Bitou Municipality

GROUNDWATER MANAGEMENT AND ARTIFICIAL RECHARGE FEASIBILITY STUDY

R Murray
Groundwater Africa
PO Box 162
Lynedoch
Stellenbosch, 7603
South Africa

www.groundwaterafrica.co.za
email: ricky@groundwaterafrica.co.za
ph & fax: +27 21 881 3082
cell: +27 823 238 303

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GROUNDWATERAFRICA

CONTENTS

EXECUTIVE SUMMARY v
ACKNOWLEDGEMENTS vii

SECTION A: INTRODUCTION 1

1. INTRODUCTION 1

- *1.1 Terms of reference 1*
- *1.2 Project objectives 1*
- *1.3 Regional planning studies 2*

2. CURRENT AND FUTURE WATER REQUIREMENTS 2

3. WATER SUPPLY INFRASTRUCTURE 6

SECTION B: HYDROGEOLOGICAL SETTING 8

4. HYDROGEOLOGY 8

- *4.1 Hydrogeological overview 8*
- *4.2 Municipal Boreholes 11*
- *4.3 Existing Reports and Studies 14*
- *4.4 Aquifer hydraulic properties 17*
- *4.5 Groundwater quality 20*
  - 4.5.1 Salinity 23
  - 4.5.2 pH 26
  - 4.5.3 Dissolved oxygen and oxidation-reduction potential (ORP) 26
  - 4.5.4 Iron and manganese 26
  - 4.5.5 Dissolved organic carbon 27
  - 4.5.6 Solutes with potential health effects 27
  - 4.5.7 Potential sources of contamination 27
- *4.6 Isotope data 28*
- *4.7 Groundwater protection 29*
- *4.8 Rainfall 29*

SECTION C: GROUNDWATER MANAGEMENT 30

5. PURPOSE OF GROUNDWATER MANAGEMENT 30

6. GROUNDWATER USE: REGISTERED AND CURRENT 31

7. GROUNDWATER MANAGEMENT STATUS PRE- AND POST-MASIBAMBANE 31

- *7.1 Pre-Masibambane groundwater management status (prior to 2006) 31*
- *7.2 Post-Masibambane groundwater management status (after 2006) 33*

8. THE PROPOSED GROUNDWATER MANAGEMENT SYSTEM 34
8.1 What groundwater management entails 34
8.2 Institutional Framework for Groundwater Management 35
8.3 Main institutional tasks and responsibilities: 36
8.4 Specific groundwater management tasks for Bitou Municipality 38
8.5 Individual borehole management 41
8.5.1 Borehole 3 (GCS1R) 41
8.5.2 Borehole 6 (GCS3R) 41
8.5.3 New Horizons Borehole 42
9. NEW ABSTRACTION RECOMMENDATIONS 42
9.1 Results of high abstraction from Bh3 from February to July 2007 42
9.2 New Pumping Recommendations 45
9.2.1 Existing equipment 45
9.2.2 Ideal New Pumping Rates: Replace all pumps 46
SECTION D: ARTIFICIAL RECHARGE 48
10. OBJECTIVES OF ARTIFICIAL RECHARGE 48
11. THE SOURCE WATER: AVAILABILITY AND QUALITY 48
11.1 Source water availability 48
11.1.1 Supply of treated water 49
11.1.2 Supply of untreated water – the Keurbooms River raw water bypass 50
11.2 The source water: quality 51
12. WATER QUALITY ISSUES 56
13. THE ARTIFICIAL RECHARGE POTENTIAL 57
13.1 Aquifer Storage Capacity 57
13.2 The borehole injection capacity 58
13.3 Water losses 59
14. OTHER ISSUES THAT AFFECT THE VIABILITY OF ARTIFICIAL RECHARGE 59
14.1 Environmental Issues 59
14.2 Economics 61
14.3 Institutional Arrangements 62
14.4 Management and Technical Capacity 64
14.5 Legal and Regulatory Issues 64
15. THE ARTIFICIAL RECHARGE PROJECT PLAN 66
16. CONCLUSIONS 66
17. REFERENCES 69

Appendix 1	Municipal borehole status report (August 2007)
Appendix 2	Down-hole logging report by Dr G Tredoux, CSIR
Appendix 3	Environmental requirements for artificial recharge - letter from Ashwin West and Mike Luger, Ninham Shand
Appendix 4	DWAF authorisation to conduct artificial recharge tests

TABLES

Table 1: Demand Projections 3
Table 2: Annual increase in demand. 4
Table 3: The main municipal boreholes 12
Table 4: Known private boreholes in and around the Kwanokathula Aquifer 13
Table 5: Boreholes in the Peninsula Formation (mostly) 14
Table 6: Summary of Kwanokathula Aquifer properties (after GCS, 1993) 17
Table 7: Transmissivity values for the main Kwanokathula boreholes 18
Table 8: Boreholes water quality: Monitoring boreholes 21
Table 9: Boreholes field EC, pH & temperature 23
Table 10: Isotope data for Bh3 28
Table 11: DWAF Registered Groundwater Use 31
Table 12: Generic groundwater management functions 37
Table 13: Specific groundwater management tasks for Bitou Municipality 39
Table 14: Newly recommended borehole pumping rates: existing pumps 45
Table 15: Newly recommended borehole pumping rates: replace existing pumps. 47
Table 16: Available flow in L/s for recharge based upon supply pipeline to Kwanokathula reservoir 50
Table 17: Source water quality 51
Table 18: Preliminary injection water quality criteria 55
Table 19: Institutional framework for artificial recharge management 63
Table 20: Artificial recharge project implementation and authorisation stages 65
Table 21: Phases of developing an artificial recharge scheme for Bitou Municipality 66

FIGURES

Figure 1: Historical and forecast water demand for Plettenberg Bay (Bitou Municipality, 2003) 3
Figure 2: Monthly variation in water demand for Plettenberg Bay 4
Figure 3: Monthly variation in water demand for Plettenberg Bay town and Kwanokathula 5
Figure 4: Kwanokathula average monthly water consumption........ 6
Figure 5: Kwanokathula annual water consumption 6
Figure 6: Schematic diagram of the existing water supply arrangements for Greater Plettenberg Bay........ 7
Figure 7: Jointed and fractured Peninsula Formation quartzite at Plettenberg Bay........ 8
Figure 8: Geological map of the Plettenberg Bay area, showing the locations of some of the main boreholes located in the Kwanokathula Aquifer........ 9
Figure 9: Map of Plettenberg Bay showing the lines of cross-section........ 10
Figure 10: N-S hydrogeological cross-section 10
Figure 11: W-E hydrogeological cross-section........ 11
Figure 12: Diagrams of Plettenberg Bay municipal boreholes 13
Figure 13: Bh 3 Production Pumping (April 2007)........ 18
Figure 14: New Horizon/Hillview borehole Constant Discharge Test (1998) 19
Figure 15: Inferred groundwater contours in mamsl (after Knight, Dames & Moore, 1985)........ 20
Figure 16: Electrical conductivity and abstraction from Bh3 during recent pumping........ 24
Figure 17: Electrical conductivity profiles 25
Figure 18: Plettenberg Bay monthly rainfall 29
Figure 19: Components of groundwater management........ 30
Figure 20: Borehole water levels at Kwanokathula 32
Figure 21: Principle Groundwater Management Tasks........ 34
Figure 22: Institutional framework for groundwater management........ 35
Figure 23: Water level response to abstraction from Bh3 42
Figure 24: BH6: Water level during abstraction from Bh3........ 43
Figure 25: NH: Water level during abstraction from Bh3........ 44
Figure 26: Bh2: Water level during abstraction from Bh3 44
Figure 27: Bh3: Groundwater salinity during abstraction 45
Figure 28: Monthly treatment works supply and spare capacity (based on current utilised treatment works capacity of 410,000 kL per month) 49
Figure 29: Monthly water demand and supply capacity for Kwanokathula (based upon the supply pipeline capacity of 24 L/s)........ 50
Figure 30: Time series graphs of electrical conductivity and pH for raw and treated potential injectant water........ 53
Figure 31: Time series graphs of iron and DOC for raw and treated water (potential injection water) 54
Figure 32: Major ion composition of groundwater and source water from Plettenberg Bay........ 55

EXECUTIVE SUMMARY

Project Aims

The aims of the project were to:

1. Develop a groundwater management system for Bitou municipality.
2. Investigate the feasibility of artificially recharging the Kwanokathula wellfield.

Groundwater management system

Prior to the Masibambane Project, groundwater monitoring was done on an ad hoc basis, and the data was insufficient to develop an assessment of the groundwater potential and the artificial recharge potential of the Kwanokathula Aquifer. All municipal boreholes in and around Kwanokathula are now equipped with data loggers and the means to collect borehole water levels and abstraction data. Water level readings are recorded every 30 minutes and the data for 2007 has been analysed (in this report). Most of the existing data has been entered into the Aquimon groundwater monitoring software package, but this still has to be handed over to the municipality and training and support in operating the software still needs to take place. All the groundwater management tasks have been defined (included in this report) and municipal staff have been informed of these tasks. A period of training and support is needed to ensure that the monitoring system is incorporated into the water supply operation and maintenance system. In summary, the platform for groundwater management has been put in place. What is outstanding, and crucially important, is for the management system to be entrenched within the municipality. This will require further training and support.

Artificial Recharge

An artificial recharge feasibility study has been completed and the findings are contained in this report. All aspects that affect the success of an artificial recharge scheme were assessed; however, it was not possible to conduct trial borehole injection tests. It is recommended that these tests be conducted to establish individual borehole injection capacities and to assess the ability of the aquifer to receive and store recharged water. The potential benefits in terms of having substantial stored, treated water reserves is substantial, and the costs of implementing artificial recharge are low in comparison to above-ground storage.

Key findings and recommendations

The main conclusions and recommendations are:

- Groundwater is currently under-utilised by the municipality. Over the past 8 years, an average of 134 000 m^3/annum (4.3 L/s) has been abstracted.
- The municipality should increase groundwater abstraction from existing boreholes to the Registered Use of 362 366 m^3/a (11.5 L/s).
- This they should do by non-stop pumping in the following manner:
    - Bh3: 4.4 L/s
    - Bh6: 4 L/s
    - Bh NH: 4 L/s

- With artificial recharge the aquifer's stored reserves could theoretically be increased by about 750 000 m^3, and together with the existing Registered Use, this could potentially increase the supply from the aquifer to over 1 Mm^3/a.
- The intention would be to transfer treated Keurbooms River water to the Kwanokathula Aquifer via existing boreholes in winter, and abstract the water from the same boreholes (and possibly other, down-gradient boreholes as well), in summer.
- At present the main limiting factor in "getting water underground" is capacity of the pipeline that would supply treated water to the Kwanokathula boreholes. This pipeline has a capacity of 24 L/s (P Lombard, *pers. comm.*) and about half of this would be required to supply the Kwanokathula settlement if the boreholes were being used for artificial recharge.
- If Kwanokathula could be supplied from another (new) pipeline, then about 300 000 – 400 000 m^3 could be used for borehole injection over a 6-month injection period (using existing pipelines).
- Borehole injection tests should be conducted to establish the recharge capacities of individual boreholes and to assess the ability of the aquifer to receive and store recharged water for seasonal use.
- It is critical that top quality water be used for injection. Iron and dissolved organic carbon concentrations must be less than 0.1 and 3 mg/L respectively.
- The Department of Water Affairs and Forestry has approved borehole injection tests, however, they require a meeting prior to the tests to discuss monitoring requirements.
- Further support to municipal staff is needed to ensure that the established groundwater monitoring system is entrenched within the municipality, and that the overall groundwater management system is incorporated into the water supply management system.

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 Bitou Municipality and gave valuable input on the town's groundwater resources and artificial recharge. Mr Piet Havenga installed DWAF data loggers in boreholes and supplied data until the municipality bought their own loggers. Valuable inputs were also provided by Dr Frans Stofberg, Mrs Issa Thompson and Mr Fanus Fourie. The groundwater management component of this project/report was supported by the Masibambane Programme.
- *Bitou Municipality.*The author would like to thank the staff of Bitou Municipality for their cooperation and assistance during the work, particularly Mr Henry Geldenhuys, Mr Pikkie Lombard, Mr Ronald Tarentaal and Mr Randall Bouwer.
- *Mr Johann Rissik,* while employed by Groundwater Africa, carried out all on-the-ground activities including data logger installations, logger downloads, etc., developed the groundwater supply and management task lists, supported municipal staff in groundwater monitoring and helped with this report.
- *Mr Phillip Ravenscroft* of Maluti GSM offered valuable engineering knowledge to borehole designs for artificial recharge and other topics, and he wrote the following sections: Current and future water requirements, water supply infrastructure, source water availability and and supply for artificial recharge water. His report to Groundwater Africa (incorporated within the body of this report) is entitled Plettenberg Bay: Aspects of Artificial Recharge Feasibility Study.
- *Dr Lisa Cave* analysed and modeled water quality (artificial recharge blending scenarios) and wrote the sections on water quality.
- *Dr Gideon Tredoux* from the CSIR offered his vast experience on artificial recharge, carried out the down-hole geochemical logging, and reviewed and provided valuable input on water quality and geochemical issues.
- *Mr Jude Cobbing* reviewed hydrogeological aspects of the report and helped compile it.
- *Ninham Shand,* and in particular Ashwin West and Mike Lugar assessed the environmental requirements for artificial recharge, and Eric van der Berg and Mike Shand shared their overall knowledge on Bitou Municipality's water supply infrastructure and related matters.

SECTION A: INTRODUCTION

1. INTRODUCTION

1.1 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). Plettenberg Bay is mentioned in the national strategy – it 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 huge increase in demand over the summer months.

Funding for implementing these projects had the following support:

- Masibambane (DWAF): 1-year support.
- Directorate of Water Resource Planning Systems (DWAF): 2-year support.
- Bitou Municipality: Purchased all groundwater monitoring equipment.

1.2 Project objectives

The overall project objective is to set up a groundwater management system that includes artificial recharge, if viable. The project needs to:

- Set up all the components of the groundwater management system including optimising existing borehole supplies and training in groundwater management.
- Establish the feasibility of artificially recharging the Kwanokathula Aquifer and providing training on operating an artificial recharge scheme.

As stated above, the Masibambane funding covered the first 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.

1.3 Regional planning 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).

2. CURRENT AND FUTURE WATER REQUIREMENTS

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

The municipal water meter records from January 2004 to April 2007 have been used to quantify the water demand of Plettenberg Bay. The medium to long-term projections of the Plettenberg Bay water demand presented in Table 1 and Figure 1 are from the Bitou Municipality water augmentation study (Bitou Municipality, 2003).

Table 1: Demand Projections

Annual Growth Rate		2002	2005	2010	2015	2020	2025
6.00% (2002-2007), 3.50% (2008-2025)	Annual Average Demand (million m^3/annum)	2.70	3.22	4.01	4.76	5.65	6.71
	Sustained Peak Demand (Ml/d) (Estimated PF=2)	14.78	17.60	21.93	26.05	30.93	36.74
6.00% (2002-2007), 4.90% (2008-2025)	Annual Average Demand (million m^3/annum)	2.70	3.22	4.17	5.30	6.73	8.55
	Sustained Peak Demand (Ml/d) (Estimated PF=2)	14.78	17.60	22.83	29.00	36.84	46.79
6.00% (2002-2007), 6.50% (2008-2025)	Annual Average Demand (million m^3/annum)	2.70	3.22	4.36	5.98	8.19	11.22
	Sustained Peak Demand (Ml/d) (Estimated PF=2)	14.78	17.60	23.89	32.13	44.85	61.45

Notes:
Annual Average Demand (AAD): the annual demand in million m^3/annum
Sustained Peak Demand: the AAD, reduced to a daily average, multiplied by a peak factor of 2, in Ml/day

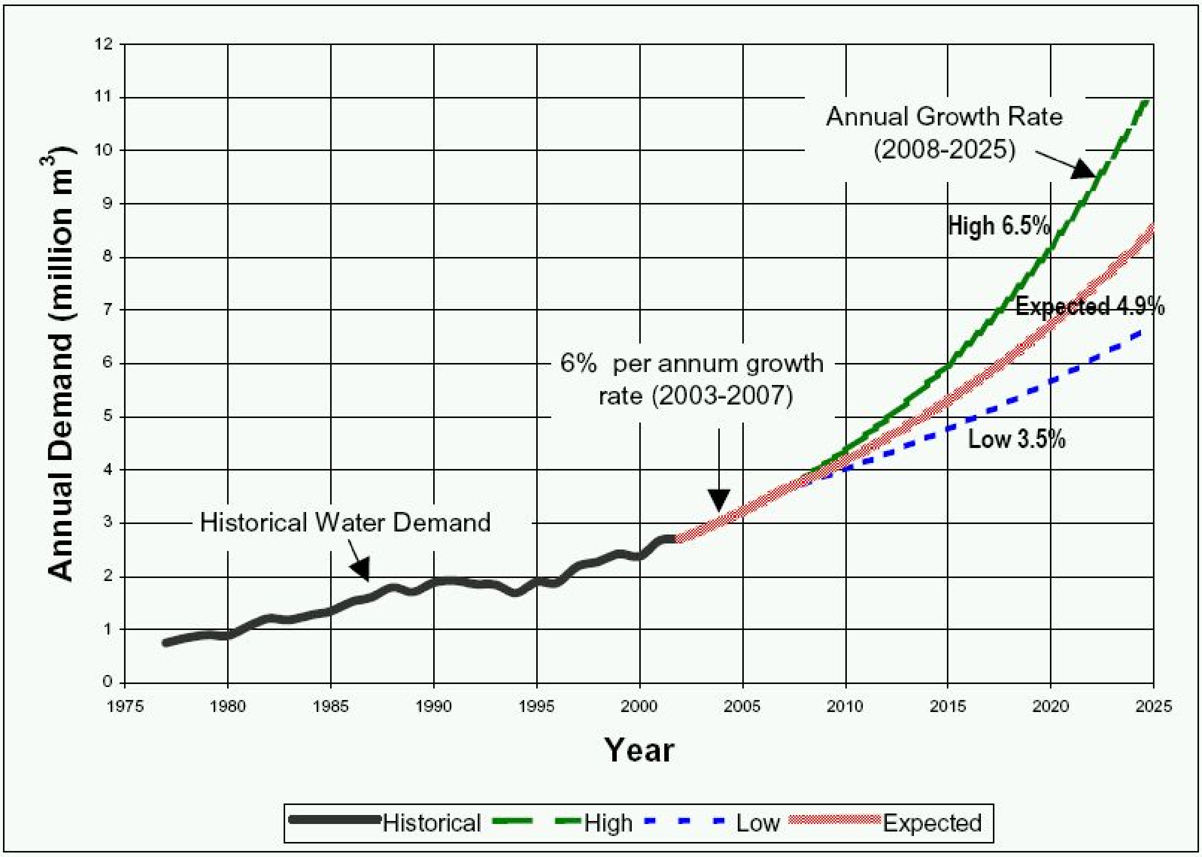


Figure 1: Historical and forecast water demand for Plettenberg Bay (Bitou Municipality, 2003)

The annual water consumption for recent years is shown in table 2 for the years 1999 to 2007. The growth in demand over the last two periods has been high (an average 13% per annum) but since 1999 the demand has grown by 7% and the 2005/2006 annual consumption of 3.28 million m^3 is in line with the figure predicted by the augmentation study of 3.22 million m^3 using the planned 6% growth rate.

Table 2: Annual increase in demand.

From	*To*	*Annual Consumption*	*Annual change in consumption*
Month	Month	ML per year	%
April 1999	April 2000	2,411	
April 2000	April 2001	2,354	-2%
April 2001	April 2002	2,668	13%
April 2002	April 2003	2,673	0%
April 2003	April 2004	*2,766	3%
April 2004	April 2005	2,881	4%
April 2005	April 2006	3,284	14%
April 2006	April 2007	3,631	11%

** Data missing and estimated from previous year for July to December 2003.*

As a seasonal holiday town, Plettenberg bay experiences a large variation in the monthly water demand. While there is a distinct peak over December and January, the general pattern is a six month period of higher demand and six months of a lower demand. Figure 2 shows the demand variation for the whole of Plettenberg bay (including the satellite settlements like Kurkland and Keurbooms) while Figure 3 shows the variation for the town of Plettenberg Bay and Kwanokathula.

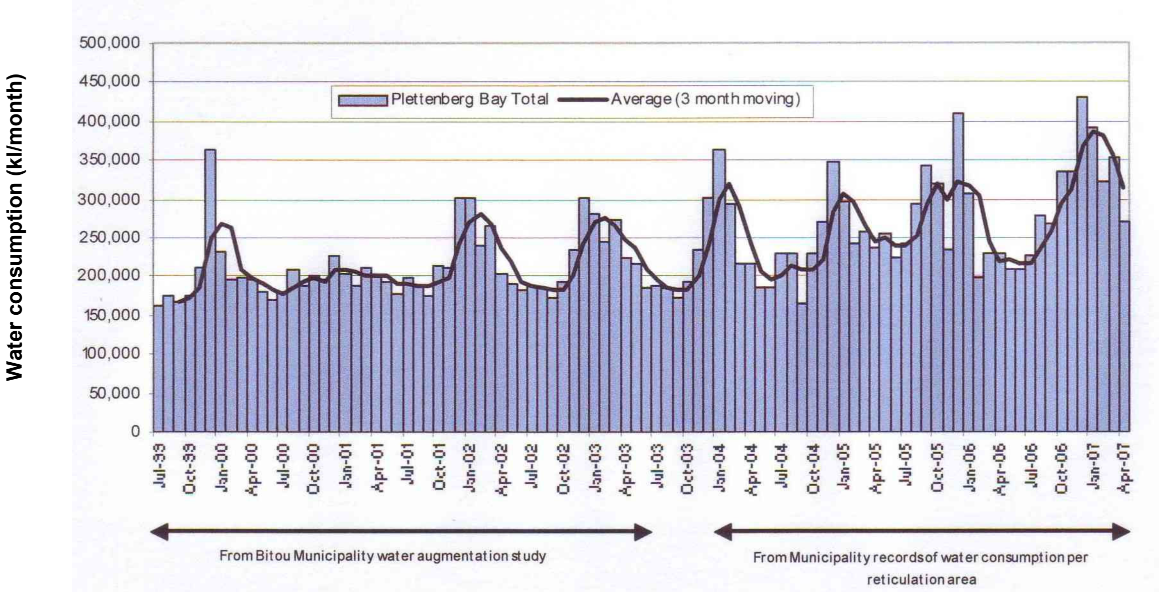


Figure 2: Monthly variation in water demand for Plettenberg Bay

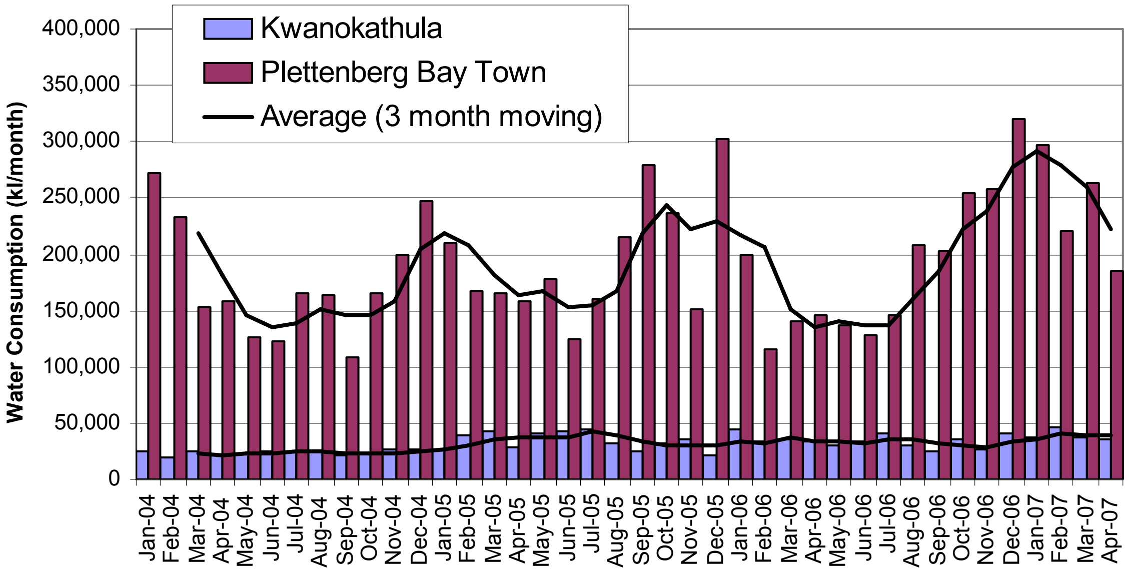


Figure 3: Monthly variation in water demand for Plettenberg Bay town and Kwanokathula

Kwanokathula does not have a large seasonal variation in water demand compared with Plettenberg Bay town. One of the benefits of the production boreholes being located in Kwanokathula is that they pump directly to the Kwanokathula reservoirs. If optimum use of groundwater and artificial recharge, if needs be, can guarantee a supply during summer months that meets Kwanokathula's requirements, then this would take reduce the need for surface water supplies during this peak-demand period. Water quality issues would have to be taken into account too ensure the quality and taste are suitable for Kwanokathula residents.

