Prince Albert Municipality

Groundwater Management and Artificial Recharge Feasibility Study

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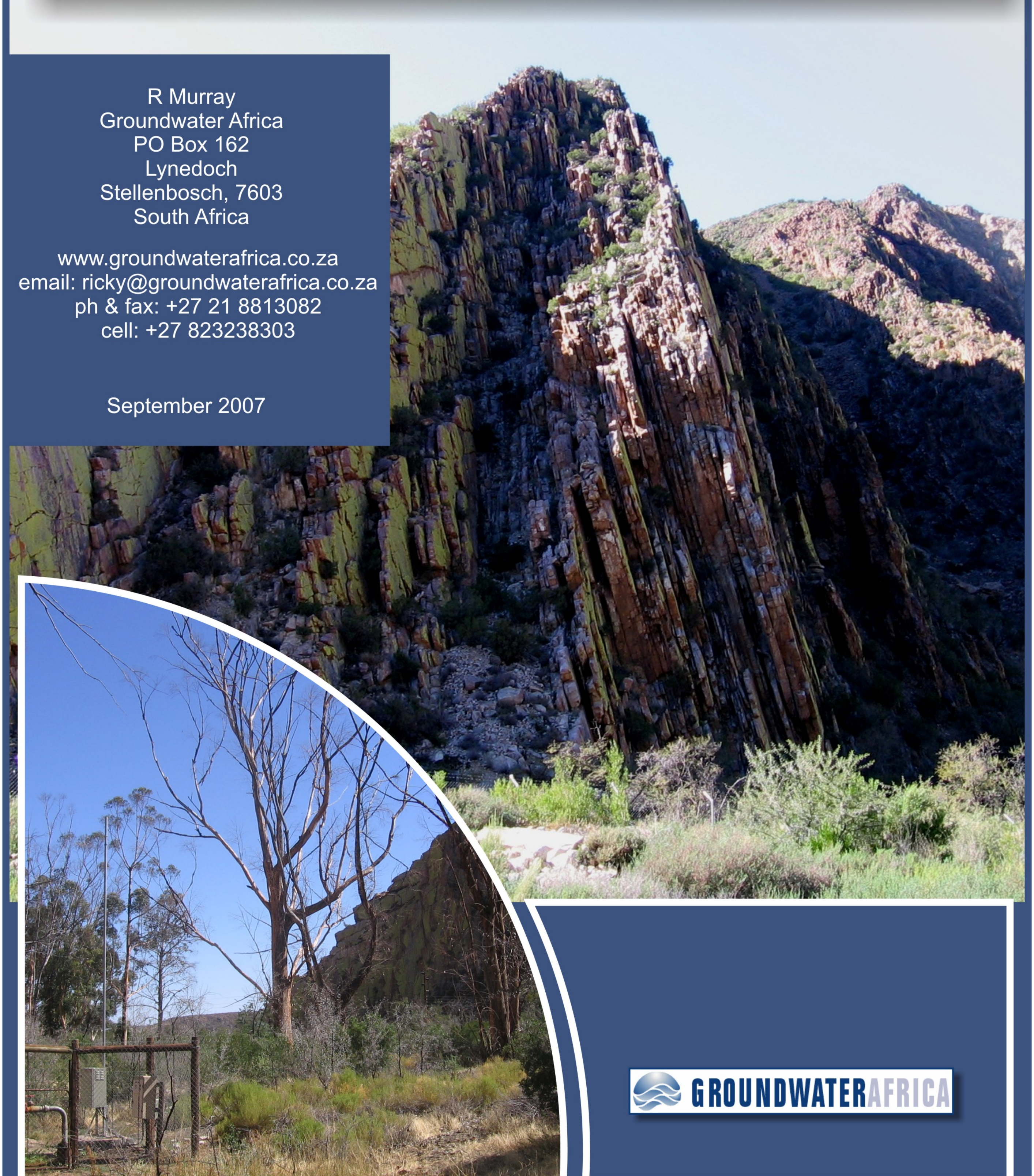

GROUNDWATERAFRICA

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EXECUTIVE SUMMARY

Prince Albert

Current water supply

In 2006 and 2007 groundwater levels and abstraction were closely monitored. Surface water supplies from the 21.25 hour/week allocation from the irrigation furrow however are not accurately known, and were estimated based on flume readings and estimated losses from the furrow. In 2006/7 the water supply to Prince Albert is estimated to be:

Total supply

- Groundwater: 400 000 m^3/annum or ~73% of the total supply
- Total: 550 000 m^3/annum

Summer supply

- Groundwater: 300 000 m^3/ 6-months or ~85% of the total supply
- Total: 350 000 m^3/ 6-months

The wise use and management of groundwater is thus crucial for the town's current and future needs.

Project Aims

The aims of the project were to:

1. Develop a groundwater management system for Prince Albert municipality.
2. Investigate the feasibility of artificially recharging Prince Albert's aquifers.

Key findings and recommendations

The findings and recommendations below come from assessing the artificial recharge potential to Prince Albert over the past two years and after intensive borehole water level and abstraction monitoring over the past year. In some cases the monitoring was for six months or less, and this followed after the exceptionally high rainfall period in 2006. Thus the findings below are based on information after a "wet" period when the aquifers were full. Although this has been taken into account, they will have to be reviewed and possibly revised after a "dry" period. The key findings are:

- No new water sources are currently needed for Prince Albert
- Artificial recharge may be required to fill the aquifers near town (Groundwater Management Unit A) prior to summer.
- The volume of water available for artificial recharge during the cleaning of the furrow is estimated to be 75 000 m^3.
- This water should be used for artificial recharge until the aquifers are full.
- Borehole injection tests should be conducted to check the estimated artificial recharge requirements of about 60 000 m^3/a (to fill the aquifers). This is the estimated volume of water

that it would take to fill the aquifers in the areas of Pumps 5, 6, 7 & 8 after these areas have been heavily pumped.

- If well managed and assuming the aquifers are full (if needs be with artificial recharge), groundwater and surface water (furrow allocations) can meet the average requirements for both summer (2 000 m^3/day) and winter (1 100 m^3/day).
- The uneven surface water allocations from the furrow make it extremely difficult to supply the peak summer requirements of 2 750 m^3/day on a consistent basis. This is the required supply rate for weeks on end during the hot summer months.
- By maximising groundwater use (and assuming the aquifers are full at the start of the summer period), the "extended" peak demand of 2 750 m^3/day can be met on Wednesdays, Thursdays and Saturdays when furrow allocations are above average. But on Mondays, Tuesdays, Fridays and Sundays, it may not be possible to meet this high demand.
- The peak-day summer requirement of 3 000 m^3/day (*ad hoc* demand on exceptionally hot days) can only be met on Wednesdays, Thursdays and Saturdays because of the longer furrow allocations.
- Prince Albert Municipality should apply to the Department of Water Affairs and Forestry (DWAF) for a groundwater use licence for 500 000 m^3/annum. This is more than double the existing registered use.

Klaarstroom

- The water supply system needs urgent attention to meet future water requirements.
- Reduce the pumping rate of borehole KS1 to 1 L/s, pump continuously (24 hours/day) and monitor KS1 and KS2.
- Install a flow meter at KS2. Halve its pumping rate and pump continuously if needed.
- Drill new boreholes to intersect the sandstones of the Boplaas Formation on the farm Klaarstroom below the irrigation dam. This is the best option to provide better water security, provide better quality water and to meet future water requirements.

Leeu Gamka

- No actions regarding the volume of water supplied are needed.
- Monitor abstraction and water levels over the 2007/8 summer and re-assess how the boreholes and aquifer are performing.
- Install water quality sampling taps at each borehole and ensure all borehole enclosures are in good condition.
- Maintain the water quality monitoring programme and if the bacteriological count becomes unacceptable (as was previously the case at borehole LG3), investigate the source of contamination.

Overall groundwater recommendations

- Modify the pumping rates on the boreholes as per individual borehole recommendations.
- Upgrade the telemetry system to accommodate the daily changes in the borehole pumping schedule (because of the irregular municipal furrow allocation).
- Incorporate the newly drilled monitoring boreholes in the groundwater monitoring and management plan.
- Maintain the groundwater monitoring system and have the data reviewed before, during and after the summer high-abstraction period.
- Appoint a dedicated person to manage the surface- and groundwater resources and supply system. This person will need to be trained in all aspects of water resource and supply management.
- Change the furrow allocation schedule to provide a continuous supply of water. This will make the management of Prince Albert’s water supply far easier and the supply of water consistent.
- Establish the water losses along the furrow; install the proposed pipeline in the furrow; determine an equitable allocation of furrow water for the municipality that takes both the existing allocation and the savings on losses into account; and meter the furrow supply. Together with groundwater management, artificial recharge and improved water demand management this would ensure the town has a reliable, long-term water supply.
- Conduct artificial recharge tests.

Figure 1 shows the location of Prince Albert’s boreholes, the Groundwater Management Units, the intake of the irrigation furrow and the rain gauges.

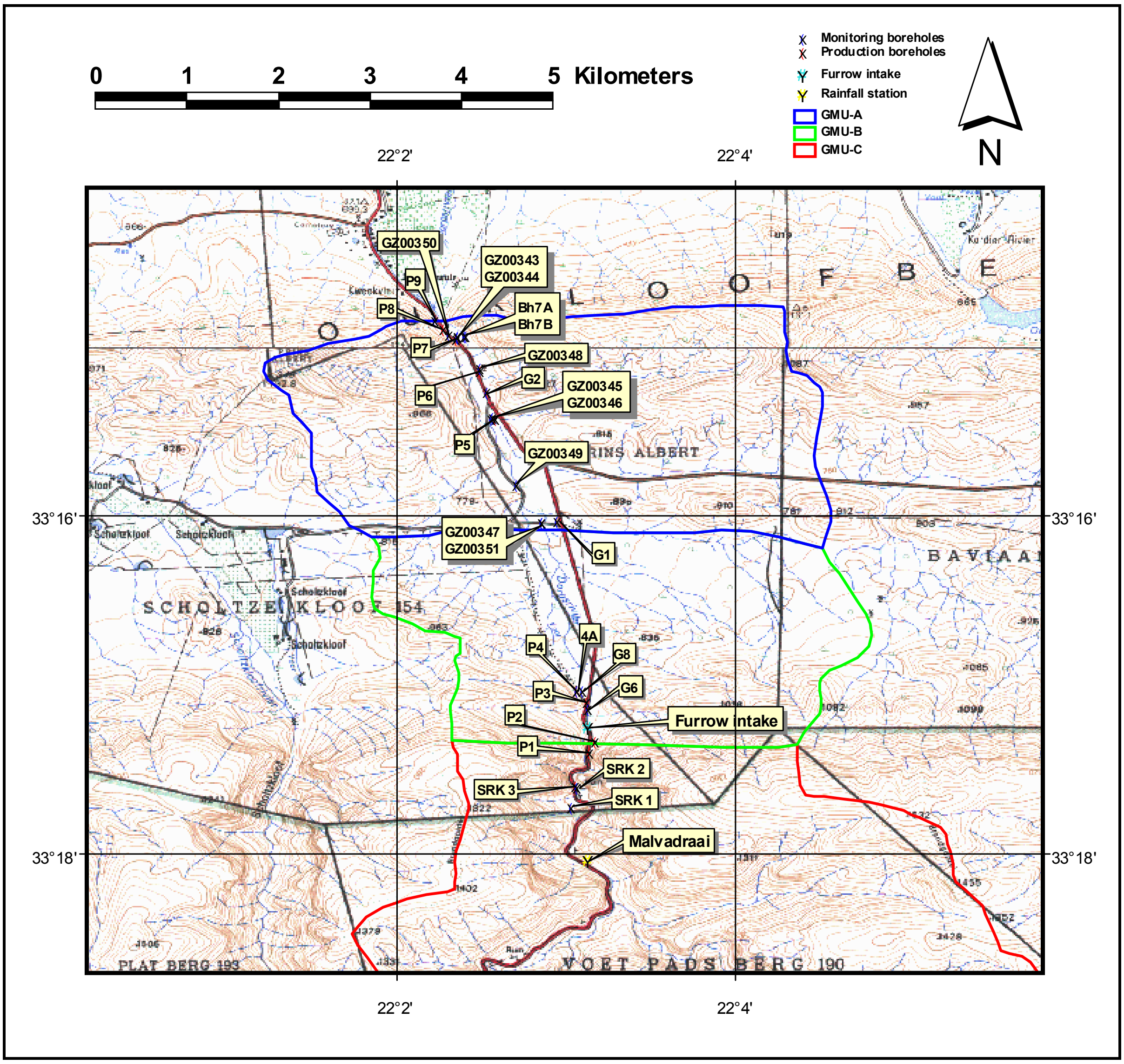


Figure 1: Prince Albert's boreholes

UITVOERENDE OPSOMMING

Prince Albert

Huidige Watervoorsiening

Gedurende hierdie projek is grondwatervlakke en wateronttrekking noukeurig gemonitor. Oppervlakswater toevoer van die 21.25 ure/week toekenning aan die munisipaliteit vanuit die besproeiingsvoor is nie akkuraat bekend nie, en is gebaseer op lesings van die meetgeute en geskatte verliese uit die voor. Gedurende 2006/7 is die water toevoer aan Prince Albert as volg geskat:

Totale voorsiening
- Grondwater: 400 000 m^3/jaar or ~73% van die totale voorsiening
- Totaal: 550 000 m^3/jaar

Somer voorsiening
- Grondwater: 300 000 m^3/ 6-maande of ~85% van die totale voorsiening
- Totaal: 350 000 m^3/6-maande

Die wyse gebruik en bestuur van grondwater is dus uiters belangrik vir die dorp se huidige en toekomstige water behoeftes.

Projekdoelstellings

Die doelstellings van die projek was om:

1. 'n Grondwater bestuurstelsel vir die Prince Albert Munisipaliteit te ontwikkel
2. die vatbaarheid van bestuurde aanvulling van die dorp se akwifers te ondersoek

Bevindings en aanbevelings

Die bevindings en aanbevelings hieronder spruit voort uit die ondersoek van die bestuurde aanvullingspotensiaal in Prince Albert en na intensiewe boorgat watervlak en onttrekkingsmonitering oor die laaste jaar. In sommige gevalle was die monitering vir ses maande of minder, en dit het die buitengewone hoë reënval van 2006. Dus is hierdie bevindings gebaseer op inligting na 'n "nat" periode wanneer akwifers "vol" was. Alhoewel die feit in ag geneem is, sal die aanbevelings moet geherevalueer word na 'n "droe" periode. Die hoof bevindinge is:

- Prince Albert benodig nie tans nuwe waterbronne nie
- Bestuurde aanvulling sal dalk nodig wees om die dorp se akwifers naby die dorp (Grondwater Bestuur Eenheid A) voor die somer op te vul
- Die volume water wat vir bestuurde aanvulling beskikbaar sal wees gedurende die "afkeer-periode", is geskat op 75 000 m^3

- Bogenoemde water behoort gebruik te word vir bestuurde aanvulling totdat die akwifers vol is
- Boorgat aanvullings toetse moet onderneem word om die geskatte bestuurde aanvulling behoeftes te verifieer. (Dit word beraam dat omtrent 60 000 m^3 nodig is om die akwifer op te vul nadat Pompe 5,6,7 en 8 gedurende die somer swaar gepomp is)
- Indien goeie bestuur toegepas word en aangeneem dat die akwifers vol is, kan die gemiddelde water behoeftes vir albei somer (2 000 m^3/dag) en winter (1 100 m^3/day) deur grondwater en oppervlak water gevul word
- Die onegalige oppervlakwater toekennings van die leiwatervoor maak dit uiters moelik om die spits somer waterbehoeftes van 2750 m^3/dag op' n gereelde basis te voorsien. Hierdie piek somer behoefte duur soms vir weke aaneen gedurende die warm somer-maande.
- Deur grondwatergebruik te maksimeer (en aangeneem dat alle akwifers "vol" is aan die begin van die somer periode), kan die verlengde spits somerbehoefte van 2 750 m^3/dag slegs Woensdae, Donderdae en Saterdae gevul word as gevolg van bo-gemiddelde leibeurte. Dit mag wees dat dit nie moontlik sal wees om Maandae, Dinsdae, Vrydae en Sondae hierdie hoë behoefte te vul nie
- Die spits daaglikse somer behoefte van 3 000 m^3/dag (die behoefte op uiters warm dae) kan slegs Woensdae, Donderdae en Saterdae behaal word weens die langer leiwater beurte wat op daardie dae toegeken is.
- Die Prince Albert Munisipaliteit moet by die Departement Waterwese en Bosbou (DWAF) aansoek doen vir 'n grondwatergebruikslisensie vir 500 000 m^3/jaar. Dit is meer as dubbel die bestaande geregistreerde gebruik.

Klaarstroom

- Die watervoorsieningsisteem het dringend aandag nodig om toekomstige waterbehoeftes te kan haal
- Verminder die onttrekkingstempo van boorgat KS1 na 1L/s en pomp aanhoudend vir 24uur/dag terwyl KS1 en KS2 noukeurig gemoniteer word.
- Installeer 'n watervloei meter by boorgat KS2. Halveer die boorgat se onttrekkingstempo en pomp aanhoudend vir 24uur/dag (indien nodig) terwyl KS1 en KS2 noukeurig gemoniteer word.
- Boor nuwe boorgate op die plaas Klaarstroom (onderkant die besproeiingsdam) om die Sandstene van die Boplaas Formasie deur te sny. Hierdie is die beste opsie om beter watersekerheid en watergehalte te voorsien, sowel as om aan toekomstige waterbehoeftes te voldoen.

Leeu Gamka

- Geen aksie is nodig aangaande die volume water wat verskaf word nie.
- Moniteer onttrekkingsvolumes en watervlakke oor die 2007/8 somer en her-evalueer hoe die boorgate en die akwifer oor die lang termyn reageer
- Installeer water moniterings krane by elke boorgat en verseker dat alle boorgat omheinings in 'n goeie toestand is

- Daar moet met die watergehalte moniteringsprogram volhou word. Indien die bakteriologiese telling onaanvaarbaar hoog word (soos voorheen die geval by boorgat LG3 was) moet die bron van besoedeling ondersoek word.

Algemene grondwater voorstelle

- Verander die onttrekkingstempos op indiwiduele boorgate soos voorgestel
- Opgradering van die telemetriestelsel is nodig om die munisipaliteit se ongelyke leibeurte in ag te kan neem
- Sluit in die onlangs-geboorde moniteringsboorgate in die munisipale grondwater-moniteringstelsel en –bestuursplan
- Onderhou die grondwatermoniteringstelsel en laat die data hersien word voor, gedurende en na die somer hoë onttrekkingsperiode.
- Stel ‘n toegewyde persoon aan om die waterbronne (oppervlaks- en grondwater) en water voorsieningsisteem te bestuur. Die persoon sal in alle aspekte van waterbron en watervoorsieningsbestuur opgelei moet word.
- Verander die leiwater allokasie aan die munisipaliteit na ‘n konstante vloei. Dit sal die bestuur van die dorp se watervoorsiening vergemaklik en die toevoer van water aan die dorp meer bestendig maak
- Ondersoek die waterverliese in die watersloot; installeer die voorgestelde pyplyn in die sloot; ondersoek ‘n billike bedeling van die leiwater vir die munisipaliteit (wat huidige toekennings aan die munisipaliteit en die verlies-besparings in ag neem); meet die hoeveelheid leiwater wat aan die munisipaliteit toegeken is. Saam met grondwaterbestuur, bestuurde aanvulling en verbeterde aanvraagbestuur, sal hierdie verseker dat die dorp ‘n betroubare, langtermyn watervoorsiening het.
- Voer bestuurde aanvullings toetse uit.

ACKNOWLEDGEMENTS

The following organizations and people contributed significantly to this project/report:

- *DWAF:* The artificial recharge component of this was conducted under the DWAF project: *Strategy development: A national approach to implement artificial recharge as part of water resource planning (DWAF Project No 2004-240)*. Dr Fanie Botha from DWAF supported the Prince Albert study, gave valuable input on the town's groundwater resources and artificial recharge, and facilitated the drilling of monitoring boreholes.
- *Prince Albert Municipality and the Prince Albert Council.* Mr. Edwin September from the municipality was key in providing municipal support and in obtaining Masibambane support. Mr Brian Hitchcock shared his knowledge of boreholes and the water supply system, and assisted with monitoring equipment installations. The Council provided full support to this project.
- *Mr Johann Rissik,* while employed by Groundwater Africa, carried out all on-the-ground activities including data logger installations, logger downloads, pumping rate adjustments, etc., developed the groundwater supply and management task lists and helped with this report.
- *Mr Phillip Ravenscroft* of Maluti GSM reviewed the water demand, estimated water availability for recharge from the furrow and addressed all engineering issues.
- *Dr Lisa Cave* wrote the section on water quality and *Dr Gideon Tredoux* reviewed it.
- *Mr Jude Cobbing* reviewed hydrogeological aspects of the report and helped compile it.

SECTION A: INTRODUCTION

1. TERMS OF REFERENCE

This report covers two projects:

1. Masibambane, Department of Water Affairs and Forestry (DWAF) project entitled: *Water Conservation, Artificial Recharge and Groundwater Management.* A five-year proposal was submitted for Masibambane funding and the first year (September 2006 to September 2007) was approved. The aim of the first year was to set up a groundwater management system, conduct the artificial recharge Feasibility Study and to start training municipal staff in managing groundwater. This report covers these activities. The other four years of the proposed project were to get the artificial recharge and water resource management system fully operational, and to optimize Water Demand Management.\

2. Directorate of Water Resource Planning Systems, DWAF project entitled: *Strategy Development: A National Approach to Implement Artificial Recharge as Part of Water Resource Planning*. As part of developing DWAF's national artificial recharge strategy, pilot study sites were identified for implementing artificial groundwater recharge. The intention of this project was to develop a national strategy for artificial groundwater recharge and sub-surface storage. The purpose of having pilot studies was to establish with "on-the-ground" experience, the issues that affect the timeous implementation of such schemes. This project ran from November 2004 to June 2007, and the final report is entitled: *Artificial Recharge Strategy: Version 1.3* (DWAF, 2007). Prince Albert is mentioned in the national strategy. Prince Albert was selected as a pilot study after the DWAF Cape Town office requested that the town be investigated as a potential artificial recharge site because of the water problems faced during summer months.

In addition to the abovementioned projects, the Directorate of Water Resource Planning Systems (DWAF) supported the drilling and testing of nine monitoring boreholes. The information from these boreholes is also presented in this report, but a full description of the work is not given.

Funding for implementing these projects had the following support:

- Masibambane (DWAF): 1-year support.
- Directorate of Water Resource Planning Systems (DWAF): 2-year support plus the drilling and testing of nine monitoring boreholes.
- Prince Albert Municipality: Purchased all groundwater monitoring equipment.

2. PROJECT OBJECTIVES

The overall project objective is develop a groundwater management strategy that will cater for Prince Albert's water requirements during the peak summer months. This strategy needs to incorporate:

- Groundwater management including optimising existing borehole supplies.
- Artificial recharge to "boost" supply during the summer peak demand period.

The specific objectives can be summarised as follows:

1. Establish optimum pumping rates for all production boreholes.
2. Describe the groundwater management system and tasks that need to be carried out on a regular basis.
3. Investigate the feasibility of artificially recharging Prince Albert's aquifers.

As stated above, the Masibambane funding covered the first year of a 4-year proposal. The main aims of the first year were to set up the groundwater monitoring system, assess optimum borehole abstraction rates and start training of staff in groundwater management. This report describes progress to date.

3. REGIONAL PLANNING AND STUDIES

Groundwater resource management is mentioned in virtually every water resource management and planning document. Unfortunately, at the municipal level, it is seldom carried out. This is set to change with the development of the national groundwater strategy.

Artificial recharge is recommended in the Gouritz Water Management Area's Internal Strategic Perspective (ISP) Version 1, 2004 as a form of water conservation and Integrated Water Resource Management. In this report, it is called Aquifer Storage and Recovery. Artificial recharge also needs to be considered within the context of the Water Services Development Plan (WSDP) and the Integrated Development Plan (IDP).

4. CURRENT AND FUTURE WATER REQUIREMENTS

This section was compiled by P Ravenscroft (Maluti GSM) with contributions by J Cobbing and R Murray (Groundwater Africa).

Numerous sources of information have been used to understand the water demand of Prince Albert. For the purpose of comparison, all figures have been converted to an average daily demand.

As part of a study on the town's water sources, Kwezi V3 Engineers (2004) calculated demand projections for the town, which are shown in Table A1.

Table A1. Water Demand Projections (from Kwezi V3)

Year	*Average Annual Daily Demand (kl/day)*	*Average Peak Month Daily Demand (kl/day)*	*Peak Day Demand (kl/day)*	*Annual percentage increase/decrease*
2006	1034	1541	1926	n/a
2011	1024	1525	1906	-0.2%
2016	1058	1577	1971	0.7%
2021	1094	1631	2039	0.7%
2026	1132	1687	2109	0.7%
2031	1171	1745	2182	0.7%

Notes:
Average Annual Daily Demand (AADD): the annual demand reduced to a daily average in kl/day
Average Peak Month Daily Demand: the AADD for one month, multiplied by a peak factor of 1.49, reduced to a daily average for that month in kl/day
Peak Day Demand: the AADD multiplied by a daily peak factor of 1.25 in kl/day
Annual percentage increase/decrease: average for the period

The town experiences a large variance in the monthly water demand. The flow recorded at the main meter (located at the inlet to the main reservoir) has been used to quantify the maximum monthly demand. Figure A1 shows the supply to the main reservoir together with the records of water supplied to consumers as metered in the town. The difference between the two equals the unaccounted for water (UFW) in the reticulation network.

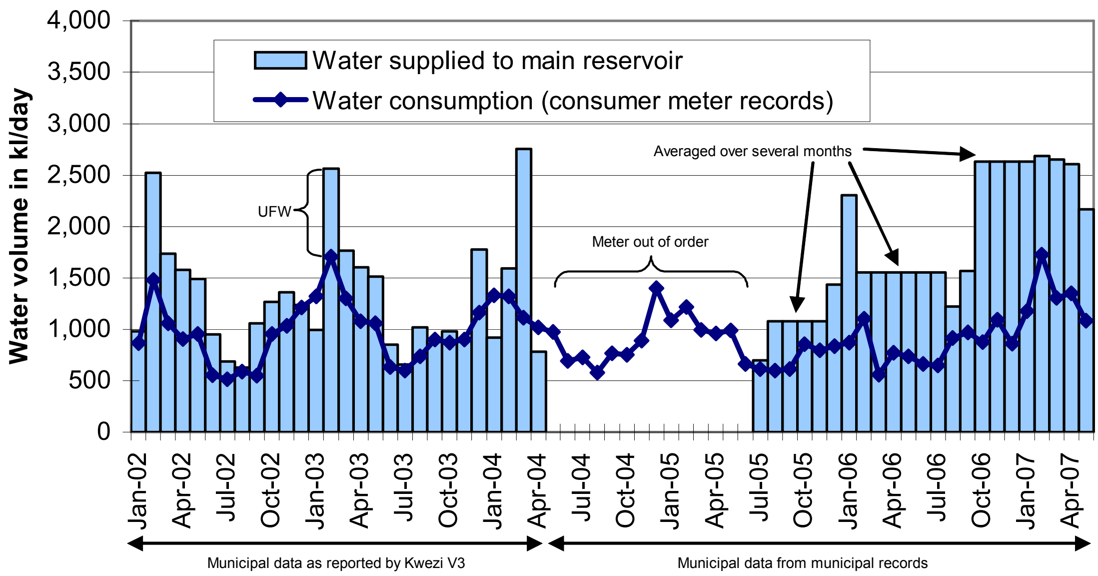


Figure A1. Water supplied to main reservoir, water consumption and unaccounted for water (UFW)

The municipal records have been used for the information from July 2004 to May 2007. The municipal data prior to July 2004 was not available and information from Kwezi V3 (2004) has been used from January 2002 to June 2004. Table A2 provides a summary of the water supply/use status.

Table A2. Annual volumes of water supplied, consumed and unaccounted for water (UFW).

Period	*Total water supplied to main reservoir (kl)*	*Total water consumed (metered) (kl)*	*Unaccounted for water (UFW) (kl)*	*Percentage UFW (UFW/total water supplied)*
May 02 to April 03	473,489	356,603	116,886	25%
May 03 to April 04	443,480	354,506	88,974	20%
May 04 to April 05	No data available - meter not working	350,355	No data available	
May 05 to April 06	453,180	280,974	172,206	38%
May 06 to April 07	783,440	372,212	411,228	52%

The large volume of water unaccounted for in 2006/07 should be investigated and could be caused by any one of the following:

- Increased water consumption that is not being metered
- Leaks (or illegal use) in the reticulation system
- Inaccuracies in the reading obtained from the main meter and/or inaccuracies in the consumer meter readings.

Only a few meter readings were available for the three reticulation meters at the reservoir outlets and the readings were not used to in the calculation of water balance. In addition, the location of the meter on the outlet to the main reservoir is incorrect and a proportion of flow bypasses the meter.

The average consumption per household has been tracked in the municipal records and is shown in Table A3. The figures are based upon the metered consumption to residential households excluding all UFW. The number of households includes only the residential households and excludes businesses, institutions and the connection to the informal settlement. The same calculation including all metered consumption (including businesses etc.) returns very similar average monthly consumption figures but 5-7% higher.

Table A3. Average monthly household water consumption of metered household connections.

Financial year	*Number of metered household connections*	*Average monthly household consumption (kl/household/month)*
2004/2005	1212	20
2005/2006	1481	14
2006/2007	1352	18

Based on the water supplied to the main reservoir, the maximum daily consumption over a sustained period was from 27 December 2006 to 23 January 2007 where the average daily water supplied was 2751 kl/day over the 26-day period. Similar peaks of over 2500 kl/day are found in the main reservoir supply in February 2002 and 2003 and March 2004.

