 2.8 m<sup>2</sup>/day and Late-T 1.8 m<sup>2</sup>/day.

The **water quality** tested Marginal with the Iron concentration being 1.17 mg/l. The initial water sample that was taken during the pump test suggested an unacceptable Total Coliform count, but a re-sample with a mobile, sterile sampling unit indicated that there is no significant bacteriological contamination. The initial bacteriological contamination therefore originated from the pumping equipment which was probably not properly disinfected before the test.

Figure 6.2.1c shows the mobile sampling unit that was used for the re-sampling of borehole EC/T60/080.



**Figure 6.2.1c: Photo showing the mobile sampling unit - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

### 6.2.2 Dwyka Formation

Table 6.2.2 indicates the boreholes drilled in the Dwyka Formation.

**Table 6.2.2: Dwyka boreholes**

BH No	Latitude	Longitude	Water strike(m) and Strike Yield (l/s) in brackets	Airlift yield l/s)	24hr yield (l/s)	BH depth (m)	Water Quality*
EC/T60/053	31.34855000	29.70891000	24(3.14), 32(1.26),71(1.1),95(1.8),126(3.7)	11	0.87	146	M - Bacteria
EC/T60/055	31.39117000	29.65699000	52(0.2), 77(0.4), 88(0.5)	1.1	0.75	98	Good
EC/T60/056	31.35509000	29.61120000		0.1	Not tested	120	
EC/T60/061	31.37449000	29.52324000	22(22)	22	2.3	120	M - Chloride & Bacteria & Iron
EC/T60/062	31.37458000	29.52327000		5	Not tested	60	
EC/T60/064	31.33744000	29.59236000	23(2.2)	2.2	0.6	86	U - Iron & Bacteria
EC/T60/065	31.42056000	29.54342000		0.1	Not tested	80	
EC/T60/072	31.38769000	29.65072000	17(5)	5	1.5	150	U- Coliforms
EC/T60/073	31.39144000	29.65567000		0.3	Not tested	33	
EC/T60/074	31.39164000	29.65579000	120(0.6)	0.6	0.34	120	P - Bacteria

**\*Note:** M = Marginal; P = Poor; U = Unacceptable; G = Good

The following statistics can be derived from the testing data:

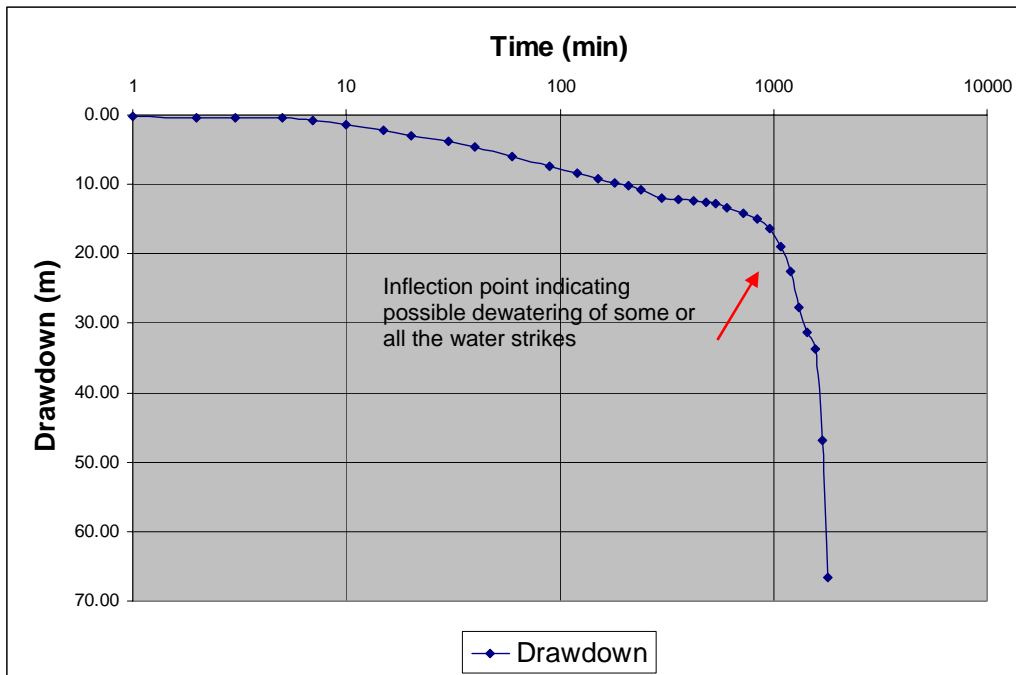
- Range of airlift yield to recommended 24-hr yield: 6.4 - 68%
- Average (airlift yield to 24-hr recommendation): 33%
- Percentage recovery after testing: 47 - 98% (average = 83%)
- Highest airlift yield 22 l/s
- Lowest airlift yield 0.1 l/s

### Borehole EC/T60/053

This borehole was drilled through the Dwyka, into the NGS, producing water strikes in the Dwyka, NGS and on the contact between the two.

The airlift yield was 11 l/s and the CD test was conducted at a rate of 4 l/s for a planned 48 hrs, but the yield drastically decreased after 1080 min (18 hrs) and the test was eventually stopped after 1800 min (30 hrs) and recovery taken. After 24 hrs of recovery the water level was still 16 m from the original static water level when the CD test was started, suggesting a 75% recovery.

Even though water strikes were recorded up to 126 mbgl, it seems from the water level drawdown graph shown in Figure 6.2.2 that all the strikes dewatered, except for the strike at ~ 24 mbgl. For the calculation of the sustainable yield, a transmissivity value was calculated on the water level drawdown gradient up to 20 m as the gradient after 20 m is considered non-responsive as the decline was too rapid. Available drawdown was therefore taken as 20 m for the purpose of the sustainable yield calculations. The 24-hr yield calculated at a disappointing 0.7 l/s due to the lack of drawdown as result of the dewatering of the deeper water strikes and the poor recovery. Early-T was calculated at 7.3 m<sup>2</sup>/day and Late-T 0.7 m<sup>2</sup>/day. The water quality can be classed as Marginal with slightly elevated levels of bacteria.