Figures 4 and 5 give Kwanokathula's average water use since 2004.

Kwanokathula's current water requirements generally lie between 30 000 and 40 000 m^3/month or 11 to 16 L/s of continuous supply.

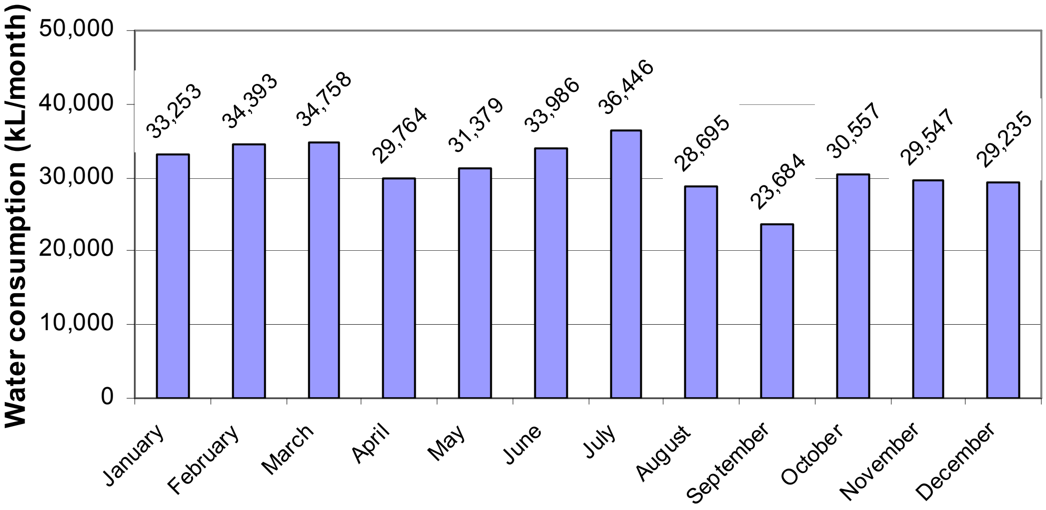


Figure 4: Kwanokathula average monthly water consumption

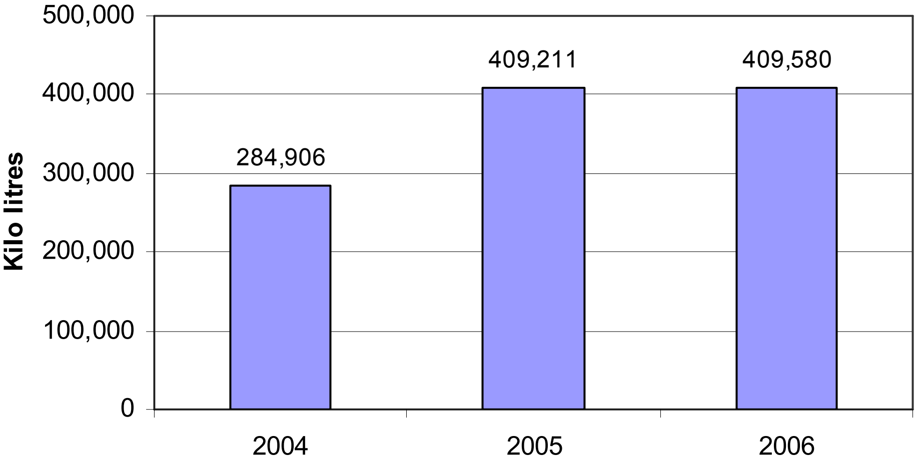


Figure 5: Kwanokathula annual water consumption

3. *WATER SUPPLY INFRASTRUCTURE*

Figure 6 shows the main water supply installations for Plettenberg Bay. At present, the town depends on surface water from the Keurbooms River for most of its domestic water supply needs. Water quality in the Keurbooms is generally very good. Pipelines carry raw water from the river to the town's water treatment plant, which has an operating capacity of 410 ML/month and a maximum capacity of 660 ML/month (about 158 L/s and 255 L/s respectively). During periods of low demand, raw water bypasses the treatment plant and is piped to the Roodefontein Dam, from where it can be retrieved when necessary. The salinity of Roodefontein Dam's water, however, is high, and this makes blending with "pure" Keurbooms River water necessary prior to supply.

In addition to the surface water resources, there are three main water supply boreholes used for water supply in the Kwanokathula area of Plettenberg Bay, drawing water from the Peninsula Formation aquifer in the Kwanokathula area (the "Kwanokathula" or "Hillview" Aquifer). Boreholes 3 and 6 are used to pump groundwater into the Kwanokathula storage reservoir. The New Horizon borehole pumps water into the New Horizon reservoir. These boreholes together (the "Kwanokathula boreholes") help to meet the current water requirements of Kwanokathula, but are not utilised for supply elsewhere in Plettenberg Bay.

The combined average yield of the Kwanokathula boreholes between 1999 and 2007 was 4.3 L/s – this is not sufficient to meet the total demand of Kwanokathula, and the balance is drawn from the Keurbooms River via the water treatment works. In summer, when demand from the treatment works is higher, the proportion of borehole water used to supply Kwanokathula rises. This has led to complaints about the water in Kwanokathula, since although the borehole water quality is generally good it has a higher conductivity than the treated Keurbooms water. The yield of 4.3 L/s presently obtained from the Kwanokathula boreholes is however not the maximum possible, but appears to be a function of logistics and operating schedules.

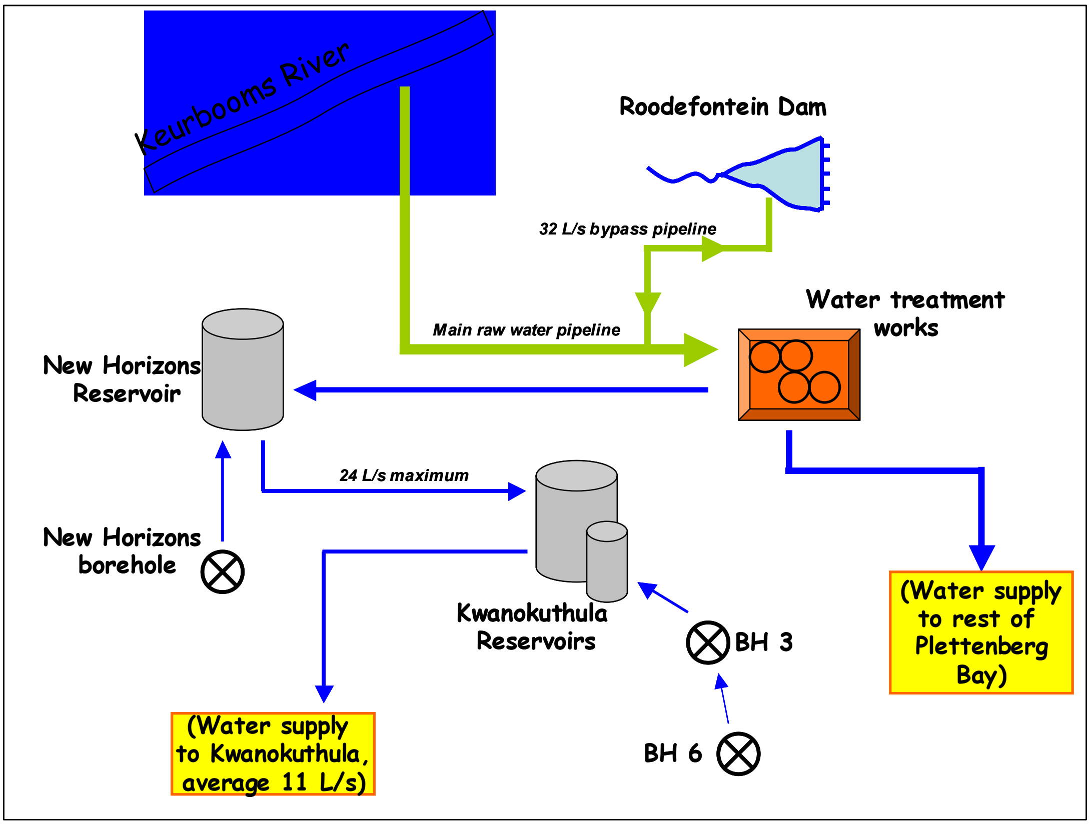


Figure 6: Schematic diagram of the existing water supply arrangements for Greater Plettenberg Bay

SECTION B: HYDROGEOLOGICAL SETTING

4. HYDROGEOLOGY

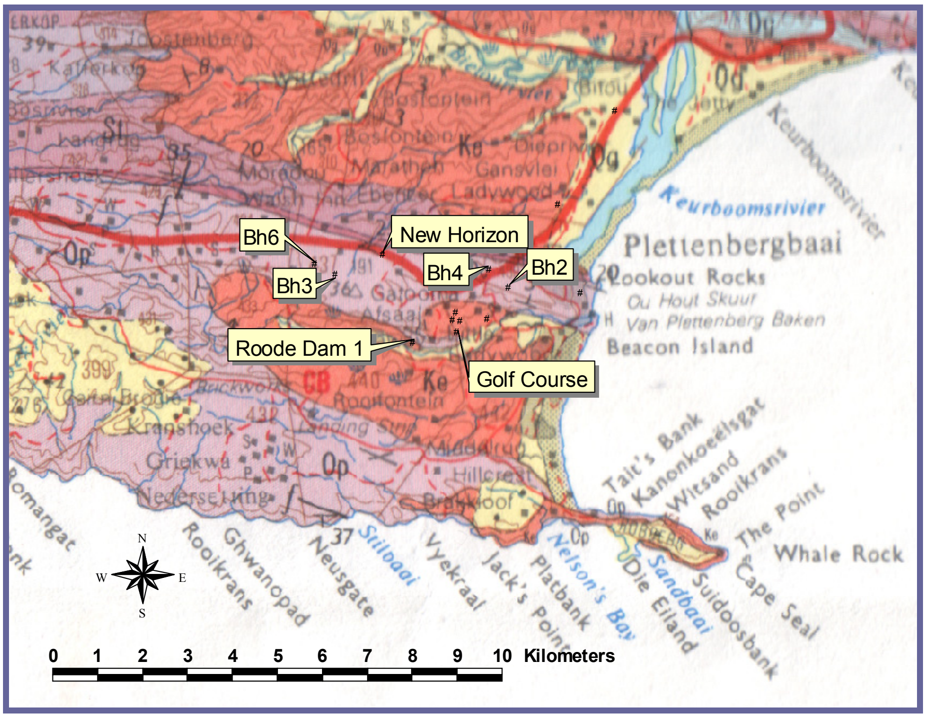
4.1 Hydrogeological overview

The town of Plettenberg Bay is underlain by rocks of the Ordovician and Silurian Table Mountain Group, Cretaceous to recent rocks including the Enon Conglomerate, and alluvium associated with the Keurbooms and Piesang Rivers. A report by Ninham Shand Ltd. (1996) identified the Table Mountain Group as by far the best aquifer in the vicinity with respect to long-term development potential. The Table Mountain Group consists mainly of quartz-arenites, with subordinate and often thin shales and siltstones, and were intensely deformed and thickened in this area by the Permo-Triassic Cape Orogeny, leading to often overturned folds, and strong fracture cleavage (Pietersen and Parsons, 2002). Thrusting and faulting is also common. Borehole yields in these rocks can exceed 30 L/s, and the water quality is generally good, with low electrical conductivity. Primary porosity and permeability in the quartz-arenites is negligible, and both storage and transmission of groundwater is via fractures, fault planes and other secondary features.

The yield and sustainability of a borehole in the Table Mountain Group is heavily dependent on the number and interconnectedness of such features encountered during drilling. Work done by Kantey and Templer Ltd. (1992) included the identification of two distinct sets of joints or fractures in the Peninsula Formation in the area, one striking roughly north-south, and the other striking 120° – 130°. The second set is more open, whilst the first is often filled with quartz (see Figure 7). Fracture geometry and the presence of shale bands of low permeability can lead to the compartmentalising of groundwater, and local perching of water tables.

Figure 7: Jointed and fractured Peninsula Formation quartzite at Plettenberg Bay

The most important aquifer unit in the Table Mountain Group in the vicinity of Plettenberg Bay, currently used for public water supply purposes, is a body of Peninsula Formation quartzite running in a roughly east to west, one-to-two kilometre wide band immediately to the north of the town centre, known as the Hillview (or Kwanokathula) Aquifer after the farm on which the township of Kwanokathula has developed (see Figure 8). This aquifer has been exploited for its high-quality groundwater for decades by farmers, smallholders and other private users. Investigations aimed at exploiting the aquifer for public water supply purposes date back more than twenty years, and today the aquifer supplies a small but important component of the water supply to users in the Greater Plettenberg Bay area. At present the main boreholes that are exploited for public water supplies in the Kwanokathula Aquifer are boreholes 3 and 6, and the New Horizons (NH) borehole.



Op = Peninsula Formation orthoquartzites; Ke = Enon Formation conglomerates; St = Cedarberg Formation shales; St = Tchando Formation sandstones; Qg = Unconsolidated gravel and sand (Source: 1: 250 000 Geological Map)

Figure 8: Geological map of the Plettenberg Bay area, showing the locations of some of the main boreholes located in the Kwanokathula Aquifer

The boundaries of the Kwanokathula Aquifer are the Cedarberg Shales to the north and Cretaceous rocks including the Enon Conglomerates to the south (including a possible fault), whilst it is considered unbounded for practical purposes to the east (where it underlies the ocean) and to the west, where it continues for many kilometres. See Figures 9 to 11 for cross sections of the aquifer.

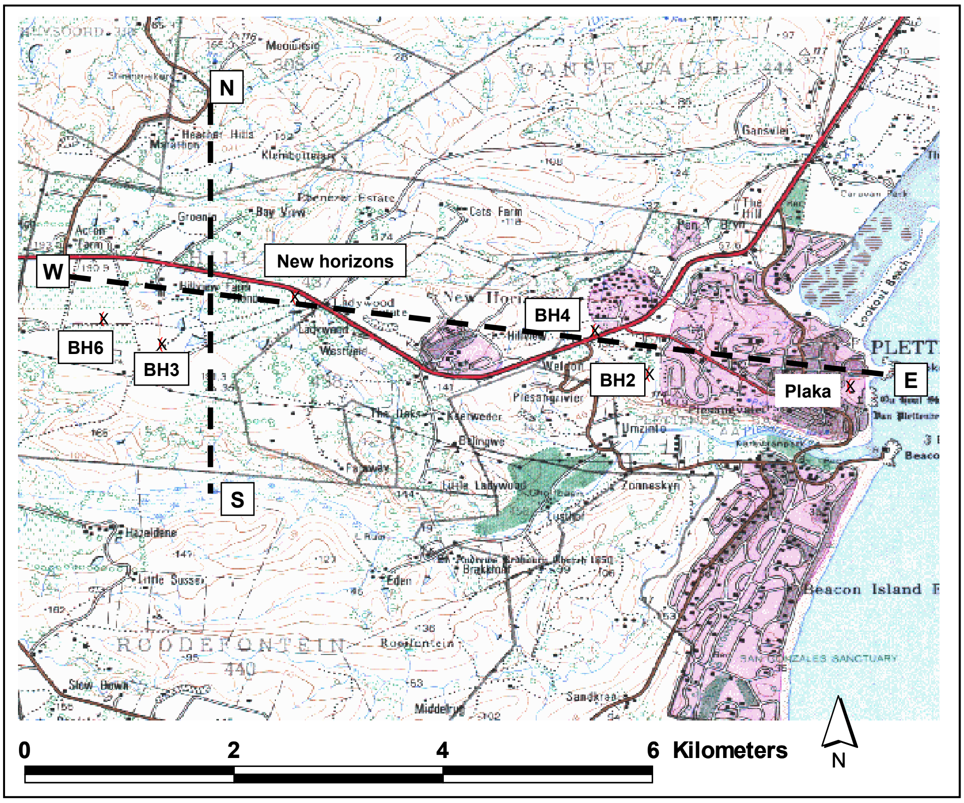


Figure 9: Map of Plettenberg Bay showing the lines of cross-section

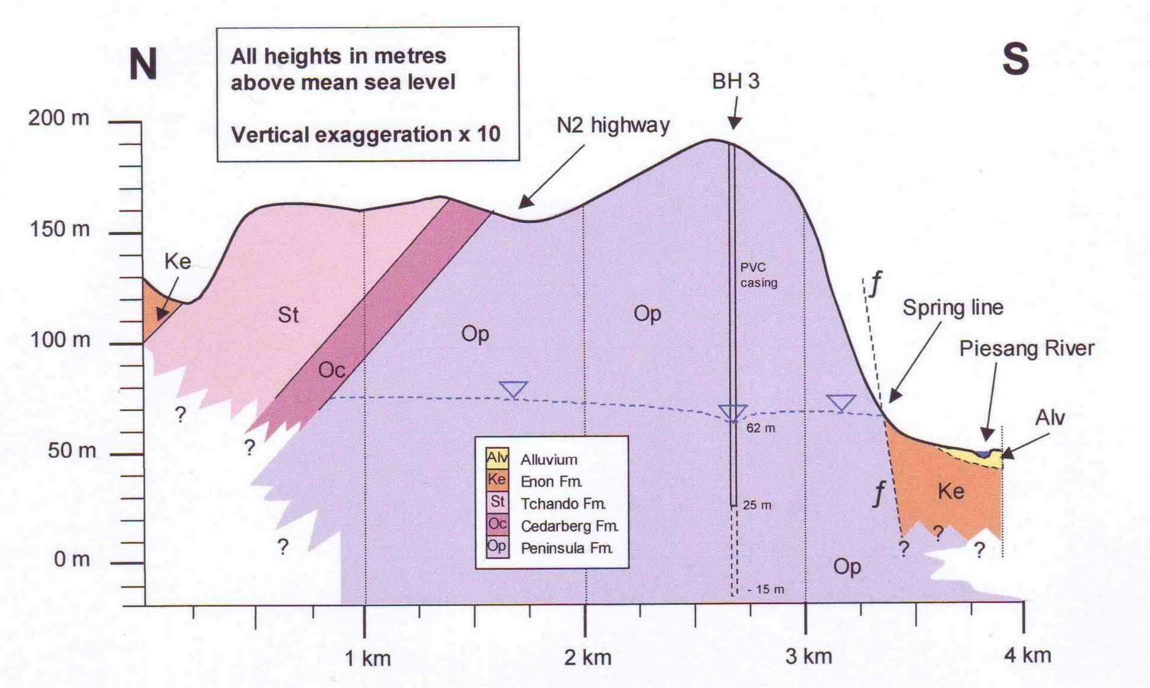


Figure 10: N-S hydrogeological cross-section

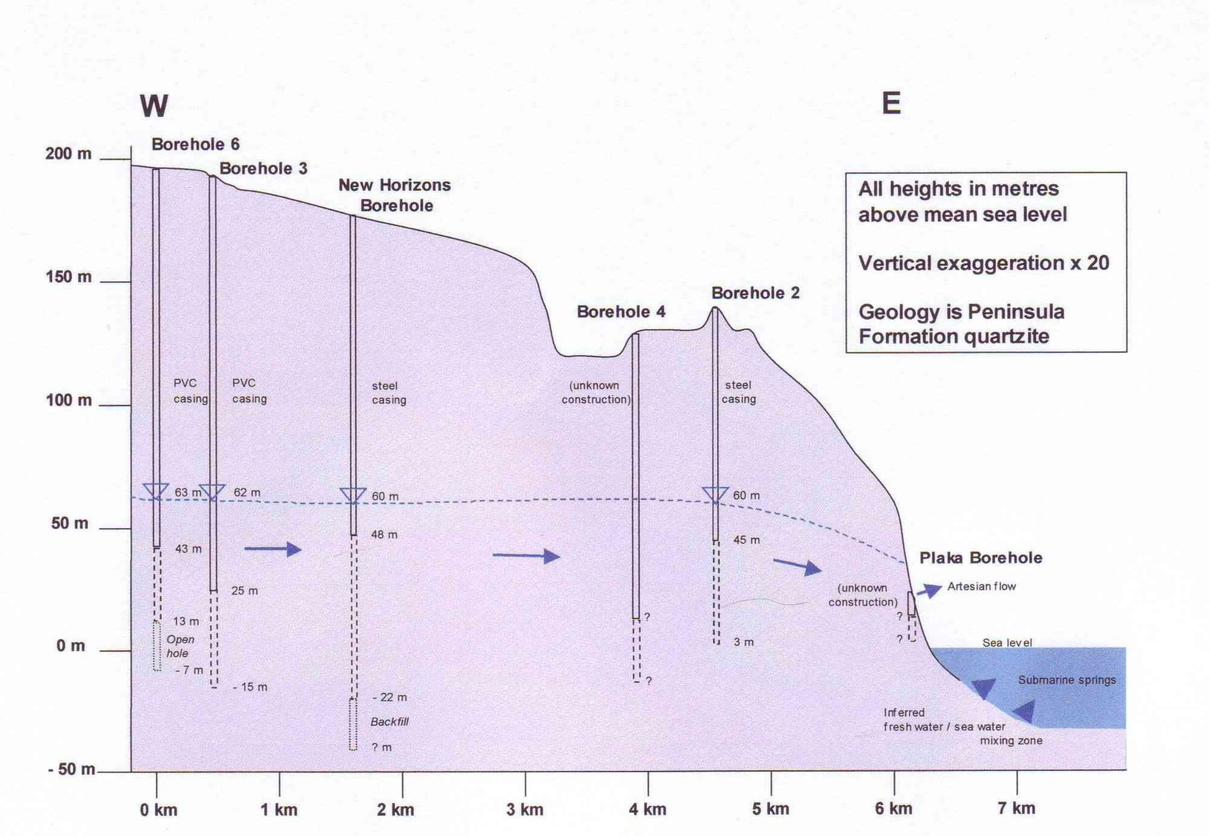


Figure 11: W-E hydrogeological cross-section

4.2 *Municipal Boreholes*

There are three boreholes currently used by Bitou Municipality for water supply to Kwanokathula – Bh3 and Bh6 (drilled in 1992), and the New Horizon (NH) borehole (drilled in 1998) (Bh NH supplies the New Horizon reservoir which is linked to the Kwanokathula reservoirs). These are also the boreholes that will most likely be used for initial testing of artificial recharge. The details of these boreholes together with other Plettenberg Bay municipal boreholes (ie excluding other municipal boreholes, eg Kranshoek and the airport) are shown in Tables 3 and 4 and Figure 12.