For planning purposes, the average demand is taken to be:

- *6-month winter period:* *1 100 m^3/day*
- *6-month summer period:* *2 000 m^3/day*
- *1-month summer peak supply[1]:* *2 750 m^3/day*
- *1-day summer peak supply[2]:* *3 000 m^3/day*

[1] Water requirements over a (particularly hot) one-month period in summer
[2] Water requirements on any given day in summer

Meters were installed between March and December 2006 on all boreholes that supply the town. Over the period March 2006 to May 2007, groundwater supplied approximately three quarters of the town's water demand and the rest was supplied from the irrigation furrow.

No measurements are taken of the water supplied from the furrow to the municipal water supply. Table A4 shows a first order water balance. Groundwater volumes are based upon actual metered supply while the furrow is based upon estimates (see Appendix 2).

Table A4. Supply from water sources (May 2006 to April 2007)

Time period	*Ground-water supply (kl)*	*Estimated supply from furrow including 31% furrow losses (kl)*	*Total supply estimate (kl)*	*Water consump-tion (user meters) (kl)*	*UFW (%)*	*Water supplied to main reservoir (kl)*	*Estimated over reading of main meter (%)*
	a	b	c=a+b	d	e=(c-d)/d	f	g=(f-c)/c
May to July 06	41,939	46,822	88,761	62,542	42%	140,940	59%
August to October 06*	57,773	46,822	104,595	84,527	24%	161,730	55%
November to January 07	148,200	24,933	173,133	95,794	81%	245,120	42%
February to April 07	154,939	25,941	180,880	129,349	40%	235,650	30%
TOTAL	**402,851**	**144,517**	**547,368**	**372,212**	**47%**	**783,440**	**43%**

* A higher than average estimate was used for the August to October 2006 period because of the 2006 floods and the resultant high flow in the furrow, both measured and observed, during this period.

5. HOLISTIC WATER RESOURCE MANAGEMENT

Groundwater management and artificial recharge should be considered as two components of a comprehensive water resource and supply management strategy. The components that need to be addressed are:

1. Optimise groundwater use
2. Artificial recharge
3. Water demand management including water conservation and minimising water losses
4. Optimise surface water (furrow allocation and timing of supply)
5. Sound future planning including realistic water demand projections, identifying additional water resources and future infrastructure requirements.

SECTION B. HYDROGEOLOGICAL SETTING

6. PAST GROUNDWATER INVESTIGATIONS

Although the town of Prince Albert has relied on the Dorps River for its water supply for more than a century, over the last twenty or so years demand for water has risen considerably and the town has increasingly turned to groundwater to augment its current allocation from the river. The first boreholes supplying water to Prince Albert were drilled fairly close to the town. When these boreholes started to show signs of stress, the municipality arranged for further groundwater development work to be carried out:

1999

A report by the engineering company Toens and Partners (1999) described work done on the groundwater supply options for Prince Albert. The work consisted of a geological and hydrogeological description, geophysical work, borehole drilling, the testing of boreholes, and a series of recommendations for the continued use of groundwater by the town. The report includes the following comments on groundwater in the area:

- The fractured Witteberg quartzites immediately south of the town are known to provide high initial yields of groundwater, but that these yields usually decline with time[1].
- Whilst the quality of groundwater from the quartzites is generally good, there are often high iron concentrations which tend to block borehole screens.
- The groundwater associated with alluvium in the valleys in the area is limited in quantity, but likely to be more dependable than groundwater from the fractured rocks. It is also often of very good quality (EC as low as 30 mS/m).
- Poor quality groundwater is associated with the Karoo Supergroup rocks (EC greater than 300 mS/m) and with the Bokkeveld Shales (Cape Supergroup).

In December 1996 four geophysical traverses (resistivity) were carried out (lines A to D), line A in the kloof near to the town and running roughly N-S, line B in the Bokkeveld Shales south of the town, running roughly E-W, line C at the foot of the Swartberg Pass to the south of the town, close to existing boreholes (roughly N-S), and line D in the pass itself (roughly N-S). Following a tender process, three boreholes were drilled on geophysical line A (PA97/1, PA97/2 and PA97/4), one borehole on line C (PA97/3) and one borehole close to the town (PA97/5) about 300 m north of borehole PA97/1 and close to the existing reservoirs.

[1] "Ongelukking is die invloei na hierdie sisteme beperk en daarom kan 'n boorgat wat 'n hoe onmiddellike lewering toon, baie maklik oorpomp word" (Toens and partners, 1999:15).

Table B1. Toens and Partners boreholes drilled in 1997

Pump No.	*Borehole No.*	*Depth (m)*	*Drilling (blow) yield (L/s)*	*Estimated safe yield (L/s)*	*Recommended yield at eight hours per day (L/s)*
P7	PA97/1	136	25	4.3	12.9
P6	PA97/2	120	12	1.9	5.7
P4	PA97/3	120	5	1.8	4.0
P5	PA97/4	90	40	2.9	8.7
P8	PA97/5	72	17.5	3.1	9.3

(Note that these yields have been revised and new pumping rates have been set)

The report concludes with recommendations for groundwater management, including the following:

- The boreholes should be pumped according to the last column in the table above.
- All boreholes should be fitted with a flow measuring device.
- All boreholes should be fitted with a dipping tube.
- Pump outflows should be fitted with a sampling tap.
- Water levels and pumped volumes should be measured regularly, and at least weekly, and this information given to a hydrogeologist for evaluation every six months so that pump settings can be adjusted if necessary.
- Water samples should be taken every six months.

Included in the report are appendices showing the geophysical results, the borehole logs, the pumping test results, and a suggested borehole/water level monitoring form.

2004

A report by Kwezi V3 Engineers (2004) described an investigation into the existing and potential water sources for Prince Albert. This followed an earlier report (2002). The 2004 report stated that:

- At the time of writing, Prince Albert was supplied by nine boreholes with varying yields, plus a 17.25 hour per week allocation from the irrigation canal.
- No monitoring of either groundwater levels or pump yields had been carried out since 1999.
- Canal water ("leiwater") rights were held by less than eighty users, who together formed the Irrigation Board ("Kweekvallei Irrigation Board"). In dry months the municipality is allocated an extra continuous flow from the canal in addition to its 17.25 hours per week.
- Losses from the canal over its length were considered to be insignificant (Note: This has been reviewed and loss estimates are provided in this report in the section on artificial recharge source water).

- The lowest flow in the canal was estimated at 44.4 L/s (from January 1995), thus the municipal water allocation amounts to at least 390 m^3 per day, or roughly ten percent of the total canal water.
- During a meeting with the Irrigation Board, it was noted that domestic water users have priority over irrigation under current water law, that current use of canal water is not always efficient, and that better use of canal water by canal water right holders would make more water available for the municipality.

SRK (Pty) Ltd. were subcontracted by Kwezi V3 to investigate the details of the existing groundwater sources, and deliver a "status quo" report (this was delivered in April 2004 by SRK, report no. 326999/1). SRK found that:

- Earlier borehole pumping recommendations had not been followed.
- Groundwater levels had dropped significantly, causing pumps to cut out.
- Uncertainty existed as to how much water each borehole delivered.
- Measurement of bulk water supply was not effective, and figures were unreliable.
- An estimated total of 1211 m^3 of groundwater was being pumped from the boreholes every day.
- It was considered that the groundwater resources could be divided into three separate compartments or management units, and that two of these (the two closest to the town) were over-utilised.
- Groundwater was likely to be available in the third compartment, closest to the Swartberg Pass, and further boreholes are recommended in this compartment.

The 2004 Kwezi V3 report's final recommendations included the following:

- A groundwater monitoring programme be instituted as soon as possible, including installation of the necessary metering equipment at boreholes.
- New boreholes be drilled in the southernmost groundwater compartment.
- Negotiations between the municipality and the Irrigation Board should be carried out aimed at ensuring a continual supply of water to the municipality from the canal.
- An assessment of the effectiveness of current irrigation practises be carried out, including the irrigation of the town sports field with drinking water.
- All water sources should be accurately measured.

The report concludes with a costing of the recommended work. Appendices include an estimate of the town's future water requirements.

2005

In August 2005 SRK submitted a second report describing further work done in the area on groundwater (SRK report no. 345194). Work done included the following:

- Geological and structural mapping work, and the preliminary definition of three groundwater management units (GMUs) in the Cape Supergroup rocks to the south of the town, of which the third unit was further subdivided into three (separated by folded beds of the Cedarberg Shale Formation).

- A survey of existing boreholes and springs. Details of these are not given in the report.
- Work on the recharge distribution across the three GMUs, and the production of a recharge map.
- Geophysics (EM and magnetics) and borehole site selection.
- The drilling of two boreholes, PA04/9 and PA04/10, also known as SRK1 and SRK3. Blow yields for these boreholes were 8 L/s and 12 L/s respectively, although recommended continuous pumping rates were lower (1.5 L/s and 5 L/s) due to considerations of recharge and other factors. Water quality was good.

SRK recommended that the boreholes be equipped with flow meters, hours run meters and dipping tubes, and that a monitoring programme be devised and implemented.

Table B2. SRK boreholes drilled in 2004

Pump No.	*Borehole No.*	*Depth (m)*	*Drilling (blow) yield (L/s)*	*Estimated safe yield (L/s)*	*Recommended yield at twenty four hours per day (L/s)*	*Current borehole status*
SRK1	PA04/9	150	8	1.5	130	Monitoring
SRK3	PA04/10	90	12	5	430	Production
SRK3A	-	14.7	-	-	-	Monitoring

2006

In July 2006, Groundwater Africa produced a report entitled Prince Albert: Geophysical Survey of Alluvial Aquifers (Murray, 2006). The consulting engineering company, Gorra Water, recommended to the Prince Albert Municipality that a collector well system in the Dorps River may be the solution to the town's water resource problems. The terms of reference stated that Groundwater Africa was to undertake geophysical surveys at the Dorps River near the turn-off to Scholtzkloof and at least one other site identified by Groundwater Africa. A good indication off the thickness of the alluvium at the selected sites was needed, together with comments on the potential for water wells in the alluvium.

In total six sites were investigated and both the Dorps River and the Swart River looked reasonably promising (although the Swart River has fairly saline water). The recommendations made after this investigation are listed below, and state that they have been made "bearing in mind that DWAF has approved funding (through the Masibambane Programme) for establishing a groundwater management system, and that the high 2006 winter rainfall has fully recharged the aquifers (as noted by recent borehole water level data) and has provided a window period that should be used to obtain data prior to developing new groundwater resources".

Recommendations:

1. Do not, at this stage, construct a collector well at Dorps River or at Swart River.
2. Revise the borehole pumping schedule based on a thorough analysis of existing borehole and aquifer data. This can be done during the Masibambane Project (2006 & 2007).
3. Monitor the borehole water level response to the new pumping schedule.
4. Decide after the summer of 2006/2007 whether new water resources are needed or not.
5. If new water resources are needed, the following is recommended, in order of priority:
    a. Drill and test the new hard-rock sites GWA 1 & 2;
    b. Cost and possibly develop the Dorps River collector well system;
    c. Cost and possibly develop the Swart River collector well system.

Now that recommendations 2 and 3 have been completed – (although No 3 needs to carry on to cover a drought period), it is evident that a collector well system (or any other new water resource) is not required at this stage or for the foreseeable future. The town's requirements can be met through proper groundwater management and artificial recharge when necessary.

In June 2006, Groundwater Africa completed an Artificial Recharge Pre-feasibility Study (Murray, 2006). From this investigation, it seemed like the Prince Albert aquifers close to town are suitable for artificial recharge. The most pressing question was: How much surface water will they accept during the limited period when surface water is available? This could only be established by regular water level and abstraction measurements (addressed in the Masibambane Project in 2006/7), and by conducting a trial injection test.

The report concluded that the most critical data requirements needed to establish the feasibility of artificially recharging the aquifer are:

- Groundwater levels and abstraction data
- The water level response in the aquifer to borehole injection
- Full water quality analysis of the source water
- Groundwater quality analyses after borehole injection.

7. HYDROGEOLOGICAL OVERVIEW

7.1 Hydrogeology

The geology and hydrogeology of the area is summarised in this report. It has previously been described in the following consultants' reports:

- Steffen Robertsen Kirsten, 2004.
- Steffen Robertsen Kirsten, 2005.
- Toens & Partners, 1999.

In summary, municipal boreholes are located in the Table Mountain Group sandstones at the base of the Swartberg Pass, the Bokkeveld Group shales immediately to the north of that, and in the Witteberg Subgroup shales and sandstones to the north of the Bokkeveld shales, immediately south of Prince Albert.

The town and its immediate environs is underlain by rocks of the Dwyka and Ecca Groups of the Karoo Supergroup, including rocks of the Dwyka, Prince Albert, Whitehill, Collingham and Vischkuil Formations of the late Carboniferous and Permian periods. In general, these rocks are argillaceous and possess little remaining primary permeability and porosity - groundwater storage and transmission is mostly due to secondary features such as fractures and bedding planes. The Karoo Supergroup is characterised by low permeabilities and consequently low borehole yields (often less than 1 L/s), although higher yields are occasionally found (Woodford and Chevallier, 2002). In addition, the quality of groundwater from Karoo rocks can be poor, with high salinity being a particular problem (often in excess of 300 mS/m). The Karoo rocks in this area are unlikely to represent an aquifer that will deliver either the quality or quantity of water required for a town water supply.

Unconsolidated alluvial aquifers are associated with the larger rivers in the area such as the Sand River, Swart River and the Dorps River. These rivers are ephemeral for much of their courses, with the occasional flows recharging the groundwater. The alluvial aquifers are fairly limited in extent (of the order of fifty metres wide, and up to about twelve metres deep). An assessment of the groundwater potential of the alluvial aquifers (Murray, 2006) concluded that, whilst there is groundwater potential in certain areas, in general they are unlikely to represent a reliable water source for the town due to problems such as deep water levels, thin alluvium and poor quality water (in the Swart River). A collector well or wells would be the most appropriate method of abstracting groundwater from the alluvium. It may also be possible to artificially recharge the alluvial aquifers using good quality surface water during the winter months, although a full evaluation and trial of this has not been carried out. Alluvium associated with the Dorps River, overlying rocks of the Cape Supergroup, contains groundwater of high quality but a collector well system should only be considered after groundwater abstraction from conventional boreholes in this area has been optimised.

About three kilometres to the south of Prince Albert the Karoo Supergroup gives way to the underlying Cape Supergroup (Witteberg, Bokkeveld and Table Mountain Groups). These rocks commonly consist of hard quartzitic sandstones and quartzites, although subordinate shale bands are found. The Bokkeveld Group has a particularly high proportion of shale. The hard, resistant sandstones and quartzites of the Table Mountain Group often form topographic high points, including the impressive Swartberg Mountains to the south of the Prince Albert. The rocks are intensely folded in this area. Although primary permeabilities are generally negligible, a considerable groundwater resource is often associated with the quartzitic Cape Supergroup rocks, where it is found in fractures, bedding and fault planes and other secondary discontinuities. Whilst transmissivities are often high, particularly where fracture networks are well connected, the storage of the rocks is lower and sustainable yields of boreholes may be considerably less than initial drilling (blow) yields suggest (Toens and Partners, 1999).

Water quality is generally good, with EC values of around 50 – 100 mS/m for the Witteberg and Table Mountain Groups and around 200 mS/m for the Bokkeveld Group (Toens and Partners, 1999). The waters may however be aggressive since little buffering capacity exists in the aquifer and pH values can be low. High iron concentrations are also common, and iron precipitation can lead to borehole screens becoming blocked. Drilling conditions in the Cape Supergroup quartzites are usually challenging since the rocks are hard and abrasive as well as fractured.

In summary, the town of Prince Albert has a considerable resource of high quality groundwater at its disposal, associated mainly with the Cape Supergroup rocks to the south of the town. The long-term sustainability of the resource is not yet fully understood, and more data over a longer period needs to be collected, via a groundwater monitoring system.

7.2 Groundwater Management Units

Three groundwater management units (GMUs) within the Cape Supergroup rocks were demarcated in order to provide a basis for assessing the groundwater resource potential (Toens and Partners 1999, SRK,2004, SRK 2005). They were given the names GMU-A (Witteberg shales/sandstones), GMU-B (Bokkeveld shales) and GMU-C (Table Mountain Group sandstones) (Figures B1 & B2). The GMUs represent areas of similar groundwater flow and boundaries and are based on the surface water drainage, geological and hydrogeological considerations, and they represent "hydrogeologically homogeneous zones wherein boreholes tapping the shallow groundwater system (<300 m) will be, to some degree or other, in hydraulic connection" (SRK, 2004). GMU-C was subsequently divided into three sub-GMUs by SRK (2005) in order accommodate the compartmentalising effect of the impermeable Cedarberg Shales Formation.

The concept of the groundwater compartments was intended for groundwater management purposes since shallow flow between compartments is thought to be restricted, making the groundwater resource in each compartment relatively independent from abstraction in the other compartments.

All of the main water supply boreholes for Prince Albert are found in the Cape Supergroup rocks. Originally, all of the boreholes were drilled into GMU-A, closest to town, and associated with the Witteberg Group rocks. This unit has seen a considerable decline in summer water levels due to heavy pumping during this peak-demand period, and is not always completely recharged during winter. Boreholes were then drilled further afield, and now two of the town's production boreholes (Pump 1 and SRK 3) are located in GMU-C. This area covers the main natural recharge area of the Swartberg Mountains. The sustainability of a borehole in the Cape Supergroup depends on a number of factors including the storage characteristics of the aquifer, but particularly important is the long-term recharge available to the borehole via the particular network of fractures or other hydraulic features which it intersects. These characteristics can be very difficult to estimate with any confidence.

The groundwater quality generally improves closer towards the mountains where exceptionally high quality groundwater is found in GMU-C.

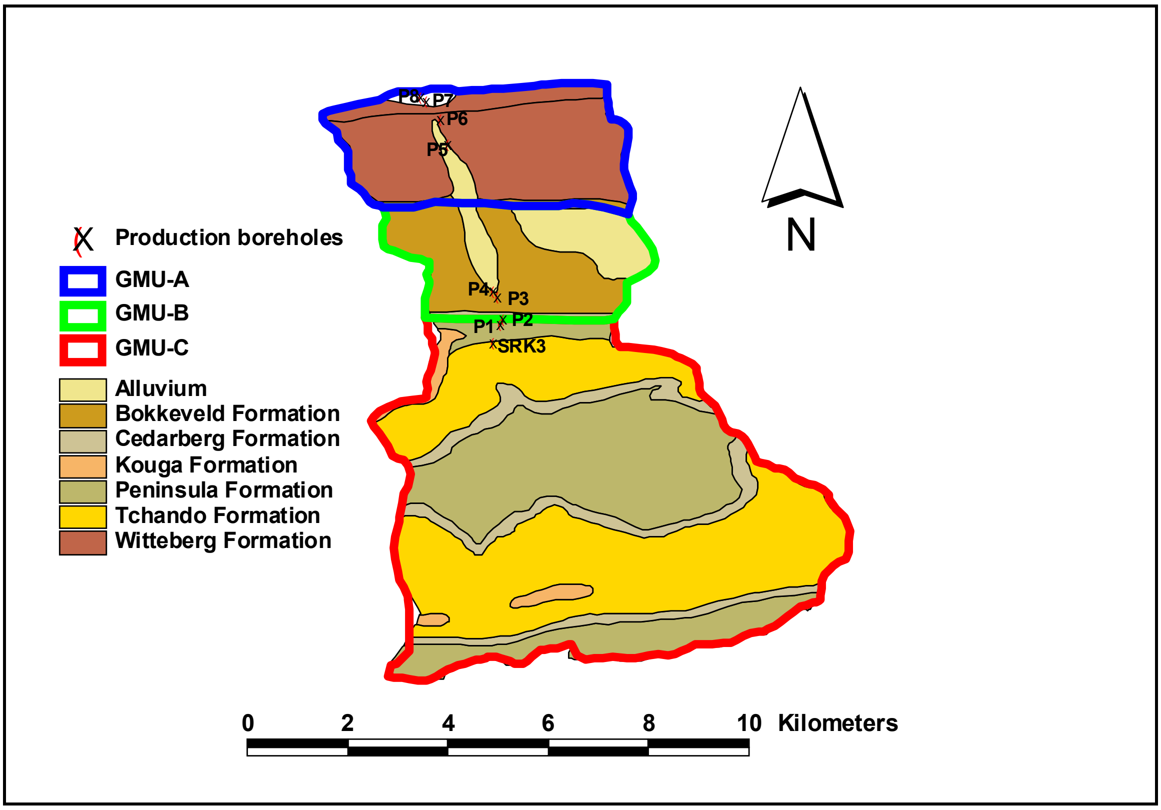


Figure B1. Geology of the Groundwater Management Units

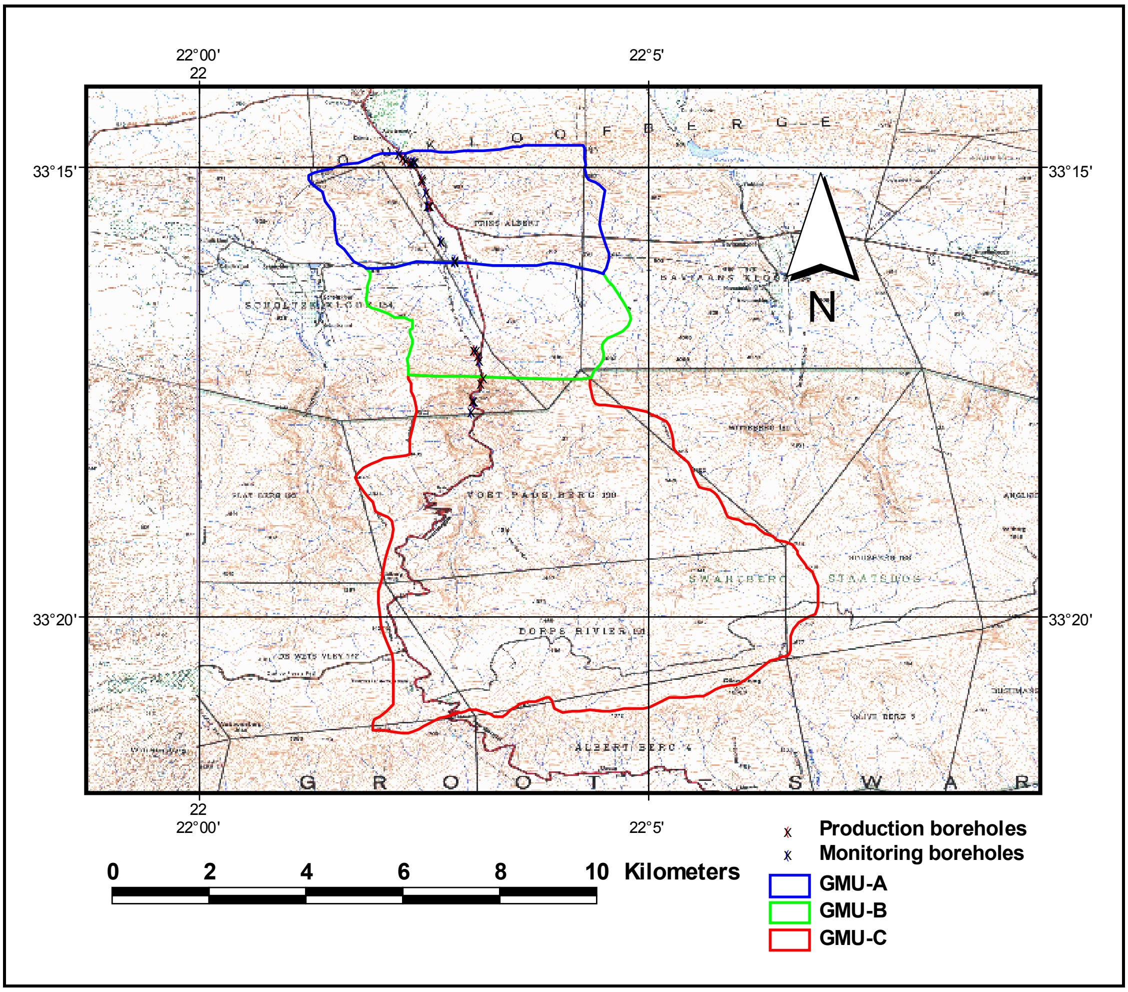


Figure B2. Groundwater Management Units and location of production boreholes

7.3 Rainfall

Rainfall, the source of all groundwater, is greatest on the Swartberg Mountains (GMU-C) and least in town (GMU A) – see Figure B3.

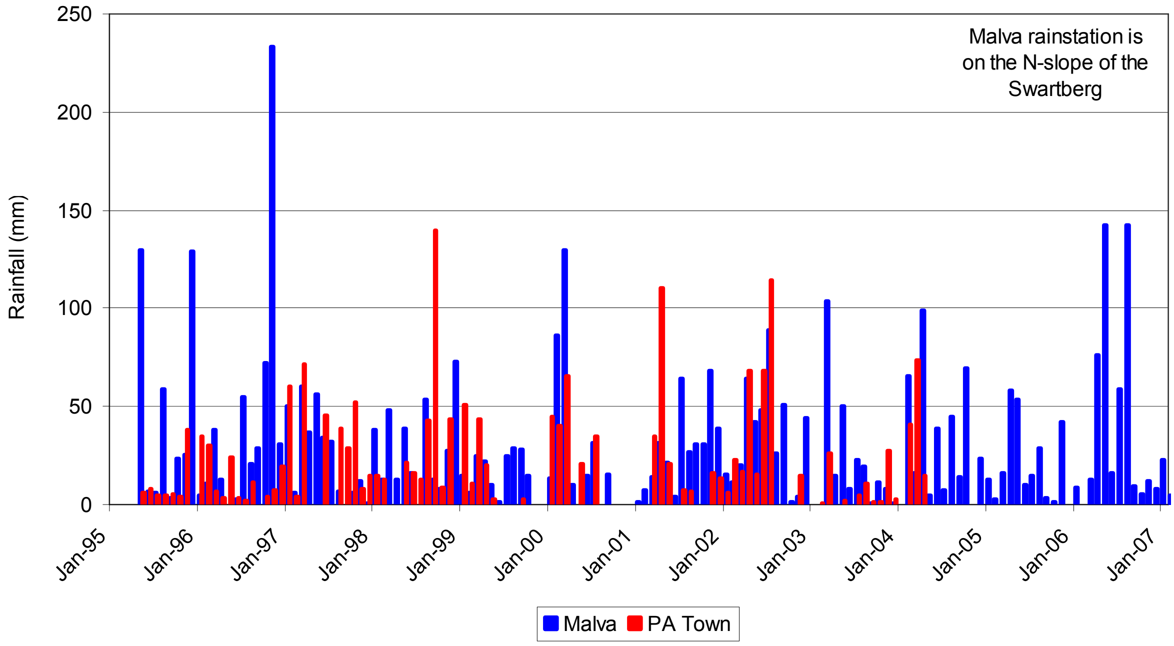


Figure B3. Rainfall

(*Source:* Cape Nature Conservation & Prince Albert Correctional Services)

8. GROUNDWATER QUALITY

Groundwater in the Prince Albert area varies in chemical composition, depending on the local geology and flow conditions, but is generally of good quality. Boreholes in the quartzite formations typically have low salinity (low electrical conductivity) water, while boreholes in shale rocks, for example Pump 6, tend to have moderately higher salinity.

Tables B3 to B7 provide available groundwater quality data for boreholes in the area, including: The southernmost areas, GMU B & C (Tables B3 and B4); the proposed artificial recharge area in GMU A – Pumps 5, 6 and 7 (Tables B5 and B7) and a borehole down-gradient of the proposed recharge area, Pump 8 (Table B6) Groundwater in the three Groundwater Management Units differs in terms of water quality, and are therefore discussed separately – starting with the "freshest" groundwater below the Swartberg Mountains. Much of the discussion is on GMU A boreholes where artificial recharge is planned. Water quality issues that relate only to artificial recharge are discussed in Section D.

8.1 Groundwater Management Unit C

Boreholes SRK1, SRK3 and Pump 1 fall within Groundwater Management Unit C. Artificial recharge is not necessary in this area as the aquifer is rapidly and naturally recharged from the relatively high rainfall in the mountains. The groundwater from these boreholes is characteristic of the Table Mountain Group aquifers and has a relatively low pH (< 7), very low salinity, and the water is of the sodium-chloride type (Table B3 and B4). Groundwaters from the Nardouw Subgroup of the Table Mountain Group are notorious for problems with iron and the total iron concentration of 11 mg/L shows that SRK1 is no exception.