**Figure 6.2.2: Time versus drawdown of CD of EC/T60/053 - (Nel 2005, Lusikisiki Groundwater Feasibility Study)**

#### Borehole EC/T60/061

The 1:250 000 geological series indicate this borehole as situated on the Ecca Group at a distance of approximately 2.5 km from the geological contact with the Dwyka and if the dip of 2% is considered, the Dwyka should have been intersected at a depth of approximate 50-60m (see Fig 6.2.2a). The drilling logs however confirmed that Dwyka Formation was drilled almost from the start and no Ecca sediments were encountered. Water was struck at 22 mbgl (22 l/s) and no further water strikes were encountered up to the drilling depth of 120m.

The borehole was yield tested at a constant yield of 7 l/s for a period of 48 hrs. Drawdown was 9.8 m and the borehole recovered to 5 m after 48 hrs which suggests a percentage recovery of only 47%, but it can be misleading as the drawdown was insignificant. If for example, the CD yield was chosen higher and more drawdown was achieved (even resulting in rapid water level drawdown), the recovery percentage would have been higher. Because of the relative poor recovery, the recommended yield calculated 2.3 l/s which might be conservative if the performance of the borehole during the CD test is concerned.

The borehole was drilled along a northeast - southwest lineament which might be a fault if the upwards movement of the Dwyka is considered. The borehole probably sourced its water from the lineament and from weathering in the upper 20 m of the diamictite (confirmed by the drilling logs).

The slow recovery is indicative of a low hydraulic water pressure arising from non-confined conditions in the upper 20m.

Early- T was calculated as 50 m<sup>2</sup>/day and Late-T at 21 m<sup>2</sup>/day. Insufficient drawdown to calculate the Late-T value was achieved as the water level reached steady state around 9 mbgl at CD yield of 7 l/s.

The **water quality** can be classed as Marginal with elevated levels of Chloride and Iron.

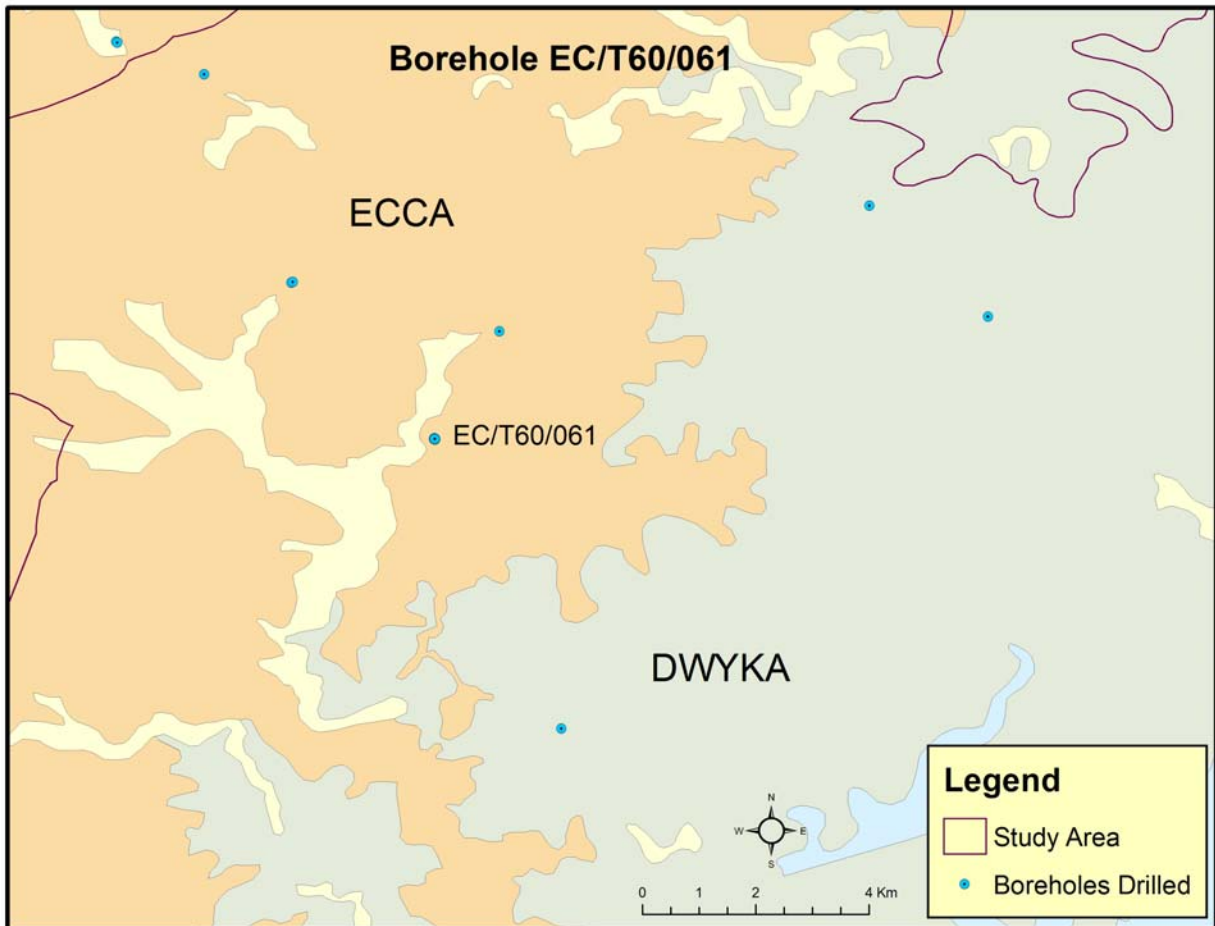


Figure 6.2.2a: Position of EC/T60/061 relative to geological contact

### 6.2.3 Ecca Group

The boreholes drilled in the Ecca sediments are shown in Table 6.2.3.