Table 3: The main municipal boreholes

Bh No	*Depth (m) & (estimated elevation (mamsl))*	*Casing (m)*	*Water Strikes (mbgl)*	*Drilling yield (L/s)*	*Pre-2007 Prodn. Yield (L/s)**	*Water Level (mbc) & date*	*Latitude (dec. deg.)*	*Longitude (dec. deg.)*	*Estimated injection capacity (L/s)*	*Current status*
3 (GCS 1R)	200 (189)	200	174 - 178 & 183 - 189	15	14	122.6 (1 July 1992)	34.0517	23.3178	15 - 20	In use
3A (GCS 1)	181 (189)	unsure	none	0	N/A	-	Adjacent to Bh3		N/A	Blocked *
6 (GCS 3R)	200 (195)	180	~175 – 180	>2	10	130.1 (7 July 1992)	34.0496	23.3128	10 - 15	Not in use
New Horizon	250 (183)	200	165 & 189	12	7	119.34 (9 May 1998)	34.0477	23.3292	20	Not in use
Bh4	150 (129)	unknown	unknown	unknown	10	62 (1987)	34.05428	23.35493	N/A	Equipped
Bh2	150 (138)	unknown	unknown	unknown	N/A	78.5 (Mar 2005)	34.06320	23.35958	N/A	Monitoring

** The recommended production yields have been reduced (see Chapter 9)*

** Bh 3A was unblocked in 2007. Drill rods were placed to 181 m and at this depth only air came out during drilling. The borehole subsequently blocked again and the open depth now is only a few metres. It needs to be re-opened and a piezometer tube installed.*

mbc = metres below casing collar at ground level

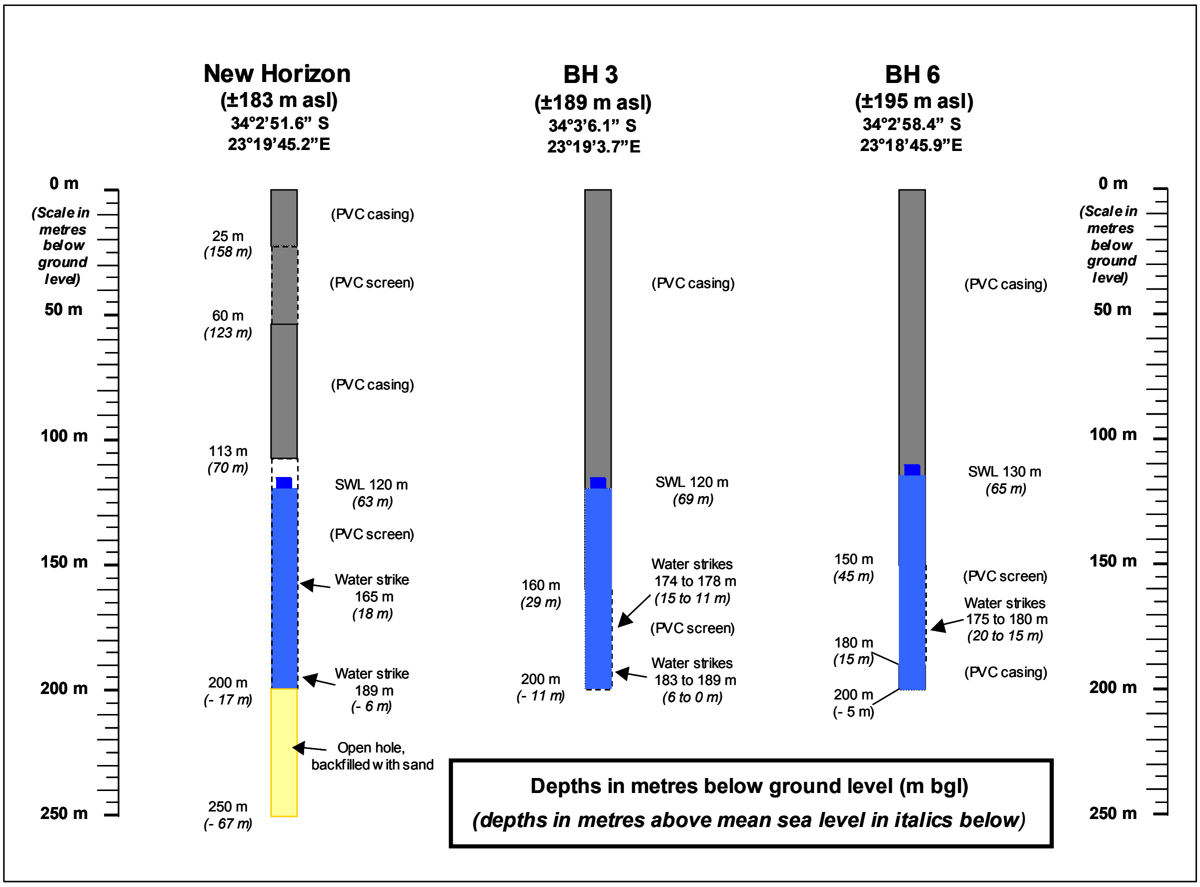


Figure 12: Diagrams of Plettenberg Bay municipal boreholes

In addition to the main Kwanokathula abstraction boreholes in the table above, a number of other boreholes have also been drilled in or adjacent to the Kwanokathula Aquifer, and are either used for monitoring or could be used for monitoring. These private boreholes are presented in Table 4 below.

Table 4: Known private boreholes in and around the Kwanokathula Aquifer

Bh No/ name	*Latitude*	*Longitude*	*Elevation (mamsl)*	*Depth (mbgl)*	*Blow Q (L/s)*	*WL (mbgl)*	*WL (date)*	*Current status*
Golf Course	34.06107	23.34722	65	60	6.8	0	1985	Artesian, in use
Skoongesig 1	34.06085	23.34793	65	80	4	40.83	Aug, 2005	unknown
Skoongesig 2	34.05933	23.34607	87	60	4			Unknown
Skoongesig 3	34.06045	23.34615	56	47	0.4	32.45	Aug, 2005	Unknown
Ouplaas	34.06543	23.35447	15	30				Unknown
Roode Dam 1 (RD1)	34.05533	23.33618	40	0		7	Aug, 2005	Used for monitoring
Plaka	34.03750	23.37688	23	100	2.5	0	2000	Artesian, in use
DW1 (Opposite Bird Farm turn-off)	34.04564	23.29589	208	211		145.56	Jun 2006	Used for monitoring

The drilling history of known boreholes drilled mostly in the Penninsula Formation is provided in Table 5.

Table 5: Boreholes in the Peninsula Formation (mostly)

Date	*Description*	*Location*	*Notes*
Pre-1985	37 boreholes, privately owned	Various in greater Plettenberg Bay area	Surveyed in first hydrocensus by Knight, Dames and Moore. Unsure how many still exist.
Pre-1985	10 boreholes in the Hillview area. (may be included in those mentioned above).	Hillview	None of these were considered suitable for public water supply purposes. Likely that all were covered during township development.
1986 and 1987	PB1 and PB2	Eastern extremity of aquifer	Drilled following work by Knight, Dames and Moore. Not sure of location.
1992	GCS1, GCS1R, GCS2, GCS3 and GCS3R	Hillview/ Kwanokuthula. Locations all known accurately.	Equipment lost in GCS1 and GCS3, so these abandoned and replaced by GCS1R and GCS3R (now known as BH3 and BH6). GCS2 was left uncased for monitoring.
1998	Kranshoek 1 and 2, Airport and New Horizon boreholes		Water quality poor in the Kranshoek boreholes.
Unknown dates	Plaka, Golf course, BH4, BH5, etc	Locations mostly known accurately.	Little other information on some of these holes.

4.3 Existing Reports and Studies

The Table Mountain Group rocks, and the Kwanokathula Aquifer in particular, have been the subject of several hydrogeological studies over the past two decades by several companies, aimed in general at securing public groundwater supplies for Plettenberg Bay. The following summaries provide an overview of these studies, and the reader is referred to the relevant reports (see references) for a more detailed understanding.

1985

A report by Knight, Dames and Moore Ltd. described work carried out on the Peninsula Formation aquifer, and discussed the feasibility of using it for augmenting the municipal water supply. The work was commissioned by Plettenberg Bay Town Council, and included a desk study and later fieldwork. This included a survey of existing boreholes in the area, structural geological mapping, establishing of piezometry, geophysics, and some water quality work. The report concluded that the potential for long-term abstraction “appears excellent”. In addition, the authors identified three main contributions made by the work:

- Establishing the investigative approach needed for this type of terrain.
- Definition of the aquifer piezometry.
- Recognition of the existence of different water qualities within the aquifer

In consultation with the Town Council, eight drill sites were selected, and two of these (PB1 and PB2) on the “eastern extremity of the aquifer” were drilled in 1986 and 1987 and put into public supply. They were equipped to yield 10 L/s on the basis of blow-yields measured during drilling.

1992

A summary report by Kantey and Templer Ltd. described work done on behalf of the then Cape Provincial Administration to investigate the groundwater supply potential of the farm “Hillview” about 3 km west of Plettenberg Bay, in anticipation of a new township development there. The farm is underlain by Peninsula Formation rocks. Demand for water from the new development was estimated to be 1000 m^3/day (11.6 L/s), and none of the ten boreholes already on the farm were deemed suitable for public supply purposes. The work done included the identification of two distinct sets of joints or fractures, one striking roughly north-south, and the other striking 120° – 130°. The second set is more open, whilst the first is often filled with quartz. Drilling targets were identified using geophysics (electrical resistivity and magnetics) in combination with aerial photograph interpretation, and five boreholes were drilled. Two of these boreholes were abandoned due to drilling difficulties, and of the remaining three, two (GCS1R and GCS3R) were equipped for supply. They were both drilled to 200 m below ground level. (These are now known as BH3 and BH6 respectively). The fifth borehole, GCS2, was left uncased as a monitoring borehole since the yield was low. It was noted at the time that the water quality for GCS1R and GCS3R was very similar.

1993

A 1993 report by Groundwater Consulting Services (GCS) describes work done on behalf of Stewart Scott International to investigate the possibility of additional groundwater resources for Plettenberg Bay. The report makes estimates of the properties of the Peninsula Formation aquifer stretching west from the town, now referred to as the “Golf Course – Hillview Aquifer” (in this report referred to as the Kwanokathula Aquifer). The boundaries of the aquifer are described (Cedarberg Shales to the north, Cretaceous rocks to the south, and the sea to the east) and the total area of aquifer estimated at 22 x 10^6 m^2. Transmissivity was estimated at 70 m^2/d, storage at 0.5 %, the groundwater gradient (roughly west to east) at 1:150 and recharge at 7 % of the total rainfall of 663 mm per annum. The average aquifer thickness at Hillview was estimated at 70 m. At the time, abstractions from the aquifer were estimated at 2510 m^3/day (29 L/s). Recharge to the aquifer was calculated at 2800 m^3/day and throughflow at 700 m^3/day, leaving about 990 m^3/day (11.4 L/s) still available for abstraction.

Recommendations made by the author included the following:

- Abstraction should cease from Plettenberg Bay Municipal Borehole No. 2, due to quality deterioration. This borehole should be replaced by a borehole or boreholes at the golf course.
- A monitoring network should be developed for both Hillview and the municipal area.
- All data should be reviewed annually.
- It is best to operate the wellfield continually rather than sporadically.

1996

Ninham Shand Ltd. was commissioned to carry out a broad, strategic-level assessment of all available groundwater data in the greater Plettenberg Bay area. This work was subcontracted to GCS, who authored the report. The work was mainly a desk study, using existing data from the Department of Water Affairs and Forestry (DWAF) archive and other sources. Four main aquifer groups in the area were identified: the unconsolidated sands associated with the Keurbooms River, the Uitenhage Aquifer, the Gydo Aquifer and the Table Mountain Group (TMG) Aquifer. Of these four, the TMG Aquifer was found to represent 88 % of the total aquifer area in the vicinity (in terms of its area or footprint), and was identified as having the best long-term development potential.

1998

In 1997 and 1998 GCS were again sub-contracted by Stewart Scott International to assist with hydrogeological investigations and borehole drilling. The golf course was ruled out as a possible drilling site due to difficulties with access. Between February and May 1998 one borehole was drilled at the airport, one at Hillview, and two at Kranshoek. The two Kranshoek boreholes were sited by Toens and Partners using aerial photography and resistivity. After two failed attempts, Kranshoek 1 was drilled to 250 m, but the water quality was poor. Kranshoek 2 was drilled nearby to 250 m, and whilst water quality was better the borehole only yielded 0.5 L/s. The airport borehole was sited using aerial photographs and EM-34 conductivity equipment. It was drilled to 250 m and an initial blow yield of 6 L/s was recorded. The borehole at Hillview was sited on a “prominent E-W lineament”, confirmed using EM-34. The borehole was drilled to 250 m and gave a blow yield of 12 L/s. This Hillview borehole came to be known as the “New Horizons Borehole”, and had by far the best water quality of all four boreholes drilled (although iron was measured at 2.44 mg/L). It was equipped with a pump, and a sustainable pumping rate of no more than 8 L/s was recommended. Chemistry, borehole completion diagrams and pumping test results for these boreholes are contained in the report.

2006

In June 2006, Groundwater Africa completed an Artificial Recharge Pre-feasibility Study (Murray, 2006). From this investigation, it seemed like the Kwanokathula Aquifer is suitable for artificial recharge, however without a good time-series of borehole water level and abstraction data it was not possible to tell whether artificial recharge is necessary or not. Bitou Municipality was recommended by DWAF (Cape Town office) as a potential artificial recharge site because the boreholes reportedly “ran dry” during. This is often deemed the case by pump operators when in reality the pumping rates have been set too high and the water in production boreholes are drawn down to pump intakes. The aquifer at large, however, may not be stressed and could be relatively “full”. The first step after providing an initial assessment of the artificial recharge potential was to install monitoring equipment and establish the effect of large-scale groundwater abstraction on the aquifer. This was done under the Masibambane project.

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.

Since 2005 Groundwater Africa cc initiated a series of groundwater studies in the Plettenberg Bay area, funded by DWAF via the Artificial Recharge and Masibambane Projects. Amongst the initiatives taken by Groundwater Africa and Bitou Municipality are the following:

- A more detailed study of the groundwater chemistry, together with the water quality implications of artificial recharge
- The down-hole hydrochemical logging of certain boreholes
- A costed appraisal of the engineering work needed to install an AR system
- The purchase and installation of automatic water level loggers
- The assessment of monitoring data

Reports completed as part of this work include a description of the hydrochemical logging (Tredoux, 2007); an assessment of required engineering infrastructure (Ravenscroft, 2007); an artificial recharge pre-feasibility study (Murray, 2006)

4.4 Aquifer hydraulic properties

The ability of the Kwanokathula Aquifer to transmit water is good, with localised transmissivity values ranging up to several hundred m^2/day. The transmissivity in the area of the New Horizon borehole is particularly high. Groundwater Consulting Services (GCS, 1993) estimated the basic hydrogeological properties of the Kwanokathula Aquifer, and these are reproduced in Table 6 below. At that time (1993), abstractions from the aquifer were estimated at 2 510 m^3/day (29 L/s). Recharge to the aquifer was calculated at 2 800 m^3/day and throughflow at 700 m^3/day, leaving about 990 m^3/day (11.4 L/s) still available for use.

Table 6: Summary of Kwanokathula Aquifer properties (after GCS, 1993)

Total aquifer area	22 x 10^6 m^2
Transmissivity	70 m^2/d
Storage	0.5 %
Groundwater gradient	1:150 (0.007), roughly from west to east
Recharge	7 % of total rainfall of 663 mm/annum
Average thickness	70 m

Various sections of the water level response in Bh 3 were analysed during the abstraction period from January to August 2007. This gave a slightly lower transmissivity value of about 60 m^2/day. Using this figure with an average hydraulic gradient of 0.015 (between Bh 6, NH and Schoongesig 3), the average throughflow (essentially outflow to sea) that is obtained is 900 m^3/day per 1 km of seepage face (the width of the aquifer). This puts the outflow from the Kwanokathula Aquifer unit at ~1350 m^3/day (or ~16 L/s), if the width of the Kwanokathula Aquifer is taken to be about 1.5 km.

Esimated flow through the aquifer is 900 m^3/day per 1 km of aquifer width (or ~10 L/s). Assuming the Hillview Aquifer is 1.5 km wide, the throughflow is ~1 350 m^3/day (or ~16 L/s).

Table 7 summarises transmissivity values and Figures 13 and 14 give the drawdown graphs of Bh 3 and NH.

Table 7: Transmissivity values for the main Kwanokathula boreholes

Bh No	*T-early (m^2/day)*	*T-late (m^2/day)*	*T-recovery (m^2/day)*
Bh 3 / GCS 1R[1]	35	86	30
Bh 3 (2007 production)[2]	60	60	-
Bh 6 / GCS 3[1]	35	94	120
New Horizon / Hillview (1998 test)[2]	~50*	~500*	-

[1] Analysed by CGS (1993)
[2] Analysed by R Murray

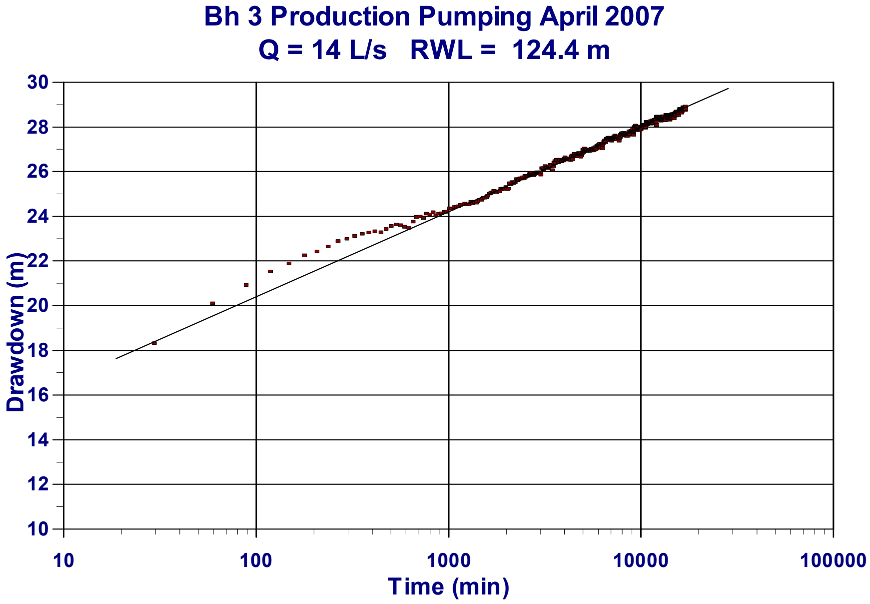


Figure 13: Bh 3 Production Pumping (April 2007)

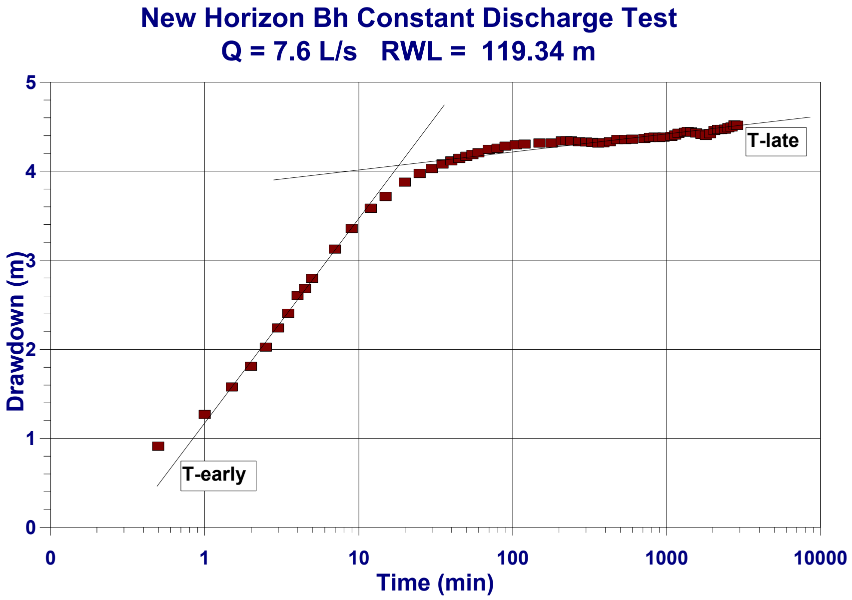


Figure 14: New Horizon/Hillview borehole Constant Discharge Test (1998)

It appears as if the groundwater levels have not significantly declined since 1985 (when Knight, Dames & Moore carried out a borehole inventory and hydrocensus). The water levels in boreholes 3 and 6 are currently much the same as they were when drilled in 1992. However, there is evidence of earlier shallower (or perched) water levels, as water strikes and borehole depths in older boreholes indicate that at some stage in the past, the water levels were shallower - water strikes as shallow as 78 mbgl have been recorded in old, farm boreholes (CGS, 1992). Unfortunately with the development of Kwanokathula, older boreholes cannot be located, and the monitoring of groundwater levels is restricted to existing (and often pumping) boreholes. The Knight, Dames & Moore (1985) hydrocensus data showed that the water level contours mirrored topography and geology (Figure 15).

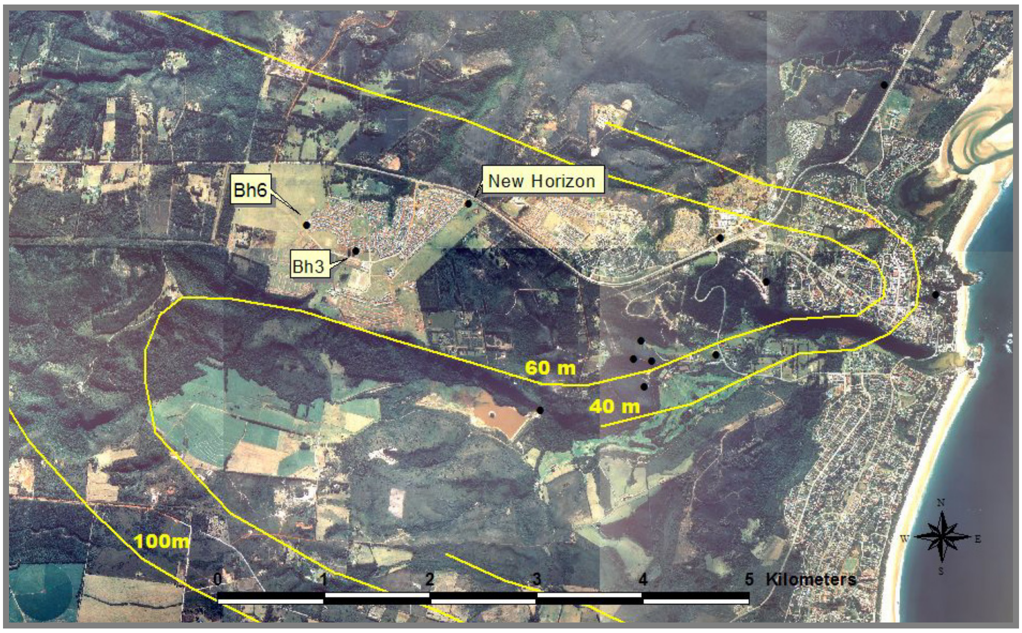


Figure 15: Inferred groundwater contours in mamsl (after Knight, Dames & Moore, 1985)

It is not known whether the failure of existing boreholes after periods of high abstraction, is due to a fall in water levels in the aquifer at large, or due to the localised, high draw down in the pumped boreholes (i.e. high well losses). Only with further monitoring can this be established.