Table B3: General borehole water quality: GMUs C & B

Groundwater Management Unit		GMU C			GMU B		
Borehole name		SRK1	SRK3	Pump 1	Pump 2	Pump 3	Pump 4
SAMPLE DATE:		11 Aug 2005	12 Aug 2005	13 Dec 2005	13 Dec 2005	13 Dec 2005	01 Jun 2007
Analytical Lab.		CSIR	CSIR	CSIR	CSIR	CSIR	CSIR
Potassium	mg/L	5	1.3	0.9	5.1	1.4	1.3
Sodium	mg/L	9.6	6.9	9.3	19	22	22.6
Calcium	mg/L	2.6	1.2	1.1	15	33	24.3
Magnesium	mg/L	2.9	1.4	1.2	2.6	7.7	6.7
Ammonium as N	mg/L	-	-	-	-	-	<0.1
Sulphate	mg/L	3.9	2.3	2.7	17	33	17.4
Chloride	mg/L	22	13	16	23	18	14
Alkalinity as $CaCO_3$	mg/L	11	5	4.5	48	108	100.3
Nitrate plus nitrite as N	mg/L	<0.1	<0.1	0.16	<0.1	<0.1	<0.1
Fluoride	mg/L	<0.1	<0.1	<0.1	0.13	0.26	0.26
Total iron	mg/L	11	2.1	0.05	0.2	0.05	0.42
Iron (filtered)	mg/L	-	-	<0.05	-	<0.05	-
Total manganese	mg/L	1.04	<0.05	<0.05	0.42	<0.05	0.14
Manganese (filtered)	mg/L	-	-	<0.05	-	<0.05	-
Silica as Si	mg/L	-	-	3.3	9.8	7.4	-
DOC*	mg/L	-	-	<1.0	<1.0	<1.0	<1
Electrical Conductivity	mS/m	11	6	7.8	22	33	27.5
pH (field)	pH	-	-	7.1	-	8	-
pH (Lab)	pH (20°C)	6.1	6	6	7.1	7.7	7.6
Hardness (calculated)	$CaCO_3$ mg/l	18	9	8	48	114	88
Arsenic	mg/L	-	-	<0.01	<0.01	<0.01	-
% Difference		-0.43	-0.60	4.74	2.61	2.92	0.14
CATIONS meq/L	meq/L	0.91	0.51	0.58	1.92	3.27	2.78
ANIONS meq/L	meq/L	0.92	0.52	0.61	1.97	3.37	2.78
Geology[1]		St	St	St	Da	Da	Da
Rock types		sand-stone	sand-stone	sand-stone	shale, siltstone	shale, siltstone	shale, siltstone
Water type		Na-Cl	Na-Cl	Na-Cl	Na -HCO_3	Ca-HCO_3	Ca/Na-HCO_3

*DOC = dissolved organic carbon
[1] **Cape Supergroup Rocks**
St = Table Mountain Group, Tchando Formation (Nardouw subgroup)
Da = Bokkeveld Group, Karies Formation (Traka subgroup)

Table B4. Water quality field data: GMU B & C

	pH					EC (mS/m)					Temp (°C)				
Date	SRK3	P1	P2	P3	P4	SRK3	P1	P2	P3	P4	SRK3	P1	P2	P3	P4
29-Sep-05		6.9					33					21			
13-Dec-05		7.1		8			6		31						
02-May-07					6.4					35					20.0
14-May-07	5.9	5.6	5.9	5.8	6.4	4	6	18	14	34	18.0	19.0	19.4	19.1	19.5

8.2 Groundwater Management Unit B

The water quality of boreholes within this GMU is given in Tables B3 and B4 above. Pumps 2, 3 and 4 occur within the Bokkeveld Group shales and siltstones, although the high quality, low salinity groundwater and good yield of these boreholes suggest that they may tap into one of the arenaceous (sandy) units or may receive most of their water from the river alluvium. Pump 2 is very near the contact with the Table Mountain Group and may also tap into groundwater from these rocks. Pump 2, 3 and 4 are sodium-bicarbonate and sodium/calcium-bicarbonate water types that show the influence of calcium carbonate minerals in the rock. These minerals help to buffer the pH above 7 and add calcium and alkalinity to the groundwater when they dissolve, so that the water is less aggressive to concrete pipes and reservoirs than the Table Mountain Group waters. As with boreholes in GMU C, artificial recharge is not necessary in this area, although in future, if boreholes are developed in the northern part of this GMU (eg along the Scholtzkloof road), they may require artificial recharge after months of heavy abstraction.

8.3 Groundwater Management Unit A

Pumps 5 to 9 are within Groundwater Management Unit A, the proposed artificial recharge area. The boreholes that have been identified for artificial recharge are Pumps 5 and 7, and possibly Pump 6. These boreholes, together with Pump 8 would be used for abstraction as well, and Pump 9 for monitoring only (it is a very low yielding borehole). Artificial recharge would take place in winter by injecting surplus water from the furrow into these boreholes. The GMU A boreholes are located within the Witteberg Group, which comprises a range of sedimentary rocks from quartzitic sandstones to siltstone and shale. Groundwaters from this group of boreholes have low to moderate salinity (measured as electrical conductivities of 17 to 111 mS/m) and neutral to slightly alkaline pH (pH 6.2 to 8.4, measured in the field). The water types are calcium-bicarbonate, calcium-bicarbonate/chloride and sodium-bicarbonate/chloride (Table B 5 to B7).

Of the proposed injection boreholes, Pumps 5 and 7 have slightly better quality water than Pump 6, due to the moderately high salinity at Pump 6. Pump 6 has an electrical conductivity slightly above the guideline range of 70 mS/m for the best quality drinking water and may taste slightly salty, but is still of good quality. Pump 8, the shallowest borehole, has the lowest salinity of the group in Groundwater Management Unit A and may be more strongly influenced by recharge from surface water than the other boreholes in this group.

Table B5. General borehole water quality: GMU A, Proposed injection boreholes

Borehole name		Pump 5	Pump 5	Pump 5	Pump 6	Pump 6	Pump 6	Pump 7	Pump 7	Pump 7
SAMPLE DATE:		13 Dec 2005	14 Jan 2007	01 Jun 2007	13 Dec 2005	04 May 2007	01 Jun 2007	13 Dec 2005	14 Jan 2007	01 Jun 2007
Analytical Lab.		CSIR	CSIR	CSIR	CSIR	CSIR	CSIR	CSIR	CSIR	CSIR
Potassium	mg/L	3	1.4	1.9	2.9	9.6	2.6	10	7.4	4.8
Sodium	mg/L	82	33	54.6	190	57	217	66	71	151
Calcium	mg/L	26	17	17.3	18	19.6	21.2	26	41	20.1
Magnesium	mg/L	28	17	18.9	22	75	21.8	13	28	12.3
Ammonium as N	mg/L	-	-	<0.1	-	-	<0.1	-	-	<0.1
Sulphate	mg/L	45	28	28.3	45	67	55.4	58	230	50.4
Chloride	mg/L	68	34	31.7	155	116	169	65	45	127
Alkalinity as $CaCO_3$	mg/L	214	102	157.8	298	271	315	122	62	211.8
Nitrate plus nitrite as N	mg/L	0.11	<0.1	<0.1	0.56	0.8	<0.1	0.14	<0.1	<0.1
Fluoride	mg/L	0.54	0.27	0.42	0.89	**1.13**	0.83	0.26	0.29	0.5
Total iron	mg/L	<0.05	0.1	0.07	<0.05	0.05	0.65	0.08	10	1.27
Iron (filtered)	mg/L	<0.05	0.1	<0.05	<0.05	<0.05	0.17	0.05	10	0.45
Total manganese	mg/L	0.08	0.91	0.05	0.1	0.09	0.68	0.17	1.1	0.29
Manganese (filtered)	mg/L	0.08	0.9	-	0.1	0.09	-	0.17	1.1	-
Silica as Si	mg/L	4.7	5.5	-	4.6	-	-	6.1	8.8	-
DOC*	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1
Conductivity	mS/m	71	37	44.5	**111**	**104**	**107**	59	80	88
pH (field)	pH	8.1			8.4			7.3	-	-
pH (Lab)	pH (20°C)	8.9	7.2	7.6	7.9	8.3	7.9	7.4	6.8	7.8
Hardness (calculated)	$CaCO_3$ mg/l	180	112	121	135	357	143	118	216	101
Arsenic	mg/L	<0.01	-	-	<0.01	-	-	<0.01	-	-
% Difference		1.02	2.09	3.86	2.8	3.22	0.67	0.21	3.67	2.18
CATIONS meq/L	meq/L	7.24	3.69	4.84	11.05	9.87	12.36	5.49	7.59	8.71
ANIONS meq/L	meq/L	7.17	3.61	4.66	11.36	10.19	12.27	5.51	7.32	8.9
GEOLOGY[1]		Dw	Dw	Dw	Dw	Dw	Dw	Dws or Dk	Dws or Dk	Dws or Dk
Rock types		shale/ sand-stone	shale/ sand-stone	shale/ sand-stone	shale/ sand-stone	shale/ sand-stone	shale/ sand-stone	sandstone/ shale	sandstone/ shale	sandstone/ shale
Water types		Na-HCO_3	Na/Ca-HCO_3	Na-HCO_3	Na-HCO_3/Cl	Mg-HCO_3/Cl	Na-HCO_3/Cl	Ca-HCO_3/Cl	Ca-HCO_3/Cl	Na-HCO_3/Cl
Heterotrophic P/C per 1 mL at 22°C			58						8	
Heterotrophic P/C per 1 mL at 35°C			70						10	
Total coliforms per 100 mL			3						0	
Faecal coliforms per 100 mL			1						0	
E.coli per 100 mL			0						0	

*DOC = dissolved organic carbon
[1] Cape Supergroup Rocks
Dw = Witteberg Group, Weltevrede Formation
Dws = Witteberg Group, Witpoort Formation
Dk = Wittberg Group, Kweekvlei Formation

Table B6. General water quality: GMU A, Pump 8

Borehole name **SAMPLE DATE:**		**Pump 8** **13 Dec 2005**	**Pump 8** **01 Jun 2007**
Analytical Lab.		CSIR	CSIR
Potassium	mg/L	5.5	9.3
Sodium	mg/L	15	31.6
Calcium	mg/L	4.9	9.1
Magnesium	mg/L	5.1	9.1
Ammonium as N	mg/L	-	<0.1
Sulphate	mg/L	20	48.6
Chloride	mg/L	15	22.1
Alkalinity as $CaCO_3$	mg/L	33	54.3
Nitrate plus nitrite as N	mg/L	0.11	<0.1
Fluoride	mg/L	0.22	0.32
Total iron	mg/L	5.2	3.66
Iron (filtered)	mg/L	3.5	3.38
Total manganese	mg/L	0.26	0.21
Manganese (filtered)	mg/L	0.25	-
Silica as Si	mg/L	4.2	-
DOC*	mg/L	1	<1
Conductivity	mS/m	17	29.5
pH (field)	pH	7.3	-
pH (Lab)	pH (20°C)	6.8	6.8
Hardness (calculated)	$CaCO_3$ mg/l	33	60
Arsenic	mg/L	<0.01	-
% Difference		4.24	2.85
CATIONS meq/L	meq/L	1.46	2.82
ANIONS meq/L	meq/L	1.52	2.74
Geology[1]		Dws/Dk	Dws/Dk
Rock types		sand-stone/ shale	sand-stone/ shale
Water type		$Ca\text{-}HCO_3$	$Ca\text{-}HCO_3$

*DOC = dissolved organic carbon
[1] **Cape Supergroup Rocks**
Dws = Witteberg Group, Witpoort Formation
Dk = Wittberg Group, Kweekvlei Formation

Table B7. Water quality field data: GMU A

	pH				EC				Temp			
Date	**P5**	**P6**	**P7**	**P8**	**P5**	**P6**	**P7**	**P8**	**P5**	**P6**	**P7**	**P8**
29-Sep-05			7.3				59				22	
13-Dec-05	8.1	8.4	7.3	7.3	62	101	57	38				
05-Feb-07	6.2		6.0		45		76		20.1		22.0	
06-Apr-07	6.4		6.3		70		90		19.7		20.7	
18-Apr-07	6.2		6.5		44		82		17.9		18.8	
23-Apr-07	6.4		6.4		74		90		20.0		20.3	
26-Apr-07	6.7		7.0		43		83		19.2		19.4	
02-May-07	6.7		7.0		45		89		21.0		20.9	
03-May-07		7.2				105				19.1		
04-May-07	6.7	7.2	6.9		78	103	88		20.1	21.4	21.5	
14-May-07	6.8	7.2	7.0	6.4	83	108	89	40	20.6	22.2	21.1	20.8
18-May-07	6.7	7.0	6.8		83	109	88		20.7	21.3	21.0	
28-May-07	6.7	7.0	6.6		45	113	96		18.5	18.2	17.5	

The aquifer was full and water levels were high at Pumps 5, 6 and 7 after the high rainfall of May and August 2006. The boreholes were rested during this period. Water levels started to decline once pumping began in October 2006. Time series data for electrical conductivity in the three proposed injection boreholes (before and during abstraction) are shown below (Figures B4 & B5). Electrical conductivity has risen slightly during abstraction from Pump 5 and Pump 6, but decreased at Pump 7, probably due to the influx of fresher groundwater during pumping.

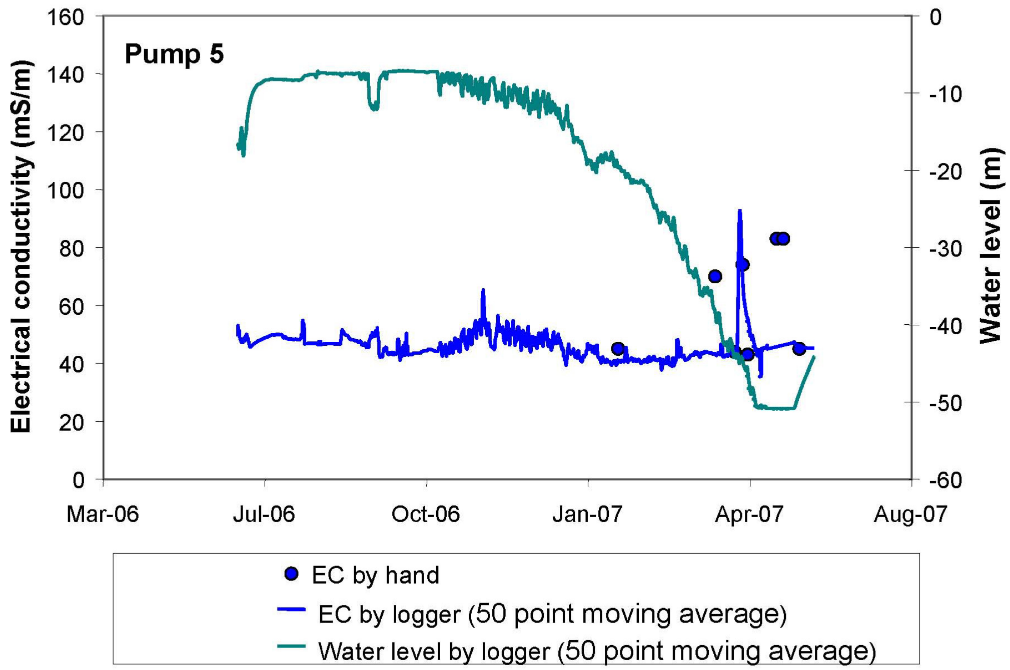
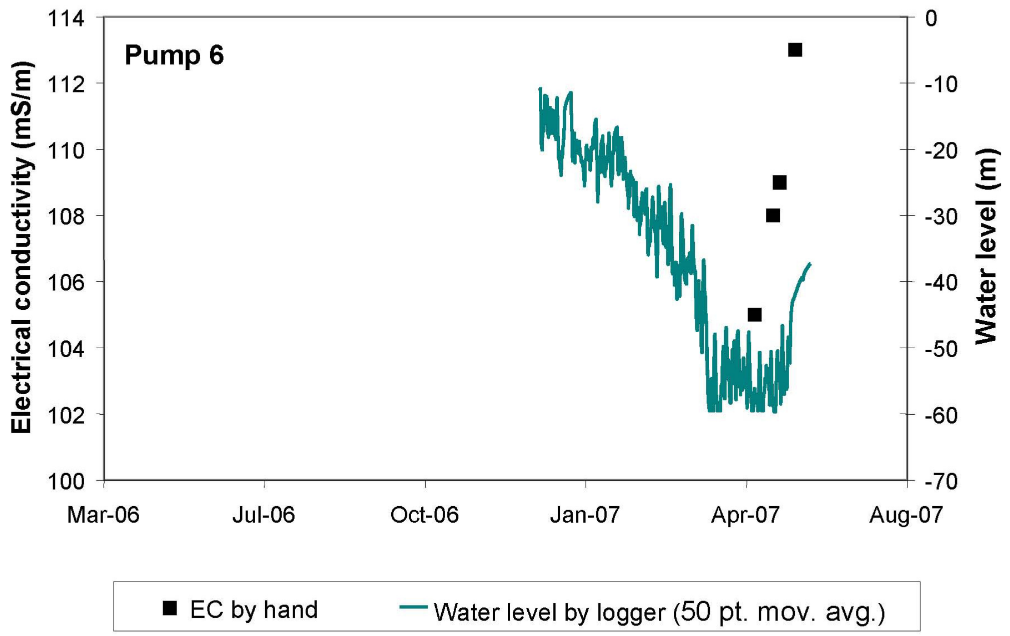


Figure B4. Pump 5 Electrical conductivity and water levels during abstraction



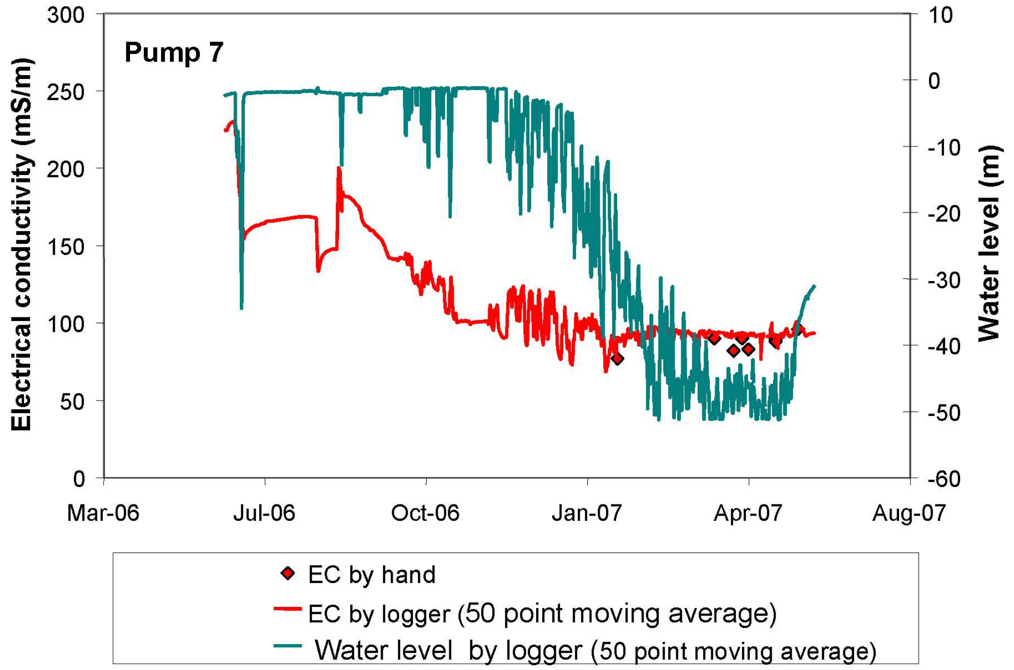


Figure B5. Pump 6 & 7 Electrical conductivity and water levels during abstraction

Pumps 5, 6 & 7 have relatively high alkalinity (62 to 315 mg/L as $CaCO_3$) and hardness (101 to 357 mg/L as $CaCO_3$) in comparison with Pump 8, which means they have the potential to precipitate calcium carbonate scale, especially if the water is heated or the pH rises.

In general, the water quality in Groundwater Management Unit A is good and groundwater is suitable as a source of drinking water. Concentrations of species which could cause potential health problems, such as nitrate, are below the safety limits (e.g. 10 mg/L as N) and arsenic was not detected in the groundwaters which were analysed for this element. Pump 6 has slightly elevated fluoride and in May 2007, the fluoride concentration was above the target guideline of 1 mg/L in this borehole. If this water alone was consumed (ie not blended with other borehole and surface water) it would pose a slight risk of mottling of dental enamel for sensitive individuals if there is long term exposure to these fluoride concentrations (DWAF, 1996). Artificial recharge with high quality surface water should maintain a suitable water quality for potable use and may dilute fluoride concentrations over the short term.

Pumps 7 and 8 tend to contain higher levels of dissolved iron at times, which could lead to staining and clogging problems from the precipitation of iron oxide minerals. Iron may be a problem in an artificial recharge scheme, because of the potential for clogging of the borehole screens and fractures in the aquifer. A relatively low pH and reducing conditions allow iron to dissolve in the form of ferrous iron (Fe^{2+}). If the water is oxidizing, such as by the injection of oxygen-rich surface water, the iron becomes ferric iron (Fe^{3+}) which is very insoluble and precipitates out. This is of concern because down-hole logging measurements have shown that the dissolved oxygen concentrations are relatively low at depth in the boreholes (around 0.1 mg/L for Pump 6, Figure B6), while the injectant is 100% saturated with dissolved oxygen (average = 6.9 mg/L on 11 January 2007). Injection will increase the levels of dissolved oxygen near the boreholes, encouraging iron oxidation. Ferrous iron will also precipitate if the pH or alkalinity rises. Manganese is another dissolved metal which is strongly affected by changes in the oxidation state of the groundwater environment and is often linked with iron problems. Dissolved manganese is present in all boreholes from Groundwater Management Unit A.

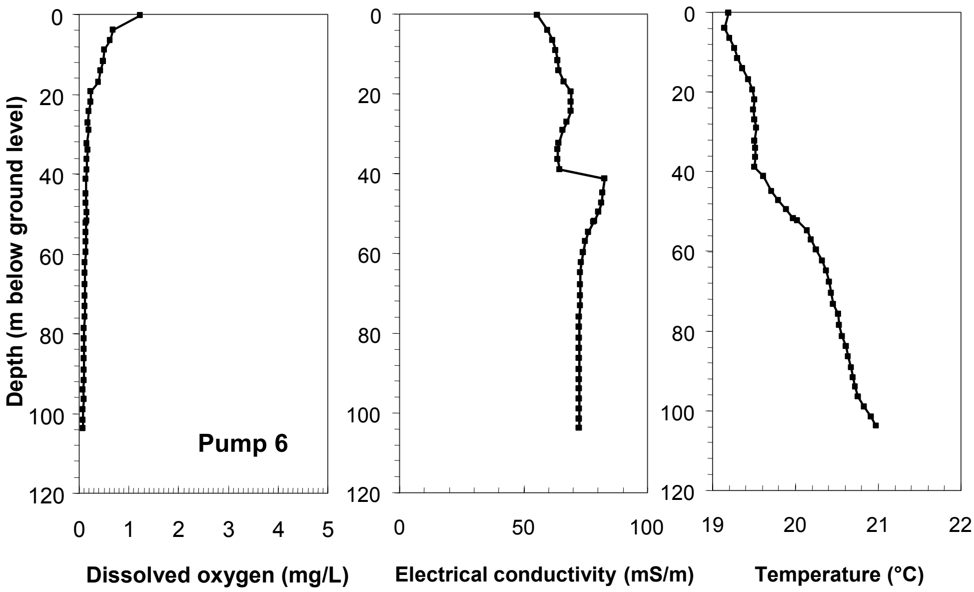


Figure B6. Down-borehole logs of dissolved oxygen, conductivity and temperature in Pump 6 borehole on 11 January 2007.

Iron and manganese do not often occur in high enough concentrations to pose a health risk, but they are still problematic for water managers because of they affect the taste of the water and cause staining of walls, laundry, etc. Iron in solution in the recovered groundwater can be treated by the municipal iron removal plant before distribution. Manganese oxides may be less likely to cause borehole clogging than iron oxides, but manganese could also require treatment if there are high concentrations in the recovered water. Monitoring of pH and iron and manganese concentrations will be needed after injection and periodic maintenance of the injection boreholes may be required if iron clogging problems start to affect the artificial recharge scheme.

High levels of dissolved iron (10 mg/L) and sulphate (230 mg/L) were noted in a sample from Pump 7 in January 2007. These concentrations appear to have accumulated in the borehole when it was being rested and have since decreased to background levels of 0.5 mg/L iron and 50 mg/L sulphate after a period of abstraction, suggesting that the concentrations in the aquifer are lower than those accumulated when water is allowed to stand in the borehole. The shallow alluvium layer may contribute towards pyrite oxidization. Iron and sulphate concentrations will need to be monitored during injection when water levels are raised. Iron and sulphate time series data at Pumps 5, 6 & 7 are shown in Figure B7.

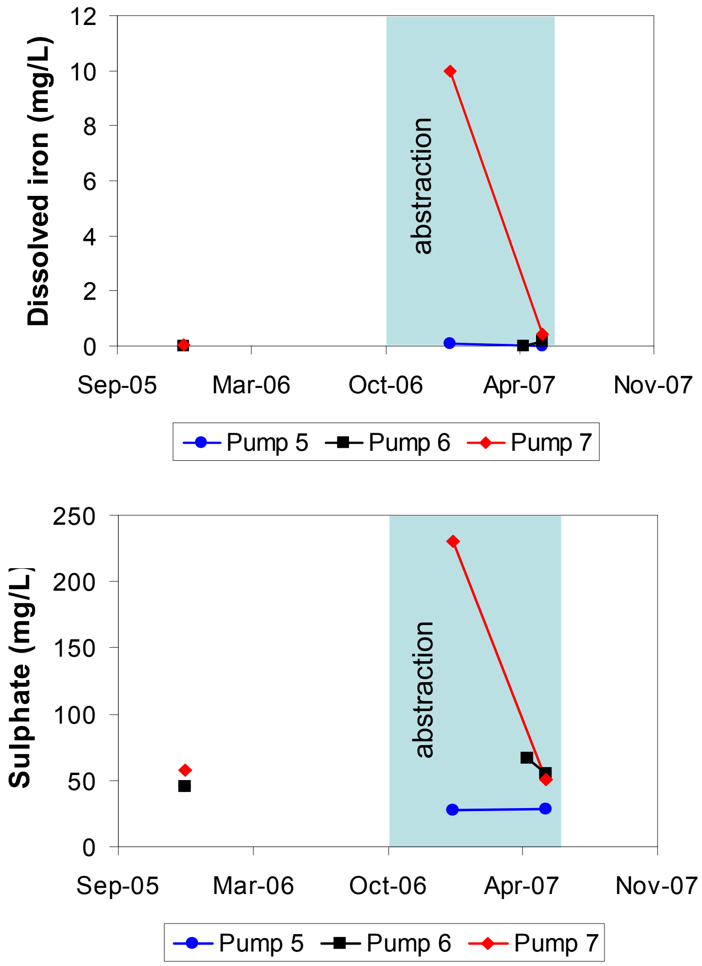


Figure B7. Time series data for dissolved iron and sulphate in proposed injection boreholes.

The groundwater in Groundwater Management Unit A generally has a low concentration of dissolved organic carbon (DOC). This is common for natural groundwater, because it is either consumed by microbial reactions over long residence times in the aquifer or they do not reach the aquifer and "disappear" in the unsaturated zone. All the boreholes in this study had DOC below the analytical detection limit (1 mg/L), except for the low concentration of 1 mg/L at Pump 8 in December 2005. Artificial recharge should try to limit the injection of DOC to maintain these low nutrient conditions and avoid the growth of micro-organisms that cause clogging and bio-fouling.

In the Witteberg Group, the quartzitic sandstones of the Witpoort Formation are probably the least reactive and should have little effect on the quality of groundwater injected during artificial recharge. Shales and siltstones in the Weltevrede Formation have smaller grains with more reactive mineral surface area, so the rocks tend to dissolve minerals faster and may have a greater impact on water quality if the water has a long residence time in the aquifer. Mineral reactions can affect the salinity of the water and concentrations of dissolved species, such as fluoride, which may affect the suitability for drinking water. Pump 6 appears to have undergone a greater degree of water-rock interaction than the other boreholes in Groundwater Management Unit A.

The presence of fluoride and nitrate in low concentrations in all the boreholes from Groundwater Management Unit A, suggest that fluorine and nitrogen (as organic nitrogen or ammonium) are present in the Witteberg rocks and soils. One of the challenges of artificial recharge is to ensure that the quality of the recovered water is maintained at a suitable level for a drinking water resource. This means that the recharge water should not add additional fluoride, nitrate (or ammonia) or other harmful species to the system. The recharge scheme should also aim not to alter geochemical conditions to make these elements more soluble and mobilise them from the rocks. After injection, the pH should be monitored to ensure that it remains between 7 and 8.5. It is not known whether other heavy metals that are present in the rocks at significant concentrations, but they are also not likely to dissolve under these pH conditions and should not pose a threat to the artificial recharge scheme.

SECTION C: GROUNDWATER MANAGEMENT

9. PURPOSE OF GROUNDWATER MANAGEMENT

The main purpose of managing groundwater is to establish how much groundwater is available for use on a sustainable basis and to ensure that it is not contaminated. There, however, are six main reasons for managing groundwater (Figure C1).

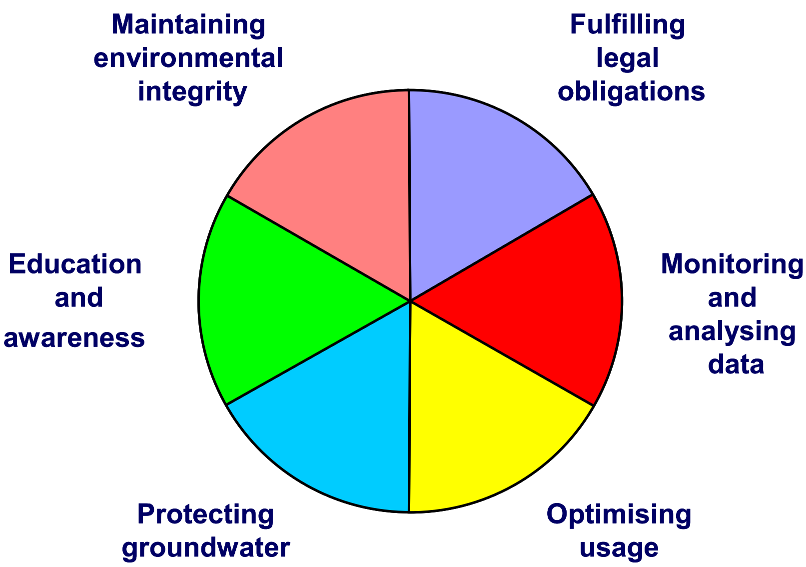


Figure C1. Components of groundwater management

During this one-year project focus has been on the following four items:

- Monitoring and analysing data: Installing groundwater monitoring equipment (as originally recommended in the Toens, 1999 report) and analysing both groundwater quantity and quality.
- Optimising usage: Optimising individual borehole pumping rates.
- Education and awareness: Delivering lectures to the Prince Albert Council, the public and to the Kweekvallei Irrigation Board.
- Maintaining environmental integrity: Installing groundwater monitoring equipment in selected environmental monitoring boreholes and drilling additional monitoring boreholes.

10. REGISTERED GROUNDWATER USE: CURRENT AND PROPOSED

10.1 Current Registered Use

The DWAF registered use to the Prince Albert Municipality for both groundwater and surface water is shown in Table C1.