**Table 6.2.3: Boreholes drilled in the Ecca**

BH No	Latitude	Longitude	Water strike(m) and Strike Yield (l/s) in brackets	Airlift yield l/s)	24hr yield (l/s)	BH depth (m)	Water Quality*
EC/T60/057	31.31655000	29.48660000	29(1.6)	1.6	0.34	86	M - Iron, Chloride
EC/T60/058	31.31135000	29.47263000	20(0.2), 36(0.85)	1.05	0.1	98	M-Iron
EC/T60/059	31.31152000	29.47281000	14(0.4)	0.4		70	U-Iron
EC/T60/060	31.35744000	29.53353000		0		11	
EC/T60/063	31.30420000	29.53667000		0		128	
EC/T60/069	31.34969000	29.50047000	35(0.1), 46(0.75)	0.85	0.13	80	P-Coliforms
EC/T60/070	31.34958000	29.50069000		0		100	
EC/T60/071	31.34960000	29.68408000		0		35	

**\*Note:** M = Marginal; P = Poor; U = Unacceptable; G = Good

The following statistics can be derived from the testing data:

- Range of airlift yield to recommended 24-hr yield: 9 - 21%
- Average (airlift yield to 24-hr recommendation): 15%
- Percentage recovery after testing: 92 - 99% (average = 96%)
- Highest airlift yield 1.6 l/s
- Lowest airlift yield 0 l/s

Although the airlift yields were relatively low compared to the Natal Group Sandstone and the Dwyka, the water levels of the tested boreholes recovered well. Transmissivity values were however low which resulted in low recommended yields, despite the good recoveries. Water strikes were relatively shallow. On average, Early-T values are in the order of 1.8 m<sup>2</sup>/day and Late-T = 0.3 m<sup>2</sup>/day. No high-yielding boreholes with significant water strikes were however encountered and these values are indicative of smaller water strikes / less developed fractured & weathered systems.

The **water quality** of the boreholes drilled in the Ecca is generally of Marginal water quality and can produce unpleasant odours which will aesthetically not be acceptable to the communities unless treated. Table 6.2.3a provide an indication of the chemical character of the boreholes that were drilled in the Ecca.

Further drilling in the Ecca was abandoned due to the limited budget and the low success rate achieved.

Table 6.2.3a: Water quality of EC/T60/057 - (Nel 2005, Lusikisiki Groundwater Feasibility Study)

DATE		21/07/05						
PROJECT		LUSIKISIKI FEASIBILITY STUDY						
PROJECT NUMBER		341320						
SAMPLE ID		EC/T60/057		Alternative ID:				
Element	Unit	Value	Ideal (B)	Good Class 1 (G)	Marginal Class 2 (Y)	Poor Class 3 (R)	Un-acceptable Class 4 (P)	Result
Ammonia (as N)	mg/l	0.24		< 2	2 - 10	> 10		Good
Arsenic (as As)	mg/l		< 0.010	0.01 - 0.05	0.05 - 0.2	0.2 - 2	> 2	
Cadmium (Cd)	mg/l		< 0.003	0.003 - 0.005	0.005 - 0.02	0.02 - 0.05	> 0.05	
Calcium (as Ca)	mg/l	48	0 - 80	80 - 150	150 - 300	> 300		Ideal
Calcium (as CaCO <sub>3</sub> )	mg/l							
Chloride (as Cl)	mg/l	239	< 100	100 - 200	200 - 600	600 - 1200	> 1200	Marginal
Conductivity	mS/m	135	< 70	70 - 150	150 - 370	370 - 520	> 520	Good
E-Coli ***	No/100 ml		0		1	> 1		Ideal
Faecal Coliforms	No/100 ml	1	0	0 - 1	1 - 10	10 - 100	> 100	Good
Fluoride (as F)	mg/l	0.41	< 0.7	0.7 - 1.0	1.0 - 1.5	1.5 - 3.5	> 3.5	Ideal
Iron (as Fe)	mg/l	1.403	< 0.5	0.5 - 1.0	1 - 5	5 - 10	> 10	Marginal
Magnesium (as CaCO <sub>3</sub> )	mg/l							
Magnesium (as Mg)	mg/l	49	< 70	70 - 100	100 - 200	200 - 400	> 400	Ideal
Manganese (Mn)	mg/l		< 0.1	0.1 - 0.4	0.4 - 4	4 - 10	> 10	
Nitrate (as N)	mg/l	8.1	< 6	6 - 10	10 - 20	20 - 40	> 40	Good
pH (lower range)	Units	7.29	5 - 9.5	4.5 - 5	4 - 4.5	3 - 4	< 3	
Potassium (as K)	mg/l	4.4	< 25	25 - 50	50 - 100	100 - 500	> 500	Ideal
Sodium (as Na)	mg/l	169	< 100	100 - 200	200 - 400	400 - 1000	> 1000	Good
Sulphate (as SO <sub>4</sub> )	mg/l	49	< 200	200 - 400	400 - 600	600 - 1000	> 1000	Ideal
Total Coliforms	No/100 ml	1	0	0 - 10	10 - 100	100 - 1000	> 1000	Good
Total Count	No/100 ml							
Total Hardness	mg/l	322	< 200	200 - 300	300 - 600	> 600		Marginal
Turbidity	NTU	71	< 0.1	0.1 - 1	1 - 20	20 - 50	> 50	Unacceptable
				9.5 - 10	10 - 10.5	10.5 - 11	> 11	
Recommended Class								MARGINAL
<p><b>NOTES</b></p> <p>Above analysis is based on "Quality of Domestic Water Supplies - Volume 1: Assessment Guide, second edition 1998" published jointly by:</p> <ul style="list-style-type: none"> <li>* The Department of Water Affairs and Forestry</li> <li>* The Department of Health</li> <li>* Water Research Commission</li> </ul> <p>*** E-Coli analysis according to the SABS 241 Guideline (Edition 5, 2001)</p>								



## 7. CONCLUSIONS

The full spectrum of geohydrological recognisance was used on this project, commencing with Landsat Lineament Mapping, Aerial Photography interpretations, Geological interpretations, in-the-field inspections and geophysical surveys. Compared to the average geohydrological investigation for rural water supply, far more work was done during this study but then the results far exceed the results of the average water supply project.

The importance of the various recognisance exercises in this study, proofed to be as follows:

- Lineament Mapping: Lineament mapping is a tedious and expensive exercise and the smaller lineaments did not add much value to the drilling programme, other than to indicate areas of possible fracturing. Most of the drilling was focussed on the major structures such as the dykes and faults and these can easily be seen from Aerial Photographs and Landsat Images. The Landsat images and aerial photos therefore added value, but the time and money spent in delineating all the minor lineaments could be re-looked.
- Field recognisance: The Transkei areas is well covered with vegetation (grass and small bush) and outcrop is hard to find, especially in the Eccca where the abundance of dolerite sheets further complicates the search for a straight-line dyke. Field inspections in the Msikaba however proved vital as could be seen in the photograph of the sandstone ridge on both sides of the dyke. Fracturing and rock outcrop is more visible than in the Eccca. In general, it can be said that field recognisance is very necessary for any drilling programme.
- Geophysical exploration: There are two main approaches to geophysical work, namely (1) target an area and do very long traverses to detect fractures or structures and (2) first locate the target fracture or structure and then try and characterise it by means of shorter geophysical traverses. The latter was done in this study and proved very successful, but in areas where outcrop is scarce and the mapping of the structures is inaccurate, the first approach should be followed.