4.5 Groundwater quality

Tables 8 and 9 present the available groundwater quality data for those samples where a full chemical analysis was made in recent years. Borehole Bh3 or possibly Bh6 are the intended injection points for the artificial recharge pilot study and the other boreholes, New Horizon, Bh2 and the far-field Golf Course borehole could be used for monitoring during and after injection trials. The Golf Course borehole and Bh2 are far from the proposed artificial recharge area and closer to the coast. Borehole Bh4, also far from the artificial recharge area can also be used for water quality monitoring once it has a sampling tap fitted. Full chemical analyses are not available for Bh2 and Bh 4. Bh 2 is not equipped with a pump and Bh 4 does not have a sampling tap.

Table 8: Boreholes water quality: Monitoring boreholes

		Bh 3 / CGS 1R	***Bh 3 / CGS 1R***	***Bh 3 / CGS 1R***	***Bh 6 / CGS 3R***	***Bh 6 / CGS 3R***	***New Horizon / Hillview***	***New Horizon / Hillview***	***Golf Course***
Sample date		*02-Jul-92*	*14-Dec-05*	*22-Feb-07*	*14-Jul-92*	*14-Dec-05*	*22-Jun-98*	*14-Dec-05*	*14-Dec-05*
Analytical Lab.		*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*
Potassium	mg/L	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.5
Sodium	mg/L	188	200	176	188	172	92	56	128
Calcium	mg/L	30.1	28	28	30.5	22	11.2	7.8	15
Magnesium	mg/L	21.1	21	21	21.3	20	6.4	12	7.9
Ammonia	mg/L	<0.1			<0.1		<0.1		
Sulphate	mg/L	27	26	26	27	30	17	31	18
Chloride	mg/L	355	378	330	356	334	162	103	220
Alkalinity as CaCO3	mg/L	47	46	47	46	24	13	21	24
Nitrate as N	mg/L	0.11			0.13		<0.1		
Nitrate plus nitrite as N	mg/L		0.14	0.25		<0.1		0.11	<0.1
Iron	mg/L	0.05	0.06	0.09	0.14	<0.05	2.44	147	0.06
Iron (filtered)	mg//L		<0.05			<0.05		0.69	<0.05
Manganese	mg/L	<0.02	<0.05	<0.05	<0.02	<0.05	<0.05	0.1	<0.05
Manganese (filtered)	mg/L		<0.05			<0.05		<0.05	<0.05
Fluoride	mg/L	0.1	0.14		0.1	<0.1		<0.1	<0.1
Silica	mg/L		4.7	4.5		4.6		2.9	4
Arsenic	mg/L		<0.01			<0.01		<0.01	<0.01
Dissolved Organic Carbon	mg/L		<0.1	<1.0		<1.0		3	<1.0
Electrical Conductivity	mS/m	128	133	132	130	115	61	44	83
pH (Field)					5.85				
pH (Lab)		6.3	6.1	6.1	6.2	6.1	5.8	6.2	5.8
Saturation pH	pHs 20 deg C	8.5			8.5		9.4		
Total Dissolved Solids (Calc)	mg/L	819			832		390		

		Bh 3 / CGS 1R	***Bh 3 / CGS 1R***	***Bh 3 / CGS 1R***	***Bh 6 / CGS 3R***	***Bh 6 / CGS 3R***	***New Horizon / Hillview***	***New Horizon / Hillview***	***Golf Course***
Sample date		*02-Jul-92*	*14-Dec-05*	*22-Feb-07*	*14-Jul-92*	*14-Dec-05*	*22-Jun-98*	*14-Dec-05*	*14-Dec-05*
Analytical Lab.		*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*	*CSIR (S'bos)*
Total Hardness as CaCO3	mg/L	162		156	164		54		
Corrosivity Index		11.25			11.53				
Langlier Index	pH-pHs	-2.17			-2.62				
Ryzner Index	2pHs-pH	2.69			2.9				
% Balance		0.78	2.5	0.07	0.55	2.76	1.44	3.88	1.16
Cations*	meq/L		11.85	10.8		10.24		3.83	6.98
Anions*	meq/L		12.14	10.81		10.53		3.98	7.06
* Non-filtered samples									

Table 9: Boreholes field EC, pH & temperature

	pH				*EC (mS/m)*				*Temp (deg C)*			
Date	***Bh 3***	***Bh 6***	***NH***	***GC***	***Bh 3***	***Bh 6***	***NH***	***GC***	***Bh 3***	***Bh 6***	***NH***	***GC***
02-Jul-92	6.3	5.9			128	130						
17-Mar-05	6.2				120							
25-Aug-05	6.2	6.6		6.6	120	94		80		19		17
14-Dec-05	6.3	6.8		6.1	123	106		77	22			

Additional water quality field measurements were collected in October 2006 in the form of down-the-hole logs of temperature, electrical conductivity, pH, oxidation-reduction potential (or Eh) and dissolved oxygen profiles with depth. The logging was conducted on boreholes Bh3, Bh2, Bh6 and New Horizon. The report by the CSIR (Tredoux, 2007) is included in Appendix 2 and key aspects are summarised below.

From the existing chemical analyses and borehole logging, the following observations were made:

4.5.1 Salinity

- The groundwater in the Kwanokuthula aquifer is good quality, sodium-chloride type water with relatively low salinity. This is typical of a Peninsula Formation aquifer where flow of groundwater through fractures in clean quartzite rock adds very little mineral content to the rainfall water that recharges the aquifer. The dominance of sodium chloride ions in solution reflects the influence of sea spray in rainwater near the coast.
- Groundwater salinity (measured as electrical conductivity in the field down hole logs) was slightly higher in Bh3 (around 130 mS/m) and Bh2 (100-120 mS/m) than in Bh6 (60 – 70 mS/m) and New Horizon (45 mS/m). The significantly different salinities suggest different water bodies in the aquifer. The conductivity in some of the boreholes is slightly higher than the best class of drinking water (< 70 mS/m), but is still acceptable for the purpose of artificial recharge. The conductivity of Bh6 decreased from 115 mS/m to below 70 mS/m between sampling in December 2005 and logging in October 2006, and then rose again to 106 mS/m when logged in June 2007. Recent large-scale abstraction from Bh3 has also caused the groundwater electrical conductivity to decrease from about 120 to 80 mS/m between February and May 2007, before it rose again to 130 mS/m in August after the abstraction rate was reduced after May (Figure 16). Injecting lower salinity treated water from the Keurbooms River could further improve the groundwater quality near Bh3.

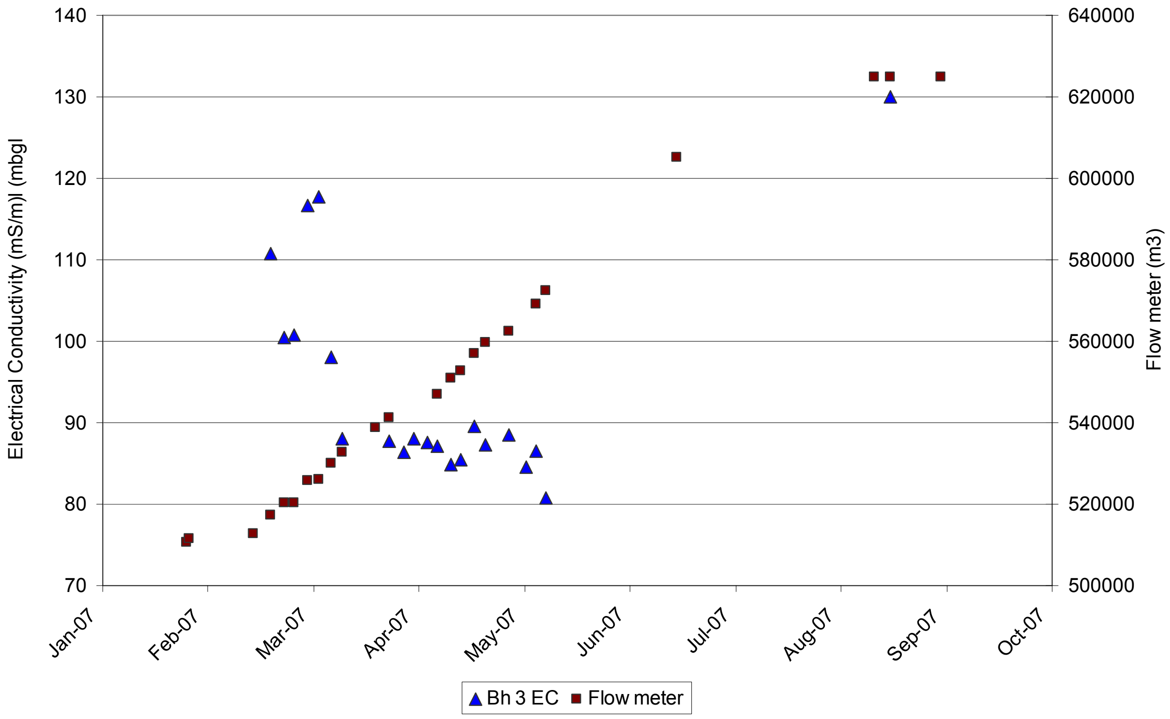


Figure 16: **Electrical conductivity and abstraction from Bh3 during recent pumping**

The down-hole salinity profile (Figure 17) shows how the salinity not only varies from borehole to borehole but how in particular boreholes, like Bh2 and Bh6, it varies with depth as well. All the depth-profiles and a discussion on them are presented in Appendix 2.

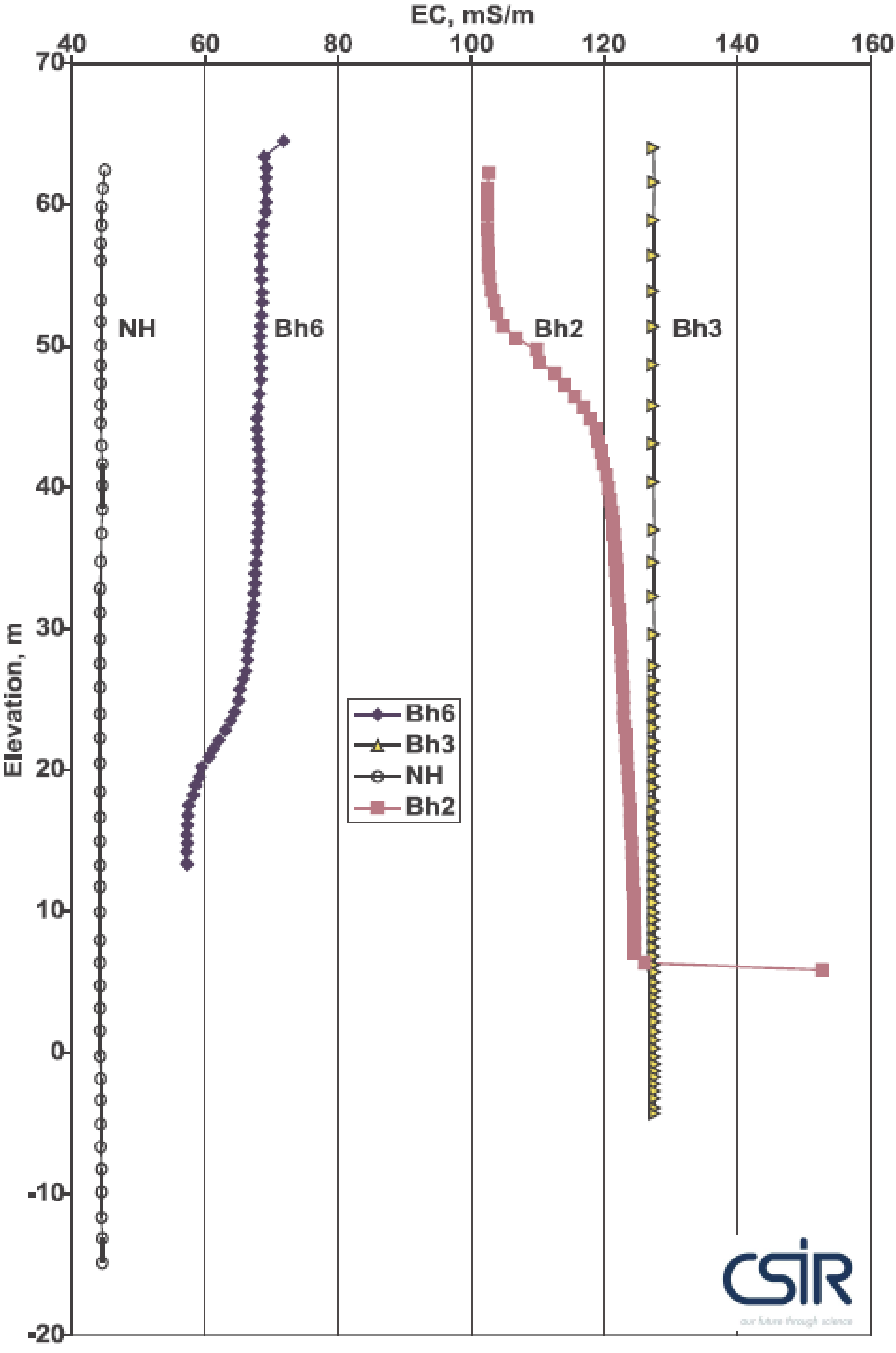


Figure 17: Electrical conductivity profiles

4.5.2 pH

- The groundwater pH is slightly acidic near the injection borehole, ranging from pH 5.5 to pH 6.7 in the field measurements with an average pH of 6.2 for the samples measured in the laboratory. The pH of groundwater in Table Mountain Group quartzite geology is often slightly acidic because the rock contains very little carbonate mineral content to buffer the pH. The slight acidity is within the recommended range for drinking water. Injection of treated water with a higher pH should bring the groundwater pH closer to neutral values (pH 7).
- The pH in the monitoring boreholes is generally slightly higher than in Bh3. Together with the decrease in salinity, the pH of Bh6 appears to have risen from below pH 6.5 during earlier sampling (2005) to between pH 7.5 and 8.0 measured during down-hole logging (2006).
- The high pH near the water table in Bh2 (around pH 10) is unusual and must be the result of corrosion of the steel casing. This monitoring borehole is, however, far from the artificial recharge area and is unlikely to be affected by the artificial recharge trials.

4.5.3 Dissolved oxygen and oxidation-reduction potential (ORP)

- Dissolved oxygen (around 60% saturation) and high ORP (490 to 500 mV) in Bh3 indicate that groundwater conditions near the injection borehole are oxidising. Low concentrations of organic matter in the soil and aquifer are a likely explanation why the oxygen dissolved in the recharge water is not used up by microbiological reactions along the flow path. In this situation, oxidising conditions are a sign of good water quality, but also a warning that injecting iron-rich water may lead to precipitation of iron oxides and clogging.
- Dissolved oxygen and ORP are also relatively high in boreholes Bh6 and New Horizon which is probably typical of the up-gradient parts of the aquifer.
- Conditions near Bh2 are more reducing, showing lower dissolved oxygen (2 – 30%) and ORP (100 – 245 mV). The reasons for this are most likely to be because of corrosion of the steel casing (as opposed to being further from the recharge zone - allowing longer times for oxygen to be consumed - or locally higher concentrations of degradable organic matter).

4.5.4 Iron and manganese

- Most of the boreholes have low to negligible total iron concentrations, which decrease to below the analytical detection limit of <0.05 mg/L when the sample is filtered in the field to measure dissolved iron only. Iron is of potential concern for an artificial recharge scheme because of the tendency of iron to be associated with clogging problems, especially in the Table Mountain Group aquifers.
- The New Horizon borehole had a very high total iron concentration (147 mg/L) which gave the groundwater a deep red-brown colour in December 2005. This iron was mainly in the form of small solid particles of iron oxyhydroxides (colloids) which were removed by filtering through a 0.45 μm filter, after which the concentration dropped down to 0.69 mg/L (and the water was absolutely clear). An older water analysis for

this borehole shows the concentration was lower in 1998, with a total iron concentration of 2.44 mg/L. Iron concentrations may have increased because of the ingress of oxygen to the aquifer when pumping and drawing down the water table and the collection of iron precipitates in the borehole. The slightly acid pH below 7 allows iron to dissolve to relatively high concentrations, provided it is in the form of ferrous iron (Fe^{2+}). If the water is oxidised, the iron becomes ferric iron (Fe^{3+}) which is very insoluble and precipitates out. The iron may also be a localised problem from rusting of the casing or pumping infrastructure. The borehole has not been re-sampled for iron since the high concentrations were recorded. According to the borehole design report (GCS, 1998), steel casing extends to a depth of 130 mbgl which is below the water table and the rusting that occurs may contribute towards the high iron when the borehole is standing. A camera was lowered into the borehole to check this, but plastic casing was installed inside the steel casing, and the condition of the steel casing could not be established.

- 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. 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. The Kwanokathula groundwater has non-detectable concentrations of manganese, except for the low concentration in New Horizon, which is also mostly in the solid form, since it is removed by filtering the sample.

4.5.5 Dissolved organic carbon

- The groundwater generally has a low concentration of dissolved organic carbon (DOC). This is common for natural groundwater, because it is typically consumed by microbial reactions over long residence times in the aquifer. The highest concentration of 3 mg/L is found in New Horizon. There may be a possible link between the DOC and the iron problem in New Horizon, with the carbon providing a source of food for the micro-organisms that catalyse the iron oxidation reaction.

4.5.6 Solutes with potential health effects

- The groundwater quality is generally very good and is suitable as a source of drinking water. Concentrations of species which cause potential health problems, such as fluoride, arsenic and nitrate, are all undetectable or below safety limits. There is also no known source of these species or other heavy metals in the quartzite aquifer that could cause potential problems with the quality of the recovered water.

4.5.7 Potential sources of contamination

- Boreholes Bh3, Bh6 and New Horizon are located in and around Kwanokathula. This is not ideal, as contamination from home industries, etc, could affect the groundwater quality. Two positive factors are that the water table sits over 100 m below ground level, and that all residents have water borne sewerage. If water-borne sewers leak, however, they can easily become a source of contamination in fractured aquifers. Fractured aquifers lack some of the filtration properties of porous aquifers, so it is especially critical to protect them from contamination, which could travel quickly along the fractures. The municipality needs to ensure that the aquifer is protected from home-industry pollutants such as motor oil, solvents, paints, etc. and that future sewage pump stations and infrastructure are placed wisely.

4.6 Isotope data

A groundwater sample from the injection borehole was collected in February 2007 and submitted for analysis of stable and radioactive isotopes in an effort to understand the origin of the water and the aquifer flow dynamics. The results of the analyses are shown in Table 10.

Table 10: Isotope data for Bh3

Date	*deuterium δD ‰ SMOW*	*oxygen-18 $\delta^{18}O$ ‰ SMOW*	*tritium TU*	*carbon-13 $\delta^{13}C$ ‰ PDB*	*carbon-14 % modern*	*apparent age (uncorrected)*	*corrected age (Tamers, 1967)*
22/02/07	-24.0	-5.08	0.4 ± 0.2	-16.2	74.5 ± 0.4	2360 ± 40 BP	750 BP

At present, isotope data for the single sample gives very limited information, but the results should prove useful for comparison if nearby boreholes are sampled in future for isotope analyses or if the injection borehole is re-sampled over time during and after the injection tests.

Oxygen-18 and deuterium values are affected by isotope fractionation processes, of which the most common is evaporation. The values reported in Table 11 are close to the global meteoric water line and also near stable isotope values for groundwater samples in Table Mountain Group aquifers at Uitenhage (Heaton *et al*. 1986) and Agter-Witzenberg (Cavé *et al*, 2002). The stable isotope data suggest that the groundwater supplying Bh3 in the Kwanokuthula aquifer is recharged directly by rainfall in the high lying areas, rather than infiltration from surface water sources such as rivers or dams.

The presence of tritium suggests that at least some component of the groundwater is made up of recent recharge (post-1952). Carbon-14 age dating is difficult to interpret for a single sample without a detailed knowledge of the geochemical reactions that affect carbon cycling in the groundwater. In general, carbon-14 is best used to determine relative ages of groundwater from a number of boreholes in the aquifer. The quartzite should add very little ancient carbon (carbon-14 = 0) from mineral dissolution, because carbonate minerals are rare, but carbon-13 fractionation shows that there has been some addition of depleted carbon-13, possibly from soil carbon dioxide, which decreased the carbon-13 ratio to -16.2 ‰. The uncorrected carbon-14 age of the water, which gives a maximum age of recharge is just over 2000 years, while applying a geochemical correction (after Tamers, 1967) gives a younger corrected age near 750 years. However, the geochemical assumptions for Tamer's (1967) model were developed for arid areas and may not necessarily be appropriate for this environment. The carbon-14 ages should not be relied on as absolute values, but rather as an indication that the groundwater was recharged relatively recently.

4.7 Groundwater protection

All three public supply boreholes at Kwanokuthula (3, 6 and New Horizons) are vulnerable to surface pollution because the compounds surrounding the boreholes are either unlocked or have broken fences, and at present members of the public have access to the boreholes. In addition, borehole 3 and New Horizons are not adequately sealed at the top of the casing, and it would be relatively easy for a polluting liquid such as oil or solvent to be poured down the borehole. Part of the headworks of borehole 3 was under water on 25 June 2007, and it is quite possible that surface water finds its way into this borehole after heavy rain. The top of the observation borehole next to borehole 3 is also not secured, and can easily be removed, allowing access to the borehole. The considerable depth to water in this area offers a degree of protection to the groundwater from surface contaminants, but the boreholes in their current state offer a shortcut for pollutants straight to the water table. If the aquifer were to become polluted clean-up would be costly and protracted, and the public health liability could be severe. Apart from securing the boreholes as soon as possible, it would be advisable to draw up basic protection zones around each borehole, and limit and monitor the surface activities within the protection zones. This would be a relatively simple task to do in a general way, and would form part of a groundwater protection policy for the boreholes which could be added to as knowledge of the aquifer increases. The immediate aim should be to ensure that waste disposal for informal industry such as mechanics, painters, etc, within the protection zones, would not pollute the aquifer.

4.8 Rainfall

Rainfall taken form a station in Plettenberg Bay (supplied by P Lombard) is shown in Figure 18. The rainfall in the town over the past 20 years averaged 820 mm/a. In six of these years the average exceeded 900 mm.