Table C1. Registered Water Use

Resource Name	*Registered Volume Start Date*	*Registered Volume (m^3/annum)*	*Register Number*
Dorps River	10th January 1998	121 000	22066354
Groundwater	10th January 1998	229 000	22066354

Averaging the above figures to daily values gives the following:

- Surface water from the Dorps River: 331.5 m^3/day
- Groundwater: 627.4 m^3/day
- Total: 958.9 m^3/day

The total registered use falls slightly short of the town's winter requirements (~100 m^3/day shortfall) and well short of the town's summer requirements (>1000 m^3/day shortfall).
This urgently needs to be addressed.

The surface water registered use is close to the 390 m^3/day averaged supply estimate by Kwezi V3 Engineers (2004), and the 350 - 395 m^3/day estimate made in this report by Mr P. Ravenscroft.

10.2 Proposed Registered Use

This report will only comment on the groundwater registered use. The existing registered use falls way short of what the town requires and what the aquifer can yield on a sustainable basis without negative environmental impacts.

SRK (2004) estimated the total effective recharge to the three Groundwater Management Units to be ~2.5 million m^3/a (6 850 m^3/day averaged over a year); and in 2005 they revised this to 1.3 million m^3/a (3 560 m^3/day averaged over a year). Recharge ultimately dictates the long-term volumes that can be pumped from boreholes. The SRK figures are ball-park estimates (based on data such as rainfall, runoff, etc), and serve as an indication of the order of magnitude of the long-term rate of aquifer replenishment. The actual rate at which groundwater can be abstracted so that the resource is not depleted and so that there are no significant negative environmental impacts can only come from monitoring water level responses to groundwater abstraction. This is what has been done intensely over the past year, and with continued monitoring, the "correct" volume on an annual basis that can be abstracted will become evident.

The recommended annual abstraction volumes are based on the past year's monitoring data and are well within what the aquifers can be expected to deliver on a sustainable basis without detrimental environmental impacts. The groundwater requirements are based on the following seasonal needs:

- Winter requirements: 600 m^3/day for 180 days/a
- Summer requirements: 1 730 m^3/day for 90 days/a
  2 475 m^3/day for 60 days/a
  2 550 m^3/day for 30 days/a

It must be stressed that in Groundwater Management Unit C, the monitoring borehole located away from the production boreholes was not impacted by groundwater abstraction at all; in GMU B, the impact on monitoring boreholes was minimal, and in GMU A where pumping water levels were drawn down by over 30 m, the water levels in monitoring boreholes dropped by about 10 m – this is the area where artificial recharge is planned if the aquifer does not re-fill naturally before summer. These figures are summarised below and the motivation for these figures is provided in Section D.

Registered water use and licensing is usually based on what the resource can supply on a sustainable basis taking environmental factors into account. As this is not known to the level of accuracy that is required, the recommended values are based on areas where groundwater is used and groundwater monitoring data in those areas. This provides for a far more realistic estimate on what should be allocated by DWAF. The current and recommended registered use/authorisation is provided in Table C2.

Table C2. Recommended Groundwater Registered Use

Current Registered Use (m^3/annum)	*Recommended Registered Use (m^3/annum)*
229 000	500 000

A groundwater licence application should be submitted to DWAF requesting 500 000 m^3/a, and it should state that the municipality will undertake to monitor and manage the groundwater resources in a scientific manner.

11. GROUNDWATER MANAGEMENT STATUS PRE- AND POST-MASIBAMBANE

11.1 Pre-Masibambane groundwater management status (prior to 2006)

Implementing groundwater monitoring and management was recommended in all previous reports (Toens and Partners, 1999; SRK, 2004; SRK, 2005 and Groundwater Africa, 2006). Unfortunately this did not happen until the Masibambane project that is being reported on here.

DWAF's Cape Town office measures borehole water levels from time to time, and besides the pump operator noting that "boreholes run dry", that is how it was known that water levels in certain areas drop dramatically over the summer, high-pumping period. Training of the pump operator in taking water level readings started during the Artificial Recharge Project, and intensified during the Masibambane Project. Figure C2 shows groundwater monitoring data up to 2006/7, prior to the start of the Masibambane project.

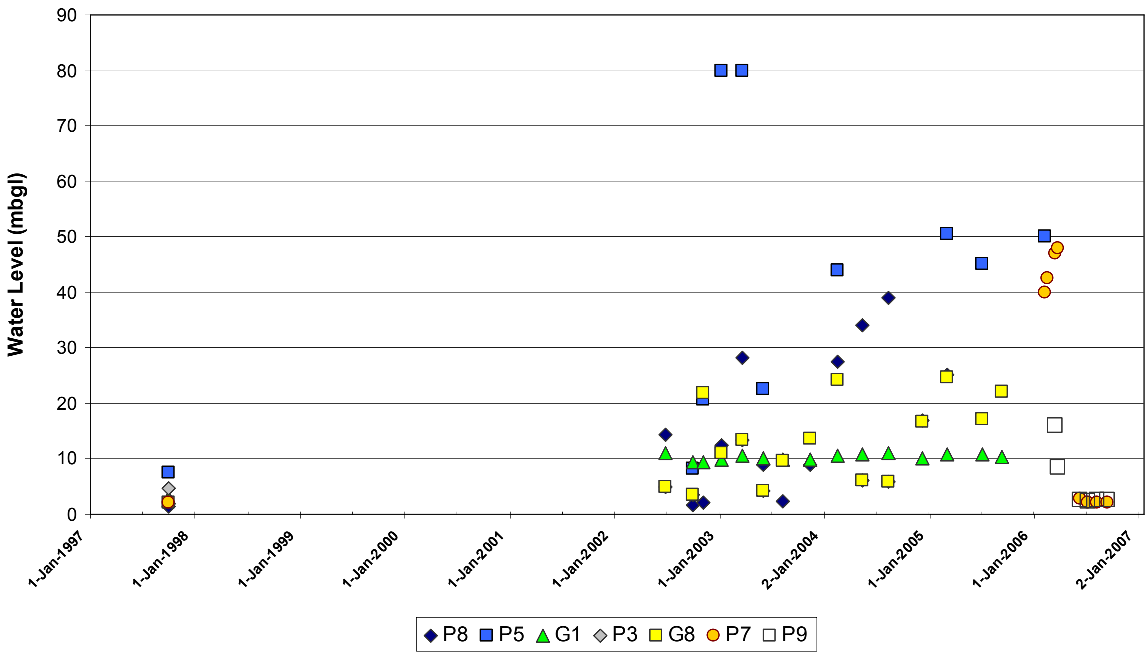


Figure C2. Groundwater monitoring prior to the Masibambane Project

Prior to Masibambane, the borehole pumping schedule was based on the operator's "gut feel" and experience. Although this kept the town going through the summer months, water restrictions had to be implemented as certain boreholes "ran dry". Virtually all boreholes were equipped with pumps that have too-high a capacity, and this did not help in using the aquifer to its potential. Water levels in boreholes were drawn down to pump intakes while the aquifers were still "far from empty". Not only did this result in getting less water than that which was available, but it also meant that the worst water quality was pumped and it seems like the boreholes became less efficient with time due to iron-related clogging.

11.2 *Post-Masibambane groundwater management status (after 2006)*

At the onset of the Masibambane project, the municipality purchased a dip meter and all municipal production boreholes were equipped with monitoring equipment:

- Flow meters
- Piezometer tubes
- Sample taps.

In addition to this basic monitoring equipment, all municipal production boreholes and selected monitoring boreholes were equipped with electronic data loggers

11.3 *Electronic data loggers*

During the Artificial Recharge Project DWAF (Cape Town) installed loggers at Pumps 5 and 7 (the two proposed borehole injection sites). These have subsequently been replaced by municipal loggers.

Monitoring equipment was also installed in most municipal production boreholes in Klaarstroom and Leeu Gamka. All monitoring equipment was bought out of municipal funds. Over the past year, water levels were monitored on a half-hourly basis, flow meters were read and water samples analysed. This report contains a summary (graphs) of all the water level and abstraction data, and it presents the groundwater quality.

A comprehensive list of all monitoring equipment is given in Appendix 1 and a list of all groundwater management tasks is given in the following chapter.

12. THE PROPOSED GROUNDWATER MANAGEMENT SYSTEM

12.1 What groundwater management entails

The groundwater management system needs to include the following main tasks: data collection; data capture; data analysis; and operational changes (Figure C3).

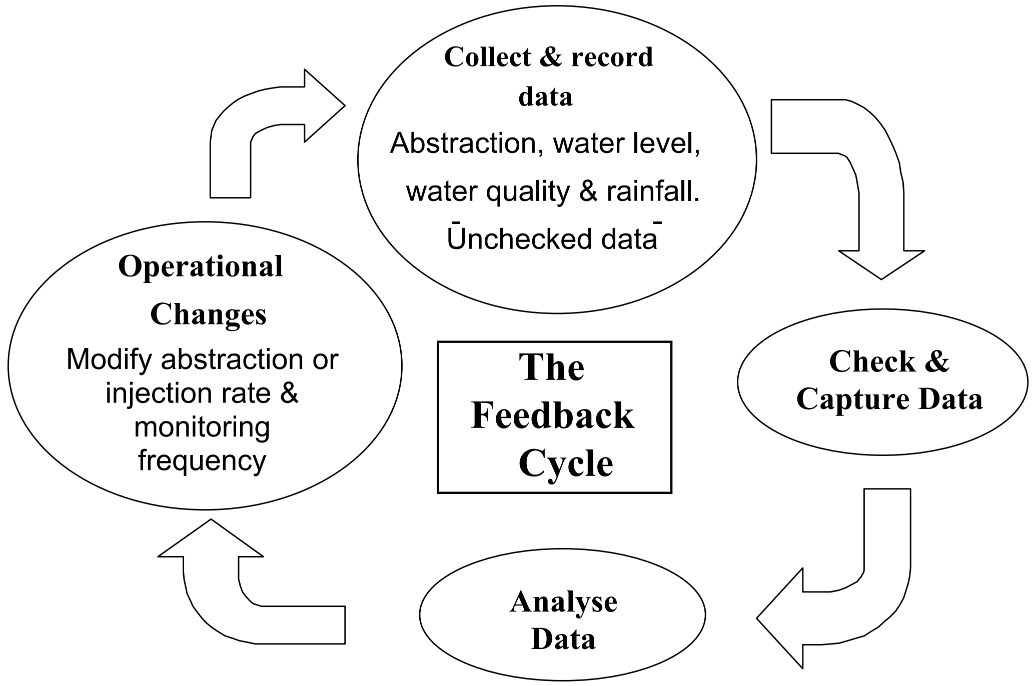


Figure C3. Principle Groundwater Management Tasks

Data collection is simple and inexpensive, and should form part of all pump operators' operation and maintenance (O&M) tasks. Information needed includes borehole water levels and abstraction data on a monthly basis, and water samples for water quality assessments on a yearly basis. Although not essential, computers make *data capture* very easy, and are useful tools when reviewing a lot of data. With the assistance of the DWAF/NORAD Programme, a simple software programme (AQUIMON) was developed for viewing data both spatially and on a time-series basis. Much of the Prince Albert data has been captured in AQUIMON.

Data analysis has been intensive over the past year, and will need to continue until all boreholes are operating at optimum rates. In some cases, boreholes are being over-pumped (such as P5, 6 & 7), and it is in these areas where artificial recharge may be required; and in others, they appear to be under-pumped (such as SRK1, P1 & P3).

The management system will only be effective if all four components in the management cycle are attended to. Integrating groundwater management into O&M procedures is thus critical for overall resource and infrastructure management.

12.2 Institutional Framework for Groundwater Management

There are four key role players in water resource management and supply. The national Department of Water Affairs and Forestry is responsible for overall water resource management. The country is in the process of establishing Catchment Management Agencies (CMAs) who will be responsible for water resource management on a large-scale catchment basis. The purpose of setting up Catchment Management Agencies is to place water resource management into more manageable "units".

"Below" the CMAs are the Water Services Authorities (WSAs) and "below" them are the Water Services Providers (WSPs). Prince Albert Municipality is both the WSA and WSP for Prince Albert town and the satellite towns such as Klaarstroom and Leeu Gamka. Figure C4 illustrates the relationship between the CMA (DWAF) and the WSA/WSP (PA Municipality) in groundwater management and supply.

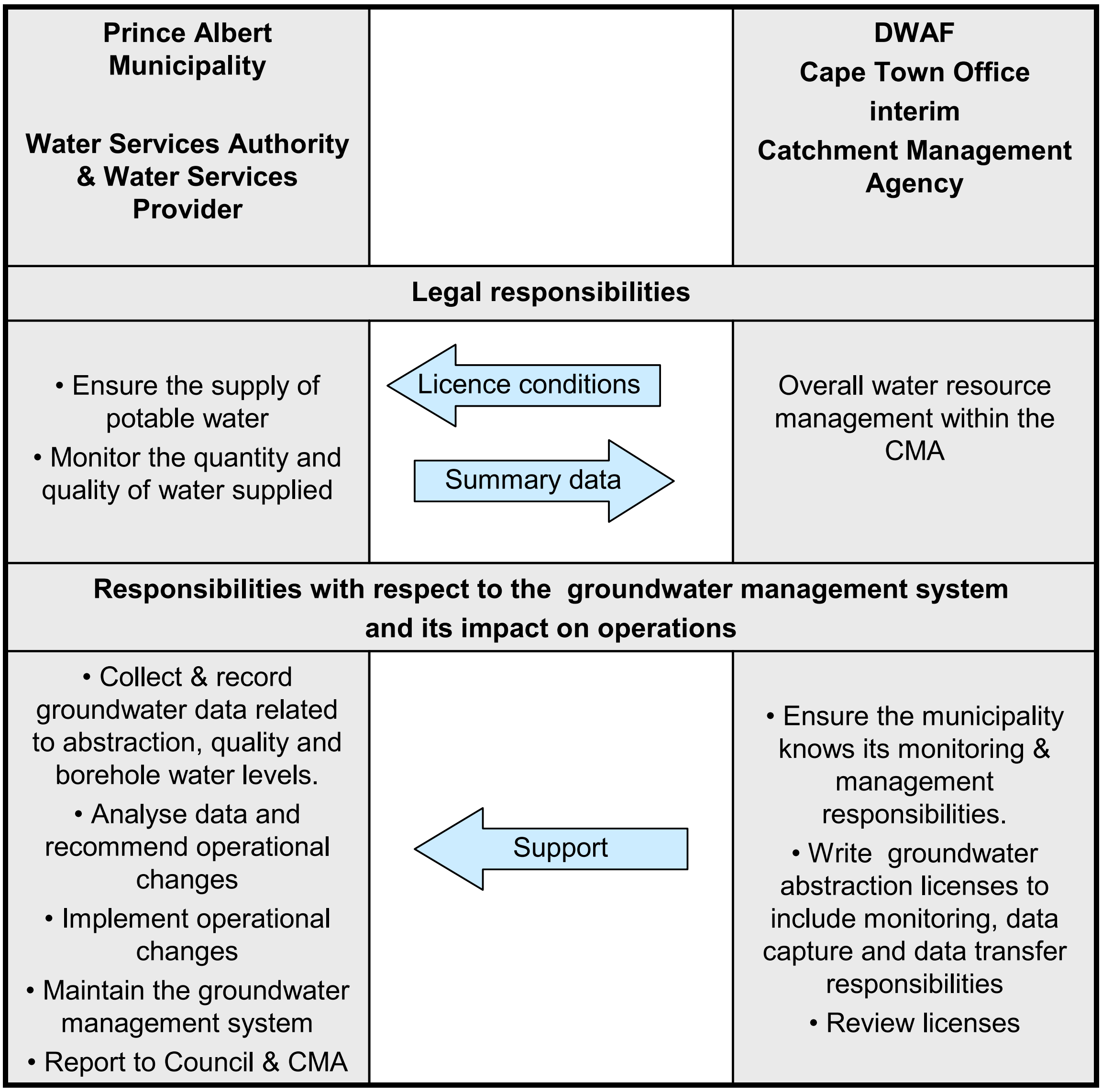


Figure C4. Institutional framework for groundwater management

12.3 Main institutional tasks and responsibilities:

- The CMA is responsible for setting up the groundwater management system. This it may do with in-house personnel or with support from the DWAF regional office or consultants.
- PA Municipality (the WSA &WSP) is effectively the groundwater manager. This is because groundwater management and O&M are closely linked.
- PA Municipality should collect and store the relevant groundwater data.
- PA Municipality will have to have the data analysed with assistance from the CMA, DWAF's regional office or consultants.

- Whoever analyses the data will need to inform PA Municipality of operational improvements that should be made such as modifying pumping schedules.
- PA Municipality should provide the CMA with a summary report on groundwater use and quality on an annual basis.
- PA Municipality should provide the Municipal Council with a report on the effectiveness of groundwater supply and management.
- PA Municipality should be responsible for maintaining the groundwater management system and for ensuring that the management recommendations are heeded.

Thus, groundwater management for water supply schemes involves the management of data collection, transfer and analysis, and the implementation of recommendations. Key to the success of this, is training pump operators to collect reliable and accurate data, and training municipal staff in capturing and storing the data. Another key factor is the availability of funds. Groundwater management does not need to be expensive. It is far cheaper to manage groundwater than to deal with the annual summer crisis, which appears to have resulted in the past from a lack of management. Table C3 describes the key management functions.

Table C3. Generic groundwater management functions

	Activity	*Responsible person*	*Skills & qualifications required*	*Resources, tools & equipment*	*Remarks*
1	Measuring and recording of water levels	Pump operator	Literacy, numeracy, trained in taking water levels	Dip meter, ruler, log book, pen	Done as part of operators' regular O&M activities
2	Measuring and recording abstraction	Pump operator	Literacy, numeracy, trained in reading water meters	Log book, pen	Done as part of operators' regular O&M activities
3	Providing data to the authority that is responsible for water supply on a regular basis (a minimum of every 2 months is recommended)	Pump operator and pump operator supervisor	Literacy, numeracy, keeping records	Postal service or public transport	Included as part of the reporting requirements of the pump operator
4	Taking water samples	The authority that is responsible for water supply	Trained in taking water samples, drivers license	Transport, sample bottles, cooler box	Sampling routine defined by sampling plan
5	Sending water samples for testing	the authority that is responsible for water supply	Keeping records	Transport to laboratory	Sent to nearest accredited laboratory
6	Defining the monitoring requirements of an individual borehole	Technical manager of operations or hydrogeologist	Hydrogeological degree or diploma, experience of hydrogeological conditions	Reports and records on borehole, monitoring data	

	Activity	*Responsible person*	*Skills & qualifications required*	*Resources, tools & equipment*	*Remarks*
7	Ensuring that boreholes are equipped with piezometer tubes for measuring water levels and water meters for measuring abstraction	The authority that is responsible for water supply	Project management	In house technical staff, suppliers, contractors, specifications	
8	Ensuring that operators have the equipment and skills to do monitoring	The authority that is responsible for water supply	Project management	Trainers, suppliers, specifications	
9	Monitoring the pump operator's competence to collect and record data	Pump operator supervisor	Staff supervision, knowledge of pump operators' tasks	Transport	Done as part of the supervision of O&M activities
10	Processing data collected at the local level	Data clerk	Data capture, record keeping, filing, trained in operating software	Computer, spreadsheet or groundwater management software, files	Maintains an electronic and physical record of data
11	Studying water level, water quality and abstraction data on a regular basis	Technical manager of operations	Technical training, operations experience	Project files, monitoring data	Done as part of the management of O&M
12	Revising pumping recommendations, and adjusting the monitoring requirements. Ensuring that the recommendations are carried out and monitoring the implementation of the recommendations	Technical manager with hydrogeologist as required	Technical training, operations experience	Reports and records on borehole, monitoring data, operational information	Ongoing management of operations and groundwater resources
13	Reporting to council and pump operator, providing summary data to the CMA	Data clerk with supervision from technical manager	Training in operating software	Computer, spreadsheet or groundwater management software, printer	Summary data defined by license. (frequency, what data, form of data)

Generic aspects of this section have been adapted from Murray and P Ravenscroft (2004).

12.4 Specific surface and groundwater management tasks for Prince Albert Municipality

The key water management and supply tasks are listed in Table C4. The names of the proposed responsible people have been included. During the Masibambane Project the pump operator left the municipality and the training afforded to him was lost. At the time of writing this, the new operator had only recently been appointed, and he still needs to be trained. Mr J Rissik, a resident of the town provided the training. Someone of his technical ability will need to provide on-going support to municipal staff until a suitably skilled municipal employee is appointed to carry out these tasks. In the table below, the support role is called Technical Support Person (TSP).

Table C4. Specific surface and groundwater management tasks for PA Municipality

	Task	*Who*	*Detailed description of what the task entails*	*Existing Impediment*	*Who should remove impediment*
			DAILY		
1	Physical level check in raw water reservoirs	MF/TD	Drive to reservoir and check levels in first reservoir	This task can be simplified if the telemetry system is modified to send out a 2-hourly raw water level report during working hours. It currently only sends out low-level alarms.	MM
2	Response to telemetry alarms	MF/TD	Carry the telemetry cellphone at all times. Receive and respond to alarms	Modify alarms Change telemetry to Afrikaans Load SMS's on phone	TSP / TO(E) SSE TSP / TO(E)
3	Filter flush	MF/TD	Flush filters for required period		
4	Pumps tripped	MF/TD	Visit pump and establish reason for tripping. Rectify as required	Timing, access to electrician	TO(E)
5	Inkeer of beurte	MF/TD	Go to waterworks and insert/remove sluice gate as required.	Much of it occurs out of normal working hours.	MM
			FORTNIGHTLY		
6	Physical check of all boreholes	MF	Drive to all boreholes. Inspect for damage, leaks, etc. Rectify, repair, report as necessary.		
7	Read all borehole water meters	MF	Read water meter while performing above. If pump is on, check that water meter is working	Get a carbon notebook to record readings	MS
8	Adjust telemetry "Schedule" page if needed	TSP/TO(E)	Adjust hours pumped or no. of pumps in use	Training of TO(E)/MF	SSE/TSP
			MONTHLY		
9	Read all supply-side water meters (bulk water meters) on the same day as domestic meters are read	MF (or could be done by meter readers)	Drive to main water meters in and around town and take readings	None. To be written in carbon notebook	
10	Log water consumption trend	MS	Keep simple spreadsheet and graph of consumption figures	Training	TSP
11	Collect rainfall data from CNC Oudtshoorn and Correctional Services, PA	MS	Phone CNC O/H and ask them to fax/email the data. Collect data from PA Prison Office	Contact persons for MS	TSP
12	EC & pH from all production boreholes	TSP	Sample water at borehole. Take E.C. and pH readings	EC & pH meter	MM
13	Logger downloads	TSP	Remove logger, download, replace.		

	Task	*Who*	*Detailed description of what the task entails*	*Existing Impediment*	*Who should remove impediment*
14	Physical Water Level readings	TSP	Use dipmeter		
15	Flow meter readings	TSP	Read flow meters		
16	Warning system if borehole water levels approach minimum levels	TSP	Frequent data downloads during summer. Data to be entered into Aquimon.	HG to set minimum levels	HG
17	Data compilation	TSP	Compensate and convert data to required format		
18	Submit data to MS/HG in specified format	TSP	Email data		
19	Capture data	MS	Capturing raw data onto a computer (Aquimon or spreadsheet)	Training of MS/TSP	MM
QUARTERLY					
20	Review data and submit brief quarterly report	HG	Review groundwater level status and recommend modifying abstraction if necessary	Budget	MM
21	Review of supply and demand balance and submit brief quarterly report	TSP	Collect supply and demand data, compare trend		
22	Report to Council	MM	Reports from items 20 & 21		
ANNUALLY					
21	Report to DWAF as per license conditions	MM	Print out and send reports from Aquimon to DWAF	Training of MS	TSP

***Key*:**

TD	Tractor Driver (Hendrik Kellerman) (shares after-hours portion of work with MF)
MF	Municipal Foreman (Piet Miennies)
MS	Municipal Secretary (Karin van der Mescht)
TO(E)	Technical Official (Electrical) (Jan Nel)
TSP	Technical Support Person (Performed by Johann Rissik during the Masibambane Project)
SSE	SSE Data in Cape Town
HG	Hydrogeologist (Performed by R Murray during the Masibambane Project)
MM	Municipal Manager (Acting) (Edwin September)

13. PRINCE ALBERT BOREHOLES

13.1 Borehole Description

Table C5 summarises existing borehole information. Coordinates are based on a hand-held GPS and elevations are either GPS-based or taken from 1:50000 topographical maps.

Table C5. Borehole information - 1

Pump No	Bh No	Site ID	Status	Latitude	Longitude	Elevation (mamsl)	Depth (mbgl)
GMU C							
	PA0409 / SRK 1		Monitoring	33.29540	22.05070	796	150
	SRK 2		Monitoring	33.29345	22.05124	781	12
SRK 3	PA0410 / SRK 3		Production	33.29342	22.05110	781	90
P1	PA 6		Production	33.29005	22.05245	764	200
GMU B							
P2	PA 7		Production	33.28900	22.05300	762	150
	G6		Monitroing	33.28575	22.05225	743	
P3	G7 / PA4	3322AC00119	Production	33.28503	22.05210	743	50
	G8	3322AC00120	Monitoring	33.28401	22.05179	743	49
P4	PA9703		Production	33.28398	22.05122	743	120
	Bh 4A		Monitoring	33.28396	22.05123	743	37
GMU A							
	GZ00347		Monitoring	33.26741	22.04777	702	120
	GZ00351		Monitoring	33.26738	22.04777	702	
	G1	3322AC00114	Monitoring	33.26362	22.04528	708	
	GZ00349		Monitoring	33.26362	22.04528	698	120
P5	PA9704	3322AC00107	Production	33.25718	22.04313	685	90
	GZ00345		Monitoring	33.25716	22.04272	681	31
	GZ00346		Monitoring	33.25710	22.04287	682	100
	G2		Monitoring	33.25457	22.04232	676	
P6	PA9702	3322AC00108	Production	33.25247	22.04170	670	120
	GZ00348		Monitoring	33.25217	22.04169	669	120
P7	PA9701	3322AA00037	Production	33.24930	22.03932	665	137
	Bh7A		Monitoring	33.24901	22.04018	665	
	Bh7B		Monitoring	33.24905	22.04026	665	
	GZ00343		Monitoring	33.24916	22.03950	665	31
	GZ00344		Monitoring	33.24910	22.03948	665	91
	GZ00350		Monitoring	33.24883	22.03862	665	
P8	PA9705	3322AA00036	Production	33.24835	22.03810	662	55
P9	PA1		Monitoring	33.24753	22.03728	660	100

13.2 Borehole site description and monitoring equipment

A list of all monitoring equipment and work required at each site is given in Appendix 1.

13.3 Recommended borehole abstraction rates

Most boreholes were equipped with over-sized pumps. The pumping rates in litres per second were generally too high, and that had the effect of drawing water levels down far further than necessary. Over the past year, pumping rates were lowered in most boreholes, and in many cases the number of hours pumped per day was increased. The aim is to get all pumps operating at relatively low rates (L/s) for 24 hours a day (or thereabouts). This places far less stress on the boreholes, pumps and aquifers.

The abstraction recommendations made below follow from a year of monitoring after one of the wettest years recorded in Prince Albert. The flooding that occurred washed away the bridge at the base of the Swartberg pass, flooded the water treatment works and flooded into some of the boreholes (unintentional artificial recharge!). Thus the aquifer was full at the start of the monitoring period. Borehole water levels will need to be closely monitored to cover a drought period at the newly recommended pumping rates. Only then will it be possible to provide a final abstraction regime.

The recommended pumping rate for each borehole is given below and these are compiled into a single table in the next section. For comparative purposes, a graph of water levels from selected production boreholes in each Groundwater Management Unit is given (Figure C5). Of note is how much further the water levels are drawn down in GMU A relative to GMU B & C. This is why artificial recharge was planned for GMU A.

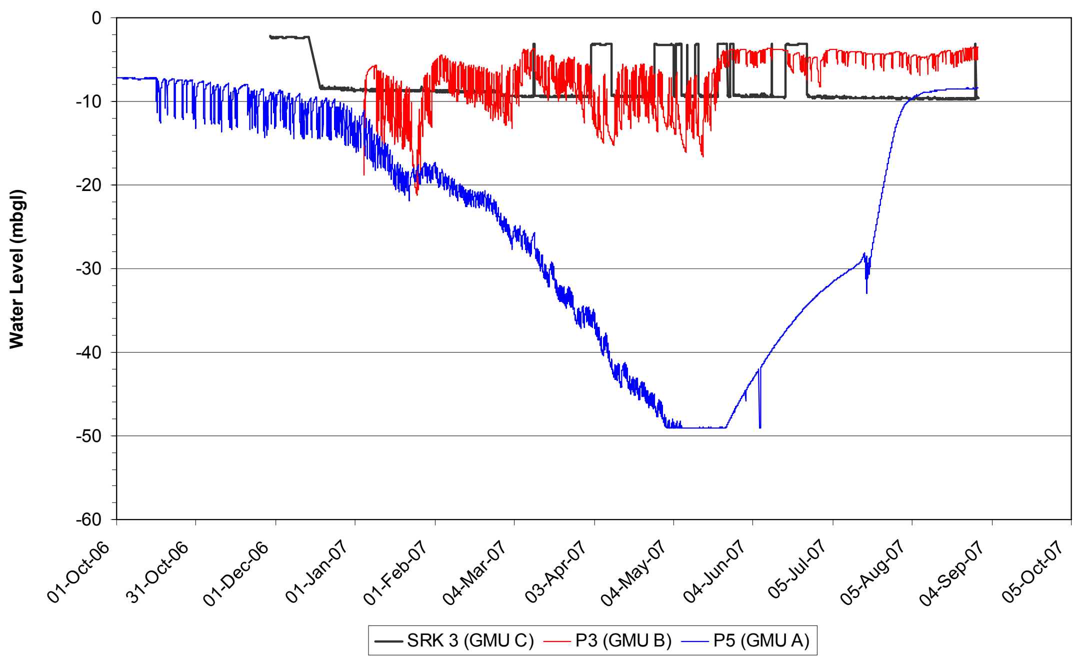


Figure C5. Groundwater levels over a one year period in each of the Groundwater Management Units

The figures from Table A4 and individual borehole flow meter readings have been used to estimate the proportion each borehole contributed towards the town's annual supply. The following totals have been used (rounded to the nearest 10 000 m^3):

Total groundwater supply (2006/7): **400 000 m^3/annum**
Total supply (groundwater and furrow): **550 000 m^3/annum**

Flow meters were installed at different times, so different time periods were used to establish averages. In estimating each borehole's contribution to the town's annual supply, the average abstraction was taken over 12 months for boreholes in GMU B & C, where boreholes were pumped throughout the year. For boreholes in GMU A, the total volume pumped over the summer months was used, as this represents more accurately the annual available volume from these boreholes. The percentages in Figure C6 and the following tables are merely ball-park estimates.