The value of full time drilling supervision and the evaluation of drilling results as the drilling progresses should also be acknowledged as it plays a critical role in as far as defining the better yielding targets as information becomes available. For example borehole EC/T60/051; if the initial drilling only focused on the dyke itself and not the fracturing away from the dyke, the high yielding EC/T60/054 may not have been drilled. The inside of the dyke proofed successful (~ 3 l/s) and hence the drilling rig could have been moved to the next site, also drilling inside the dyke. It is therefore important to accurately define the target that must be drilled during the initial stages of the project and then learn from it. On the first target, namely the dolerite dyke in the Msikaba, two

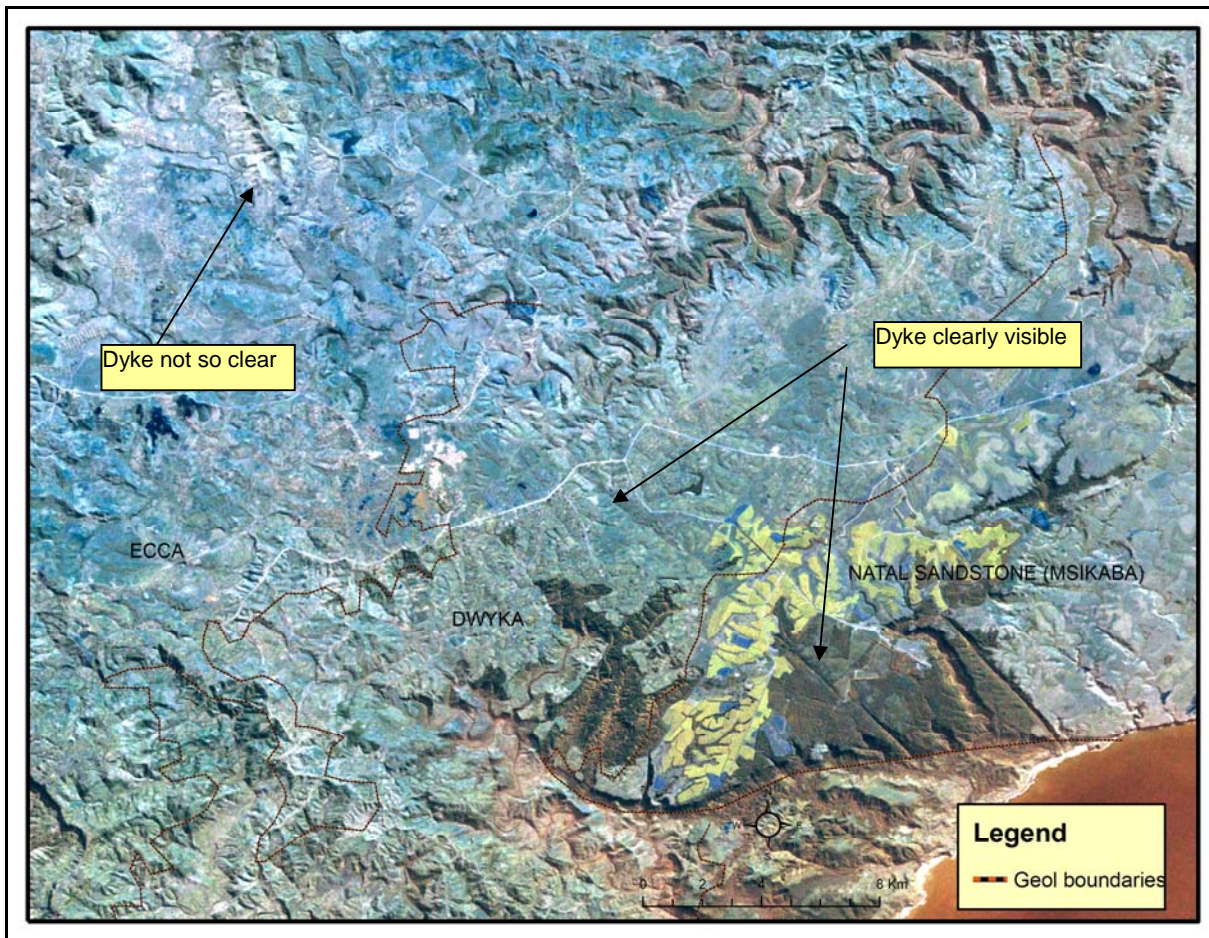
boreholes were drilled; the first next to the dyke as indicated by the geophysical profile, and the second inside the dyke to compare. The airlift yield of the first attempt was 22 l/s and the second 3 l/s. From this information it was decided to target the fracturing next to the dolerite dykes where they occur in the Msikaba. The results were good, including an 85 l/s airlift yield in borehole EC/T60/054. The same approach did however not work as well in the Dwyka and Eccca and water was struck mostly on the dyke contact (Dwyka) and inside the sediments (Eccca).

The high yielding boreholes that were drilled as part of this study were a combination of:

- **Landsat Images and Aerial Photography** - the regional dykes could be clearly identified;
- **Geophysical exploration** - the EM-34 clearly defined the fractured zones alongside the dykes in the Msikaba Sandstone;
- **Full-time drilling control** - as the drilling progressed, more information became available and contributed to the success of the project.

Another important aspect that contributed to the low success of the drilling in the Eccca, was the fact that the **positions of the dolerite dykes and sheets as shown on the 1:250 000 geological maps proofed inaccurate**. This can however be ascribed to the abundance of dolerite sheets in the Eccca and the fact that the sheets "masks" the positions of the dykes. It must therefore be very difficult to map the positions of the dykes with only using aerial magnetic methods. Comprehensive field geological and structural mapping, followed by exploration drilling and core sampling would be required to find these dykes. Even on the Landsat Image the positions of the regional dykes could not be determined as they "disappear" as soon they enter the Eccca (See Figure 7). To detect them with geophysical equipment that depends on magnetic changes (EM-34 and Magnetometer) also proofed difficult.

The **depth of drilling** varied, depending on the types of targets drilled and no clear assumptions can be made. When drilling the dolerite dykes, the dip of the dyke is determined and then the drilling is aimed at intersecting the dyke (or fractures next to the dyke) at a given depth, usually 30-40 metres below the expected water level. In general, no significant water strikes were encountered beyond a drilling depth of 100m and where water was struck beyond 100m, the strikes dewatered during pump testing. The only exception can be when targeting the geological contacts (e.g. Dwyka / Msikaba and Dwyka / Eccca) which did not produce results during the study, but then only 1-2 boreholes were drilled and at shallow depth (<100m).