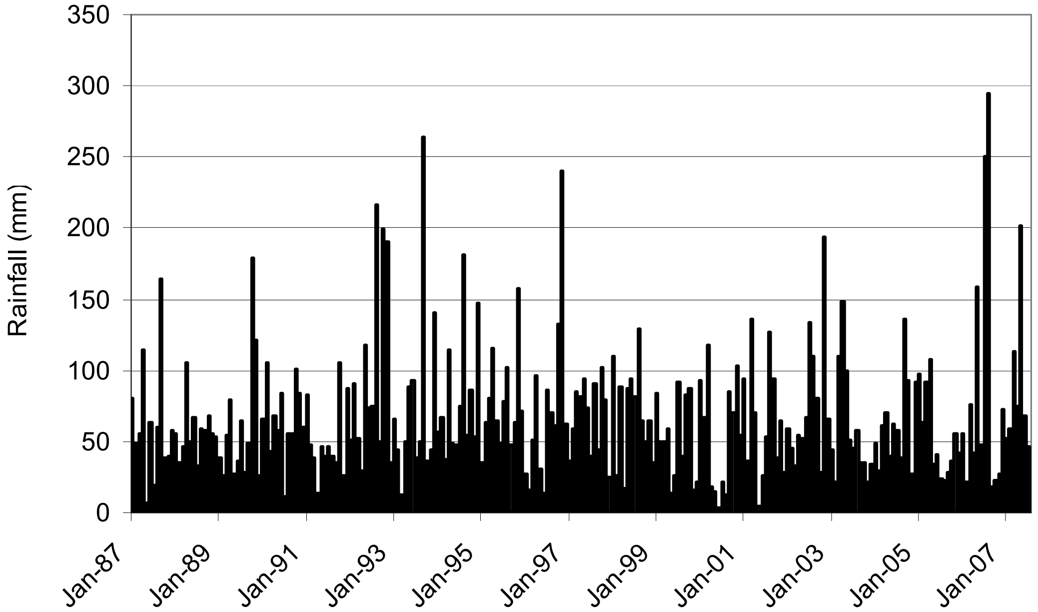


Figure 18: Plettenberg Bay monthly rainfall

SECTION C: GROUNDWATER MANAGEMENT

5. 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 are six main reasons for managing groundwater (Figure 19).

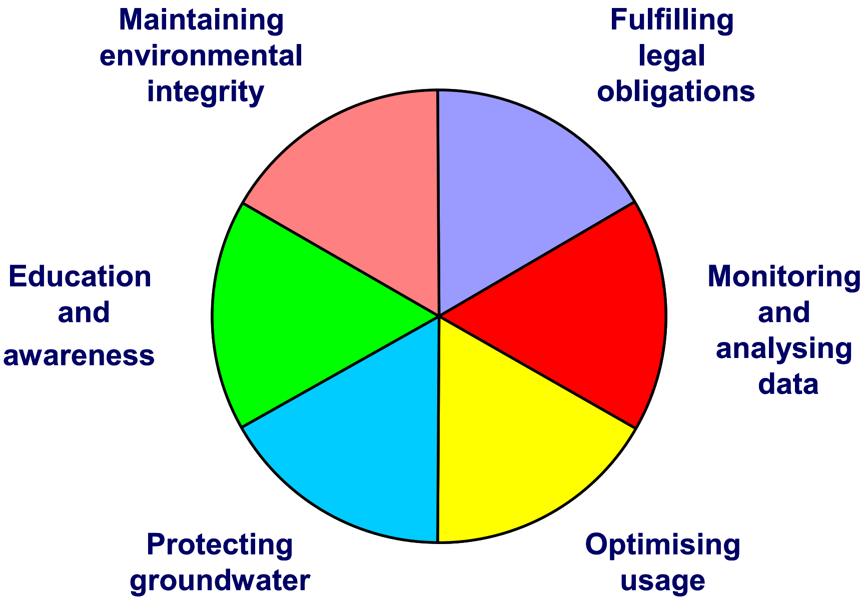


Figure 19: Components of groundwater management

Over the past year focus has been on monitoring and analysing data: Installing groundwater monitoring equipment (as originally recommended in the GCS, 1993 report) and analysing both groundwater quantity and quality.

6. GROUNDWATER USE: REGISTERED AND CURRENT

The DWAF groundwater registered use for Bitou Municipality is shown in Table 11:

Table 11: DWAF Registered Groundwater Use

DWAF Registered Use	*Actual Use March 1999 – Sept. 2007*	*Difference*
362 366 m^3/annum	134 000 m^3/annum	228 000 m^3/annum
993 m^3/day	370 m^3/day	620 m^3/day
11.5 L/s	4.3 L/s	7.2 L/s

Current groundwater abstraction is less than half of the existing Registered Use.

The aquifer is currently underutilised.

7. GROUNDWATER MANAGEMENT STATUS PRE- AND POST-MASIBAMBANE

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

Implementing groundwater monitoring and management was recommended in all previous reports (CGS and Groundwater Africa). Unfortunately this was not properly implemented until the Masibambane project that is being reported on here.

The municipality has taken occasional water level measurements in Bh6 since 2003, and in late 2006 after piezometers were installed in the boreholes, more frequent readings were taken (Figure 20). These show that in early 2004 the water level dropped in Bh6 due to high abstraction. Between April and September 2004, the water levels were about 20 m lower than those during the summer months prior to and after this period. A similar drop of 20 – 30 m took place in the summer of 2005/6, where after the water levels started recovering. Note that there is concern regarding the accuracy of some of these water levels. At the time taking some of the recent measurements, there were problems such as inadequate piezometer tubes (eg ending before the water level), a crude dip meter, etc.

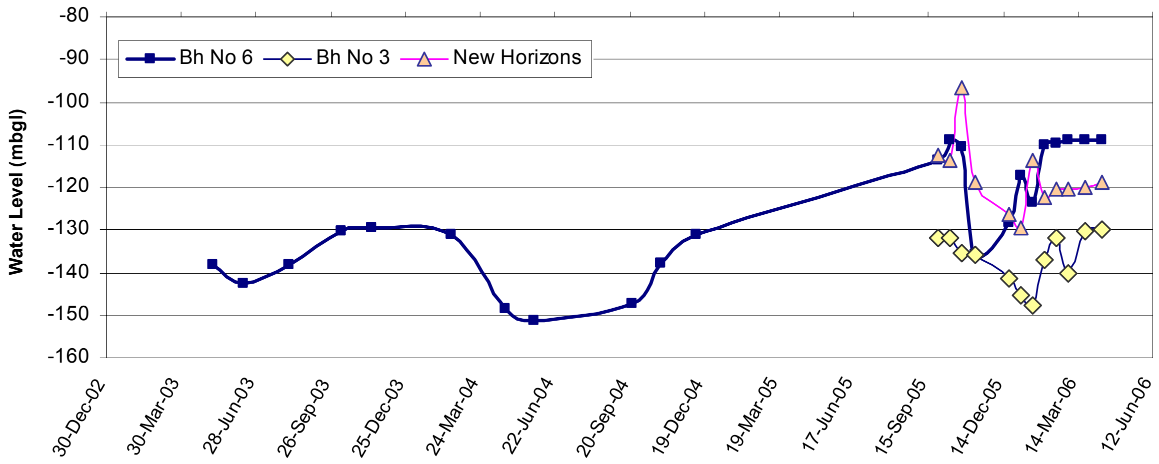


Figure 20: Borehole water levels at Kwanokathula

Prior to the Masibambane Project it was not know whether the deep water levels measured in pumping boreholes during the high abstraction times (eg 2004) was due to aquifer dewatering or borehole inefficiencies. The pump operator thought that when the water levels were drawn to pump intakes that the aquifer had been depleted. Now that all boreholes are quipped with data loggers and flow meters and after a season of high abstraction, it is evident that the deep water levels were largely due to borehole inefficiencies rather than the dewatering of the aquifer. Indeed, the high abstraction of Bh3 have virtually no impact on regional aquifer water levels (as will be shown in a later section). Thus it appears as if 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. In the past, water levels in boreholes were drawn down to pump intakes while the aquifer was possibly fairly full. Not only did this result in getting less water than that which was available, but it also meant that boreholes could have become less efficient with time due to iron-related clogging.

The Golf Course Artesian Borehole

At attempt was made to establish whether the flow in the artesian borehole at the golf course had indeed dropped between 1985 and 1993 as was recorded in previous reports. A decline in flow would indicate that either water levels in the aquifer have dropped over time, or that the efficiency of the borehole has decreased (possibly due to clogging). The measured flows are as follows:

Hand measurements:

1985: 6.8 L/s
1993: 3.0 L/s
2005: 1.3 L/s (measured on 26 Aug & 14 Dec 05).

Flow meter measurement:

2007: 0.95 L/s (average between 24 Jan 07 and 17 May 07)

In 2006 Mr Lombard informed the project team that the hand measurements made at the discharge point (on a farm south of the golf course) were not indicative of the full flow since a portion of this flow is diverted prior to the holding tank where the hand measurements were taken. The hand measurements above could therefore be incorrect, and if so, they are conservative measurements since a portion of the flow may not have been accounted for.

During the Masibambane project a flow meter was installed on the pipeline leading from the borehole. The average flow measured between the 24th January 2007 (when the meter was installed) and the 17th May 2007 was 0.95 L/s.

From the data above, it appears as if the flow from this borehole has decreased over the years. Continual monitoring of the flow meter together with accurate water level monitoring will give an indication of the cause of this apparent decline.

7.2 Post-Masibambane groundwater management status (after 2006)

In 2006 DWAF (Cape Town office) installed loggers at Bh2, and DW1 (which was removed after this hole collapsed during the 2006 floods). Bh2 has subsequently been replaced by a municipal logger and DW1 has been rehabilitated but is currently not equipped with a logger.

The municipality purchased a dip meter and in late 2006 Bh3 was equipped with a piezometer tube. The pumps were out of Boreholes 2, 6 and NH which made water level measurements and logger installations possible. The pump in Bh4 was recently removed, and a piezometers and data logger installed. Data loggers are now in all Plettenberg Bay municipal boreholes (purchased with municipal funds). Water levels are monitored on a half-hourly basis, flow meters are read and water samples are analysed from time to time. 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.

8. THE PROPOSED GROUNDWATER MANAGEMENT SYSTEM

8.1 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 21).

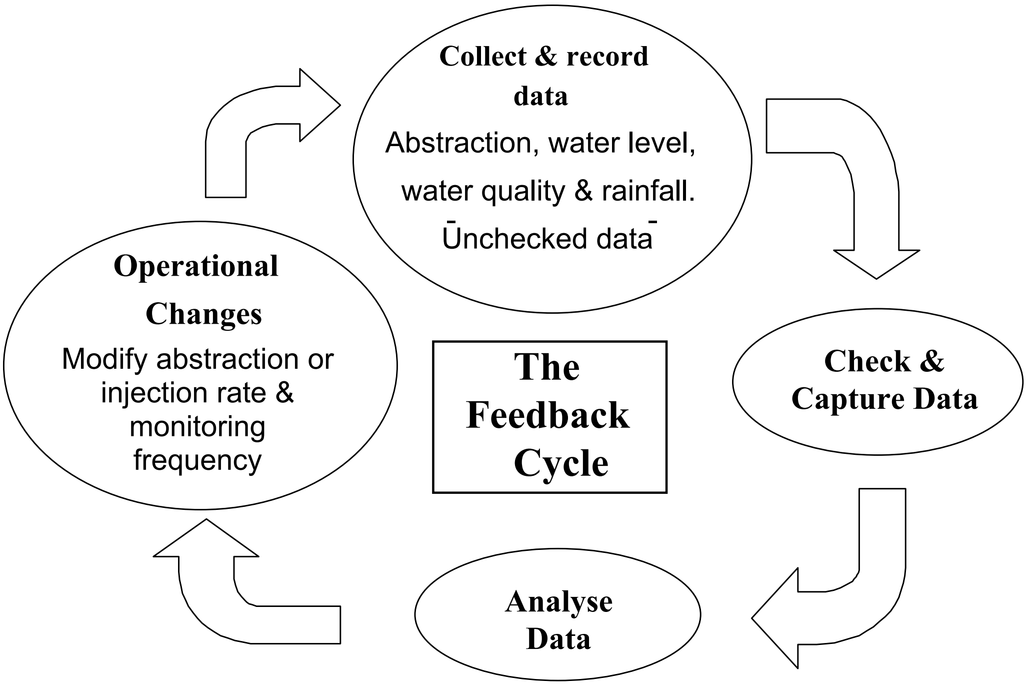


Figure 21: Principle Groundwater Management Tasks

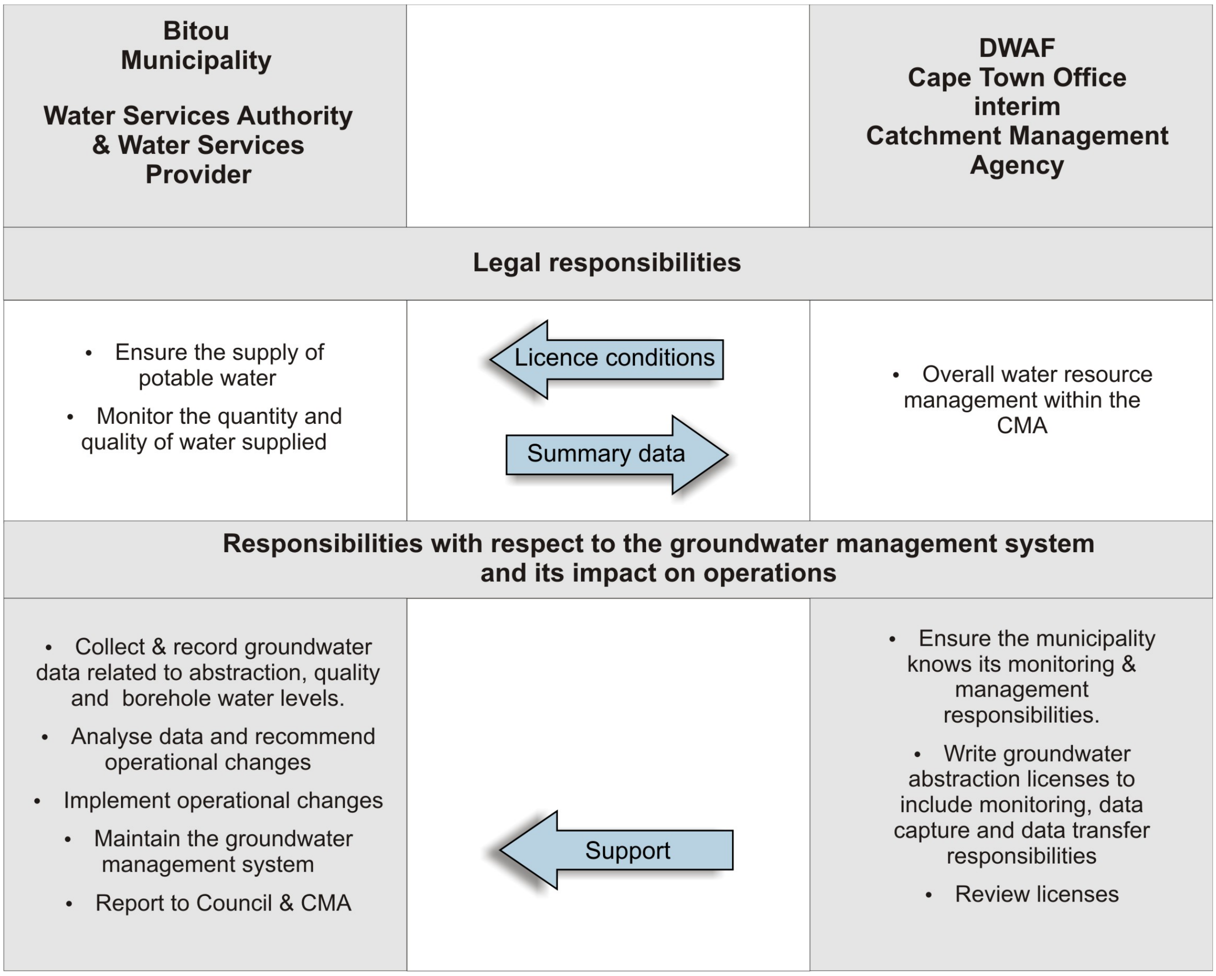
Data collection is simple and inexpensive, and should form part of all pump operators' operation and maintenance (O&M) tasks. Information needed includes borehole water levels and abstraction data on a monthly basis, and water samples for water quality assessments on a yearly basis. Although not essential, 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 Bitou Municipality 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. The management system will, however, 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.

8.2 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). Bitou Municipality is both the WSA and WSP for the Greater Plettenberg Bay area. Figure 22 illustrates the relationship between the CMA (DWAF) and the WSA/WSP (Bitou Municipality) in groundwater management and supply.



Bitou Municipality **Water Services Authority & Water Services Provider**		**DWAF Cape Town Office interim Catchment Management Agency**
Legal responsibilities		
• Ensure the supply of potable water • Monitor the quantity and quality of water supplied	Licence conditions Summary data	• Overall water resource management within the CMA
Responsibilities with respect to the groundwater management system and its impact on operations		
• Collect & record groundwater data related to abstraction, quality and borehole water levels. • Analyse data and recommend operational changes • Implement operational changes • Maintain the groundwater management system • Report to Council & CMA	Support	• Ensure the municipality knows its monitoring & management responsibilities. • Write groundwater abstraction licenses to include monitoring, data capture and data transfer responsibilities • Review licenses

Figure 22: Institutional framework for groundwater management

8.3 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.
- Bitou Municipality (the WSA &WSP) is effectively the groundwater manager. This is because groundwater management and O&M are closely linked.
- Bitou Municipality should collect and store the relevant groundwater data.
- Bitou 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 Bitou Municipality of operational improvements that should be made such as modifying pumping schedules.
- Bitou Municipality should provide the CMA with a summary report on groundwater use and quality on an annual basis.
- Bitou Municipality should provide the Municipal Council with a report on the effectiveness of groundwater supply and management.
- Bitou 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 12 describes the key management functions.

Table 12: 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	
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

	Activity	*Responsible person*	*Skills & qualifications required*	*Resources, tools & equipment*	*Remarks*
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).

8.4 Specific groundwater management tasks for Bitou Municipality

The key water management and supply tasks are listed in Table 13. The following assumptions have been made:

1. *Bh3, Bh4, Bh6 and BhNH are equipped and in use*
2. *Bh NH pumps directly to the New Horizons Reservoir*
3. *Water is pumped from the New Horizons Reservoir to the Kwanokuthula reservoir*
4. *Bh3, and Bh6 pump directly into the Kwanokuthula reservoir*
5. *Bh 4 pumps to the WTW*
6. *There is no automated control system on any of the boreholes*
7. *Both New Horizons and Kwanokuthula reservoirs are connected to the telemetry system at the water works*
8. *Bh2, Bh SG3, BH GC, Bh Plaka, Bh RD1 and Bh DW1 are monitoring boreholes*

In the table below, all tasks are assigned to in-house (ie municipal) personnel except where external support is needed. Until in-house skills are developed, technical support will be required for data management – to be provided by a Technical Support Person (TSP) (performed by Johann Rissik during the Masibambane project). A hydrogeologist will be needed to evaluate data on a regular basis until the aquifer is better understood and all production boreholes are operated optimally.

Table 13: Specific groundwater management tasks for Bitou Municipality

	Task or Function to be performed	*Who*	*Detailed description of what the task entails*	*Existing Impediment*	*Who should remove impediment*	*Notes*
DAILY						
1	Continual monitoring of water level in Kwanokuthula reservoir	PO / SWP	Telemetry system at waterworks			
2	Start/Stop pumps in Bh3, Bh4, Bh6, BhNH as required	PO / SWP	Drive to borehole to start / stop the pump	Pumps not installed in Bh6, BhNH	MWP/MCW	This needs to be tied in with the water blending requirements
WEEKLY						
3	Check that pump in Bh4 is running	PO/SWP	Drive to pump and inspect	No flow meter	MWP	
MONTHLY						
4	Collect monthly water samples from Bh3, Bh4, Bh6, BhNH	PO / SWP	Collect water samples from each borehole, deliver to Plett WTW lab.	No sampling points at Bh3, Bh4, Bh6, BhNH	MWP	
5	Test monthly water samples	SO	Test EC, pH, E.coli (if possible)			1.Bh3: Contamination potential 2. BH4: E.C.
6	Send results to SWP/MRIC /TSP/CHG	SO	Enter results of tests into simple Excel spreadsheet and email to intended recipients	Template of revised spreadsheet required	TSP to develop template of spreadsheet and email to SO/SWP/ MRIC/MWP/ CHG	
7	Respond to water quality data as required Bh3 if E. coli high Bh4 if EC high	SWP/MWP	If E.coli over limit, take appropriate action If E.C. over limits, take appropriate action			
8	Measure water levels in monitoring boreholes: Bh2, BhSG3, BhRD1 and Bh DW1	SWP	Drive to each borehole site and record date, time and actual water level.	Dipmeter broken	TSP to repair dipmeter	
9	Collect water meter reading BMCWC	SWP		Occasional flooding of meter box		
10	Monthly data logger download: Bh2, Bh3, Bh4, Bh6, BhNH	PO + MRIC/SWP	Visit borehole site, download logger onto Leveloader, measure water levels, collect water meter reading	Levelogger training of SWP/MRIC	TSP to train SWP/MRIC	
11	Send data to SWP/MRIC/	SO	Enter results of tests into template of	Template of revised	TSP to develop template of	

	Task or Function to be performed	*Who*	*Detailed description of what the task entails*	*Existing Impediment*	*Who should remove impediment*	*Notes*
	TSP/CHG		Excel spreadsheet and email to intended recipients	spreadsheet required	spreadsheet and email to SO/SWP/ MRIC/MWP/ CHG	
12	Capture data in Aquimon	MRIC	Transfer logger data from Leveloader to PC in office. MRIC to capture manual data in Aquimon	Load Aquimon on municipal system	TSP to load Aqimon on municipal computer	
QUARTERLY						
13	Print quarterly reports for Council Meeting	MRIC	MRIC managing Aquimon and printing reports	Aquimon training SWP/MRIC	TSP to train MRIC	
ANNUALLY						
15	Print annual reports and submit to DWAF	MRIC MM	MRIC managing Aquimon and printing reports			

Key:

PO	Pump Operator
SO	Scientific Officer
SWP	Superintendent Water Purification
MWP	Manager Water Purification
MRIC	Manager Roads Infrastructure and Cleansing
TSP	Technical Support Person
MCW	Manager Civil Works
CHG	Consultant Hydrogeologist
MM	Municipal Manager

8.5 Individual borehole management

Due to the fairly aggressive groundwater chemistry and the reducing conditions found in parts of the Kwanokathula Aquifer, it is desirable that the production boreholes are pumped at a continuous low(er) rate rather than for intermittent periods at a higher rate. This avoids the oxidation and iron precipitation problems associated with repeatedly dewatering parts of the aquifer and steel borehole casing, and then allowing aquifer water back into these zones. The exact (sustainable) pumping rates will need to be established following a period of water level monitoring, which ideally would include observation boreholes to establish the water levels in the aquifer as a whole. Unfortunately the only observation hole is Bh 3A which is currently blocked.

This section provides general comments on the three Kwanokathula boreholes. A complete borehole status report is provided in Appendix 1. The following section presents the water level response in these boreholes to abstraction from Bh3, and then new pumping recommendations are made for these production boreholes.