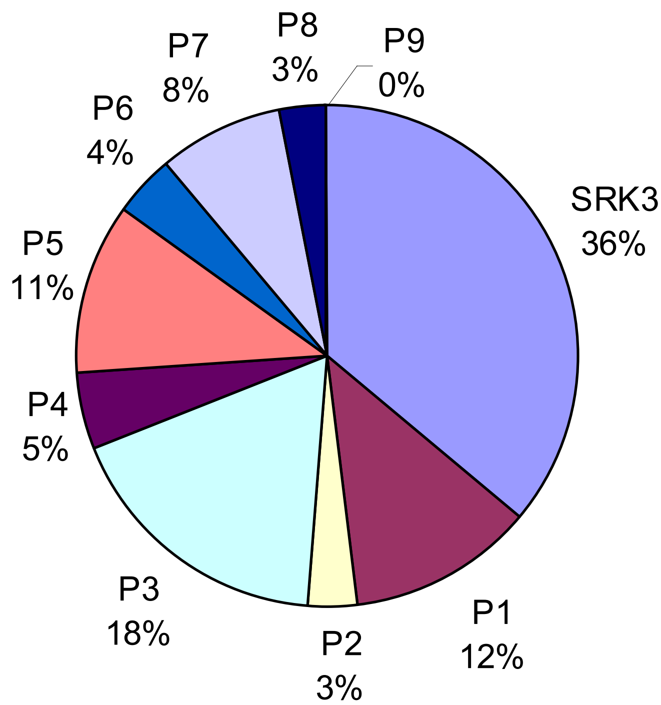


Figure C6. Estimated individual borehole contributions to total groundwater supply

In the tables below, the term "maximum water levels" means that borehole water levels should not be drawn below these levels. If they are, they may not be able to hold the set yield and the daily pumped volumes may have to be reduced.

13.3.1 SRK3

Table C6. SRK 3 Recommendations

Current pumping rate	6.1 L/s
Volume abstracted in 2006/7	115 420 m^3 (275 days between 29 Nov 06 & 30 Aug 07) = 420 m^3/day = 4.9 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 36 %
% of town's total supply	~ 26 %
Effect on SRK3 water levels	The water levels drop rapidly to between 8 and 10 mbgl and immediately rise to ~ 3 mbgl when pumping stops. The borehole performs fine at this abstraction rate.
Effect on monitoring boreholes	The effect of abstraction on SRK 2, which is adjacent to SRK 3, is minimal. The water level drops by about 0.5 m and recovers rapidly when SRK 3 is rested. There is no effect on SRK 1 located ~ 200m upstream of SRK 3.
Comments	At an average abstraction rate of 420 m^3/day, the aquifer is not affected. Abstraction has no negative environmental effects. Monitoring must however continue.
Recommended pumping rate	The current pumping rate of 6.1 L/s or 530 m^3/day should be maintained. It could probably be increased to ~ 7 L/s or 600 m^3/day without any negative borehole or environmental effects. This should be tested whilst monitoring SRK 1, 2 & 3.
Maximum/critical water levels	Pumping water level: 15 mbgl

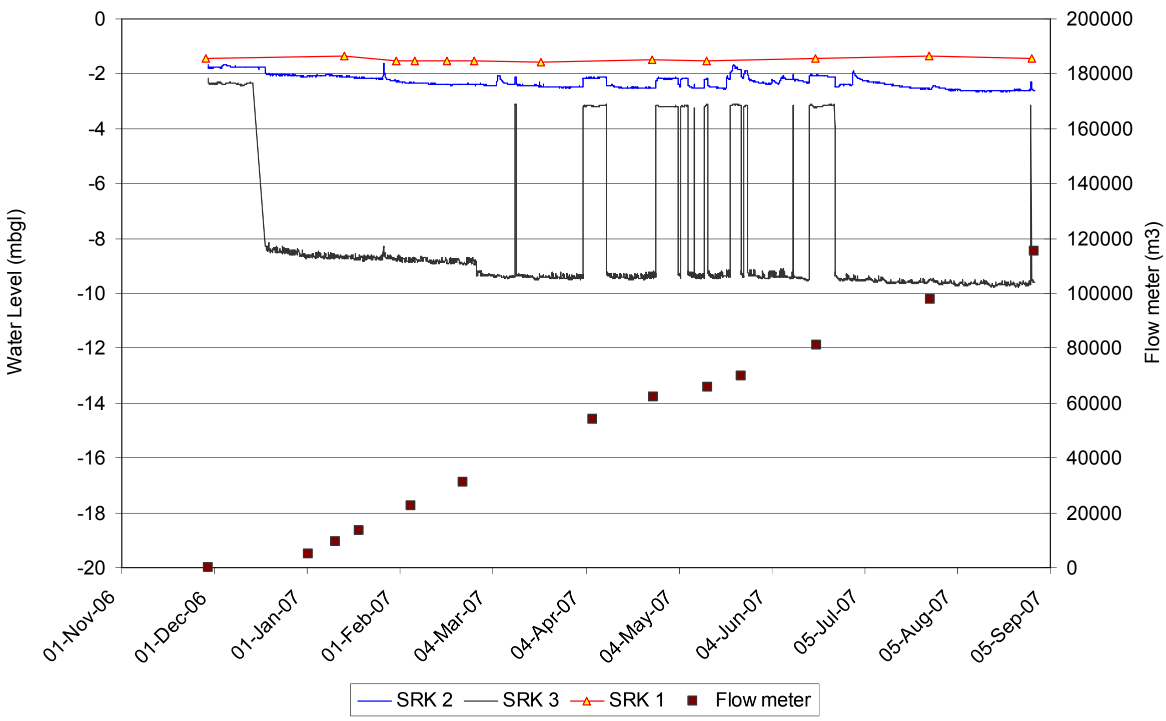


Figure C7. SRK 3 Effect of abstraction on groundwater levels

13.3.2 Pump 1

Table C7. Pump 1 Recommendations

Current pumping rate	3.5 L/s
Volume abstracted in 2006/7	31 027 m^3 (197 days between 11 Jan 07 & 31 Jul 07) = 158 m^3/day = 1.8 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 12 %
% of town's total supply	~ 9 %
Effect on P1 water levels	The pumping rate was initially set at ~ 11 L/s which was way too high for the borehole. This was reduced to 5 L/s. The aquifer can handle this, but the borehole water levels were fluctuating too much. The rate was reduced to 3.5 L/s. This had the desired effect of minimising the borehole water level fluctuations, but the aquifer was under-utilised. The borehole should be operated for more hours per day at this rate. Later the rate was increased to 6.6 L/s, but is has subsequently been reduced to 3.5 L/s which is about right for the borehole.
Effect on monitoring boreholes	Borehole G6, a few 100 m away is unaffected.
Comments	The aquifer can provide more water in this area than is being abstracted without impacting on the aquifer at large or the environment. Pump at recommended daily abstraction rate and monitor.
Recommended pumping rate	3.5 L/s or 345 m^3/day
Maximum/critical water levels	Pumping water level: 53 mbgl

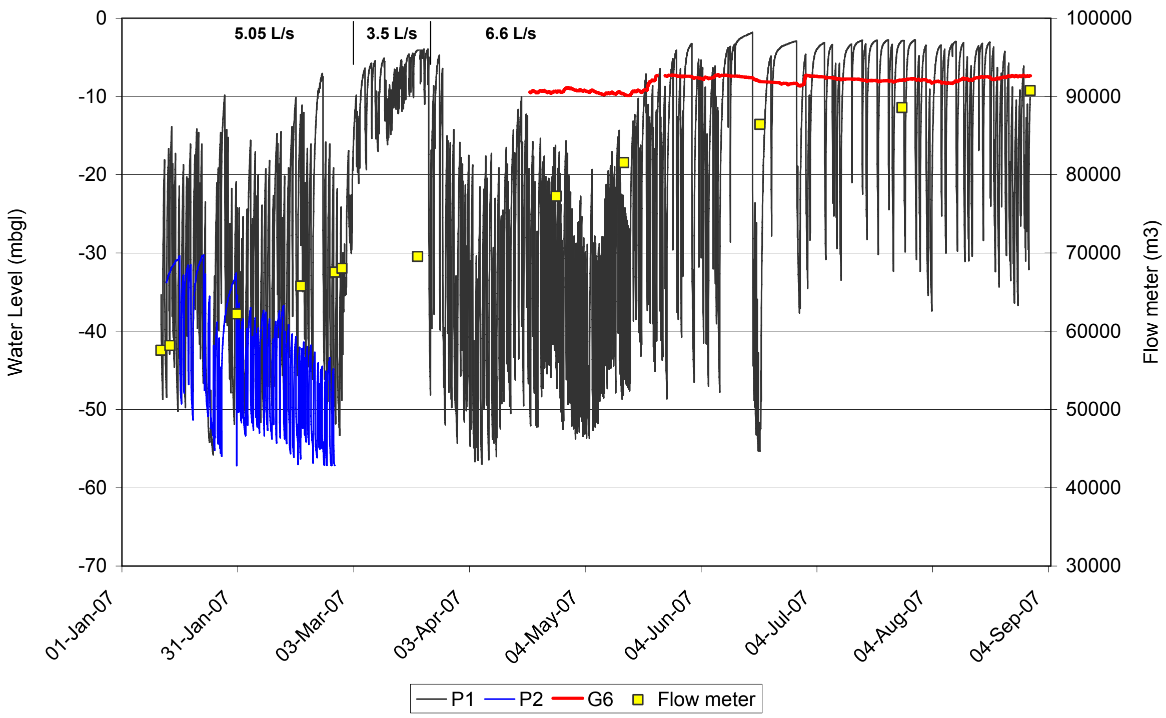


Figure C8. P1, P2 & G6 Effect of abstraction on groundwater levels

13.3.3 Pump 2

Table C8. Pump 2 Recommendations

Current pumping rate	1.8 L/s
Volume abstracted in 2006/7	30 772 m^3 (545 days between 03 Mar 06 and 30 Aug 07) =56 m^3/day = 0.7 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 3 %
% of town's total supply	~ 2 %
Effect on P2 water levels	Both resting and pumping water levels show that 1.8 L/s is too high for this borehole. The effect that this has on the aquifer, however, is negligible.
Effect on monitoring boreholes	Nearby Borehole G6 was not affected by abstraction from P2. (Note that the piezometer tube gave problems in this hole and thus water level monitoring stopped, but abstraction continued).
Comments	The pumping rate should be reduced to ~1 L/s.
Recommended pumping rate	1 L/s or 86 m^3/day
Maximum/critical water levels	Pumping water level: 54 mbgl

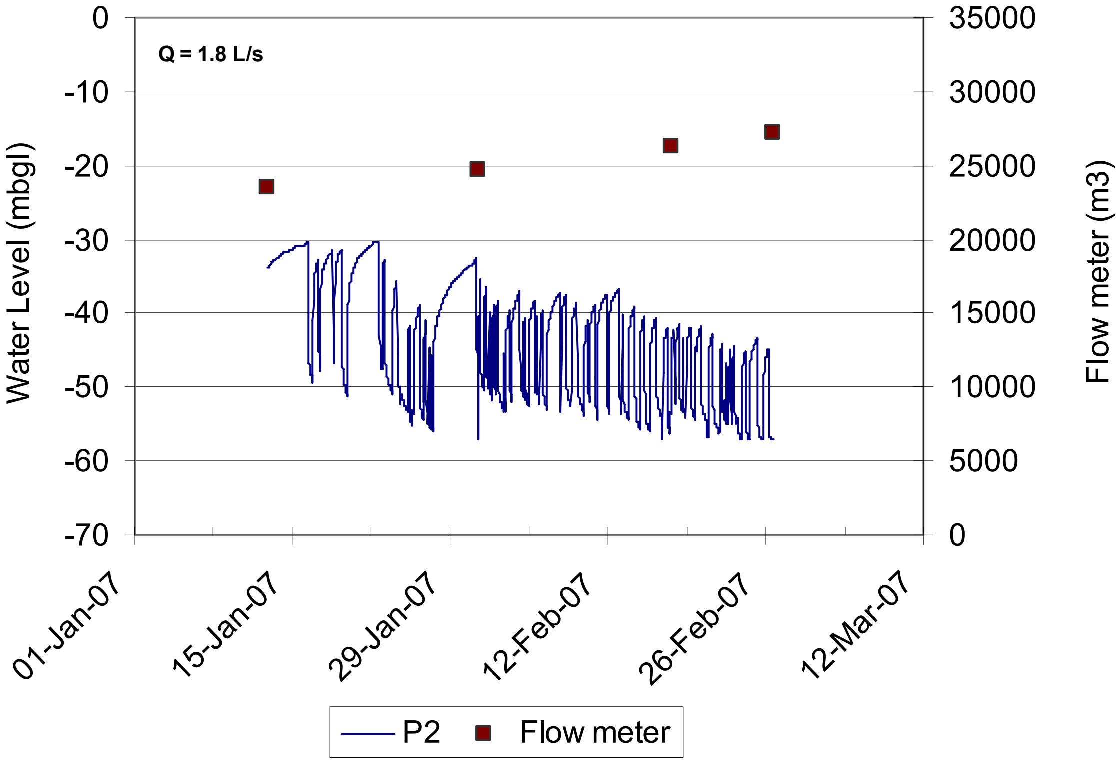


Figure C9. P2 Effect of abstraction on groundwater levels

13.3.4 Pump 3

Table C9. Pump 3 Recommendations

Current pumping rate	6.3 L/s
Volume abstracted in 2006/7	37 237 m^3 (121 days between 13 Jan and 14 May 07) = 309 m^3/day = 3.6 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 18 %
% of town's total supply	~ 13 %
Effect on P3 water levels	During the period from Jan to May 07 when this borehole was used heavily the water levels showed no sign that the aquifer was under stress. The pumping rate was reduced from over 10 L/s to ~ 6 L/s and both the pumping and rest water levels showed that the borehole could, on average yield more than the 3.6 L/s it gave.
Effect on monitoring boreholes	The monitoring boreholes show that abstraction from P3 had little effect on the aquifer.
Comments	The aquifer was underutilised at the average abstraction of 3.6 L/s. The current rate of 6.3 L/s should be tested with continuous pumping.
Recommended pumping rate	6.3 L/s or 540 m^3/day. Monitor and adjust if necessary.
Maximum/critical water levels	Pumping water level: ~ 30 mbgl

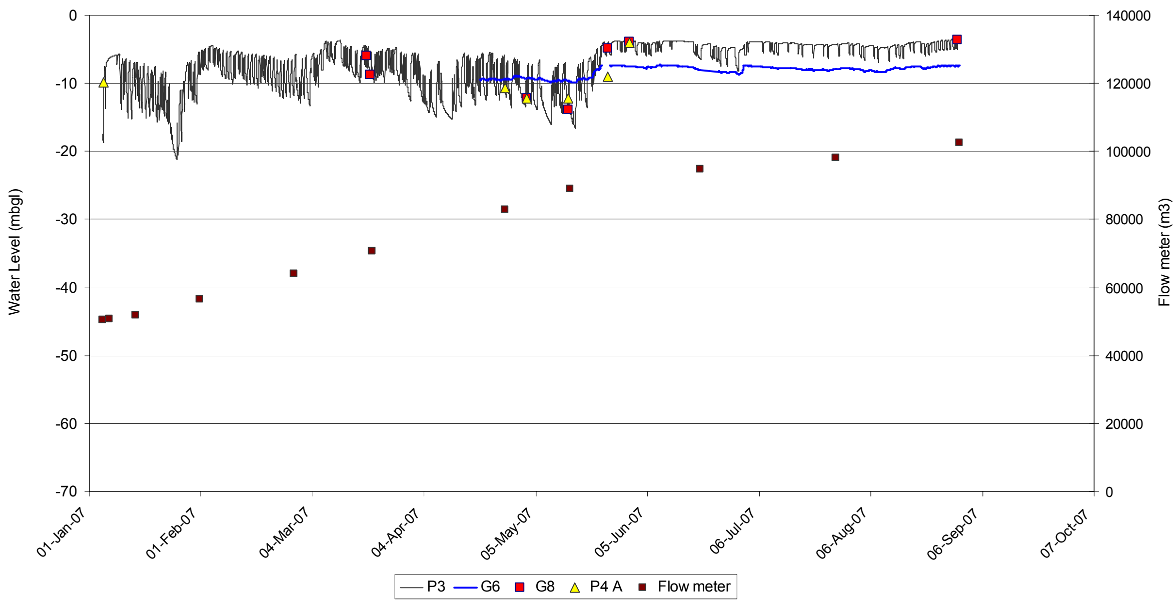


Figure C10. P3 Effect of abstraction on groundwater levels

13.3.5 Pump 4

Table C10. Pump 4 Recommendations

Current pumping rate	2.4 L/s
Volume abstracted in 2006/7	14 360 m^3 (158 days between 12 Jan and 19 Jun 07) = 91 m^3/day = 1.1 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 5 %
% of town's total supply	~ 4 %
Effect on P4 water levels	The pumping rate was reduced from ~ 6 L/s to 2.4 L/s. This had the desired effect of reducing the pumped water levels from ~40 m to acceptable levels between 10 and 20 mbgl.
Effect on monitoring boreholes	The volume of water taken from the aquifer in this area (from both P3 & P4) is small in relation to what the aquifer can provide. This is reflected in the monitoring boreholes.
Comments	The aquifer can provide more water in this area without negative environmental impacts.
Recommended pumping rate	2.4 L/s or 207 m^3/day. It still needs to be tested whether simultaneous abstraction from P3 & P4 at the newly recommended rates is OK for the boreholes. The aquifer should have no problem delivering the water, but whether the boreholes can do so on a continuous basis needs to be established.
Maximum/critical water levels	Pumping water level: ~ 40 mbgl

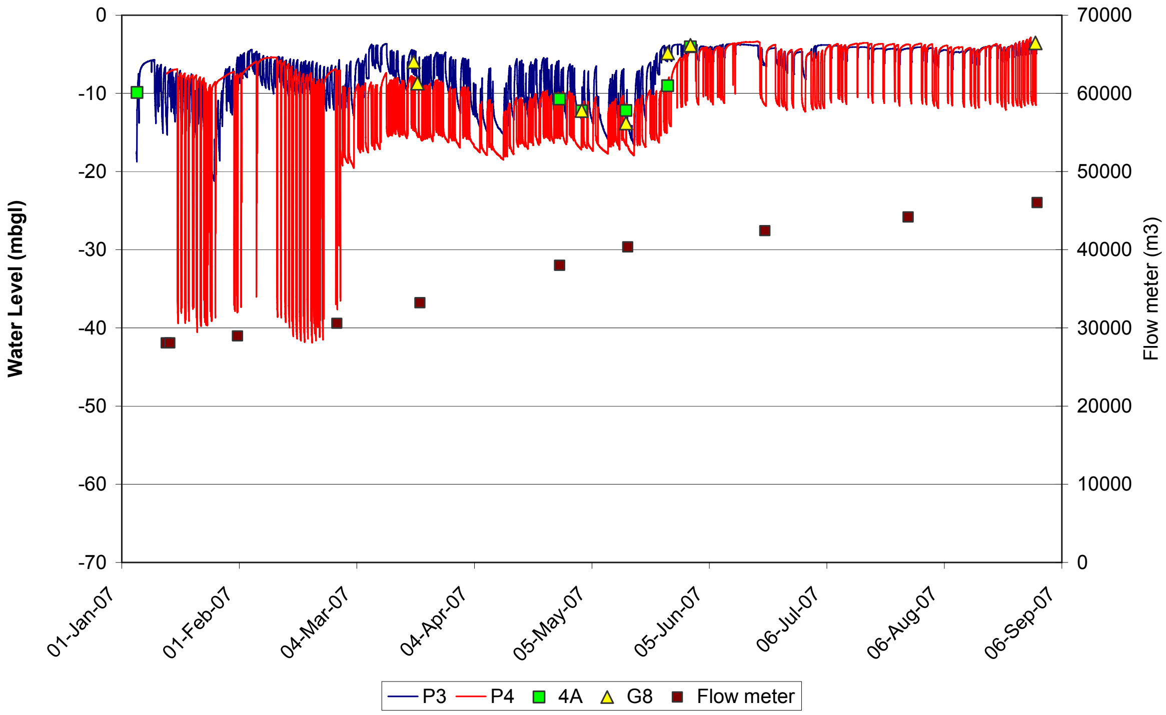


Figure C11. P4 Effect of abstraction on groundwater levels

13.3.6 Pump 5

Table C11. Pump 5 Recommendations

Current pumping rate	5.3 L/s
Volume abstracted in 2006/7	46 991 m^3 (221 days between 05 Oct 06 to 14 May 07) = 212 m^3/day = 2.5 L/s (average assuming non-stop pumping over this 221-day period)
% of town's total groundwater supply	~ 11 %
% of town's total supply	~ 8 %
Effect on P5 water levels	The pumping rate was reduced from its original rate of ~11 L/s to 5.3 L/s. The water levels still declined to the pump-intake level after 7-months of heavy abstraction, but the reduced pumping rate meant that water levels were not being drawn down too steeply as was the case in the past.
Effect on P5 water quality	The high abstraction had little effect on the salinity at P5. It remained between 40 – 50 mS/m which is very good quality water. It is best to pump this borehole continuously rather than in a stop-start manner. This would minimise the salinity spikes observed from pumping - where the salinity rises to ~70 mS/m (Figure C12).
Effect on monitoring boreholes	Borehole G2, located between P5 & P6 shows that the hard-rock aquifer at large was hardly affected by the abstraction from P5 (and P6). .
Comments	Pumping from P5 (and P6) has a localised effect on the aquifer.
Recommended pumping rate (prior to the newly drilled monitoring boreholes)	3 L/s or 260 m^3/day for 6 months of the year if the aquifer is full at the start of the 6 month period. Artificial recharge may be necessary to ensure the aquifer is full for the summer.
Maximum water levels	Pumping water level: 50 mbgl
Effect of newly drilled borehole (GZ00346)	Newly drilled monitoring borehole GZ00346 penetrated fractures that were under pressure (note the rapid water level rise in Jul-07). This had the effect of "recharging" and filling up the P5 compartment.
Recommended pumping rate (after the newly drilled monitoring boreholes)	Continuous abstraction throughout the year at the pump's current setting of 5.3 L/s or 460 m^3/day needs to be tested. If water levels are drawn down too far while the aquifer is full then pump at 3 L/s continuously and monitor.
Critical water levels	12 mbgl: Reduce pumping rate to 3 L/s (260 m^3/day) if continuous abstraction is needed. Ie if the rest water level drops below 12 m then reduce abstraction to 260 m^3/day.

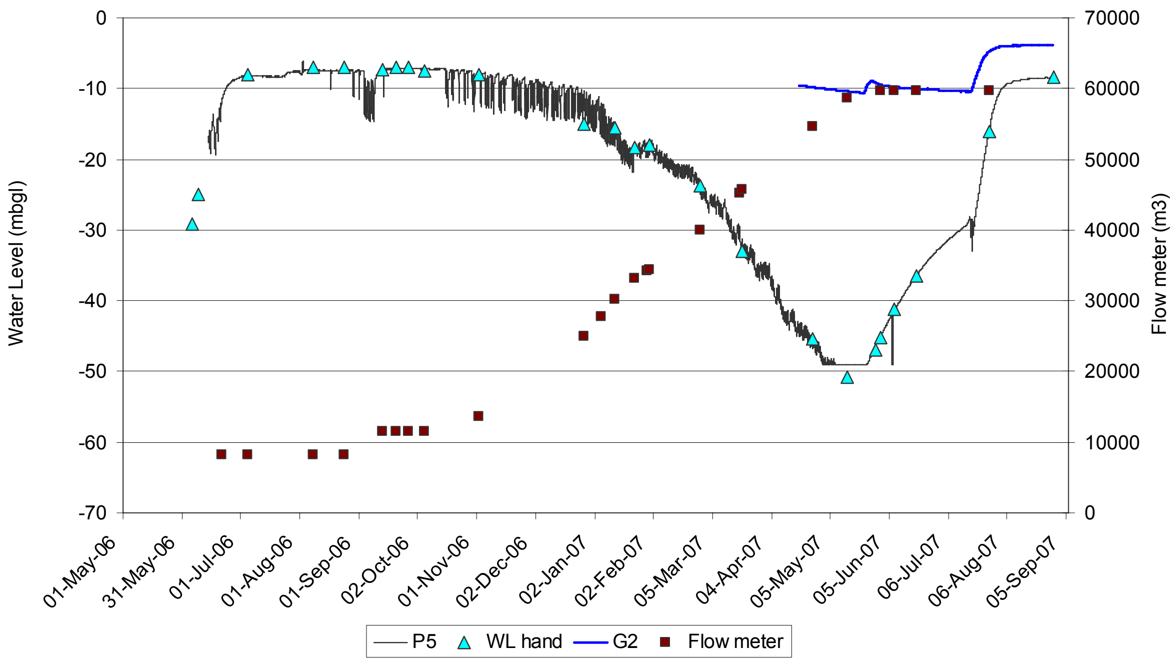


Figure C12. P5 Effect of abstraction on groundwater levels

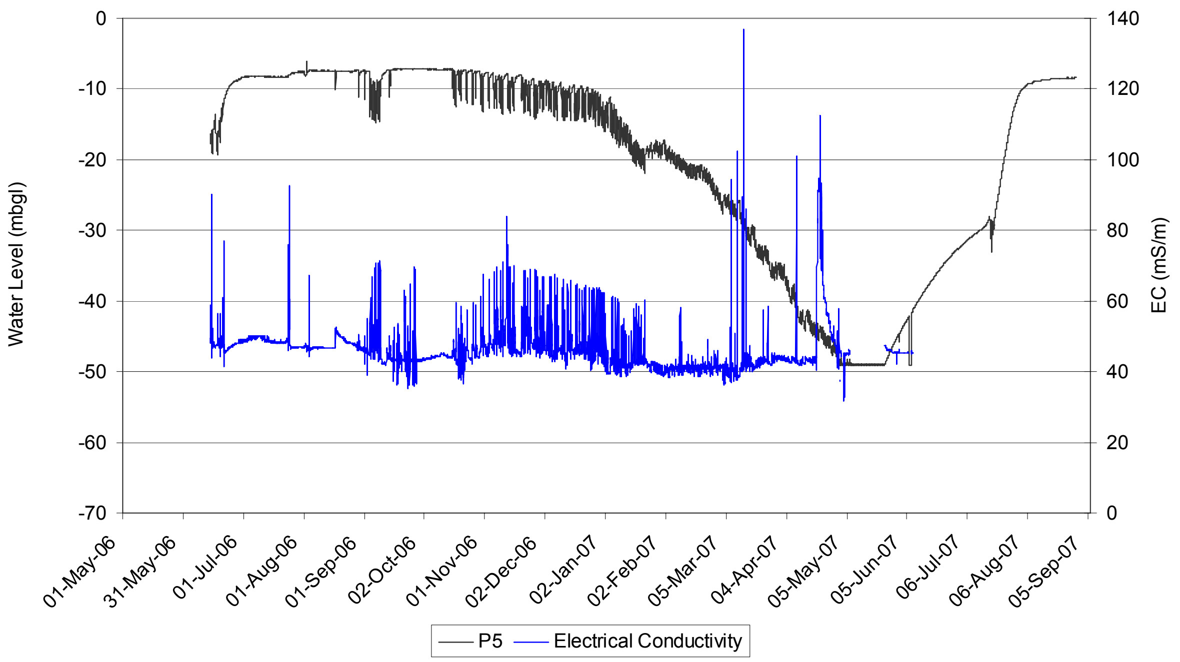


Figure C13. P5 Effect of abstraction on water quality

13.3.7 Pump 6

Table C12. Pump 6 Recommendations

Current pumping rate	3.3 L/s
Volume abstracted in 2006/7	22 830 m^3 (145 days between 19 Dec 06 to 14 May 07) = 157 m^3/day = 1.8 L/s (average assuming non-stop pumping over this 145-day period)
% of town's total groundwater supply	~ 4 %
% of town's total supply	~ 3 %
Effect on P6 water levels	Water levels dropped from about 10 m to around 40-50 mbgl with heavy pumping. It took about 3 months of pumping (Jan – Mar) for the pumping water levels to be drawn down to the pump intake.
Effect on monitoring boreholes	Borehole G2, located north of P6 shows that the hard-rock aquifer at large was hardly affected by the abstraction from P6. .
Comments	Pumping from P6 has a localised effect on the aquifer. The pumping rate of 3.3 L/s is too high for the borehole.
Recommended pumping rate (prior to the newly drilled monitoring boreholes)	1.5 L/s or 130 m^3/day for 6 months of the year if the aquifer is full at the start of the 6 month period. Artificial recharge may be necessary to ensure the aquifer is full for the summer.
Maximum water levels	Pumping water level: 60 mbgl
Effect of newly drilled borehole (GZ00346)	The artesian flow of monitoring borehole GZ00346 affected P6. This may positively affect P6's yield.
Recommended pumping rate (after the newly drilled boreholes)	1.5 L/s or 130 m^3/day for 365 days. Monitor, and if rest water levels drop below 14 m reduce daily pumping hours.
Critical water levels	14 mbgl