**Figure 7: Landsat Image**

The **electromagnetic geophysical technique (EM-34)** was highly successful in the Msikaba where the dolerite dykes were targeted, but less successful where only lineaments were targeted (Msikaba). In the Dwyka and Ecca, the EM-34 produced less exciting and even contradicting results (Ecca). The **Magnetic method** complimented the EM-34 in most cases, but proved more successful where lineaments in the Msikaba Sandstone were targeted even though there were no dykes present. The mineralization inside the fractures or fissures must be magnetic to produce anomalies. In the Ecca, **electrical resistivity methods** should be considered in conjunction with exploration drilling (probing<sup>2</sup>).

<sup>2</sup> Probing is where boreholes are drilled in a fixed sequence to calibrate or test the geophysical profiles or to see the differences in rock composition.

## 7.1 Geological Properties:

- The study area comprises three Lithological units namely the Ecca Group, Dwyka Formation and the Natal Group Sandstone Group (also called the Msikaba Sandstone) with each of them having different hydrogeological properties.
- The Ecca have intensively been intruded by dolerite in the form of sheets, inclined sheets and dykes. The Dwyka Formation contains very few dolerite sheets and the occurrence of dolerite dykes are largely controlled by regional faults, extending from the Natal Group Sandstone.
- Lineaments are in abundance in all three units with the larger-scale lineaments following a northwest - southeast and close to east - west orientations, again dictated by the faulting.

## 7.2 Geophysical exploration:

The magnetic (Geotron G5 Proton Magnetometer), electromagnetic (Geonics EM-34) and resistivity (Geonics Direct Current – Wenner Configuration) methods were used throughout the study area with varying successes.

- Natal Group Sandstone: The magnetic (Mag) and electromagnetic (EM) methods proved very successful in the Natal Group Sandstone where dykes were targeted. The geophysical graphs reflected true readings and the contact zones of the dykes, the dyke itself and associated weathered & fractured zones could be identified and drilled with success.
- Dwyka: Limited successes were achieved in the Dwyka with both techniques mainly because of the similar conductivities of the Dwyka and the intrusive dolerite. The magnetic surveys identified the dykes, but the extend (width) of the near-vertical dykes could not easily be detected with the EM.
- Ecca: Non-conclusive results were achieved with all three geophysical techniques and the drilling contradicted the results of the geophysical surveys. Where regional dykes were targeted and where no outcrop was visible, the detection of the dykes proved to be difficult (even impossible in some instances) with the geophysical techniques applied. The magnetic properties of the dolerite sheets mask the anomalies of the dykes and hence "false anomalies" are achieved. Even in areas where no sheets are indicated on the 1:250 000 geological maps, underlying sheets were encountered.

## 7.3 Geohydrological properties:

To determine the exact geohydrological properties of the three geological units, more research is needed. Only one observation borehole could be monitored and no water level drawdown

was achieved, hence no storativity values could be determined. The aquifer parameters (e.g. Transmissivity) were calculated from the pumping borehole and without observation boreholes.

The limited information obtained through this study however suggests the following:

- Transmissivity values in the Natal Group Sandstone, along regional dykes are high ( $T = 15 - 20 \text{ m}^2/\text{day}$ ). Away from the dykes they are generally low ( $< 5 \text{ m}^2/\text{day}$ ).
- Transmissivity values in the Dwyka varied between  $4 - 22 \text{ m}^2/\text{day}$  depending on the degree of fracturing & weathering that was encountered.
- Transmissivity values in the Eccca were low ( $< 3 \text{ m}^2/\text{day}$ ). Dolerite sheet contacts generally produced no significant water strikes.

In general, only the Dwyka Formation produced relatively high transmissivity values where dolerite was not drilled, but then also only produced shallow water strikes and the higher transmissivity is probably due to shallow weathering & fracturing.

#### **7.4 Landsat Lineament Mapping:**

The lineament mapping highlighted the regional structures such as the dolerite dykes and faults and was more accurate in determining the positions of the lineaments, dykes or faults than the 1:250 000 geological maps. The smaller lineaments were not drilled, but they provided a good indication of the fracturing patterns associated with the larger lineaments or dolerite dykes and faults.

Since a limited number of boreholes could be drilled in each geological unit, the focus was on the larger, more prominent lineaments and not on the smaller ones. In the Mkambati area, mixed results were achieved with the drilling on the smaller lineaments and only 1 in 4 attempts yielded results. The lineament drilled in the Dwyka Formation produced an airlift yield of  $\sim 5 \text{ l/s}$ .

The lineament mapping further highlights the structural intensity of areas which contributed to the selection of targets.

#### **7.5. Production boreholes**

Table 7.5 lists the production boreholes that resulted from the feasibility study and that can be utilised as part of the existing scheme or for future water supply purposes. If the boreholes are all used in conjunction with surface water and linked into the existing surface water scheme, their water qualities should not affect the distribution point's water qualities except if the boreholes are placed near the distribution points.

Distinction is made between those boreholes that have potable water quality (Ideal to Marginal) and those that require treatment prior to use. Only boreholes that yielded more than 0.5 l/s (12-hr recommended pumping cycle) are considered as production boreholes for the purpose of this assessment.

**Table 7.5: Recommended production boreholes**

BH No	Latitude	Longitude	Airlift yield (l/s)	12-hr yield (l/s)	24-hr yield (l/s)	** Water Quality
EC/T60/051	31.30908000	29.75960000	22	4.6	3.2	M - Iron
EC/T60/052	31.30313000	29.75283000	2.75	1.3	0.9	M - Bacteria
EC/T60/053	31.34855000	29.70891000	11	1.2	0.9	M - Bacteria
EC/T60/054	31.39673000	29.66307000	85	10.5	7.5	Good
EC/T60/055	31.39117000	29.65699000	1.1	1.1	0.8	Good
EC/T60/057	31.31655000	29.48660000	1.6	0.5	0.3	M - Iron & chloride
EC/T60/061	31.37449000	29.52324000	22	3.3	2.3	M - Chloride & Bacteria & Iron
EC/T60/064	31.33744000	29.59236000	2.2	0.8	0.6	U - Iron & Bacteria
EC/T60/072	31.38769000	29.65072000	5	2.1	1.5	U-Coliforms
EC/T60/074	31.39164000	29.65579000	0.6	0.5	0.3	P - Bacteria
EC/T60/076	31.35342000	29.82075000	1.0	0.6	0.4	U - Iron, Bac
EC/T60/078	31.31758000	29.7708000	15	1.3	0.9	GOOD
EC/T60/080	31.33175000	29.95383000	2.5	0.7	0.5	M - Iron