8.5.1 Borehole 3 (GCS1R)

This borehole has a dipper tube attached to the rising main, allowing access for a data logger. The borehole is located in a small fenced compound which is open, and there is consequently a risk of surface contamination as well as vandalism. Part of the headworks of the borehole is also below ground level, and is frequently flooded with surface water. The first attempt at drilling a borehole at this site (GCS1) resulted in a 200 m borehole, but the drill bit and other components were lost in the hole during reaming, and the borehole had to be re-drilled 5 m away (resulting in borehole 3GCS1R). Borehole GCS1 is still present, although it is blocked. It was recently unblocked (in 20007) and the drill bit was inserted to a depth of 181 m (P Lombard, *pers comm.*), however it has collapsed again and at the moment cannot be used for water level monitoring. During the unblocking, and at a depth of 181 m, no water was blown out (using air percussion drill rods/bit) even though 5 m away, Bh3 was being pumped at 14 L/s. Borehole GCS1 is clearly a very low yielding borehole, but it would probably still make a good aquifer monitoring borehole. Note that there are no other existing monitoring holes in Kwanokathula). At present the steel cap on borehole GCS1 is not secure, and the borehole presents a direct route for contaminants to bypass the soil zone and penetrate into the aquifer. Borehole 3 currently pumps at rates of around 14 L/s (average of 4.3 L/s over several months) and supplies the Kwanokathula reservoirs.

8.5.2 Borehole 6 (GCS3R)

This borehole is currently not in use (Sept. 2007), as the pump and rising main have been removed for maintenance. The borehole is located in a small fenced compound which is not secure, and there is consequently a risk of surface contamination as well as vandalism. It is recommended that this borehole be brought back into service as a water supply borehole, and the compound and headworks be restored to a secure state.

8.5.3 New Horizons Borehole

The New Horizons Borehole is located in a fenced compound, but the compound gate was missing in June 2007 and there is consequently a risk of vandalism and contamination. The pump and rising main have been removed from the borehole, and it is not currently used for water supply. It is recommended that this borehole be brought back into service as a water supply borehole, and the compound and headworks be restored to a secure state. It is possible that with on-going pumping at a lower rate the high iron concentrations associated with groundwater from this borehole will diminish.

9. NEW ABSTRACTION RECOMMENDATIONS

9.1 Results of high abstraction from Bh3 from February to July 2007

Bh3 was pumped heavily between the end of February and early July 2007. No other municipal boreholes were pumped during this period. The water level response in the the pumped and observation boreholes is shown in Figure 23.

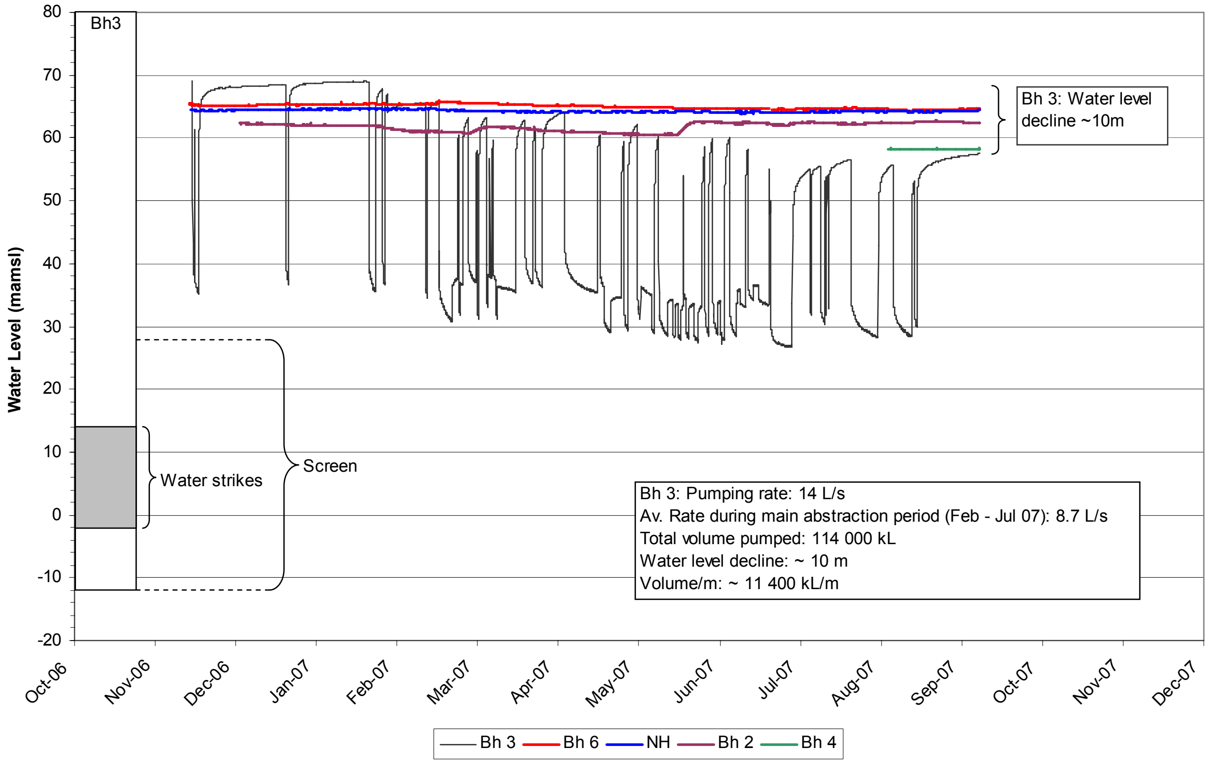


Figure 23: Water level response to abstraction from Bh3

Key conclusions that can be drawn from the extended pumping test done on Bh3 are:

1. Towards the end of the high pumping period (July 07) the drawdown in Bh3 was approaching the casing screens. To minimise water quality problems, it's best to keep the water levels above the screens. The pumping rate should be reduced.
2. Water levels in the aquifer around Bh3 dropped by about 10 m as a result of withdrawing 114 000 m^3 (~ 11 400 m^3/m)
3. Water levels in monitoring boreholes show that the aquifer as a whole was hardly affected:
    a. Water levels in Bh6 (520 m away) dropped by ~ 1 m (Figure 24)
    b. Water levels in NH (1 150 m away) dropped by ~ 0.5 m (Figure 25)
    c. Water levels in Bh2 (3.9 km away) was not affected. This borehole responds well to rainfall – note the effect of 200 mm rainfall in May/June 2007 (Figure 26).
4. The groundwater salinity decreased with pumping (Figure 27). During abstraction the salinity dropped from 110-120 mS/m to 80-90 mS/m. After stopping pumping it rose again to 130 mS/m. This borehole should be pumped continuously if logistically possible.
5. The overall conclusion is that the aquifer can supply far more than the 114 000 m^3 that was pumped over the 5-6 month period. The average abstraction of 8.7 L/s can be increased and this should be distributed over the three Kwanokathula production boreholes.

Figure 24: BH6: Water level during abstraction from Bh3

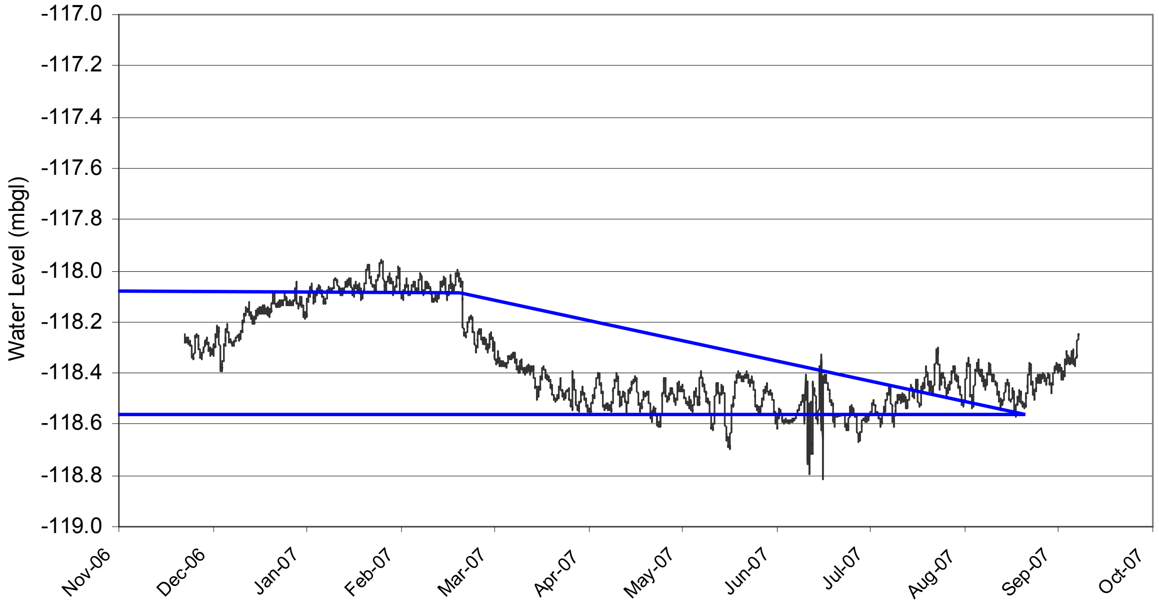


Figure 25: NH: Water level during abstraction from Bh3

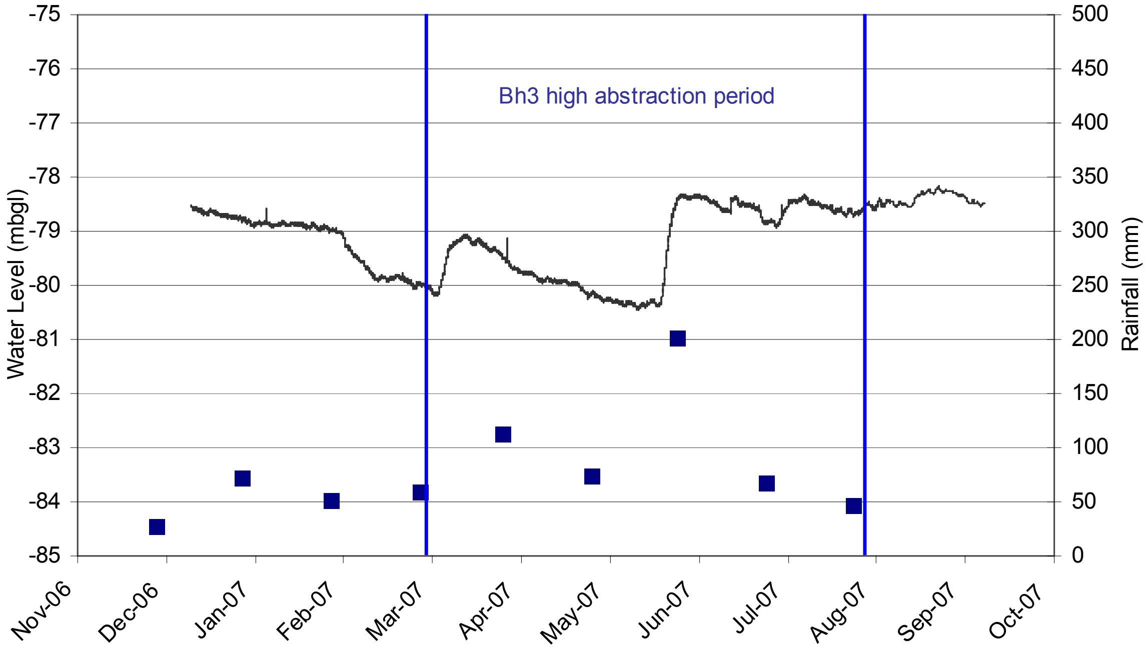


Figure 26: Bh2: Water level during abstraction from Bh3

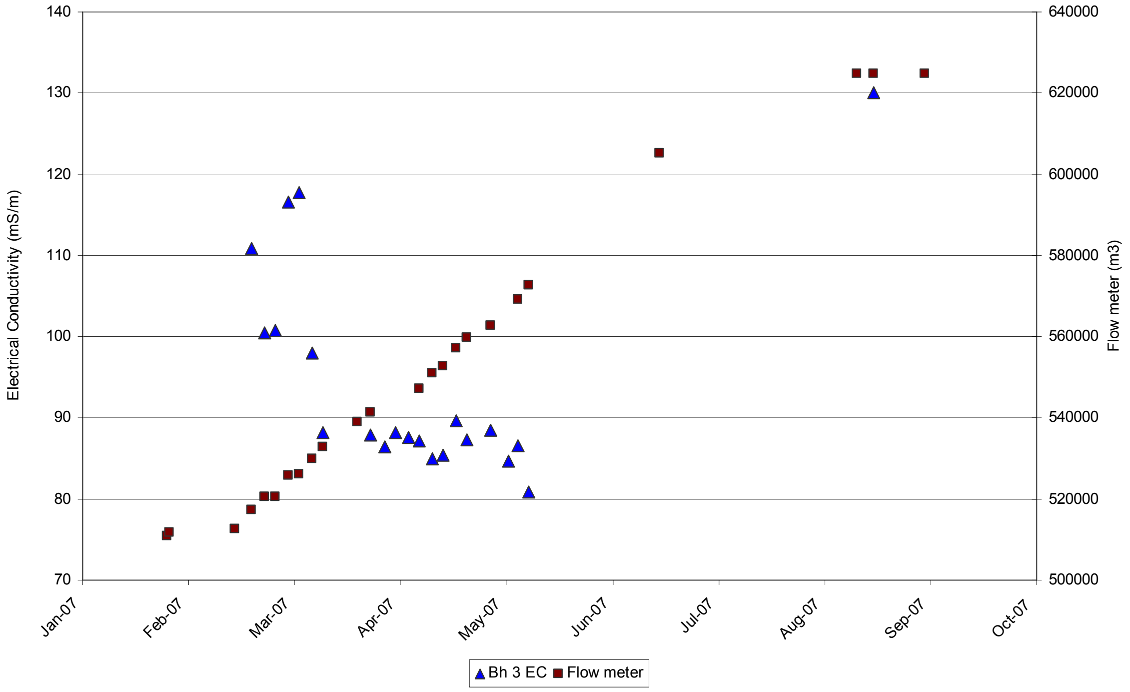


Figure 27: Bh3: Groundwater salinity during abstraction

9.2 New Pumping Recommendations

9.2.1 Existing equipment

In 2007, Bh3 was pumped at its current rate of 14 L/s and water level monitoring with data loggers was carried out on boreholes Bh3, Bh6 and NH. The recommendations made below are thus based on pumping data fro Bh3, and on estimates for Bh6, NH and Bh4. These estimates are based on comments by Mr P Lombard, water quality (especially iron and salinity) considerations, and Bh3's response to pumping. Thus they have not been scientifically determined, but are based on available information and at this stage, a best "gut feel". They will have to be pumped at the recommended rates and their water levels monitored. They all are equipped with data loggers. Table 14 thus provides a best estimate of the maximum abstraction potential from these boreholes.

Table 14: Newly recommended borehole pumping rates: existing pumps

Bh No.	*Recommended Pump Intake Depth (m bgl)*	*Rest Water Level (mbgl)*	*Available Drawdown (m)*	*Pumping rate (L/s)*	*Maximum Daily Abstraction (m^3/day)*
Bh3	170	120	50	10*	860
Bh6	170	130	40	4	340
NH	160	120	40	4	340
Bh4	<115	65	<50	10*	?
Total (excl Bh4)				**18**	**1 540**

* Existing installed pumps

Notes on Table 14

1. *Bh3 is equipped with a pump that delivers 14 L/s. It can be reduced to deliver about 10 L/s whilst still operating "on the pump curve". Ideally this borehole should be pumped at a lower rate (4 - 8 L/s) to prevent the water levels from dropping too much in the borehole. This can possibly be achieved by removing one stage from the pump.*
2. *Bh6 and NH are not equipped at present and the pumps that deliver 4 L/s should be obtained for these boreholes. Either their old pumps which deliver 10 L/s and 7 L/s respectively should be modified to lower their yields (remove a stage) or new pumps should be obtained.*
3. *Ideally the pump intake for NH should be above the screens because of Fe problems, but since the screens go from 113 m onwards, the pump may as well be placed closer to the main water strike at 165 m.*
4. *Bh4 is currently equipped with a pump that delivers 10 L/s. The plan is to leave it as is and pump it at this rate whilst monitoring water levels and salinity (the correct logger has been ordered). The data will be analysed and a new pumping rate set after this analysis. It is likely that this pump too powerful for the borehole and that a lower yielding pump will need to be obtained in future. It is essential that the pump be installed above sea level. The recommended pump intake depth is 115 mbgl.*
5. *If the above recommendations were implemented on a continual basis (ie 24 hours a day pumping) then the daily total of 1 540 m^3/day would be greater than DWAF's annual registered use of 362 336 m^3/a or 993 m^3/day. Abstraction of 18 L/s from the three main supply boreholes for 15 hours a day every day of the year would match DWAF's registered use.*

Boreholes 3 and 6 together can meet Kwanokathula's demand. However abstraction to meet Kwanokathula blending requirements of 60% groundwater to 40 % surface water (i.e. ~ 720 m^3/day groundwater + 480 m^3/day surface water) means that the boreholes will be under-utilised.

9.2.2 Ideal New Pumping Rates: Replace all pumps

Ideally all boreholes should be equipped with pumps that are best matched to the borehole's capacities and to minimise iron problems. Table 15 gives the estimated ideal pumping regime (at this stage, since only after monitoring at these rates will it be possible to establish the truly ideal rates for each borehole).

Besides being "better" yields for the boreholes, the recommendations below are also close the DWAF's registered groundwater use. Allowing for down-time due to power failures, pipe-bursts, etc, these recommendations will fall within DWAF's registered use.

Table 15: Newly recommended borehole pumping rates: replace existing pumps

Bh No.	*Recommended Pump Intake Depth (m bgl)*	*Rest Water Level (mbgl)*	*Available Drawdown (m)*	*Pumping rate (L/s)*	*Maximum Daily Abstraction (m^3/day)*
Bh3	170	120	50	4.4	380
Bh6	170	130	40	4	340
NH	160	120	40	4	340
Bh4	<115	65	<50	4	340*
Total (excl Bh4)*				**12.4**	**1 060**

* At this stage the sustainable yield of Bh4 is not known.

All new pumps should be sized to operate between 4 – 8 L/s for the following two reasons:

1. *The higher flow of 8 L/s per borehole may be required to meet emergency requirements.*
2. *If with artificial recharge it is found that the daily abstraction volumes can be increased (because the water levels are raised higher than usual), then the pumping rates (L/s) will need to be raised to accommodate this.*

SECTION D: ARTIFICIAL RECHARGE

10. OBJECTIVES OF ARTIFICIAL RECHARGE

The main objective of artificial recharge is to allow an aquifer to deliver more water during times of peak demand than would otherwise be possible. This presupposes a source of surplus water during times of low demand, to use as recharge water. Plettenberg Bay has both a high demand for water in the summer and a surplus of water in the winter, making it potentially a good candidate for artificial recharge. It is estimated that the Kwanokathula Aquifer, the best aquifer available in the vicinity of the town, can easily yield the DWAF's Registered Use volume of 362 000 m^3/annum, and that this could possibly be tripled with artificial recharge (see Chapter 14).

With artificial recharge, the existing DWAF Registered Use of 362 000 m3/a could potentially be tripled with artificial recharge in the Kwanokathula area alone.

The current DWAF Registered Use of 362 000 m^3/a, which equates to 11.5 L/s continuous supply or about 1 000 m^3/day, could potentially be tripled to ~ 3 000 m^3/day if the Kwanokathula Aquifer can store artificially recharged water. It would need to hold this water between winter when the aquifer is recharged until summer when the water is pumped back out. This would offer a valuable additional water supply to the town when it is most needed.

A potential additional benefit would be that the Water Treatment Works (WTW) could run at greater capacity during winter (to treat the artificial recharge water) and at lower capacity during summer (as the recharged water would not have to be re-directed through the WTW). During summer it is already run to near-capacity. By having a sizeable volume of treated, stored water on the town's doorstep it would add to the water security during the time of greatest need.

11. THE SOURCE WATER: AVAILABILITY AND QUALITY

11.1 Source water availability

Two sources of water have been considered for recharging; the Keurbooms River raw water bypass that runs past Kwanokathula and treated water supplied from the water treatment plant.

11.1.1 Supply of treated water

There are two main constraints in the current capacity of the water supply system that must be considered for the supply of treated water for artificially recharging the boreholes. Firstly the capacity of water the treatment works and the capacity of the supply pipelines to Kwanokathula.

Figure 28 shows the volume of water treated per month and the spare capacity per month based on an assumed monthly operating capacity of 410 000 kL/month (410 ML/month). The maximum capacity of the works is 22 000 kL/day (22ML/day) or 660 000 kL/month (660 ML/month).

There is sufficient treatment works capacity during the winter months to supply the treated water required for artificial recharge (30-50 L/s).

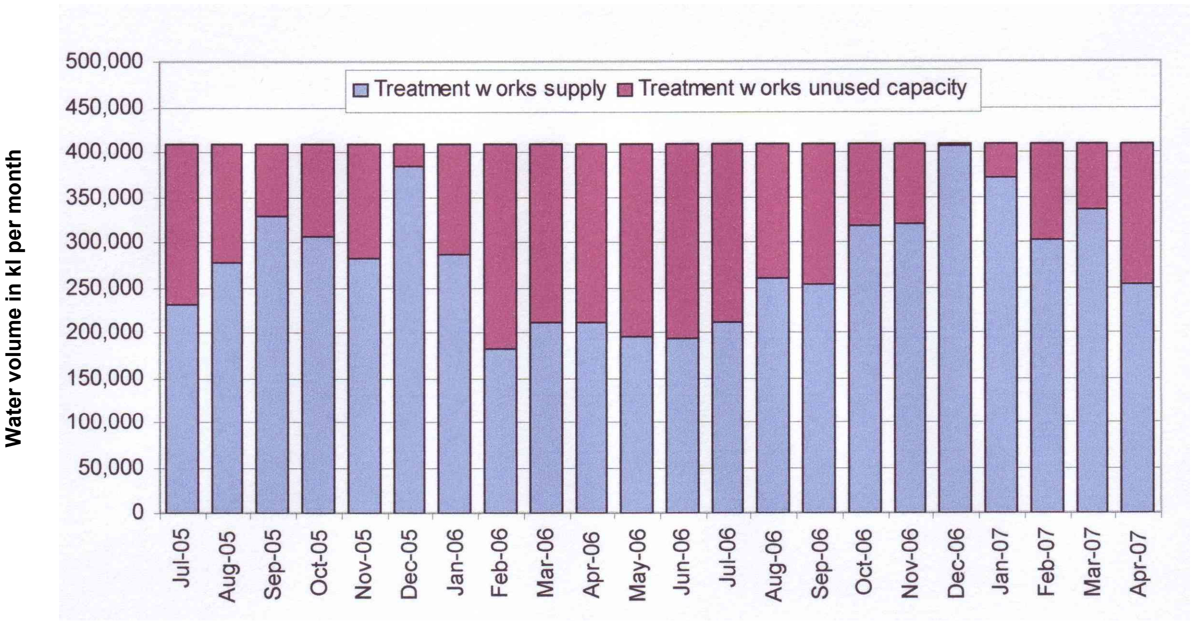


Figure 28: Monthly treatment works supply and spare capacity (based on current utilised treatment works capacity of 410,000 kL per month)

Figure 29 shows the monthly water demand of Kwanokathula and the capacity of the pipeline useable for AR if it is run at 24 hours a day. Table 16 shows this pipeline capacity as the flow useable for artificial recharge in litre per second. This is lower than the target recharge flows of 20 to 30 L/s (for borehole 3 and 6 combined).