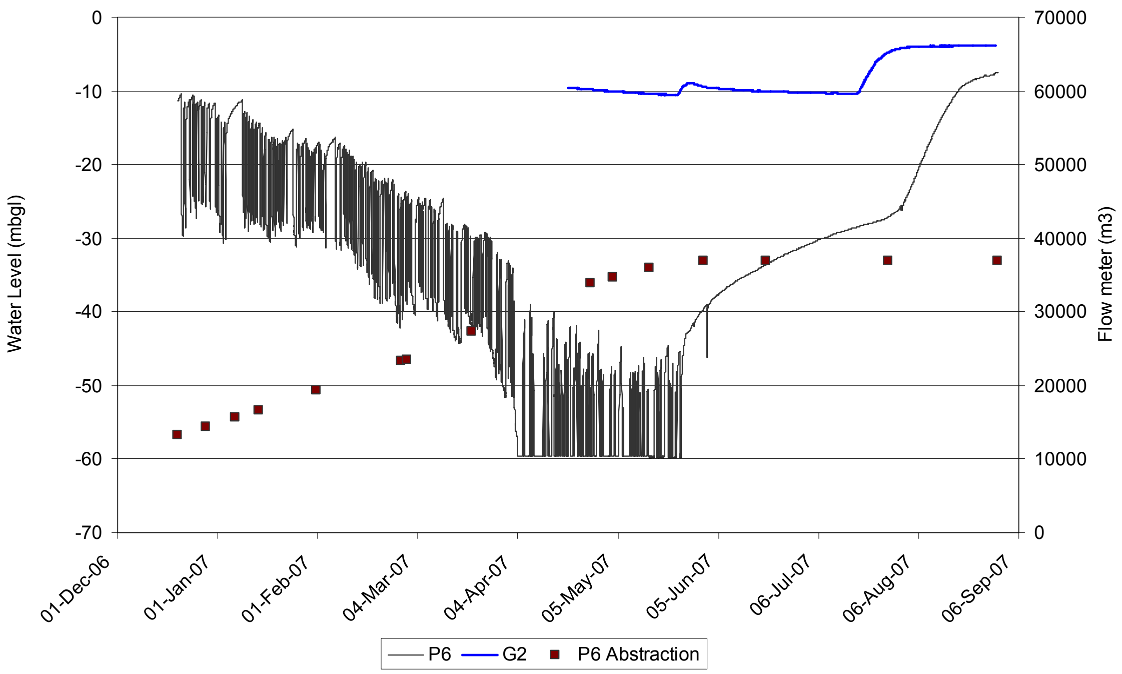


Figure C14. P6 Effect of abstraction on groundwater levels

13.3.8 Pump 7

Table C13. Pump 7 Recommendations

Current pumping rate	4.2 L/s
Volume abstracted in 2006/7	36 164 m^3 (191 days between 3 Nov 06 to 13 May 07) = 190 m^3/day = 2.2 L/s (average assuming non-stop pumping over this 191-day period)
% of town's total groundwater supply	~ 8 %
% of town's total supply	~ 6 %
Effect on P7 water levels	Water levels dropped by ~ 40 m with heavy pumping. It took about 3 months of pumping (Dec -Feb) for the pumping water levels to be drawn down to the pump intake.
Effect on P7 water quality	The salinity dropped from above 150 mS/m to ~ 90 mS/m with heavy abstraction (although the logger did not work properly the whole time). The deeper water appears to be less saline.
Effect on monitoring boreholes	No borehole near P7 was monitored. New monitoring boreholes have now been drilled (GZ00343 and GZ00344). As with P5 and P6, it is likely that abstraction from P7 only resulted in a localised water level decline and had little effect on the aquifer at large.
Comments	The pumping rate for this borehole was originally set at ~ 8 L/s. During this monitoring period, it was reduced to ~4.2 L/s. This rate is still too high, and the rate should be reduced again.
Recommended pumping rate (prior to the newly drilled monitoring boreholes)	2.4 L/s or 207 m^3/day for 6 months of the year if the aquifer is full at the start of the 6 month period. Artificial recharge may be necessary to ensure the aquifer is full for the summer.
Maximum water levels	Pumping water level: 50 mbgl
Effect of newly drilled borehole (GZ003)	The artesian flow of monitoring borehole GZ00346 affected P7. This may positively affect P7's yield.
Recommended pumping rate (after the newly drilled boreholes)	2.4 L/s or 207 m^3/day for 365 days. Monitor, and if rest water levels drop below 5 m reduce daily pumping hours.
Critical water levels	5 mbgl

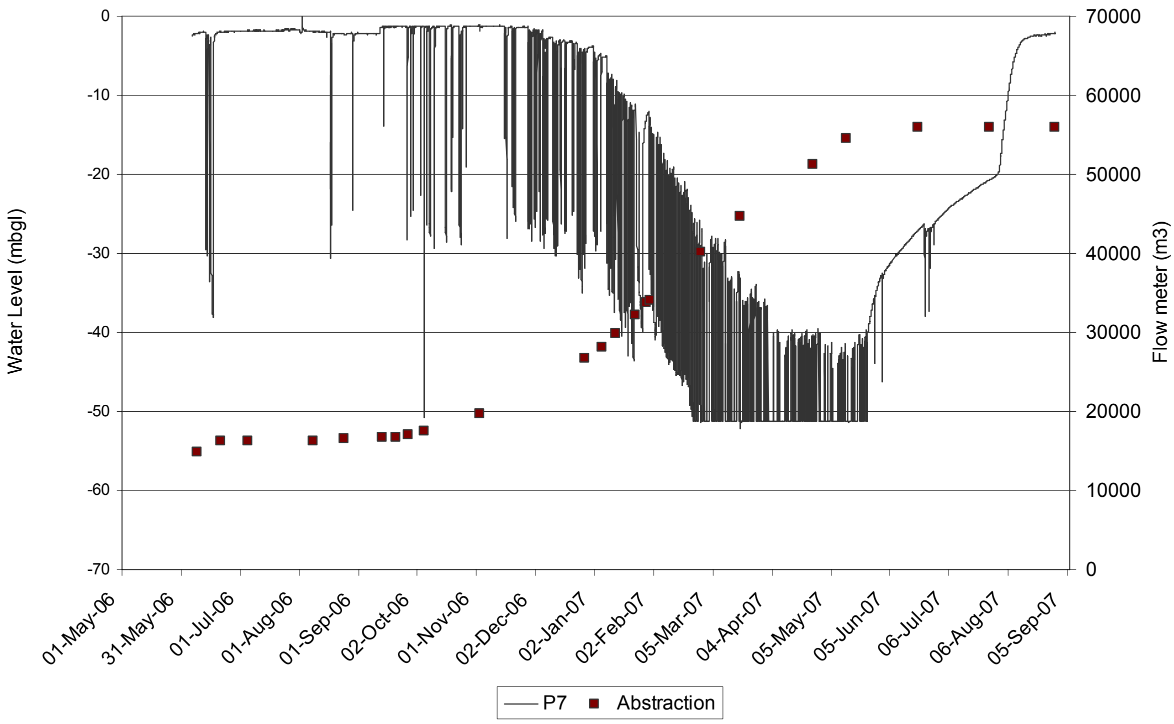


Figure C15. P7 Effect of abstraction on groundwater levels

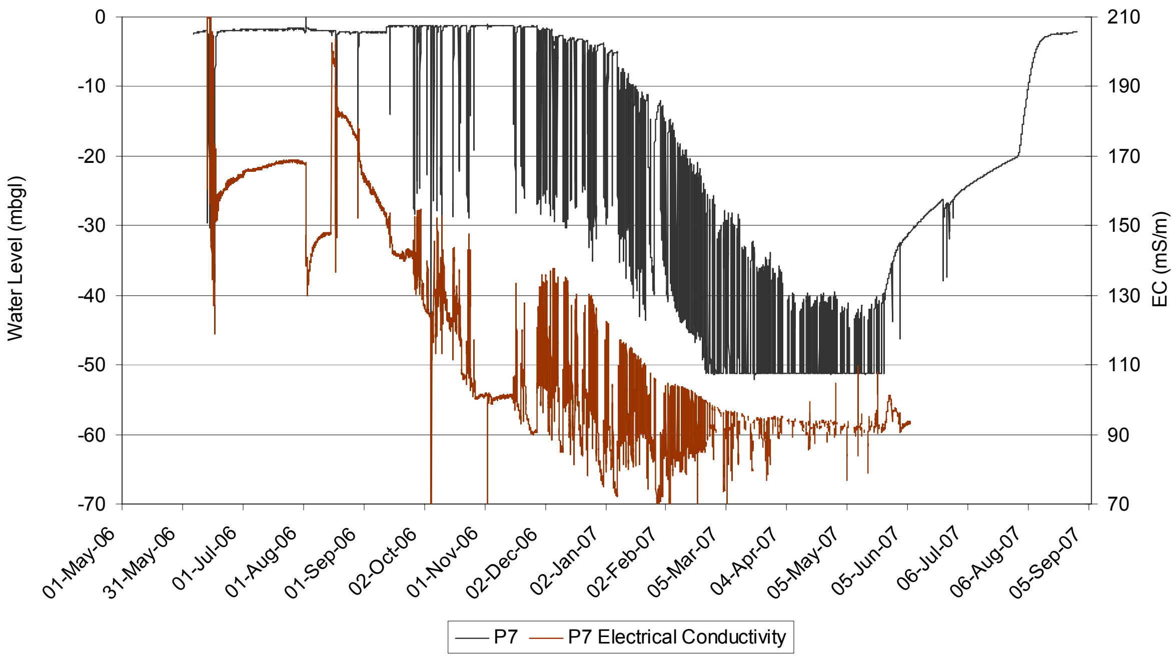


Figure C16. P7 Effect of abstraction on water quality

13.3.9 Pump 8

Table C14. Pump 8 Recommendations

Current pumping rate	1.9 L/s
Volume abstracted in 2006/7	18 175 m^3 (229 days between 27 Sep 06 to 14 May 07) = 80 m^3/day = 0.9 L/s (average assuming non-stop pumping over this 229-day period)
% of town's total groundwater supply	~ 3 %
% of town's total supply	~ 2 %
Effect on P8 water levels	The pumping rate was reduced to 1.9 L/s because the water was being drawn down to the pump intake at ~ 47 m. The borehole performed much better at this rate, but it is still too high for the hole.
Effect on monitoring boreholes	P9 is linked to P8 and abstraction from P8 and possibly P7 had the effect of dropping P9's water level by ~ 10 m.
Comments	P8 should only be used as an emergency, back-up borehole, where it can give ~100 m^3/day if needed.
Recommended pumping rate	1.1 L/s or 95 m^3/day for 6 months of the year if the aquifer is full at the start of the 6 month period.
Maximum water levels	Pumping water level: 45 mbgl
Effect of newly drilled borehole	P8 was affected by the newly drilled borehole. This however will not affect its pumping rate, but may affect the number of days per year it can be used.
Recommended pumping rate (after the newly drilled boreholes)	1.1 L/s or 95 m^3/day for 365 days. Monitor, and if rest water levels drop below 7 m reduce daily pumping hours.
Critical water levels	7 mbgl

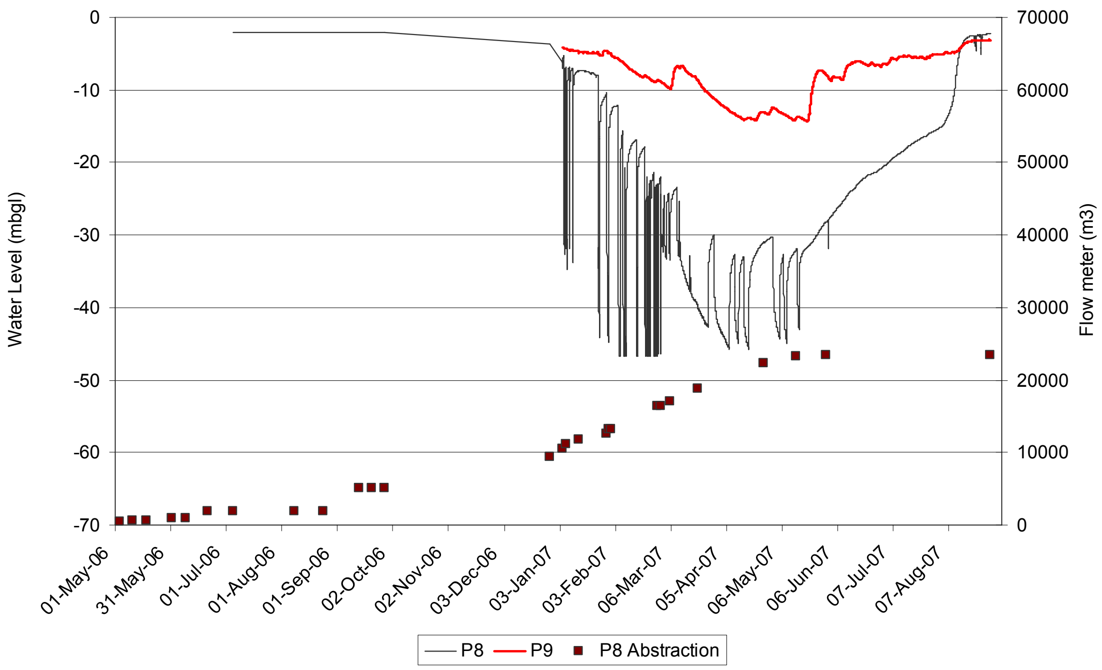


Figure C17. P8 Effect of abstraction on groundwater levels

13.3.10 Pump 9

Table C15. Pump 9 Recommendations

Current pumping rate	Unsure
Volume abstracted in 2006/7	0
% of town's total groundwater supply	0 %
% of town's total supply	0 %
Comments	P9 was not used for abstraction in 2006/7. It is a low-yielding borehole and is best suited for monitoring purposes. It is crucial to continue monitoring this borehole. So far it shows that abstraction from P8 and possibly P7 causes the water levels on P9 to drop by ~ 10 m.
Recommended pumping rate	0 L/s

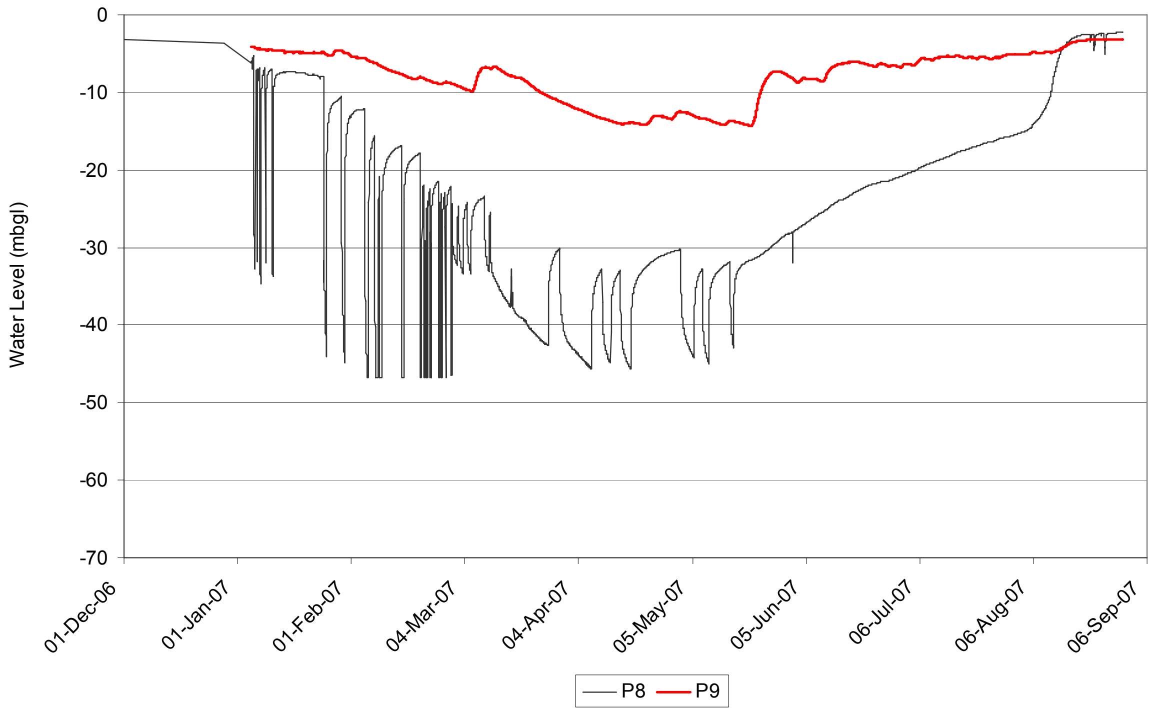


Figure C18. P9 Effect of abstraction on groundwater levels

13.4 Summary of Recommended Pumping Rates

Table C16 provides a summary of the recommended borehole abstraction rates for winter months, for normal summer requirements, and for the period in summer when the demand is exceptionally high.

Table C16. Summer and winter pumping schedule

Pump No	Pumping Rate	Winter Pumping Hours	Winter Supply	Summer Average Pumping Hours	Summer Average Supply	Summer Extended Pumping Hours	Summer Maximum Extended Supply
	(L/s)	(hrs/day)	(kL/day)	(hrs/day)	(kL/day)	(hrs/day)	(kL/day)
Supply requirements			**1100**		**2000**		**2750**
SRK 3	6.1	14	307	24	527	24	527
Pump 1	3.5	0	0	12	151	20	252
Pump 2	1.0	0	0	0	0	20	72
Pump 3	6.3	13	293	24	540	24	540
Pump 4	2.4	0	0	0	0	22	190
Pump 5	5.3	0	0	14	267	24	458
Pump 6	1.5	0	0	16	86	24	130
Pump 7	2.4	0	0	18	156	24	207
Pump 8	1.1	0	0	0	0	24	95
Pump 9	1.0	0	0	0	0	0	0
Groundwater Total			**600**		**1727**		**2471**
Furrow			500		280		280
Total			**1100**		**2007**		**2751**
Water Balance			**0**		**7**		**1**

Summer Average Supply: Average requirements during summer
Summer Maximum Extended Supply: The month-or-so during summer when demand is considerably higher than average.

Table C17 and C18 give recommended daily pumping schedules to accommodate the irregular allowance from the irrigation furrow.

Table C17. Daily pumping schedule: Average summer supply

Pump No	Pumping Rate (L/s)	Mon		Tues		Wed		Thur		Fri		Sat		Sun		Week Total
		hrs		hrs		hrs		hrs		hrs		hrs		hrs		
Supply requirements			**2000**		**2000**		**2000**		**2000**		**2000**		**2000**		**2000**	**14000**
SRK 3	6.1	24	527	24	527	24	527	24	527	24	527	24	527	24	527	3689
Pump 1	3.5	12	151	20	252	0	0	0	0	20	252	0	0	5	63	718
Pump 2	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump 3	6.3	24	540	24	540	24	540	24	540	24	540	24	540	24	540	3780
Pump 4	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump 5	5.3	14	267	14	267	14	267	14	267	14	267	7	134	14	267	1736
Pump 6	1.5	24	130	24	130	0	0	18	97	24	130	0	0	24	130	616
Pump 7	2.4	24	207	24	207	24	207	24	207	24	207	0	0	24	207	1244
Pump 8	1.1	24	95	24	95	0	0	0	0	24	95	0	0	24	95	380
Pump 9	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Total			1917		2018		1542		1639		2018		1201		1829	**12164**
Furrow	**86**	1	86	0	0	5	452	4	370	0	0	9	800	2	172	1879
Total			**2003**		**2018**		**1993**		**2009**		**2018**		**2000**		**2001**	**14043**
Water Balance			3		18		-7		9		18		0		1	**43**

Table C18. Daily pumping schedule: Summer maximum extended supply

Pump No	Pumping Rate (L/s)	Mon		Tues		Wed		Thur		Fri		Sat		Sun		Week Total
		hrs		hrs		hrs		hrs		hrs		hrs		hrs		
Supply requirements			**2750**		**2750**		**2750**		**2750**		**2750**		**2750**		**2750**	**19250**
SRK 3	6.1	24	527	24	527	24	527	24	527	24	527	24	527	24	527	3689
Pump 1	3.5	24	302	24	302	24	302	20	252	24	302	0	0	24	302	1764
Pump 2	1.0	24	86	24	86	0	0	0	0	24	86	0	9	24	86	355
Pump 3	6.3	24	540	24	540	24	540	24	540	24	540	24	540	24	540	3780
Pump 4	2.4	24	207	24	207	5	43	20	173	24	207	0	0	24	207	1045
Pump 5	5.3	24	458	24	458	24	458	24	458	24	458	24	458	24	458	3205
Pump 6	1.5	24	130	24	130	24	130	24	130	24	130	24	130	24	130	907
Pump 7	2.4	24	207	24	207	24	207	24	207	24	207	24	207	24	207	1452
Pump 8	1.1	24	95	24	95	24	95	24	95	24	95	24	95	24	95	665
Pump 9	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Total			2553		2553		2303		2382		2553		1966		2553	**16863**
Furrow	**86**	1	86	0	0	5	452	4	370	0	0	9	800	2	172	1879
Total			**2639**		**2553**		**2754**		**2752**		**2553**		**2766**		**2725**	**18742**
Water Balance			-111		-197		4		2		-197		16		-25	**-508**

14. KLAARSTROOM

14.1 Borehole abstraction and water levels

The water supply to Klaarstroom stays constant throughout the year at about 84 m^3/day. In the summer of 2006/7 it averaged about 90 m^3/day and in winter 81 m^3/day. This is the supply from borehole KS1, which is backed up when needed by borehole KS2 (Figure K1). The pumping rates for both of these boreholes are too high. Their yields need to be reduced (halved) and their pumping hours doubled in order to get the same daily volume. The water is brackish (slightly saline) and there is a constant smell of hydrogen sulphide (rotten eggs) at the reservoir. Good aeration is sufficient to get rid of this odour. No water samples were taken from KS1 and KS2 as no sample tap exists. This needs to be urgently addressed.

The borehole infrastructure status summary is given in Appendix 1.

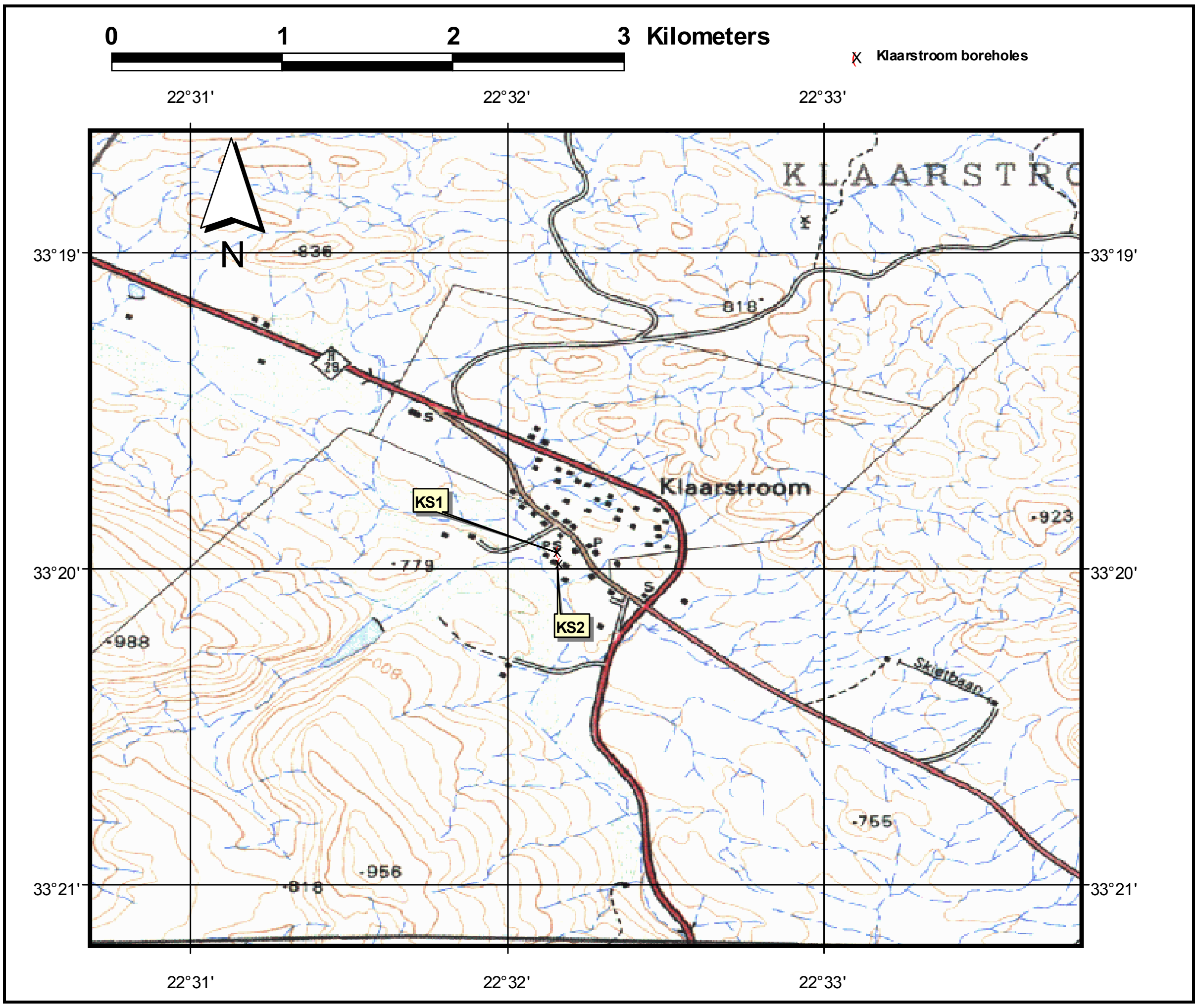


Figure K1. Location Klaarstroom municipal boreholes

Klaarstroom needs another water source – both for the purpose of supplying more water, which the aquifer can give without detrimental environmental impacts, and because groundwater of far better quality is available in the area. New sites should be drilled south of the existing boreholes (between the river and the dam) into the sandstones which will in all probability have better quality water.

Table K1. Klaarstroom borehole information

Pump No	Status	Latitude	Longitude	Depth (mbgl)
KS1	Production	33.33244	22.53551	75
KS2	Production	33.33276	22.53553	65

Individual borehole recommendations are provided in Tables K2 and K3 below.

Table K2. Recommendations for borehole KS1

Current pumping rate	2.0 L/s
Volume abstracted in 2006/7	19 490 m^3 (232 days between 9 Jan & 29 Aug 07) = 84 m^3/day = 1.0 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 95 %
% of town's total supply	~ 95 %
Effect on KS1 water levels	The abstraction rate of 2 L/s is twice as high as it should be for this borehole. Every day the water level is drawn down to pump intake and every day a combination of water and air is pumped from the borehole to the reservoir. This is bad for the pump and for the borehole, and it is a waste of energy. In summer this is particularly bad as the pump is often left running for days on end, and vast amounts of air are being transferred from the borehole to the reservoir!
Effect on monitoring boreholes	KS2, located 29.4 m from KS1 is used as a stand-by borehole for KS. It is critical to keep this borehole as a back-up, as shown in late March 07 when KS1 was out of order and this borehole kept the supply going. But like KS1 this borehole is also pumped at too high a rate, and water levels are also rapidly drawn down to pump intake. The water levels in KS2 show that the aquifer can handle the daily average abstraction of 84 m^3. In fact, more water could be drawn form the aquifer – but it must be done with a few boreholes, all pumping at low rates (for 24 hours/day if needs be).
Comments	The aquifer can provide more water than is currently being abstracted, but the borehole pumping rates (L/s) are too high. The pumping rates must be reduced and the hours of pumping per day increased.
Recommended pumping rate	1.0 L/s or 86 m^3/day
Maximum water levels	Pumping water level: Unsure, possibly ~ 40 mbgl

Table K3. Recommendations for borehole KS2

Current pumping rate	Unknown (no flow meter). Probably ~ 2 L/s
Volume abstracted in 2006/7	Unknown. Used as a back-up borehole to KS1.
% of town's total groundwater supply	~ 5 %
% of town's total supply	~ 5 %
Effect on KS2 water levels	
Effect on monitoring boreholes	The pumping rate (L/s) is too high. It must be reduced to prevent the water level being drawn down to pump intake.
Comments	The aquifer is doing fine with the current abstraction rate (m^3/day), but the borehole pumping rate should be reduced.
Recommended pumping rate	Unsure. Estimated to be ~1 L/s or 86 m^3/day when KS1 is not in use.
Maximum water levels	Pumping water level: Unsure, possibly ~ 40 mbgl

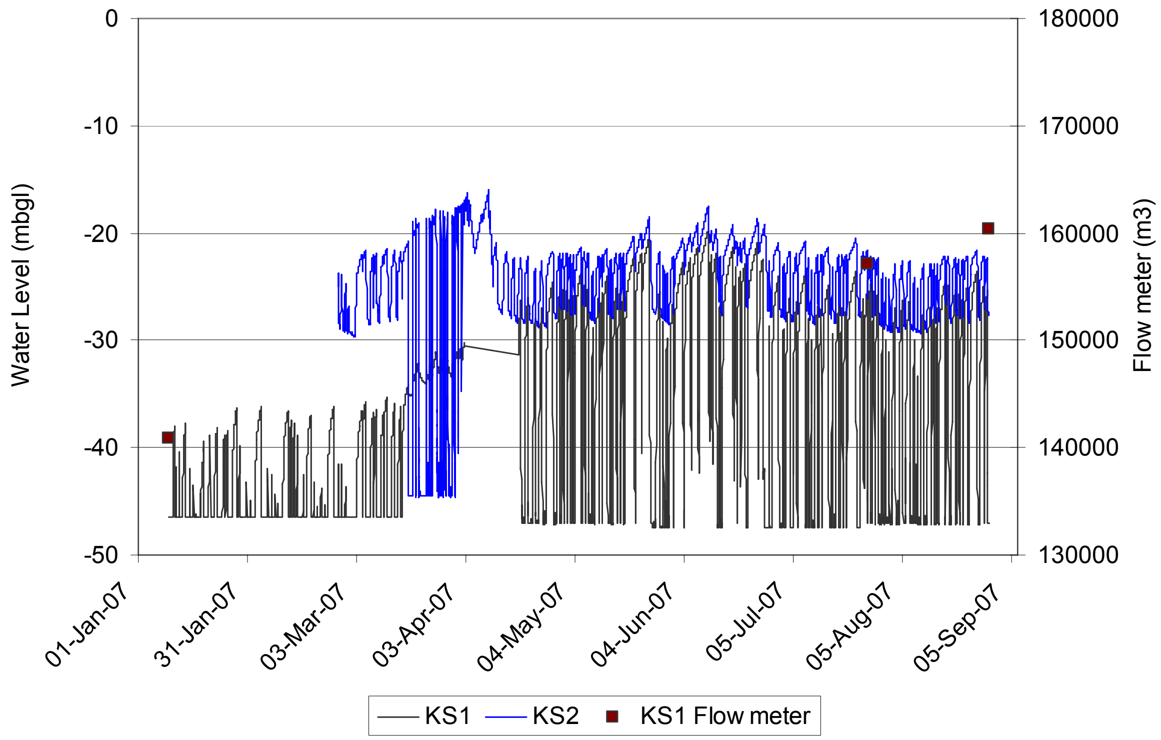


Figure K2. KS1 & KS2 Effect of abstraction on groundwater levels

14.2 Klaarstroom recommendations

The following actions should be implemented in Klaarstroom:

- Reduce the pumping rate of KS1 to 1 L/s, pump continuously (24 hours/day) and monitor KS1 and KS2.
- Install a flow meter at KS2. Halve its pumping rate and pump continuously if needed. Monitor KS1 and KS2.
- If more water is needed, drill new boreholes to intersect the sandstones of the Boplaas Formation on the farm Klaarstroom below the irrigation dam.