\* **P = Poor, M = Marginal, U = Unacceptable**

Although the project was not entirely aimed at the drilling of high yielding boreholes, the best possible targets in each Lithology were targeted. The following statistics reflect the success of the project in terms of drilling:

- Success rate (BH's > 0.1 l/s): 73%
- Percentage dry boreholes: 27% (incl. calibration boreholes)
- Percentage boreholes with airlift yield > 1 l/s: 47%
- Percentage boreholes with airlift yield > 5 l/s: 27%
- Total airlift yield (30 boreholes): 180 l/s
- Total 24-hr recommended yield: 20 l/s (11 % of total airlift yield)

## 8. RECOMMENDATIONS

The exploration drilling programme was successful and produced high yielding boreholes, some of which are records for that part of the Eastern Cape. The approach followed can therefore be seen as the correct one and if compared to previous drilling in the area where Landsat Imagery was not used, the successes were amazing. It must however be noted that only 30 boreholes were drilled in a very extensive area and the findings of this report are based on the results of those 30 boreholes. There are still a number of areas / targets that can be investigated and that might also produce high yielding boreholes. This study must therefore not be seen as the first and last for the area.

1. The areas where there are still exploration options that need further attention, include:

- **Deep drilling** through the Ecca, the Dwyka and into the Natal Group Sandstone (Natal Group Sandstone). Borehole depths exceeding 150 m are envisaged. The deep drilling could be combined with drilling the regional dolerite dykes to intersect the dykes in depth, i.e. drilling through the Dwyka to intersect the fractured zones next to the dolerite dykes (e.g. BH EC/T90/054).
- Drilling on **opposite sides of the regional dolerite dykes** and pump testing to determine the degree of impermeability of the dykes. In theory, another borehole can be drilled on opposite side of the dyke (BH EC/T90/054) and the two boreholes should operate without significant impact on each other.
- The regional **dyke** that runs through the **Ecca** could not be located during the geophysical exploration and subsequent drilling and needs to be found using more comprehensive geophysical techniques (non magnetic / non StrataGem) and should be drilled to determine its yield and water quality prospects.
- The drilling indicated a possible northeast - southwest fault or series of faults in the area of borehole EC/T60/072 which is not indicated on the geological map. If the dip of the NGS is taken as being  $2^{\circ}$ , borehole 072 should have penetrated the Dwyka and entered the NGS at approximately 50 m. The NGS was however only reached at a drilling depth of 148 m. The fault has been intruded by a dolerite dyke. Although successful, borehole EC/T60/072 can produce a higher yield if drilled through the Dwyka and into the NGS, penetrating the regional dyke on which borehole EC/T60/054 was drilled. The fault itself was also not drilled extensively and should also produce high yields. Figure 8 indicates the possible position of the fault which is assumed to be the same as the dyke (the position of the dyke was field confirmed) as the dyke might have intruded into the fault as is the case with many of the regional dykes in the area. Fig 8a show the geological map (1:250 000 3128 Umtata) which does not indicate any dyke, fault or lineament.

2. Communities are still using **springs** despite proposed and existing water schemes and these springs are unprotected and are also being used by livestock for drinking. The communities must be educated in spring protection measures and in the prevention of contamination. In addition to proper education, formal spring protection construction needs to be done in the areas that cannot / will not be served by either borehole or surface water schemes. The villages that were excluded in the hydrocensus need to be included as part of further studies.