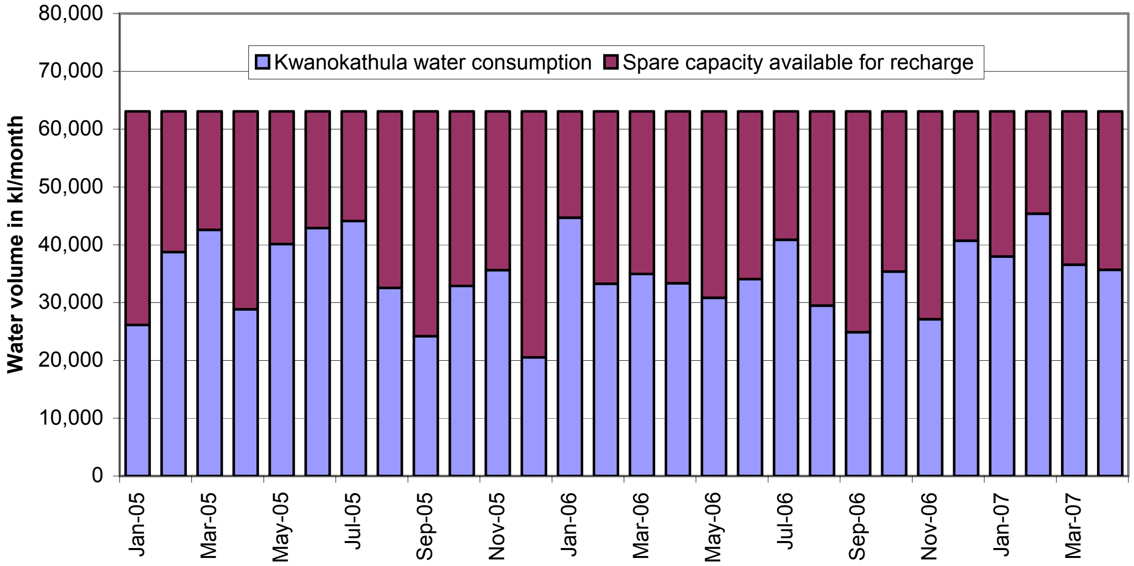


Figure 29: Monthly water demand and supply capacity for Kwanokathula (based upon the supply pipeline capacity of 24 L/s).

Table 16: Available flow in L/s for recharge based upon supply pipeline to Kwanokathula reservoir

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
2005	13.8	9.1	8.5	12.8	8.9	7.5	7.3	11.4	14.5	11.6	10.2	16.4
2006	6.9	11.1	11.6	11.1	12.4	10.8	8.6	12.5	14.3	10.7	13.4	8.6
2007	9.4	6.6	11.0	10.2	11.0							
Average	10.0	8.9	10.3	11.4	10.8	9.2	7.9	12.0	14.4	11.2	11.8	12.5

The main constraint for treated artificial recharge supply water is the pipeline supplying the Kwanokathula reservoirs from the New Horizon Reservoir, which has a capacity of 24 L/s (Pikkie Lombard pers. comm.).

New horizons borehole can be supplied directly from the New Horizons reservoir and is not limited by the flow in the supply pipeline.

11.1.2 Supply of untreated water – the Keurbooms River raw water bypass

The Keurbooms River raw water bypass is designed to transfer water to the Roodefontein Dam. This happens during off peak demand times when the treatment plant is unable to receive all the water from the Keurbooms pipeline and the Roodefontein Dam has the capacity to receive the water.

It is fair to assume that the full flow of 32 L/s of untreated water would be available for artificial recharge during the winter, low demand months.

11.2 The source water: quality

The source of water for injection is either raw (untreated) or treated surface water from the Water Treatment Works. The water is obtained from the Keurbooms River and sometimes blended with water from the Roodefontein Dam. The Keurbooms River water is likely to be compatible with the groundwater, since the sandstone geology of the river catchment is similar to that of the aquifer. Table 17 summarises the available chemical analyses for these water sources.

Table 17: Source water quality

SAMPLE ID:	***Blended & Treated***	***Blended & Treated***	***Keurbooms untreated***	***Keurbooms untreated***	***Roodeftn Dam Untreated***
SAMPLE DATE:	*26- Mar-07*	*22-Nov-05*	*Oct-05*	*22-Nov-05*	*22-Nov-05*
Potassium as K mg/L	0.9	3	-	-	-
Sodium as Na mg/L	35	37	-	-	-
Calcium as Ca mg/L	14	12	8	-	-
Magnesium as Mg mg/L	4.2	6.8	6	-	-
Sulphate as SO4 mg/L	38	29	-	-	-
Chloride as Cl mg/L	51	68	0	-	-
Alkalinity as CaCO3 mg/L	12	13	5	-	-
Nitrate plus nitrite as N mg/L	0.1	<0.1	-	-	-
Total iron as Fe mg/L	<0.05[1]	0.15	-	0.41	1.66
Total manganese as Mn mg/L	<0.05	<0.05	-	-	-
Dissolved Organic Carbon mg/L	3.2	4.2	-	10	12.3
Electrical Conductivity mS/m (25°C)	25	33	6.7	13	148
pH (Lab) (20°C)	7.5	7	6	-	-
% Difference	4.59	2.25		-	-
CATIONS meq/L	2.59	2.84		-	-
ANIONS meq/L	2.48	2.78		-	-

[1] *Filtered sample, dissolved iron reported.*

The chemical water quality of the Keurbooms River is of a very high standard. The water flows over the relatively inert sandstones of the Table Mountain Group. This is in contrast to Roodefontein Dam's water quality, which is significantly more saline, being located on the saline Enon conglomerates. Untreated Roodefontein Dam water has a relatively high conductivity (salinity), DOC and iron concentration. These three factors combined make the Dam water a poor choice for artificial recharge into a lower salinity aquifer with the potential for iron clogging problems.

The blended water after treatment is of better quality and has lower salinity, DOC and iron, than raw Roodefontein Dam water but the carbon and iron are still higher than that occurring naturally in the aquifer at Bh3 and Bh6. The November 2005 sample probably represents a "worst case" of treated injectant quality if treated water is used, since at the time of sampling a relatively high proportion of Dam water was being used by the municipality (estimated to be a 50/50 blend of River and Dam water by Mr Lombard). Water quality was better in the March 2007 sample. Keurbooms River water typically has an electrical conductivity less than 15 mS/m, while water which is blended with the Roodefontein Dam has a conductivity range of 15 to 25 mS/m.

Weekly monitoring records of the treated water quality are kept by the Municipality. Electrical conductivity and pH records have been plotted for the raw and treated water to provide an indication of the long term water quality that may be available for artificial recharge (Figure 30).

Figure 30/...

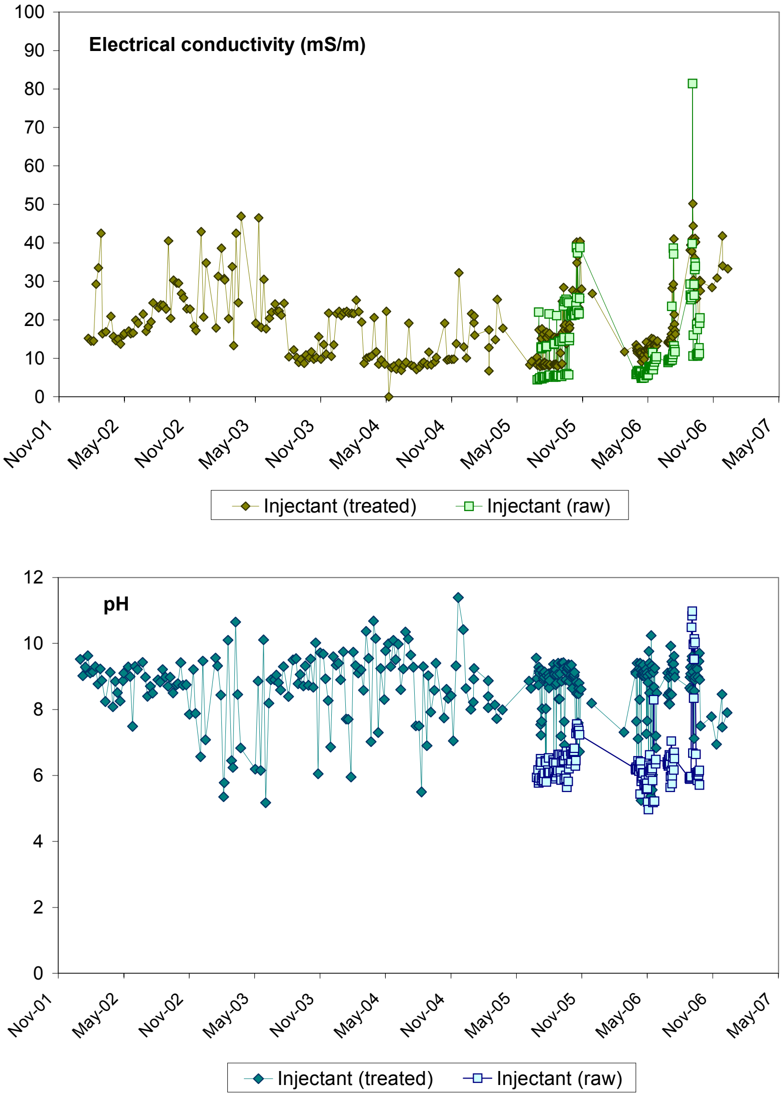


Figure 30: Time series graphs of electrical conductivity and pH for raw and treated potential injectant water

Treated water is of generally good quality, with low salinity, typically between 10 and 40 mS/m. This may help to reduce the slightly higher salinity of the groundwater in the vicinity of Bh3. Salinity varies over the seasons and from one year to the next, probably related to timing and volume of rainfall in the catchment and the blending of River and Dam water sources. Salinity tends to rise in the summer, when both water demand and evaporation are higher.

The pH is higher in the treated water (around pH 9) than in the raw water (about pH 6 to 7). All iron oxides are very insoluble in the pH range 8 to 9 and injecting a high pH, oxygenated water into the aquifer could increase the amount of iron precipitation and potentially cause clogging if high dissolved iron concentrations are present in the groundwater or injectant. If the iron is kept low (<0.1 mg/L), the addition of higher pH water may increase the groundwater pH to near neutral and help to decrease the aggressive and corrosive properties of the groundwater.

The preferred option for artificial recharge is to use treated water from the Keurbooms River. The use of the untreated water is less favourable. While the salinity of both raw and treated water is ideal for artificial recharge, higher DOC and iron concentrations in the raw water might encourage borehole clogging and plugging of aquifer fractures around the injection boreholes.

Aeration and filtration will usually remove some of the dissolved iron. Treated water has a lower iron content than either of the raw water sources from the Roodefontein Dam or Keurbooms River. There is, however, also iron in the groundwater, especially at the New Horizon borehole which will still be present and should be avoided as a recharge location if possible. An option may be to fix iron in the aquifer at New Horizon by injecting oxygenated water in this area (as is done in other parts of the world to curb iron problems, such as in The Netherlands).

Treatment also removes DOC, which improves the likely success of artificial recharge, particularly if microbial reactions are contributing to the oxidation of iron in the aquifer. Another benefit of treatment is that the water is disinfected by chlorination. Residual chlorine in the treated water could help to sterilise the injection borehole and limit potential clogging from the growth of biofilms. From a water quality perspective, treated water would be the recommended source for injection, provided a constant high quality could be maintained.

Monitoring of the raw and treated water quality over the past few months has shown that the treated water has consistently lower iron and DOC concentrations than the raw water, which make it more suitable as a source of the injectant water (Figure 31).

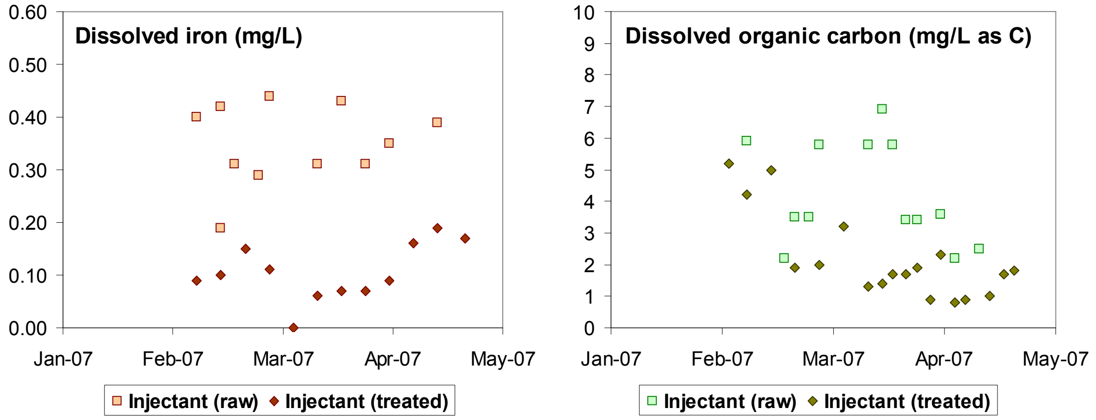


Figure 31: Time series graphs of iron and DOC for raw and treated water (potential injection water)

The major water types of all boreholes and the source water are summarised in the trilinear diagram (Figure 32). Waters of similar composition (excluding evaporation and dilution effects) will plot near each other in the diamond-shaped field of the diagram. The treated surface water from the Water Treatment Works (WTW) is of similar composition to the groundwaters and should be compatible for artificial recharge.

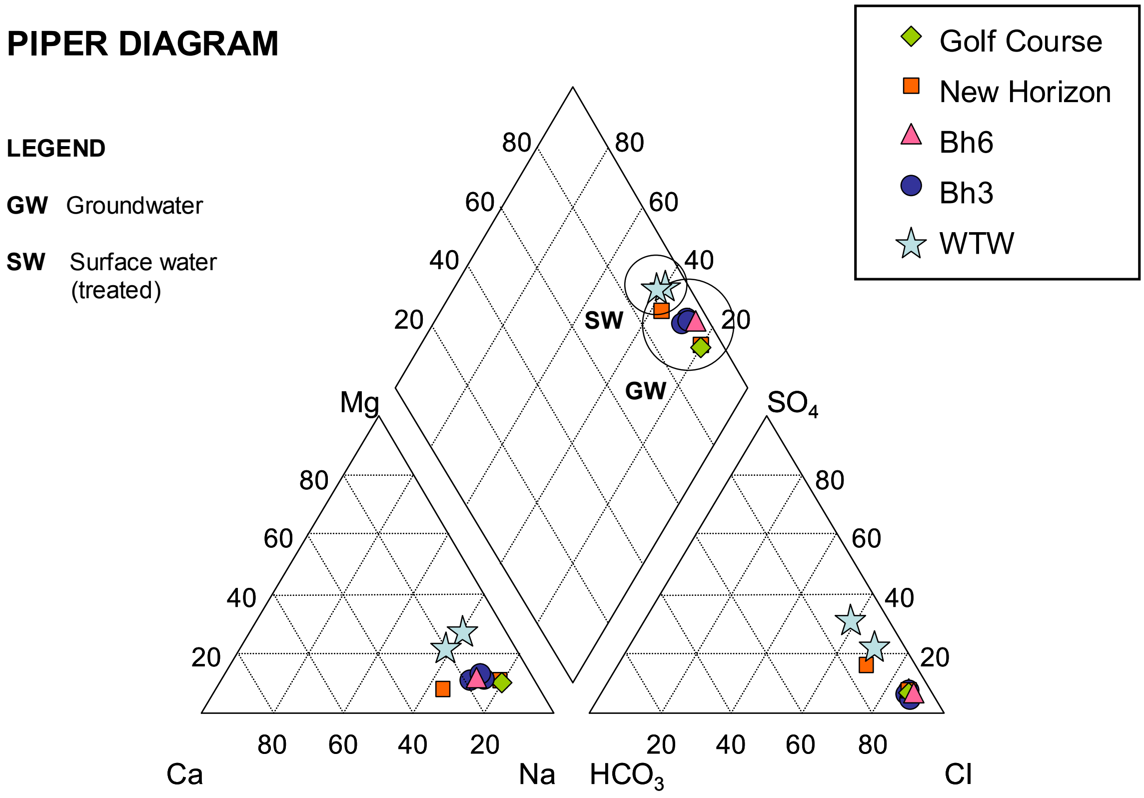


Figure 32: Major ion composition of groundwater and source water from Plettenberg Bay

Preliminary injection water quality criteria are given in Table 18:

Table 18: Preliminary injection water quality criteria

DOC < 3 mg/L	Fe (total) < 0.1 mg/L
EC < 70 mS/m	DO > 9 mg/L
pH >or = to 9	

12. WATER QUALITY ISSUES

The two major water quality issues with artificial recharge are likely to be (1) reactions between the recharge water and the host aquifer, and (2) clogging of the borehole screens due to iron-biofouling. Because the quartzite rocks of the Table Mountain Group are relatively chemically inert, water-rock interactions during storage in the aquifer are not expected to introduce any unsafe chemical species to the water, and with present data it appears that, with the exception of high iron concentrations, no water quality problems are likely to emerge as a result.

The major water quality concern from an artificial recharge point of view relates to iron in the groundwater and bacterial biofouling. These two issues are related since they both rely on relatively high iron concentrations in the groundwater. Iron-related problems are common in the Table Mountain Group aquifers, specifically in boreholes which target the Nardouw subgroup in the Gouritz Water Management Area, and both the Peninsula and Nardouw groups in the Eastern Cape (Smart and Tredoux, 2002). High concentrations of dissolved iron affect the potability of the groundwater and often require additional treatment before reticulation. “Iron biofouling”, which is a precipitation of iron oxyhydroxides and development of associated microbial biofilms, can clog boreholes and aquifer formations causing losses in production capacity. Plettenberg Bay is one of the areas in the Table Mountain Group known to be affected by iron biofouling (Jolly and Engelbrecht, 2002).

The dissolved oxygen and oxidation-reduction potential in the aquifer near the injection point are relatively high. This suggests that the any iron present in the groundwater will already be oxidised and precipitated. Both the down-hole measurements of pH and ORP (Eh vs pH – see Appendix 2) and geochemical stability calculations using measured iron concentrations and oxidation potentials show that the ferric (Fe^{3+}) oxides are unstable in this environment and would rapidly precipitate. Introducing an additional oxygenated water source, in the form of the injected surface water, is not likely to cause a dramatic change in oxidation environment, provided the iron and organic content of the injection water are kept at low concentrations. It is even possible that the injection of oxygenated water into the aquifer will immobilise iron (cause it to precipitate) in the natural groundwater (i.e. before it gets to the borehole), and thus lower the dissolved iron concentration in the recovered water. The same may happen with manganese (Tredoux, 2007). Treated water would be the preferred source for injection because of lower iron and DOC content, and chlorine in the treated water will inhibit microbiological growth. Whilst ideally the New Horizon borehole should not be used for injection because of its particularly high iron concentration (measured in December 2005), it would be worth trying to establish whether it is possible to fix the iron in the aquifer by injecting oxygenated water into this borehole. This should be tried by conducting one injection run, and if successful, it may be a very effective way of minimizing the iron problem at this site.

One of the main objectives of the artificial recharge pilot tests should be to establish whether iron-related clogging is likely to occur and, if so, whether the problem is at a scale that can be managed effectively by borehole maintenance and pumping strategies. Although the conditions are suitable for iron precipitation, the quantity of iron precipitated may be very small if the dissolved iron concentrations are kept low and microbial growth is discouraged. The best indication of the clogging potential will be derived from careful monitoring during the injection trials. Monitoring includes measuring responses in water levels, production capacity and water chemistry over time, following the injection test.

13. THE ARTIFICIAL RECHARGE POTENTIAL

13.1 Aquifer Storage Capacity

The exact storage potential of the Kwanokathula Aquifer is unknown. Estimates of the Peninsula Formation aquifer (which includes the Kwanokathula Aquifer) made by GCS (1993) put it as follows:

Aquifer Storage = Aquifer area x saturated thickness x storage coefficient
= 22 x 106 m^2 x 70 m x 0.005
= 7.7 Mm^3

Whilst this is a substantial volume of water (sufficient to last the town for about two years), it is not accessible using existing borehole infrastructure, and it is 13 times greater than the estimated natural recharge (CGS, 1993). This means that if it was used during a continuous period of abstraction, it would take over a decade for the aquifer to be naturally replenished.

If it is assumed that an additional 20 m “slice” of aquifer can be used for storage if artificial recharge were implemented on a large scale, then the (artificial recharge) storage potential can be estimated to be 2.2 Mm^3.

In order to estimate the potential artificial recharge storage based on a limited area around the Kwanokathula boreholes, the following assumptions are made:

- The area of the Kwanokathula Aquifer that can currently be artificially recharged is 7 500 000 m^2 (~5 km x ~1.5 km)
- The additional vertical thickness of the aquifer that can be utilized is 20 m (ie by raising water levels 20 m higher than current “high” levels)
- The storage coefficient of the aquifer is 0.005.

Artificial Recharge Storage = Aquifer area x saturated thickness x storage coefficient
= 7 500 000 m^2 x 20 m x 0.005
= 750 000 m^3 (or ~ 37 500 m^3/m of vertical aquifer thickness)

Even if the saturated thickness and the storage coefficient are halved, it still allows for more than 180 000 m^3 to be stored in the aquifer (which, if abstracted over the six summer months, is about the same as Kwanokathula’s summer demand of about 11.5 L/s).

DWAF's Registered Groundwater Use is 362 366 m^3/annum. By adding a 10m "slice" to the aquifer (ie using 10 m more of vertical storage in the Kwanokathula area), this figure could be doubled, and by adding a 20 m "slice", the figure could be tripled to be in excess of 1 Mm^3.

It must be noted that the true nature of the aquifer, and thus its artificial recharge storage potential, is not fully understood at this stage. The low density of monitoring boreholes makes it difficult to be conclusive about the characteristics of the aquifer. Certain indicators suggest that the aquifer is unconfined and others suggest that it behaves in a confined manner. Extended pumping at relatively high rates (ie up to the DWAF Registered Use), will help in developing the understanding of the aquifer and its storage characteristics.

13.2 The borehole injection capacity

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, and in particular, long-term borehole abstraction rates, provide a reasonable estimate of the aquifer's ability to receive water. There are three existing municipal boreholes in Kwanokathula: Bh 3, Bh 6 and the borehole called New Horizon. The injection capacities of each of these boreholes need to be established. It may not be wise to inject in the New Horizon borehole because it is down-slope in the hydraulic gradient, and water is more likely to be lost if it is injected at this point as opposed to using Bh 3 and Bh 6 (although boreholes 4 and 2 further down-gradient of the New Horizon borehole could be used to retrieve water injected at New Horizon). From a water quality management perspective (iron management), however, it may be a good option to inject water into the New Horizon borehole. This option is discussed in the chapter in water quality issues.

Taking possible injection boreholes for the time being to be Bh3 and Bh6; their injection capacities can only be estimated from drilling, test pumping and current abstraction records.

Minimum estimated injection capacities:

Bh 3	15 L/s
Bh 6	5 L/s
Total	**20 L/s**

This translates to about 300 000m^3 over a 6-month winter injection period.

13.3 Water losses

At this stage it is not known if there will be water losses due to leakage away from the capture zone of the boreholes. Some water may flow out of the springs in the low lying areas south of Kwanokathula, and some of the water may flow towards the east within the aquifer. Water flowing out of springs will be permanently lost, while water flowing away from the point of injection can usually be recaptured by pumping either at the points of injection (reversing the hydraulic gradient),or from boreholes located down the hydraulic gradient (intercept the injected water). Both of these options may need to be explored if it is evident that there would be losses. If the latter option were to be pursued, then new abstraction boreholes would need to be drilled – possibly south, and/or south-east, and/or east of Kwanokathula. Depending on their location, they would not necessarily need to be deep boreholes (ie ~100m deep).

If it is assumed that 10 % of the estimated potential artificial recharge storage (750 000 m^3) is lost, then 675 000 m^3 can be considered to be the current estimated artificial recharge potential of the Kwanokathula Aquifer. This equates to about a fifth of the town's annual water requirements.