15. LEEU GAMKA

15.1 Borehole abstraction and water levels

Leeu Gamka has good groundwater resources. The town uses on average 260 m^3/day (from January to August 2007). This was abstracted mostly from two of the three production boreholes, LG1 & 2 (Figure L1 and Table L1). Data loggers were installed in June 2007 and water level responses to abstraction from June to August show that there is no effect on the aquifer (Figure L2). This still needs to be monitored throughout the summer. Unintentional recharge from LG1 to LG2 took place up to mid-July due to a faulty non-return valve. This has now been fixed.

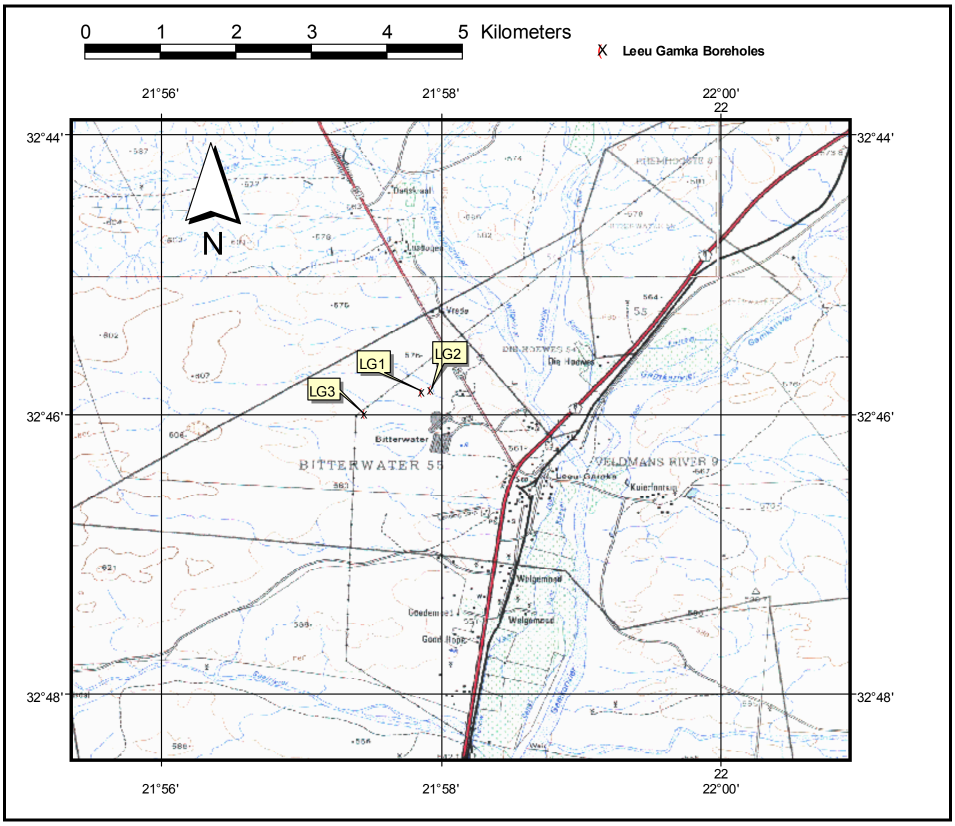


Figure L1. Location of boreholes at Leeu Gamka

Table L1. Leeu Gamka borehole information

Pump No	Status	Latitude	Longitude	Depth (mbgl)
LG1	Production	32.76402	21.96443	
LG2	Production	32.76376	21.96546	
LG3	Production	32.76657	21.95752	51

The borehole infrastructure status summary is given in Appendix 1.

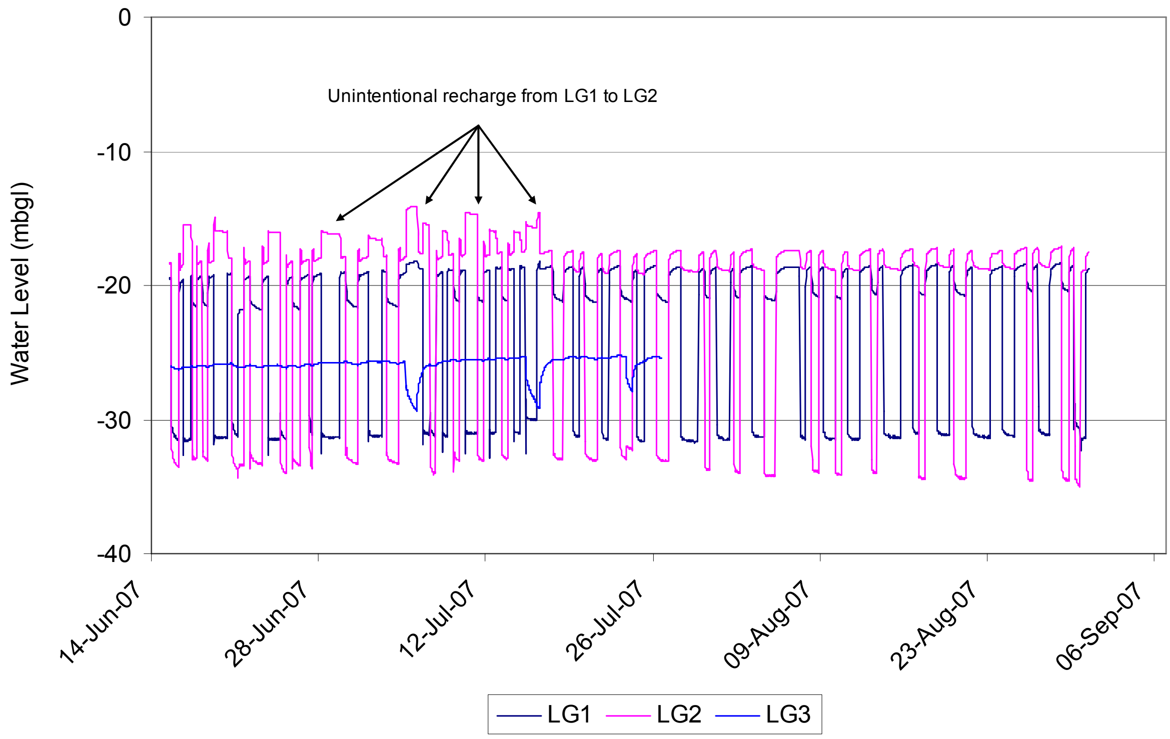


Figure L2. Leeu Gamka borehole water levels in response to abstraction

Individual borehole recommendations are provided below (Table L2).

Table L2. Leeu Gamka recommendations for borehole LG1

Current pumping rate	3.7 L/s
Volume abstracted in 2006/7	27 946 m^3 (229 days between 14 Jan & 30 Aug 07) = 122 m^3/day = 1.4 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 47 %
% of town's total supply	~ 47 %
Effect on LG1 water levels	This borehole is doing fine as it is although it would probably be better to pump it continuously rather than in the current start-stop manner.
Effect on monitoring boreholes	There are no monitoring boreholes, although LG2, about 75 m away, is affected by abstraction from LG1.
Comments	The borehole and aquifer are doing fine.
Recommended pumping rate	As is – ie 1.4 L/s or ~ 120 m^3/day
Maximum water levels	Pumping water level: As is – i.e. ~32 mbgl

Figure L3. Water levels in borehole LG1

Table L3. LG2 Leeu Gamka recommendations for borehole LG2

Current pumping rate	1.4 L/s
Volume abstracted in 2006/7	27 241 m^3 (229 days between 14 Jan & 30 Aug 07) = 119 m^3/day = 1.4 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 46 %
% of town's total supply	~ 46 %
Effect on LG2 water levels	The borehole is doing fine as it is although it would probably be better to pump it continuously rather than in the current start-stop manner.
Effect on monitoring boreholes	There are no monitoring boreholes, although LG1 is affected by abstraction from LG2.
Comments	The borehole and aquifer are doing fine.
Recommended pumping rate	As is – ie 1.4 L/s or ~ 120 m^3/day
Maximum water levels	Pumping water level: As is – ie ~32 mbgl

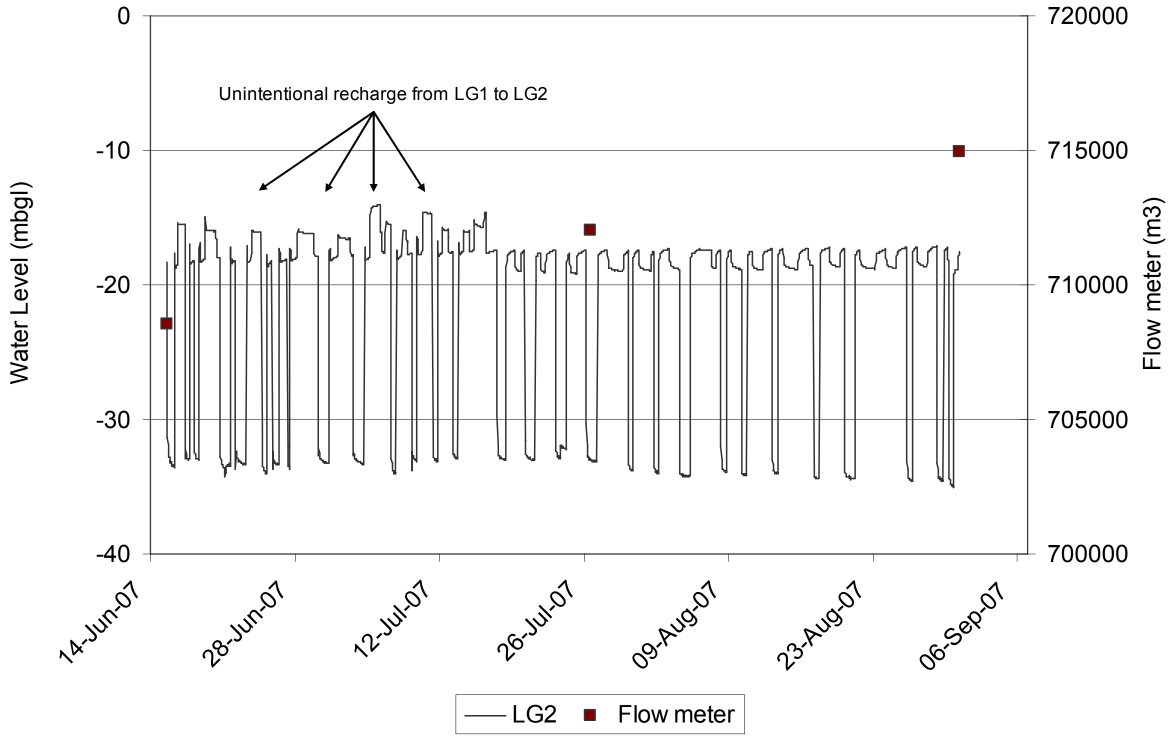


Figure L4. LG Effect of abstraction on groundwater levels

Table L4. Leeu Gamka recommendations for BH LG3

Current pumping rate	Unsure
Volume abstracted in 2006/7	704 m^3 (41 days between 15 Jun & 26 Jul 07) = 17 m^3/day = 0.2 L/s (average assuming non-stop pumping)
% of town's total groundwater supply	~ 7 %
% of town's total supply	~ 7 %
Effect on LG3 water levels	During the 2007 winter, the borehole was hardly used. The borehole is currently under-utilised.
Effect on monitoring boreholes	There are no monitoring boreholes.
Comments	The borehole and aquifer are doing fine. This needs to be monitored over the summer months before it will be possible to say how the borehole is doing.
Recommended pumping rate	As is.
Maximum water levels	Pumping water level: Unsure.

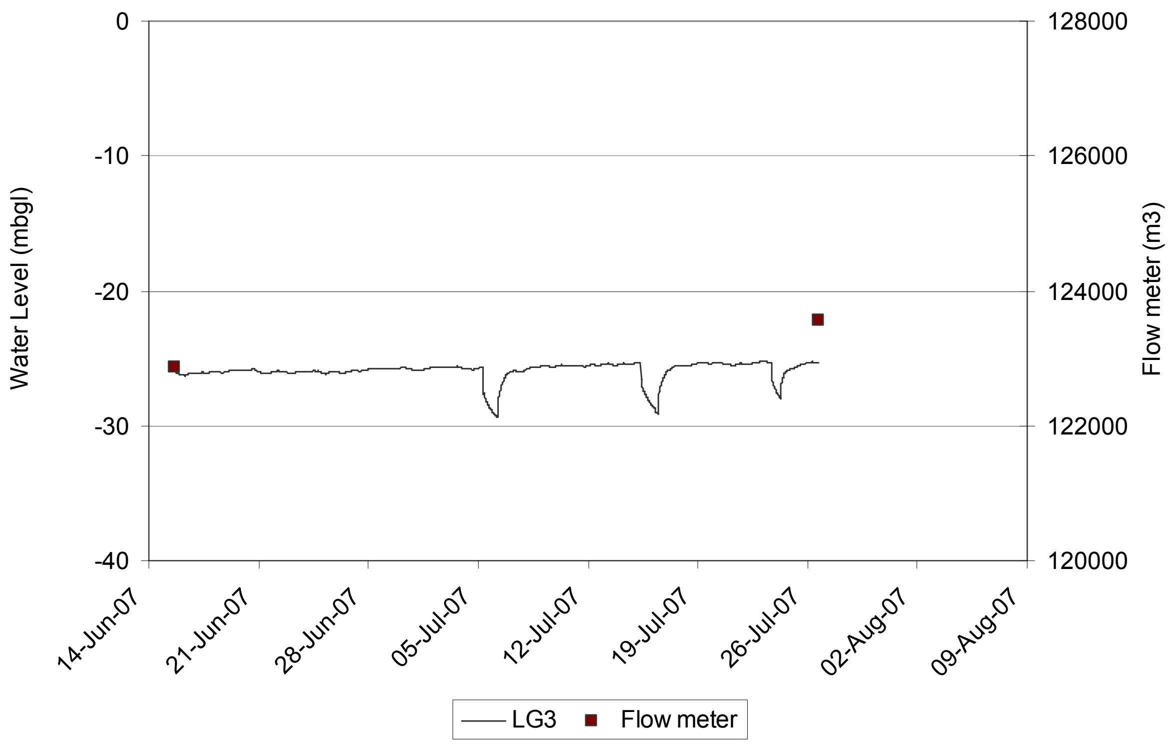


Figure L5. LG3 Effect of abstraction on groundwater levels

15.2 Water quality

Leeu Gamka's groundwater quality is generally good, although a microbiological analysis in January 2007 showed a high faecal coliform count (Tables L5 and L6). All analyses were done by the CSIR lab in Stellenbosch.

Table L5. Leeu Gamka water quality analyses

SAMPLE ID:	LG3	LG2	LG1
SAMPLE DATE:	14-Jan	14-Jan	14-Jan
Potassium as K mg/L	1.9	1.7	1.8
Sodium as Na mg/L	67	96	88
Calcium as Ca mg/L	72	70	72
Magnesium as Mg mg/L	9.9	6.6	7.4
Sulphate as SO4 mg/L	70	117	110
Chloride as Cl mg/L	44	57	53
Alkalinity as CaCO3 mg/L	215	205	212
Nitrate plus nitrite as N mg/L	2.5	<0.1	<0.1
Fluoride as F mg/L	0.65	1.0	1.0
Iron as Fe mg/L	0.06	0.13	<0.05
Manganese as Mn mg/L	<0.05	0.11	0.12
Silica as Si mg/L	9.9	9.8	9.6
Dissolved Organic Carbon mg/L	<1	<1	<1
Conductivity mS/m (25°C)	70	80	79
pH (Lab) (20°C)	7.6	7.8	7.6
Saturation pH (pHs) (20°C)	7.4	7.4	7.4
Hardness as CaCO3 mg/L	220	202	210
Turbidity NTU	1.6	0.8	0.8
Colour mg Pt/L (unfiltered)	<5	5.0	5.0
Arsenic as As mg/L	<0.01	<0.01	<0.01
% Difference	2.34	0.64	0.19
CATIONS meq/L	7.38	8.26	8.07
ANIONS meq/L	7.21	8.20	8.09

Table L6. Leeu Gamka micro-biological analyses

Sample received and analysed: 15 January 2007
Analysis completed: 17 January 2007

Sample description: Water, Leeu Gamka

Sample	Heterotrophic P/C per 1mℓ at 35℃	Total coliforms Per 100 mℓ	Faecal coliforms per 100 mℓ	*E.coli* * per 100 mℓ
7, BH 3	± 120 000	* ± 1 300	* ± 1 000	0
9, BH 2	2 305	40	0	0
11, BH 1	2 345	16	5	0

Not tested/requested indicated by: (-)

* An accurate number was not possible due to the high density of non-coliforms on the culture plates

Note: BH 1 = LG1; BH 2 = LG2; BH 3 = LG3

15.3 Leeu Gamka recommendations

From the monitoring data between January and August 2007, it appears as if the Leeu Gamka's aquifer is under-utilised. If the town requires more water the first step should be to increase the pumping hours of LG1, 2 & 3 and see how the boreholes and aquifer respond. If they don't handle this then new boreholes should be drilled.

The following actions should be implemented in Leeu Gamka:

- No actions regarding the volume of water supplied are needed.
- Monitor abstraction and water levels over the 2007/8 summer and re-assess how the boreholes and aquifer are performing.
- Install water quality sampling taps at each borehole and ensure all borehole enclosures are in good condition.
- Maintain the water quality monitoring programme and if the bacteriological count becomes unacceptable again in LG3, investigate the source of contamination.

SECTION D: ARTIFICIAL RECHARGE

16. Introduction to Artificial Recharge

16.1 Objectives of artificial recharge

At this stage it does not appear necessary to artificially recharge GMUs B and C, as natural recharge is adequate in these areas. The natural recharge to GMU A, however, is less than in GMUs B and C, and with large-scale abstraction in summer, artificial recharge may be necessary to fill the aquifer prior to the onset of the summer season.

The aim of artificial recharge is to rapidly replenish the aquifer when needed in the areas of Pumps 5, 6 & 7 to ensure that the aquifer is full prior to summer.

16.2 The source water

16.2.1 Source water: availability

The furrow supplying Prince Albert with surface water from the Dorps River delivers a minimum summer flow of about 44 L/s or 3 802 m3/day (Appendix 2). Winter flows are higher, at about 63 L/s or 5 443 m3/day (measured in October 2006). Siltation and plant growth slowly reduce the efficiency of the furrow, and as a result it needs to be cleaned annually. This is carried out over four weeks in winter, when water demand from the town is relatively low. The cleaning takes place in two sessions of two weeks each, with a two-week break in-between, between June and August each year. Stored water and groundwater constitute the town supply during this time. At present the water that would otherwise flow down the furrow is left in the river, but it is proposed that a proportion of this water could be used to artificially recharge GMU A boreholes instead.

The availability of artificial recharge water is as follows:

Winter furrow flow:	3 800 m3/day (44 L/)
Municipal winter requirements:	1 100 m3/day (13 L/s)
Available for recharge:	2 700 m3/day (31 L/).

The available volume for recharge during the 4-weeks when the furrow is being cleaned is thus about 75 000 m3. This equates to about 5-weeks of supply during summer – when the water will be abstracted (and where the average requirements are 2 000 m3/day).

If the water levels have been drawn down to pump intakes in Pumps 5, 6, 7 & 8 areas (ie the aquifers have been heavily pumped in these areas), there will be sufficient space for them to accept the available 75 000 m^3.

16.2.2 The source water: quality

The source water for injection would come directly from the furrow. That is, it would be untreated river water that runs off from the Swartberg Mountains and enters the furrow near borehole P2 (unless there has been recent rainfall in the mountains, most of this water will be groundwater that has day-lighted as springs in the Swartberg Mountains).

Samples of this surface water were collected from the upper part of the Furrow and the chemical and microbiological analyses are presented in Table D1. The bacteriological levels in the source water are normal as there are baboon and other animals in the area. Field water quality parameters and flow data are reported in Table D2.

Table D1. Source water quality

SAMPLE ID: SAMPLE DATE:	Furrow 13 Dec 2005	Furrow 14 Jan 2007	Furrow 21 Mar 2007
Analytical lab	CSIR	CSIR	CSIR
Potassium as K mg/L	0.2	0.3	0.2
Sodium as Na mg/L	4.4	5.3	5.5
Calcium as Ca mg/L	2.4	1.2	1.7
Magnesium as Mg mg/L	1	0.8	1
Ammonium as N mg/L		<0.1	
Sulphate as SO_4 mg/L	1.5	1.1	3.7
Chloride as Cl mg/L	6.9	9	8.3
Alkalinity as $CaCO_3$ mg/L	8.3	4	5.6
Nitrate plus nitrite as N mg/L	<0.1	<0.1	<0.1
Fluoride as F mg/L	-	<0.1	-
Total iron as Fe mg/L	-	0.26	0.16
Dissolved iron as Fe mg/L	-	0.12	0.11
Total manganese as Mn mg/L	-	<0.05	<0.05
Dissolved manganese mg/L	-	<0.05	<0.05
Silica as Si mg/L	-	3.3	-
Dissolved Organic Carbon mg/L	<1	-	<1
Electrical Conductivity mS/m (25°C)	4.9	4.5	4
pH (Lab) (20°C)	6.9	6.7	7.1
Hardness as mg/L $CaCO_3$	10	6	6
% Difference	1.71	2.01	2.84
CATIONS meq/L	0.4	0.36	0.41
ANIONS meq/L	0.39	0.36	0.42
Water type	Na/Ca-Cl/HCO_3	Na-Cl	Na-Cl
Heterotrophic P/C per 1 mL at 22°C	-	1690	-
Heterotrophic P/C per 1 mL at 35°C	-	1690	-
Total coliforms per 100 mL	-	145	-
Faecal coliforms per 100 mL	-	16	-
E.coli per 100 mL	-	6	-

- = not analysed

Table D2. Water quality field data and flow rates

		Water quality			Flow	
Date	Time	EC (mS/m)	pH	Temp (°C)	Lower (L/s)	Upper (L/s)
29-Sep-05		1	7.7			
13-Dec-05		4	7.9			
06-Jan-07					42.5	24
31-Jan-07					40.5	22.4
05-Feb-07	12:00	3	6.19	25.70		
26-Feb-07	15:25				36.6	19.2
06-Mar-07	18:15				86.3	61.9
19-Mar-07	12:30				50.8	36.6
06-Apr-07		4	6.82	18.4	46.6	29.2
18-Apr-07		5	6.95	13.9	46.6	29.2
23-Apr-07	18:00	5	6.92	17.8	44.5	25.7
26-Apr-07		1	7.01	16.5	44.5	25.7
02-May-07	12:15	3	7.12	18.3	53	36.6
04-May-07	14:30	3	6.35	18.8	53	32.8
14-May-07	11:00	1	6.01	15.6		
18-May-07	14:30	1	7.13	16.8		
23-May-07	9:30	2	7.06	8.2		
25-May-07	10:00	2	7.1	8.9		
28-May-07		1	6.88	9.2		

Field measurements were also made of dissolved oxygen, temperature and electrical conductivity in the Furrow (10 m above the upper flume) at 15 minute intervals over a 7 hour period on 11 January 2007. The results plotted in Figure D1 show that dissolved oxygen and conductivity were relatively stable, averaging 6.9 mg/L (100% saturation) and 4.1 mS/m, respectively, despite the temperature fluctuations on this hot afternoon. The ambient air temperature was around 40°C.

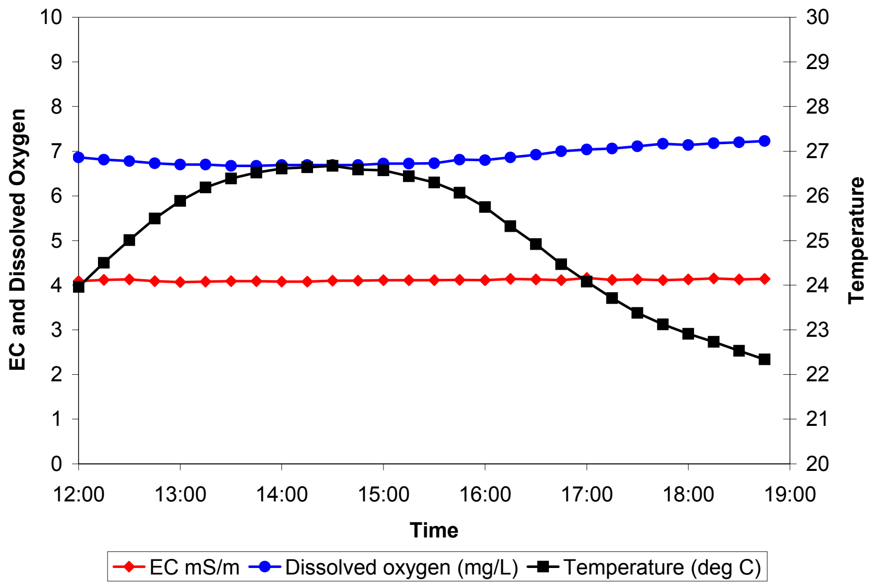


Figure D1. Temperature, conductivity and dissolved oxygen in the source water furrow on 11 January 2007

The quality of the source water appears to be of a consistently high standard. The surface water flows from the high rainfall region in the Swartberg Mountains over inert sandstones of the Table Mountain Group and has a neutral pH, low salinity and low mineral content. No dissolved species of concern were identified in the source water that could indicate chemical contamination and most solutes with potential health effects such as nitrate, fluoride and ammonium were below laboratory detection limits. The microbiological values (plate counts) are common in untreated surface waters and chlorination is recommended for drinking water. The recovered water may also require disinfection before being used for public supply. Dissolved iron may also be of concern due to aesthetic effects and may also require treatment if problems develop.

The available data show no definite signs that this water would be unsuitable for injection in Groundwater Management Unit A. The water has a neutral pH and low dissolved organic carbon and would probably be suitable for injection without treatment. The very low salinity may help to improve the water quality in the vicinity of the injection boreholes, except perhaps for fluoride.

The major water types of all boreholes and the source water are summarised in the trilinear diagram in Figure D2 Waters of similar composition (excluding slight evaporation and dilution effects) will plot near each other in the diamond-shaped field of the diagram.

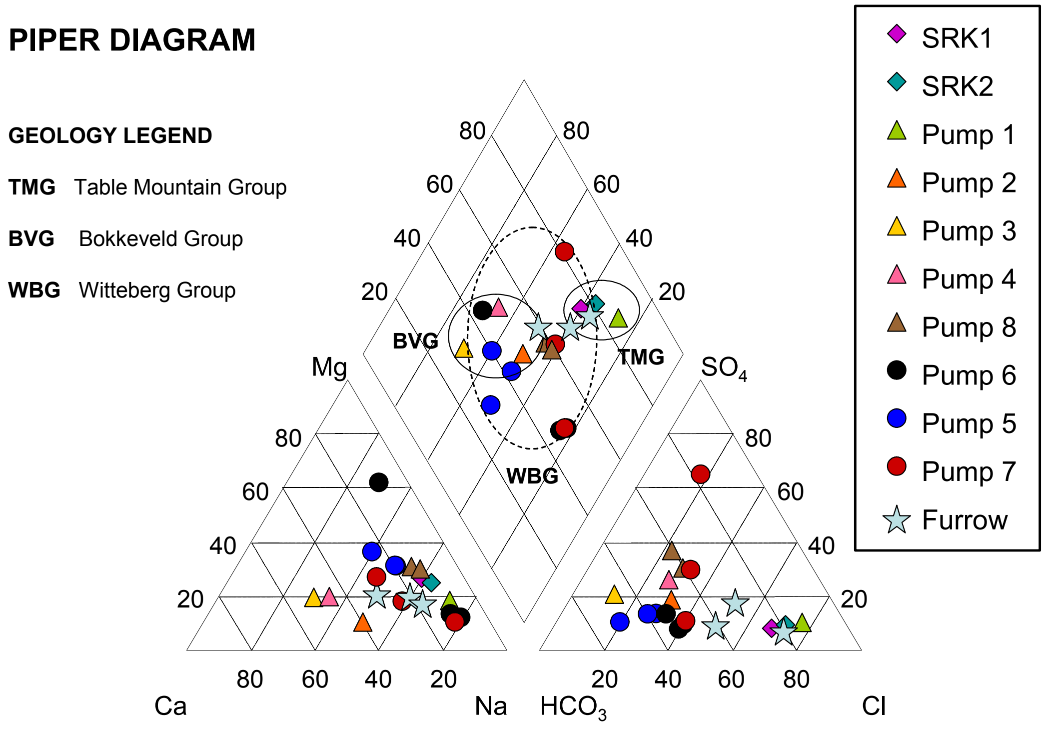


Figure D2. Major ion composition of groundwater and source water from Prince Albert

Figure D2 indicates that the groundwater in Groundwater Management Unit A (Witteberg Group) has a wide range of compositions, probably due to mixing of various recharge sources and variable periods of reaction with different types of aquifer rocks. The source water in the Furrow is closest in composition to the Table Mountain Group boreholes in Groundwater Management Unit C, but should also be compatible with Witteberg Group groundwater, especially from Pump 7 and Pump 8 in terms of major ion chemistry.