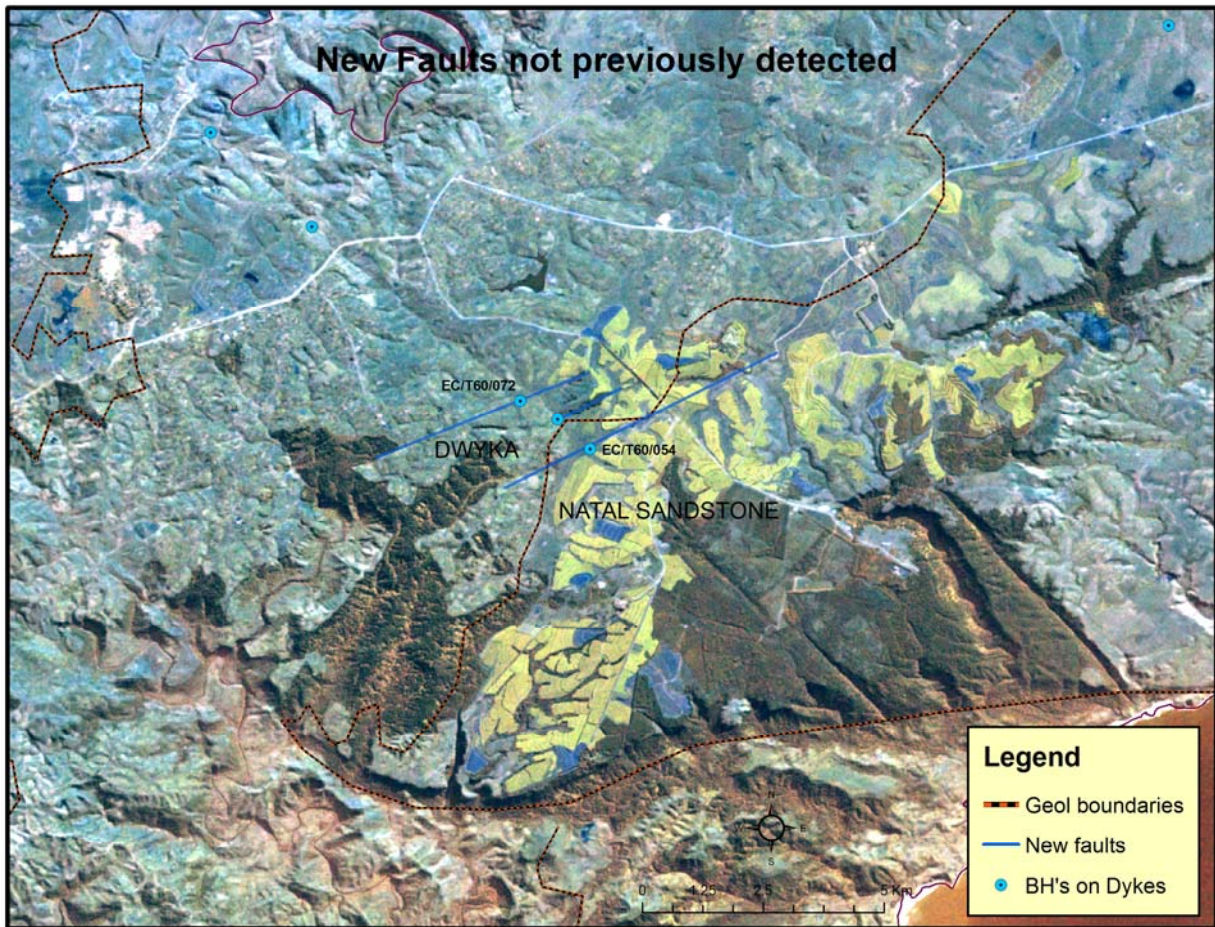


Figure 8: Positions of possible faults



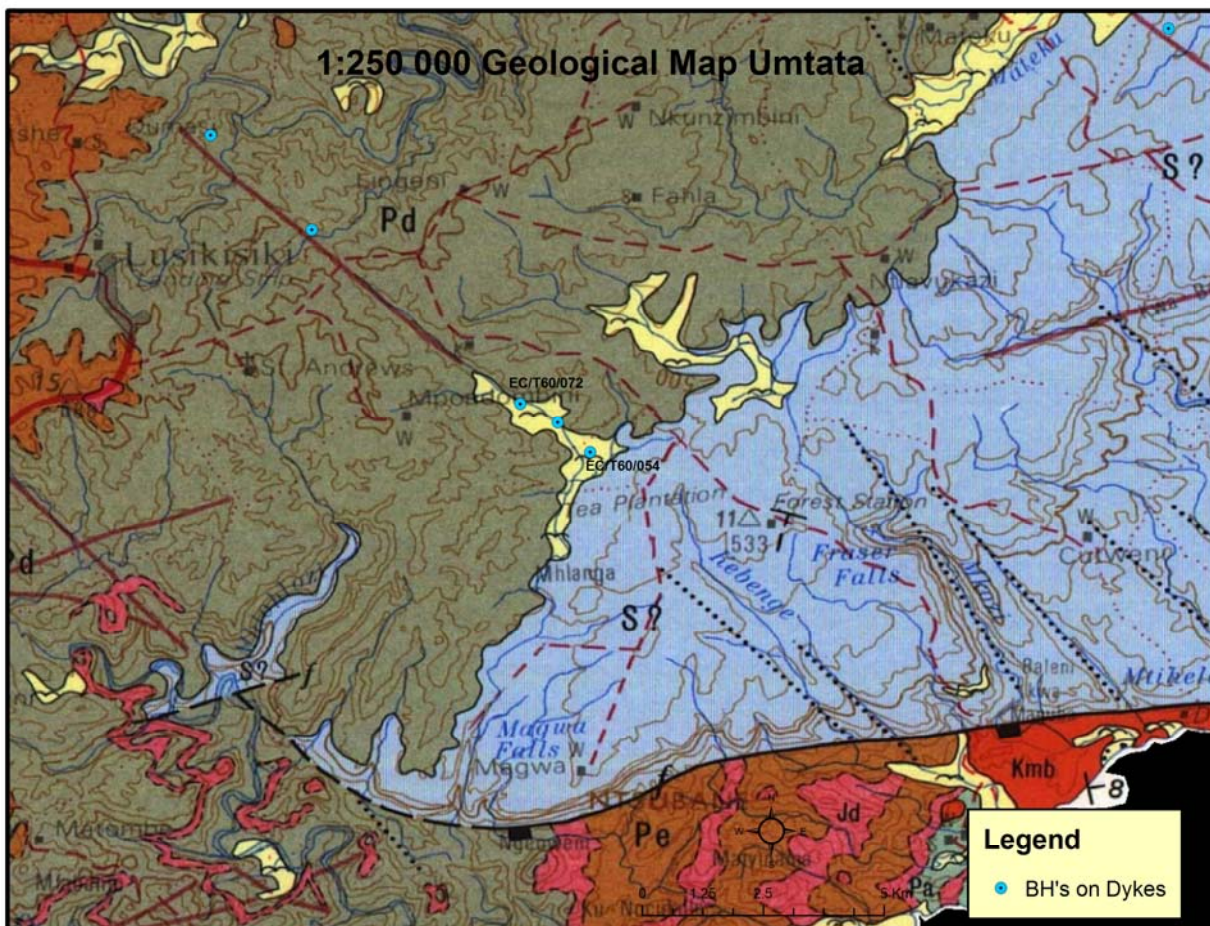


Figure 8a: 1:250 000 Geological Map – Umtata (Council for Geoscience)

Based on the results of the Lusikisiki Groundwater Feasibility Study, the following target areas are considered the most significant for future drilling programmes:

- **Dolerite dykes** occurring in the **Natal Group Sandstone (NGS)**, Dwyka and to a lesser extend, the Ecca can be targeted for drilling. The dykes in the Ecca are included as they still have potential, but are difficult to locate and have not extensively been explored as part of the Lusikisiki study. The dykes in the Natal Group Sandstone, especially where they occur inside a fault or extend from a fault, are considered the most promising targets and can be successfully targeted with relatively simple geophysical and field mapping techniques. The physical properties (e.g. thickness) of the dykes in the Dwyka are harder to determine since the Dwyka rock is not so susceptible to fracturing and weathering than the Natal Group Sandstone. The dykes in the Dwyka can produce high yields, but no as high as the NGS. The regional dykes in the Ecca, i.e. those extending from the NGS and the Dwyka, theoretically must produce good yields, but because they are surrounded by dolerite sheets, their exact positions and width are almost impossible to determine. The

borehole yields do however seem to increase towards the NGS and the higher rainfall and recharge in the Dwyka and NGS areas can contribute to this scenario.

- **Lineaments** proved successful in the Dwyka and to a lesser extent the NGS. Mixed results were achieved in the NGS, but drilling on the East - West orientated lineaments proved successful. Not all the different orientations were however drilled and no conclusive statement can be made in this regard.
- The **Faults** that occur mainly in the NGS and Dwyka can be targeted with success, especially where they have been intruded by dykes. The major faults are however very difficult to gain access to and extensive access road construction will have to be done in order to drill them where they occur inside well-developed drainage systems.

Based on the results of the investigation, the following targets did not yield any significant results:

- **Dolerite sheets** (shallow dipping to horizontal) in the **Ecca**. The few dolerite sheets that occur in the Dwyka were not drilled and no conclusion can hence be made on their groundwater potential where they occur in the Dwyka.
- **Small-scale lineaments** in the NGS.
- **Geological contacts** - The contacts between the Natal Sandstone and Dwyka; and the Dwyka and Ecca did not produce the expected results, but more drilling need to take place to assess the potential.

The potential of **deep-drilling** through the Dwyka into the Natal Group Sandstone was not fully tested in the Lusikisiki study and still is considered a viable option to locate good quality, artesian boreholes. Some of the boreholes that were drilled as part the Lusikisiki study did penetrate the Dwyka into the NGS at shallow depth (~ 70 m) and although the water strikes on the Dwyka / NGS contact did yield spectacular results, water was found on one of the boreholes.

Key points describing the thesis:

- Groundwater development within the Msikaba, Dwyka and Ecca Groups
- Groundwater exploration methods
- Geophysical techniques
- Drilling targets
- Borehole drilling
- Pump testing
- Groundwater quality
- Geology and geological structures
- Groundwater recharge
- Further research

## 9. SUMMARY (E - English, A - Afrikaanse opsomming)

**E:** The study focused on the three major geological units, namely the Natal Group Sandstone (NGS or also called Msikaba Sandstone), the Dwyka Formation and the Ecca Group and was aimed at investigation the geohydrological properties of these units and their potential to produce sustainable groundwater supply. The methodology included Landsat lineament mapping, aerial photography mapping, geological mapping, geophysical exploration, drilling and testing.

The investigation can be considered successful as various high yielding boreholes were drilled, some of which constituted new records for the Eastern Cape. Although the entire approach can be commented, it was the geophysical exploration that proved conclusive in the Msikaba Sandstone where the high yields were obtained. Especially the EM-34 produced excellent anomalies where dolerite dykes were targeted and the fracturing on the sides of the dykes were very well defined.

Recharge was calculated using the GIS / GRID based approach where a percentage recharge based on lithological properties was used. The percentage recharge seemed high when compared to the Chloride method where the two scenarios, coastal and inland, were considered. When the coastal scenario was used, the percentage recharge was in the same order of magnitude (10 - 12% of rainfall), but if the inland scenario was used the percentage recharge was much lower (<5%). If the pumping test results are considered, it seems that recharge mostly occurs along the fractured zone associated with the dykes on which the boreholes were drilled and not from the host rock in the case of the Msikaba Sandstone. No monitoring boreholes were available to test this theory in the Dwyka and Ecca, but it should be same in the case of the Dwyka. The Ecca produced low yields and poor water quality and hence it is possible that the overlying dolerite sheets have a negative influence on the recharge from rainfall. The fact that dolerite sheets were intersected at shallow depth (30m) without yielding groundwater, substantiate this.

The water quality was acceptable in both the Msikaba and Dwyka, but mostly poor to unacceptable in the Ecca. In terms of ranking the three geological units according to their envisaged groundwater potential, they would rank as follows:

- Msikaba Sandstone                      Ranked first
- Dwyka    Ranked second
- Ecca    Ranked third

Main targets for drilling would include:

- Regional dolerite dykes
- Faults and larger lineaments
- Geological contacts

**A:** Die study het gefokus op die drie hoof geologiese eenhede, naamlik die Natal Group Sandstone (ook genoem NGS of Msikaba Sandstone), die Dwyka Formasie en die Eccca Group. Die vermoë van die drie eenhede om standhoudende water te gee, is ondersoek. Die metodiek wat gevolg is sluit in Landsat lineament kartering, lugfoto interpretasie, geologiese kartering, geofisika en boor- en toetswerk. Die study kan as suksesvol beskou word omrede verskeie hoë lewering boorgate geboor is, waarvan sommige rekords was vir die Oos Kaap. Alhoewel die hele benadering as korrek beskou kan word, is dit die geofisiese ondersoek wat veral uitstekende resultate gelewer het, veral in die Msikaba sandstone waar dit die gefrakteurde sones langs die doleriet gange duidelik uitgewys het (EM-34).

Grondwater aanvulling is geskat vanaf hoofsaaklik twee benaderings, naamlik die karterings metode waar benaderde waardes gebaseer op die litologiese eienskappe van die gesteente geneem is en tweedens die Chloried metode. In laasgenoemde is twee verdere onderverdelings gebruik, naamlik kuslans en binnelands. Indien die kus waardes gebruik word is die persentasie aanvulling naastenby dieselfde as die litologiese metode (10 - 15%), maar indien die Chloried waardes van binnelanse reeval gebruik word, is die aanvulling minder as 5%. Indien die pomptoets inligting gebruik word waar wel observasiegate beskikbaar was, het dit geblyk dat aanvulling slegs saam met die gefrakteurde sone (langs die strekking van die gange) plaasvind en min of geen aanvulling geskied vanaf die wandgesteentes (veral in die Msikaba). Dieselfde behoort te geld vir die Dwyka, maar die swakker lewering en ook swakker water gehalte in die Eccca kan moontlik as gevolg wees van die oorliggende doleriet plate. Die feit dat doleriet plate geboor en getref is op vlak diepte (30m) en geen water gelewer het nie, alhoewel geleë in 'n goeie dreinerings, is verdere bewys daarvan.

Daar is gevind dat die water gehalte goed is in die Msikaba en Dwyka, maar swakker is in die Eccca. Indien die drie eenhede in prioriteit geplaas word vanaf hoë grondwater potensiaal to lae grondwater potensiaal, lyk dit soos volg:

- o Msikaba eerste
- o Dwyka tweede
- o Eccca derde

Die hoof grondwater teikens sal wees:

- o Doleriet gange (regionaal en waar in verskuiwings ingedring)
- o Regionale verskuiwings en lineamente
- o Geologiese kontakte

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**APPENDIX 1:**

Hydrocensus Information

**APPENDIX 2:**

Geophysical Graphs

**APPENDIX 3:**

Drilling Logs



**APPENDIX 4:**

Pump testing information  
Water Qualities  
Management Recommendations