16.3 Water quality issues

The groundwater quality in the proposed artificial recharge areas is described in Section B, Chapter 9. This section deals only with issues pertaining to artificial recharge, and should be read in conjunction with Section B, Chapter 9.

16.3.1 Water quality issues: water rock interactions

Because the rocks and soils contain fluorine, water rock interactions during storage in the aquifer might introduce unsafe levels of fluoride over long storage periods. The threat is greater if the injection causes the pH to rise to 9 or above. Fluoride appears to be associated with the shale formations and is highest in waters from Pump 6. Saturation index calculations for all boreholes show that the fluoride concentrations have not reached a limit imposed by the solubility of the mineral, fluorite. This means that if there are fluoride-bearing minerals in the aquifer, they may still dissolve and add more fluoride to the recovered water. The good quality of the recharge water suggests that the species of concern may be diluted by blending the artificial recharge water *in situ*, especially if the injected water is not left in the ground for long time periods. Since storage of recharged water in the aquifer will only be for a few months (typically from July to April and only in years when artificial recharge is needed), it is unlikely that fluoride will become a problem. However, it is recommended that ammonium, nitrate and fluoride are monitored regularly, e.g. every 6 months after injection (if the water is stored in the aquifer for long periods).

16.3.2 Clogging

Two potential causes of clogging are the precipitation of calcium carbonate minerals (scaling) and the formation of iron oxides and biofilms of iron oxidizing bacteria (iron biofouling). A chemical modelling approach was used to determine whether these could pose a threat to an artificial recharge scheme. The geochemical equilibrium model calculates the chemical effects of blending various proportions of two different waters: injection borehole groundwater and Furrow source water. These calculations are based on the June 2007 analyses of Pump 5, 6 and 7 and the March 2007 analysis of the Furrow water.

As with all modelling approaches, the results are based on the quality of the available data and certain assumptions, and are not always an accurate reflection of reality. In particular, this modelling exercise is limited by the lack of data on the redox potential of the water, which strongly influences iron reactions. Dissolved oxygen concentrations from the logging of Pump 6 borehole and the Furrow were used as a substitute to estimate oxidation-reduction potential. The modeling also only considers blending of two water compositions and assumes there are no reactions with the aquifer minerals. Modelling does, however, provide a basis for predicting whether or not certain trends are likely to occur which can be useful in making decisions such as whether or not to proceed with artificial recharge. Graphs from the modeled blending of Furrow and injection borehole waters are shown in Figure D3.

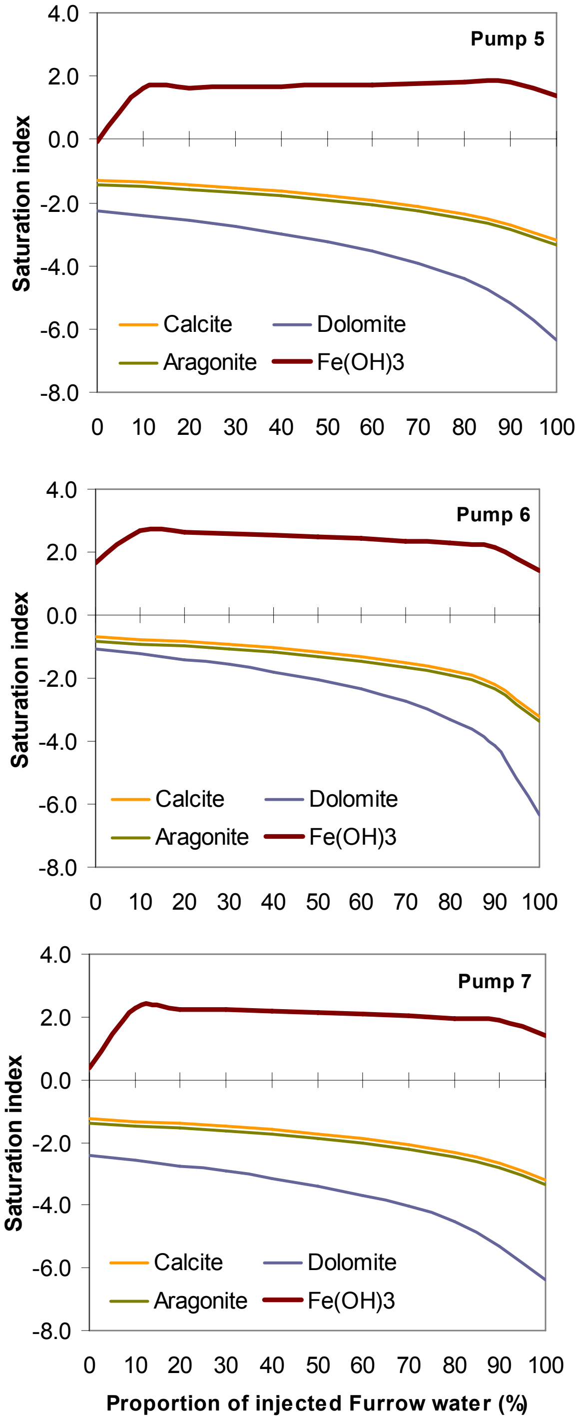


Figure D3. Water blending simulations – tendency to precipitate iron and scaling minerals

The graphs show the changes in the saturation indices for scaling (calcite, dolomite, aragonite) and amorphous iron oxide minerals ($Fe(OH)_3$) as higher and higher proportions of water from the Furrow are added to the groundwater from Pump 5, 6 and 7. A saturation index, plotted on the y-axis, predicts whether a mineral is likely to precipitate or dissolve. All values above the horizontal line (saturation index 0.0) indicate where the mineral would tend to precipitate. Values below saturation index 0.0 show a tendency for dissolution.

The graphs can be interpreted as showing that there should be no significant threat of scaling, since all the calcite, aragonite and dolomite values are below the precipitation limit. Artificial recharge with surface water creates conditions that would discourage calcium carbonate mineral scaling, especially since the recharge water is colder than the groundwater in the winter months and scale usually forms at higher temperatures. Scaling would, therefore not be considered a clogging threat to the artificial recharge plans.

Iron precipitation calculations for all boreholes, however, show that the blended waters may be more likely to precipitate iron minerals than either the boreholes or Furrow water alone. The injection of oxygenated surface water would favour increased iron oxidation and precipitation and iron-related clogging should be monitored in the injection trials. Monitoring includes measuring responses in water levels, production capacity and water chemistry over time, following initial injection tests, to determine whether clogging is occurring.

16.4 Recommendations for water quality monitoring

Based on the water quality, either Pump 5 or Pump 7 are suitable for injection or the two may be used in conjunction. Pump 6 has the poorest quality water in terms of salinity and fluoride content but could be a possible additional injection borehole if extra capacity is required. Groundwater from Pump 7 is of slightly better quality than Pump 5 and Pump 6 and may produce a better recovered water quality. It also appears to be in a slightly less reactive rock unit and may have fewer problems with water-rock interactions during storage. Pump 5 has lower concentrations of dissolved iron and would be the preferred injection borehole if iron clogging is found to be a problem.

Water quality measurements are recommended for two purposes:

- to establish the clogging potential, and
- to ensure that the recovered water is of suitable quality for domestic water supply

The boreholes (and injection water) to be sampled are listed in Table D4.

Table D3. Recommended water quality analysis

Analysis required	Water samples	Frequency
General water chemistry:		
pH (field & lab), conductivity, alkalinity (if possible: field Eh and dissolved oxygen)	Pump 5, 6, 7 Pump 8	after injection (within 1 month) after injection (prior to abstraction)
Major cations & anions & silica Sodium, potassium, calcium, magnesium, chloride, sulphate, silica	Pump 5, 6, 7 Pump 8	after injection (within 1 month) after injection (prior to abstraction)
Dissolved organic carbon	Pump 5, 6, 7 Pump 8	after injection (within 1 month) after injection (prior to abstraction)
Species of concern:		
Iron and manganese	Pump 5, 6, 7, 8	after injection (prior to abstraction)
Fluoride, nitrate, ammonium	Pump 5, 6, 7, 8	after injection (prior to abstraction)
Iron bacteria:	Pump 5 & 7	after injection (prior to the next injection run)

The pH, Eh, alkalinity and calcium concentrations are important for the mobility of iron, fluoride and nitrate. Dissolved oxygen (or Eh), pH, alkalinity, Fe and Mn and DOC are relevant to the clogging issue.

Clogging by iron bacteria is a slow process which takes place over months or years. It is recommended that the injection boreholes be re-sampled after at least three months have passed since the injection trial to look for changes in the iron geochemistry that might give early signs of iron-related problems. It is also recommended that a pre- and post-injection assessment of iron bacteria be conducted. The pre-injection study would be to obtain the current status, and the post-injection study would be necessary if clogging was suspected.

16.5 Artificial recharge storage potential

The artificial recharge potential is governed by four main factors:

1. The rate at which surface water can be supplied for artificial recharge.
2. The storage capacity of the aquifer at the time of surface water (injectant) availability.
3. The rate at which the aquifer can receive the water.
4. The rate at which water is lost from the aquifer after injection/prior to abstraction.

Items 3 and 4 will be dealt with under each borehole, but first to re-cap on the water availability:

As stated earlier, the rate at which surface water can be supplied during the four weeks when it is available for recharge is about 31 L/s or 2 700 m^3/day. This allows for the town to draw off the 1 100 m^3/day that they require during winter. The available volume for recharge during the 4-weeks when the furrow is being cleaned is thus about 75 000 m^3.

16.5.1 Borehole injection potential

The rate at which an aquifer can receive water depends on its hydraulic conductivity. Aquifers with a high hydraulic conductivity can transmit large volumes of water, and hence receive water at high rates. Boreholes yields provide a reasonable estimate of the aquifer's ability to receive water.

The boreholes that are recommended for artificial recharge are Pumps 5 and 7, and possibly Pump 6. It appears from the drilling records and from measured pumping rates that the boreholes at Pumps 5, 6 & 7 should be able to receive up to 60 L/s over a short term, and about 30 L/s over the month-long period when water is available. As stated previously, the length over which the boreholes will be able to receive water will depend on how full the aquifer is at the time of injection.

Table D4. Estimated injection capacities

	Pump 5	Pump 6	Pump 7	Total
Drilling "blow" yield (L/s)	40	12	25	-
Pre-2007 pumping rate (L/s)*	11.4	6.6	7.9	-
Estimated injection capacity (L/s)	~15	~5	~10	~30

* SRK (2004)

Some of the boreholes appear to have lost efficiency (especially P7) and if these injection rates cannot be achieved then the municipality should use the adjacent newly drilled monitoring boreholes for injection, and use P5, 6 & 7 for monitoring. DWAF should not have a problem with this as the intention is to implement a successful artificial recharge scheme and collect good quality data, and both objectives would be met if the new DWAF boreholes wee used for recharge. These boreholes should easily be able to receive the available 31 L/s from the furrow.

16.5.2 The Pump 5 Area: Storage potential

The total volume of water abstracted from the Pumps 5 – 8 area during the 2006/7 summer was 126 400 m^3. Pumping started when the water levels were at "aquifer full" levels (after the 2006 floods), and stopped when water levels dropped to the pumping boreholes' pump intakes. Table D5 summarises the volume of water that was abstracted from Pump 5 during this period.

Note that with reference to Pump 5, 6 & 7 areas, the aquifers at large were not "dewatered" and that the drop in water levels was a function of localised groundwater abstraction and in some cases, poor borehole efficiencies. Nevertheless, the figure presented in the tables below give the volume that can be supplied from when the aquifers are full to when the boreholes can no longer be pumped (because the water levels are at pump intakes). The water that makes up these volumes comes form both storage and inflow into the localised hydraulic depressions. It must also be noted that since the drilling of the new monitoring boreholes, water has flowed into these areas, and that this rate of inflow has not been taken into account when considering artificial recharge rates. Monitoring over the up-coming summer (and longer) is necessary to establish the long-term effect of inflow from the newly drilled boreholes.

Table D5. Pump 5 Artificial recharge and abstraction potential

Aquifer zone	Thickness (m)	Volume/m (m^3/m)	Total Volume (m^3)
Aquifer full: 7 m			
7 – 12 m	5	3 200	16 000
12 – 49 m	37	800	30 000
Current PID: 49 m			
Total			**46 000**
Maximum abstraction rate over 6-months: 250 m^3/day			

PID = Pump intake depth

At this stage natural inflow to this area is not known (and it may decrease with time from the newly drilled borehole). Thus it is not possible to quantify the volume of water required from artificial recharge. A rough estimate would put it at about 50% of the volume that was abstracted or 23 000 m^3.

Water losses

The aquifer is full when water levels are 7 mbgl. Raising water levels above this level will contribute towards river base flow and will be lost from this area.

Artificial recharge should stop at a rest water level of 10 mbgl.

16.5.3 The Pump 6 Area: Storage potential

Table D6 gives Pump 6's artificial recharge potential.

Table D6. Pump 6 Artificial recharge and abstraction potential

Aquifer zone	Thickness (m)	Volume/m (m^3/m)	Total Volume (m^3)
Aquifer full: 5 m			
7 – 14 m	9	1 500	13 600
14 – 46 m	32	320	10 400
Current PID: 59 m			
Total			**24 000**
Maximum abstraction rate over 6-months: 130 m^3/day			

PID = Pump intake depth

The artificial recharge volume estimate (50%) of abstracted volume is 12 000 m^3.

Water losses
The aquifer is full when water levels are ~5 mbgl.
Artificial recharge should stop at a rest water level of 9 mbgl.

16.5.4 The Pump 7 Area: Storage potential

Table D7 gives Pump 7's artificial recharge potential:

Table D7. Pump 7 Artificial recharge and abstraction potential

Aquifer zone	Thickness (m)	Volume/m (m^3/m)	Total Volume (m^3)
Aquifer full: 2 m			
2 – 5 m	3	3 500	10 600
5 – 40 m	35	800	27 800
Current PID: 59 m			
Total			**38 400**
Maximum abstraction rate over 6-months: 210 m^3/day			

PID = Pump intake depth

The artificial recharge volume estimate (50%) of abstracted volume is 19 200 m^3.

Water losses
The aquifer is full when water levels are ~2 mbgl.
Artificial recharge should stop at a rest water level of 5 mbgl.

16.5.5 The Pump 8 Area: Storage potential

Table D8 gives Pump 8's abstraction/depth figures. Pump 8 is likely to be affected by recharge at Pump 7, and thus this borehole's yield potential is included here.

Table D8. Pump 8 Artificial recharge and abstraction potential

Aquifer zone	Thickness (m)	Volume/m (m^3/m)	Total Volume (m^3)
Aquifer full: 2 m			
2 – 7 m	5	1 400	6 800
7 – 30 m	23	500	11 300
Current PID: 46 m			
Total			**18 000**
Maximum abstraction rate over 6-months: 100 m^3/day			

PID = Pump intake depth

The artificial recharge volume estimate (50%) of abstracted volume is 9 000 m^3.

Water losses
The aquifer is full when water levels are ~2 mbgl.
Artificial recharge should stop at a rest water level of 5 mbgl.

16.5.6 Artificial recharge potential

Table D9 summarises the total groundwater abstracted from Pumps 5, 6, 7 & 8 during the summer of 2006/7 and the estimated artificial recharge potential (all figures are rounded off).

Table D9. Total groundwater abstracted from pumps 5 to 8

	Injection potential		Total injection potential over the 28-days of water availability	
	L/s	m^3/day	Total potential (m^3)	Estimated requirement (m^3)
Surface water availability	**31**	**2 700**	**75 000**	**62 000**
Borehole / aquifer potential				
P5	15	1 300	36 000	23 000
P6	5	430	12 000	12 000
P7	11	950	27 000*	27 000*
Total injection potential	**31**	**2 680**	**75 000**	**62 000**

* P7 & P8 areas

Note that after an extended drought, inflow into the P5, 6 & 7 areas may be limited and the storage space available for recharge may be closer to 120 000 m^3 than 60 000m^3. In this case, it would be best to inject as much water from the furrow as possible to ensure the aquifers are full prior to the up-coming summer.

Summary of artificial recharge potential:

- The volume of water available for recharge over the 28-day period when the furrow is being cleaned is estimated to be about 75 000 m^3.
- If the water levels in the aquifer have been drawn down to current pump intakes in the P5, 6, 7 & 8 areas, the maximum volume of water that could be recharged is about 125 000 m^3.
- Allowing for natural inflows, the artificial recharge requirement is estimated to be about half this or 62 000 m^3. After droughts, this figure may be about 100 000 m^3.
- Because the newly drilled monitoring boreholes affected the inflow to these areas, they will need to be monitored after heavy abstraction to establish to what extent they contribute (over the long term) towards the inflow to these areas.

16.6 Other Issues that affect the viability of artificial recharge

16.6.1 Environmental issues

An environmental study was conducted by Prof S Milton from Sukaroo. The study raised environmental concerns, undertook a vegetation baseline investigation of the artificial recharge areas and assessed the environmental regulatory requirements (Appendix 3). For borehole injection testing no environmental authorisation is required. Environmental authorisation may be required prior to the Implementation Phase of the project, but this will depend on the design which will be finalised after the injection tests. Is so, a Basic Environmental Assessment may be required.

The main benefit of artificial recharge will be:

- A greater assurance of water supply to Prince Albert
- On-going groundwater management to ensure optimal conjunctive use of surface and groundwater.
- The Pump 5, 6 & 7 areas will rapidly be re-filled after heavy summer abstraction.

The main environmental concern with groundwater use in the P5, 6 & 7 areas are:

- The lowering of the water table by tens of metres.

Since water level monitoring began in 2003, the water levels have been drawn down to pump–intakes every year (Figure C18) and prior to that the pump operator at the time noted that in summer “the boreholes run dry”. This practice has been going on for years, and with artificial recharge, these water levels will rapidly be restored to “full” levels every July/august when the furrow is cleaned.

The main environmental concern with artificial recharge is:

- Introducing “foreign” water into the aquifer.

The recharge water is from runoff from the Swartberg (which includes a high proportion of spring flow – ie naturally discharging groundwater). The water quality assessment shows that the waters are compatible, although the recharge water is of better quality (lower salinity) than the groundwater in the Pump 5, 6 & 7 areas.

The report by Sukaroo describes the environmental requirements for each project implementation stage including the general duty of care obligations that cover all activities in terms of Section 28 of NEMA.

Based on the activities proposed, it is not likely that any environmental authorisation will be required.

16.6.2 Engineering issues

Three boreholes have been identified for injection, P5, P6 and P7. P 5 & 6 share a single 100mm asbestos cement pipeline and P7 has a dedicated 100mm asbestos cement pipeline.

For the testing phase injection the following is proposed:

1. The existing pumps and pumping mains be removed from the boreholes during the pumping test.
2. Each borehole be equipped with a 30m long section of 2 inch or 3 inch diameter lay flat hose with a flow disperser attached to the down hole end.
3. The flow disperser will be made up stainless steel pipe with holes drilled to dissipate the flow. The desired flow rate and residual pressure will dictate the number and size of the holes.
4. The pipe and valve work at the borehole wellhead will be changed to suit the purpose of recharging including pumping to waste before injection. This requires placing a gate valve between the pump and the scour, reversing or removing the non-return valve, reversing or removing the water meter, installing a pressure gauge and installing a disk filter if required.
5. The existing supply pipelines will be used in reverse, to pump the recharge water from the raw water reservoir back to the boreholes.
6. The capacity of the existing borehole pumps will be verified when they are removed and if appropriate, installed in the raw water reservoir and used to pump the recharge water back to the three recharge boreholes.

If the injection tests are successful and the project progresses to full implementation, permanent recharge infrastructure must be designed and sized for the final recharge flows and conditions. This will include the following components:

1. Dedicated recharge boreholes
2. Gravity supply lines from the planned pipeline (replacing the furrow) to the recharge boreholes

3. Wellhead recharge components: scour, line valve, disk filter, pressure gauge, flow meter (agricultural), observation section, air valve, line valve, coupling to down hole piping.
4. Down hole recharge piping and flow control and pressure control components

16.6.3 Economics

Neither the capital nor the operation and maintenance costs of the proposed artificial recharge scheme have been costed. Most of the capital items have been paid for – new monitoring boreholes have been drilled and water level logging equipment has been bought. The engineering capital costs for the infrastructure to conduct injection tests in three boreholes is estimated to be R 100 000. After conducting the injection tests it will be possible to do the final design for production. The additional capital items are likely to be gravity supply lines (if the proposed new pipeline is installed in the furrow), permanent wellhead recharge infrastructure and permanent down-hole recharge piping. For the testing phase, the hydrogeological and engineering design costs are estimated to be about R 120 000 giving a total artificial recharge testing costs of about R 220 000. Without the testing results it is not possible to develop a budget for the final design and construction. A ball-park estimate would put it at about R 300 000, giving a total scheme cost in the order of R 500 000 (incl VAT).

A reasonable comparison would be to be to compare this cost to that of storing the available source water supply of 75 000 m^3 in a dam. The costs of this would include identifying a dam site, undertaking an environmental assessment, designing the dam and constructing it (including the conveyance infrastructure). Assuming a 120 000 m^3 rock-fill dam is required to give an assured supply of 75 000 m^3, the design and construction costs would be in the order of R 3 500 000, and this excludes the environmental study and conveyance infrastructure, which could be substantial.

The difference between a surface dam and sub-surface storage is that with artificial recharge a minimum supply of 75 000 m^3 can be guaranteed every year. This is a conservative figure as it only accounts for the volume of water available for artificial recharge and assumes no natural inflow into the aquifers. In reality the aquifers should be able to be filled every year (both naturally and with artificial recharge) and the total volume available would be about 120 000 m^3.

The best way to consider the economic aspects of the proposed artificial recharge scheme is to say that it will cost about R 500 000 to guarantee about 2 months of water supply during summer. This is over and above the summer supply from the furrow and the main summer supply from boreholes in Groundwater Management Units B & C.

In terms of operational costs, the two key on-going expenses are monitoring injection rates, water levels and water quality, and the periodic rehabilitation of boreholes if clogging becomes a problem.

16.6.4 Institutional Issues

Artificial recharge schemes require a licence from DWAF and they may require environmental authorisation if any NEMA-listed activities are conducted. Associated with artificial recharge scheme licences are monitoring and reporting requirements. The institutional capacities of both the scheme operator and the regulatory authority need to be sufficient to ensure that the scheme is operated according to design standards. Reporting and performance monitoring systems need to be in place to maintain optimal scheme operation.

The institutional framework for artificial recharge management is presented in Table C.3 (DWAF, 2007).

Table D10. Institutional framework for artificial recharge management

	DEAT regional office		Licensee or user		Catchment Management Agency
Key legal responsibilities	Overall environmental resource management	Environmental authorisation conditions (→) Information & reports (←)	Operate schemes according to licence conditions	Licence Conditions (←) Information & reports (→)	Overall water management within the CMA
Responsibilities with respect to monitoring and management of AR schemes	Support users to establish environmental monitoring requirements Ensure users know their monitoring & reporting responsibilities Review reports and environmental permits	Information & reports (←) Support & monitoring (→)	Manage, operate and monitor schemes within the conditions of the water use licence and environmental permit Collect monitoring data on water quality, water levels, abstraction injection and environmental aspects Store & process monitoring data and compile reports for the CMA/DWAF and DEAT. Analyse data and recommend operational changes	Information & reports (→) Support & monitoring (←)	Support users to establish the groundwater & AR management needs Ensure users know their monitoring & management responsibilities Draft water use licences to include monitoring, data and reporting requirements Review reports and licences

Source: DWAF, 2007

16.7 Management and technical capacity

Prince Albert municipality has ample technical capacity to monitor boreholes and water quality. However, the operation of an artificial recharge scheme can give rise to technical issues (such as iron precipitiation or bio-fouling) which require specialist advice. Prince Albert's planned artificial scheme is small and simple, but it will need to be managed or else it will become inefficient. The management skills required are not demanding, but the responsible person will require support until the operational tasks are fully understood.

16.8 Legal and regulatory issues

DWAF have approved the conducting of injection tests (Appendix 4). Once these tests have been finalised and the final injection volumes established, the municipality will have to apply for a licence to store water underground. The project implementation and authorisation stages are listed in Table D11:

Table D11. Artificial recharge project implementation and authorisation stages

Project Stage	Key Activities	Status	Authorisation requirements
Pre-feasibility Stage	Identify the potential AR project and describe the information currently available.	✓ (Groundwater Africa, 2006)	None.
	Based on existing information, comment on the feasibility of the project.	✓ (Groundwater Africa, 2006)	
	Describe the work required for the Feasibility Stage and estimate the cost of undertaking the feasibility study.	✓ (Groundwater Africa, 2006)	
	Establish existing water use licence conditions and authorisation requirements from DWAF and DEAT.	✓	
Feasibility Stage	Inform DWAF & DEAT of injection tests.	✓	None. No NEMA listed activities will be done, and DWAF has given the go-ahead for injection testing (but a meeting with DWAF needs to be held prior to the tests to discuss monitoring requirements)
	Conduct the feasibility study. This should include AR testing (eg injection tests, infiltration tests, pumping tests, water quality assessments, etc)	✓ (This report, except injection testing)	
	Develop a preliminary infrastructure design.	Outstanding	
	Identify the project implementation phases if a phased approach is necessary (eg starting small and expanding after successive recharge cycles).	Not necessary.	
	Estimate the costs of the project.	After injection testing.	

Project Stage	Key Activities	Status	Authorisation requirements
	Identify funding sources	After injection testing.	
	Compile a detailed project implementation plan.	After injection testing.	
Implementation Stage	Obtain the necessary water use licence and environmental authorisation for the AR scheme.	After injection testing.	Water use licence and possibly environmental authorisation
	Drilling and testing new injection and abstraction boreholes	Not necessary (use existing Bhs)	
	Set up the groundwater and recharge water monitoring system	Largely been done. Finalise after injection testing.	
	Develop the detailed infrastructure design, carry out the tendering processes, and construct the project.	After injection testing.	
	Compile monitoring, operation & maintenance procedures.	After injection testing.	
Operation and Maintenance Stage	Carry out performance monitoring during production.		Compliance monitoring and reporting.
	Modify operation & maintenance procedures based on scheme performance.		
	Develop final monitoring and reporting system.		

17. CONCLUSIONS

In terms of understanding the town's water resources, Prince Albert has come along remarkably over the past three years. Prior to the DWAFs Artificial Recharge and Masibambane Projects, little was known about the availability of groundwater resources and the idea of recharging aquifers was unheard of. Now the town has a good knowledge of the available water resources, their water quality, and how to use them optimally and in a conjunctive manner.

The conclusions have been drawn mainly from the close monitoring of groundwater level responses to abstraction over a period of less than one year (in most cases). This monitoring period was preceded by exceptionally high rainfalls in 2006, and this resulted in filling the aquifers. All conclusions are preliminary as monitoring data needs to be gathered to cover the dry years as well. In the interim, the following conclusions and recommendations can be made:

17.1 Prince Albert

The following conclusions can be made at this stage:

- No new water sources are currently needed for Prince Albert
- Artificial recharge may be required to fill the aquifers near town (Groundwater Management Unit A) prior to summer.
- The volume of water available for artificial recharge during the cleaning of the furrow is estimated to be 75 000 m^3.
- This water should be used for artificial recharge until the aquifers are full.
- Borehole injection tests should be conducted to check the estimated artificial recharge requirements of about 60 000 m^3/a (to fill the aquifers).
- If well managed and assuming the aquifers are full (if needs be with artificial recharge), groundwater and surface water (furrow allocations) can meet the average requirements for both summer (2 000 m^3/day) and winter (1 100 m^3/day).
- The uneven surface water allocations from the furrow make it extremely difficult to supply the peak summer requirements of 2 750 m^3/day on a consistent basis. This is the required supply rate for weeks on end during the hot summer months.
- By maximising groundwater use (and assuming the aquifers are full at the start of the summer period), the "extended" peak demand of 2 750 m^3/day can be met on Wednesdays, Thursdays and Saturdays when furrow allocations are above average. But on Mondays, Tuesdays, Fridays and Sundays, it may not be possible to meet this high demand.
- The peak-day summer requirement of 3 000 m^3/day (*ad hoc* demand on exceptionally hot days) can only be met on Wednesdays, Thursdays and Saturdays because of the longer furrow allocations.
- The furrow allocation schedule should be changed to provide a continuous supply of water. This will make the management of Prince Albert's water supply far easier and the supply of water consistent.

- The proposed pipeline should be installed in the furrow and a fair portion of the savings on water losses along the furrow be allocated to the municipality. Together with groundwater management, artificial recharge and improved water demand management this would ensure the town has a reliable, long-term water supply.

17.2 Klaarstroom

The following conclusions can be made at this stage:

- Reduce the pumping rate of borehole KS1 to 1 L/s, pump continuously (24 hours/day) and monitor KS1 and KS2.
- Install a flow meter at KS2. Halve its pumping rate and pump continuously if needed. Monitor KS1 and KS2.
- If more water is needed, drill new boreholes to intersect the sandstones of the Boplaas Formation on the farm Klaarstroom below the irrigation dam.

17.3 Leeu Gamka

The following conclusions can be made at this stage:

- No actions regarding the volume of water supplied are needed.
- Monitor abstraction and water levels over the 2007/8 summer and re-assess how the boreholes and aquifer are performing.
- Install water quality sampling taps at each borehole and ensure all borehole enclosures are in good condition.
- Maintain the water quality monitoring programme and if the bacteriological count becomes unacceptable (as was previously the case at borehole LG3), investigate the source of contamination.

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