Key to establishing Kwanokathula Aquifer's artificial recharge potential is an understanding of the groundwater flow patterns. Where would injected water flow, and how fast? The most reliable way of assessing these is to monitor groundwater levels and discharges from artesian boreholes and springs. The floods of 2006 presented a great opportunity to establish groundwater flow under "aquifer full" conditions, but the monitoring equipment had not been installed. The monitoring infrastructure is now in place and the mechanisms for collecting crucial data has been set up.

14. OTHER ISSUES THAT AFFECT THE VIABILITY OF ARTIFICIAL RECHARGE

14.1 Environmental Issues

Ninham Shand provided input on environmental requirements for conducting artificial recharge tests (see Appendix 3). Their opinion was that the proposed tests and scheme "does not trigger the requirements of Regulation 385 and 386 in terms of the National Environmental Management Act (NEMA)". However, it may nonetheless be necessary to follow an Environmental Impact Assessment (EIA) process in terms of section 28 of NEMA.

Whatever the final legal and environmental requirements, a better understanding of the aquifer in terms of throughflow and discharge is needed to establish the possible impacts of water table changes due to cycles of abstraction and injection. Essentially, little is known about the environmental impacts of long-term cycles of abstraction and artificial recharge to the Kwanokathula Aquifer. It is likely that water abstracted from the aquifer would otherwise have discharged under the sea to the east of Plettenberg Bay, and thus no terrestrial ecosystems are likely to suffer harm. The springs on the southern edge of the aquifer, along the north bank of the Piesang River, need to be mapped and their discharges measured. Groundwater may also contribute towards baseflow in the Piesang River.

Since it is desirable that the water levels in the aquifer are kept at a roughly similar level to those that currently exist (by managing abstractions and by artificial recharge) it is likely that no serious changes to the discharges along the southern boundary of the aquifer will occur. Ideally the measurement of springs and borehole water levels along the southern boundary of the aquifer would be done before an artificial recharge trial is started, since this will allow a "background" picture to be established.

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. If so, a Basic Environmental Assessment may be required.

The main benefit of artificial recharge will be:

- A greater assurance of water supply to Plettenberg Bay
- On-going groundwater management to ensure optimal conjunctive use of surface and groundwater.
- The Kwanokathula Aquifer will rapidly be re-filled after heavy summer abstraction.

The main environmental concern with groundwater use (not artificial recharge) in Kwanokathula area is:

- The lowering of the water table.

Since water level monitoring began in 2003, the water level in Bh6 has varied between 110 m and 150 m bgl (see Figure 20). These levels may be incorrect (as new data suggests aquifer "full" level is around 130 m and not 110 m – see Figure 24); but if they are correct, then this borehole has a historical use of operating over a 40 m vertical column. Even with artificial recharge, water levels should not be dropped below historical deepest water levels. Rather, with artificial recharge, it is proposed that water levels should be raised above what they normally return to each year after the summer abstraction period. But even this may not be different to the original water levels in Kwanokathula. Information from old farm boreholes (now covered up under township development) show that water levels were as shallow as 80 mbgl in places (two boreholes had recorded water strikes of 78 m and 80 m bgl).

The main environmental concern with artificial recharge is likely to be:

- Introducing "foreign" water into the aquifer.

The recharge water is of better quality (lower salinity) than the groundwater. The biggest concern is around clogging associated with iron. This will have to be monitored during the trial injection tests and during production and the best management practice put in place.

14.2 Economics

Neither the capital nor the operation and maintenance costs of the proposed artificial recharge scheme have been costed. Most of the infrastructure is already in place – as existing pipelines and boreholes will be used, and data loggers for water level monitoring have been installed in all key boreholes. The engineering capital costs for the infrastructure to conduct injection tests in two boreholes is estimated to be R 150 000. The most expensive item is layflat piping. It is the best down-hole piping to use for borehole injection as it helps prevent cascading whilst maintaining a positive pressure. After conducting the injection tests it will be possible to do the final design and costing for production.

In order to conduct the injection tests, the hydrogeological supervision and analysis costs, and the engineering design costs are estimated to be about R 130 000, giving a total artificial recharge testing costs of about R 280 000. 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 600 000 (incl VAT).

An artificial recharge scheme with greater capacity would require more boreholes, a dedicated pipe system and ancillaries, with capacity for redundancy (i.e boreholes could be shut down for repair or maintenance without impacting on the yield). Only after the trial injection tests and a period of production will it be possible to determine if, and to what extent the scheme should be expanded. The cost of implementing an artificial recharge scheme should be compared with the current estimate of R60 M for an off-channel storage system on the Keurbooms River.

It is also very likely that some degree of controlling demand for water in the summer will become increasingly necessary – most likely through differential pricing (i.e. water will get progressively more expensive as more is used per household per month) together with public education. Whilst a full discussion of this topic is beyond the scope of this report, controlling demand for water will impact on the plans for engineering infrastructure needed to supply the Greater Plettenberg Bay area. For example, if the “worst case” figure for peak demand in 2025 of 61 Mm^3/year (706 L/s) comes to pass, then even a modest 10 % saving in water use equates to 70 L/s, or the sustainable capacity of around 10 properly spaced boreholes in the Peninsula Formation aquifer. It is a certainty that future water planning will increasingly extend from a consideration of supply to one that includes demand control measures.

Aquifer storage is relatively cheap. Possibly the best way to consider the economic aspects of the proposed artificial recharge scheme is to say that it will cost about R 600 000 to test and set up the infrastructure to store about 300 000 m$^{3/}$a. This assumes injection into existing boreholes at about 20 L/s over 6 months using (mostly) existing supply infrastructure.

14.3 Institutional Arrangements

Since the municipality is the only groundwater user at Kwanokathula, the basic institutional issues are currently uncomplicated. However, with increasing developments in the Piesang River valley area and the increasing number of new boreholes being drilled in the Penninsula Formation it is evident that at some stage control on groundwater use will be needed.

Clearly the municipality will not want water that they have injected into the aquifer to be used by others. The approach and timing of controlling “other” users from over-pumping groundwater will need to be explored during the project. Essentially this is a DWAF task, although the municipality (as the WSA) can assist and be pro-active in this regard (and will benefit from having controlled use). The technical insights gained during a trial injection test study will help to determine the extent and movement of a body of injected water in the Hillvier Aquifer, and allow a groundwater “exclusion zone” to be considered.

Registering use, licensing use, and possibly having the area classified as a water control area are also approaches that will need to be considered during the project.

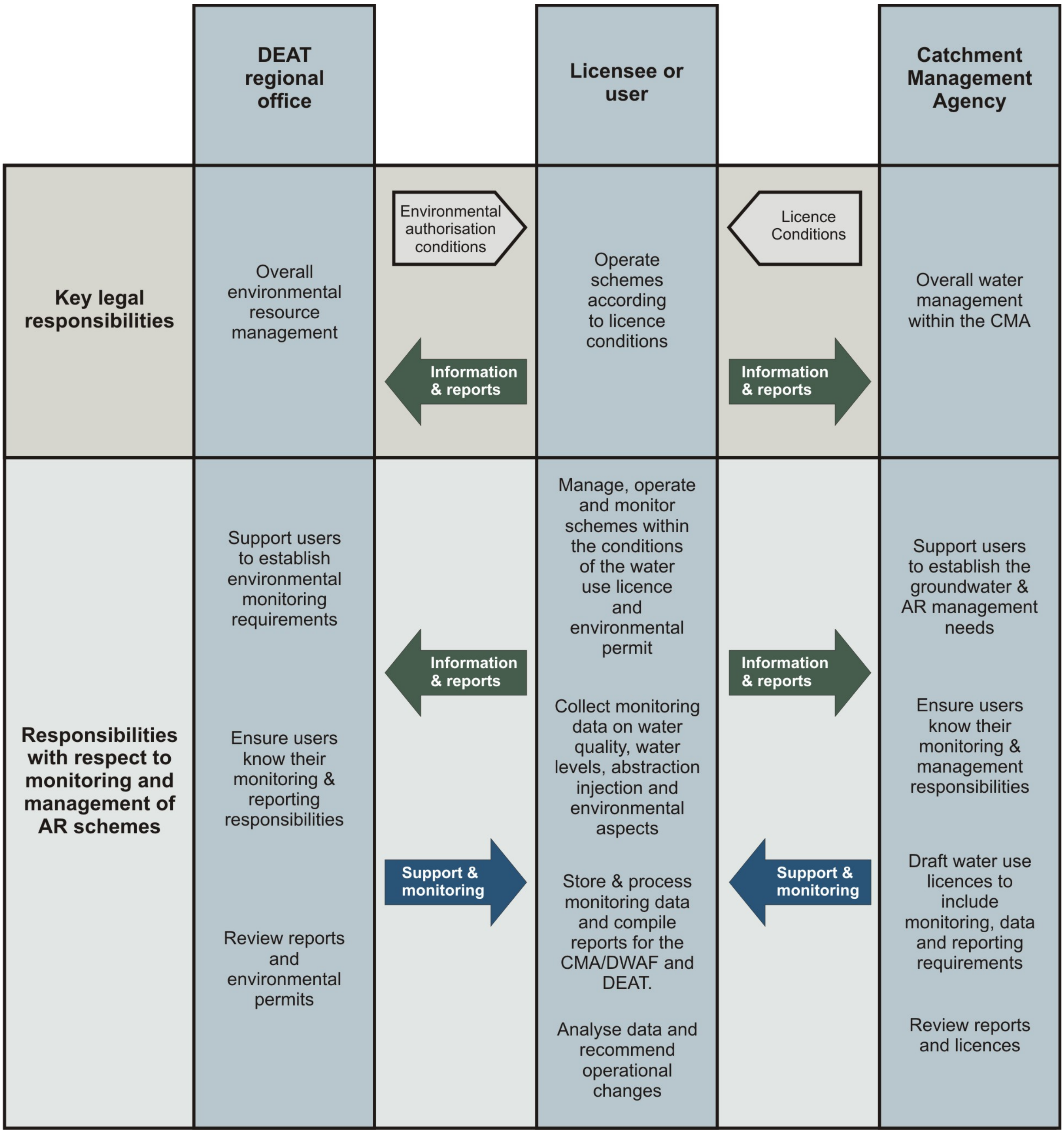
Essentially, a comprehensive inventory of groundwater users abstracting water from the Peninsula Formation in the area is needed, together with abstraction quantities and the locations of the abstracting boreholes. This is a pre-requisite to the institutional cooperation (e.g. between DWAF and Bitou Municipality) needed to manage the water resource. (Note that GCS (1993) estimated that 29 L/s were being abstracted from the Peninsula Formation aquifer at that time by “private” users.)

A comprehensive inventory of current users in the vicinity of Kwanokathula is needed.

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 19 (DWAF, 2007).

Table 19: 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

14.4 Management and Technical Capacity

All artificial recharge schemes require management - without management, schemes become inefficient. Most of the tasks required to operate the planned scheme do not require new skills, and existing staff can easily perform routine operation and maintenance tasks. However, like operating a water treatment plant, certain tasks have to be done routinely, and the management will need to be such that these tasks are properly carried out. Of key importance is the quality of the injectant – this will need (together with other things) to be closely monitored and a shut-down mechanism put in place if the quality drops below the recommended standards. A hydrogeologist will need to analyse the data after each borehole injection “run”, and set pumping schedules for the up-coming summer. With time the aquifer will be better understood, and the role of outside specialists will diminish. But for the first few years, specialist input will be essential, and probably a DWAF licence requirement.

14.5 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 20:

Table 20: 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, 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.	
	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.		

15. THE ARTIFICIAL RECHARGE PROJECT PLAN

It is recommended that a phased approach be developed to assess the artificial recharge potential and to put the scheme into production. The phases are outlined in Table 21.

Table 21: Phases of developing an artificial recharge scheme for Bitou Municipality

Phase	*Description*	*Key tasks*	*Completion date*
Phase1	Pre-feasibility study	Initial indication of scheme viability & identifying key issues	Complete (this report)
Phase 2	Feasibility study – Injection testing	Assess borehole injection capacity, aquifer storage and recovery potential	Injection: May - Sep 2008 Rest: Oct - Nov 2008 Abstraction: Dec - April 2009 Completion: May 2009
Phase 3	Design & construction	Engineering design Equip existing boreholes for production injection Operation & maintenance procedures	Completion: Jul 2009 (Assuming only minor infrastructure changes are required; Ready for 1st production run in Aug 2009)
Phase 4	Production & Post-project support	Performance monitoring during production Modified operation & maintenance procedures Final monitoring and reporting strategy	Aug 2009 to June 2010 Completion: June 2010

If the results from the injection tests are positive, and assuming that there are no major obstacles to implementation, then full-scale injection would be possible from winter 2009.

16. CONCLUSIONS

Work done over the last two years on the groundwater resources available to the town of Plettenberg Bay has confirmed that the town has access to a reliable source of groundwater contained within the Kwanokathula Aquifer. Over the past eight years the municipality has used less than half its Registered Groundwater Use of 362 366 m^3/a. The sustainable yield of the aquifer has not been determined, but it appears as if this annual volume is well within the aquifer’s capacity, and that the municipality could abstract this (ie 11.5 L/s) on a continuous basis without affecting the aquifer’s stored reserves. This, however, needs to be tested by pumping at this rate and monitoring the aquifer’s response.

Trial borehole injection tests are recommended, and if feasible, then the option of artificially recharging the aquifer during the winter months (using surplus, treated surface water) could potentially triple the current Registered Use, making around 1 Mm^3/a available from the aquifer.

If groundwater is only ever intended to supply Kwanokathula, and will not be used to an appreciable extent for the water supply to the greater area, then artificial recharge will probably not be necessary. Boreholes 3 and 6 together can meet Kwanokathula's demand. However abstraction to meet Kwanokathula blending requirements of 60% groundwater to 40 % surface water (i.e. ~ 720 m^3/day groundwater + 480 m^3/day surface water) means that the boreholes will be under-utilised, and that the aquifer as a whole will be under-utilised by about 150 000 m^3/a.

An improved system for monitoring the Kwanokathula Aquifer is necessary to manage the groundwater resource effectively, whether artificial recharge is ultimately used or not. For example, it is reported that the New Horizons borehole failed after pumping continually for 17 days. It is not clear whether this was due to the over-pumping of the borehole, thereby drawing the water level down to the pump intake, or to a more general decline in the water table in the vicinity of the borehole. Analysis of current data suggests the former, and that the aquifer at large was not “dewatered” during this period. Proper monitoring would provide the necessary information to allow this and other questions to be answered. The recently installed monitoring programme makes use of existing borehole infrastructure, however, in the longer term, additional boreholes within and adjacent to the Kwanokathula wellfield need to be added to the monitoring network. This would help in developing a better understanding of the aquifer and ensure that its supply is optimised within the context of environmental sustainability.

Monitoring has been recommended in various reports dating back to the early 1990s, and once licences have been granted by DWAF, this will become a legal requirement in terms of current legislation. The monitoring system was set up during the Masibambane Project, however, support is required to ensure municipal staff know their responsibilities regarding data collection, storage and analysis.

At present all three of the main Kwanokuthula boreholes are vulnerable to surface contamination and vandalism. The boreholes need to be sealed at the surface, and the compounds need to be secured. The standing water around Borehole 3 needs to be drained, and the space filled, since at present this presents a possible health risk. Contamination of the fractured Kwanokathula Aquifer would be expensive and difficult to reverse.

The main conclusions and recommendations are:

- Groundwater is currently under-utilised by the municipality. Over the past 8 years, an average of 134 000 m^3/annum (4.3 L/s) has been abstracted.
- The municipality should increase groundwater abstraction from existing boreholes to the Registered Use of 362 366 m^3/a (11.5 L/s).
- This they should do by non-stop pumping in the following manner:
    - Bh3: 4.4 L/s
    - Bh6: 4 L/s
    - Bh NH: 4 L/s

- With artificial recharge the aquifer's stored reserves could theoretically be increased by about 750 000 m^3, and together with the existing Registered Use, this could potentially increase the supply from the aquifer to over 1 Mm^3/a.
- The intention would be to transfer treated Keurbooms River water to the Kwanokathula Aquifer via existing boreholes in winter, and abstract the water from the same boreholes (and possibly other, down-gradient boreholes as well), in summer.
- At present the main limiting factor in "getting water underground" is capacity of the pipeline that would supply treated water to the Kwanokathula boreholes. This pipeline has a capacity of 24 L/s (P Lombard, *pers. comm.*) and about half of this would be required to supply the Kwanokathula settlement if the boreholes were being used for artificial recharge.
- If Kwanokathula could be supplied from another (new) pipeline, then about 300 000 - 400 000 m^3 could be used for borehole injection over a 6-month injection period (using existing pipelines).
- Borehole injection tests should be conducted to establish the recharge capacities of individual boreholes and to assess the ability of the aquifer to receive and store recharged water for seasonal use.
- It is critical that top quality water be used for injection. Iron and dissolved organic carbon concentrations must be less than 0.1 and 3 mg/L respectively.
- The Department of Water Affairs and Forestry has approved borehole injection tests, however, they require a meeting prior to the tests to discuss monitoring requirements.
- Further support to municipal staff is needed to ensure that the established groundwater monitoring system is entrenched within the municipality, and that the overall groundwater management system is incorporated into the water supply management system.

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Appendix 1: Municipal borehole status report (August 2007)

Bh No.	Borehole Site Status	Monitoring Equipment	Recommendations
Bh 2 Municipal monitoring borehole	**General Security** Fair, susceptible to damage by construction works when the property on which it is situated is developed. **Borehole Enclosure** None. **Borehole Closure** Good, DWAF spec. cap. **Contamination risk** Low	**Water Levels** Solinst Barologger Serial No: 11024326 Solinst F100/M30 LT data logger, serial no: 51024788 **Comment** This borehole is a critical monitoring point. The casing is severely corroded and will collapse in due course. A piezometer tube must be installed to preserve the hole for monitoring.	1. Enclose with covered access chamber in order to secure the borehole for future monitoring purposes. 2. Install SABS HDPE 40mm Cl 10 P-tube to at least 100 mbgl, top of P-tube to be secured inside borehole.
Bh 3 Municipal production borehole	**General Security** Poor, gate unlocked, fence cut, electrical control box standing open. **Borehole Enclosure** Dirty, unkept, litter, standing water around well-head and in enclosure. **Borehole Closure** Pump installed and working. **Headwork** Bad leak at flange above ground. **Contamination risk** High. Polluted standing water could run down the annulus space on the outside of the casing. Also see Bh3A.	**Water Levels** Solinst F300/M100 LT data logger, serial no: 61025706 P-tube installation inadequate. Dip meter gets stuck in the P-tube (at the moment no hand-readings are taken for fear of the dip meter breaking off inside the P-tube. Is problematic to get data logger in and out of P-tube. **Water Meter** Installed in access chamber below ground level; meter frequently unreadable due to flooding by leakage and rainwater. **Sampling Tap** None.	1. Lock gate with keyed-alike lock to enable convenient authorised access to enclosure. 2. Repair fence. 3. Clean and clear enclosure. 4. Install drainage as required. 5. Repair leak at headworks. 6. Move water meter to be 600mm above ground in access chamber with cover (as per Boreholes 6 and New Horizons) 7. Install SABS HDPE 40mm Cl 10 P-tube to pump intake depth. 8. Install water sampling point. 9. Lay gravel around well-head. 10. Erect signage explaining the function of the borehole. **The above-mentioned items are URGENT for groundwater management, security of logger and pollution prevention purposes.**

Bh No.	Borehole Site Status	Monitoring Equipment	Recommendations
Bh 3A Municipal monitoring borehole	**General Security** As for Bh3 **Borehole Enclosure** As for Bh3 **Borehole Closure** Not closed. The hole is now blocked after it was cleared recently. This time the blockage is at about 19,5mbgl. **Contamination risk** **High**. Having an open borehole within 5m of the town's highest-yielding production borehole poses **a serious health risk**. Groundwater and Borehole 3 can easily be polluted at this site (Bh 3 is pumped untreated into the reservoir supplying Kwanokuthula).	**Water Levels** None **Comment** This borehole was recently opened (with a drill rig) to serve as a monitoring hole. It was left with an inadequate cap and subsequently blocked again prior to camera-logging the hole.	1. Re-open the borehole. 2. Disinfect borehole with chlorine. 3. Immediately secure borehole to DWAF specifications. 4. Install HDPE 40mm Cl 10 P-tube to bottom of hole. **The above-mentioned items are URGENT for both health and groundwater monitoring purposes.**
Bh 4 Municipal production borehole	**General Security** Fair, gate locked but broken. **Borehole Enclosure** Filled with litter and muck. **Borehole Closure** The casing fortunately stands +/- 500mm above ground level, preventing ingress of the surrounding filth. **Headwork** Inadequate. **Contamination risk** Low. This will be re-checked to establish whether runoff from the road and upslope seepage could be leak into the borehole via the annulus space under the pump house.	**Water Levels** Pump installed, cables have been cut. Solinst F300/M100 LT datalogger installed, serial no: 61023230 **Water Meter** None. **Sampling Tap** None.	1. Repair gate. 2. Lock gate with keyed-alike lock to enable convenient authorised access to enclosure. 3. Clean and clear enclosure. 4. Install drainage as required. 5. Install water meter at least 600mm above ground level. 6. Install water sampling point. 7. Erect signage explaining the function of the borehole. **The gate must be repaired urgently for security of the logger.**

Bh No.	Borehole Site Status	Monitoring Equipment	Recommendations
Bh 6 Municipal Production Borehole (currently not equipped)	**General Security** Poor. Gate not locked. **Borehole Enclosure** Dirty, unkempt. **Borehole Closure** Adequate until pump is re-installed. **Headwork** Good, in enclosed, above-ground access chamber. **Contamination risk** High, due to enclosure not being secured.	**Water Levels** Solinst F300/M100 LT Datalogger, serial no: 61023170 **Water Meter** In access chamber, above ground level. **Sampling Tap** None.	1. Lock gate with keyed-alike lock to enable convenient authorised access to enclosure. 2. Clean and clear enclosure. 3. Install water sampling point. 4. Install drainage as required. 5. Erect signage explaining the function of the borehole. 6. Lay gravel around well-head. 7. Install SABS HDPE 40mm Cl 10 P-tube to pump intake depth. **Urgent: Lock the enclosure to protect against contamination and to secure the logger.**
Bh New Horizon Municipal Production Borehole (currently not equipped)	**General Security** Poor. Gate not locked. **Borehole Enclosure** Dirty and unkempt. **Borehole Closure** Adequate until pump is re-installed. **Headwork** Good, enclosed in access chamber with cover. **Contamination risk** High, due to enclosure not being secured.	**Water Levels** Solinst F300/M100 LT Datalogger, serial no: 61024162 **Water Meter** In access chamber, above ground level. **Sampling Tap** None. **Comment** Casing possibly severely corroded where steel casing lies below water level.	1. Lock gate with keyed-alike lock to enable convenient authorised access to enclosure. 2. Clean and clear enclosure. 3. Install drainage as required. 4. Lay gravel around well-head. 5. Install SABS HDPE 40mm Cl 10 P-tube to pump intake depth. 6. Install water sampling point. 7. Erect signage explaining the function of the borehole. **Urgent: Lock the enclosure to protect against contamination and to secure the logger.**

Bh No.	Borehole Site Status	Monitoring Equipment	Recommendations
Bh Airport Municipal Production Borehole (Unused)	**General Security** None, it appears that this borehole has not been used for many years. **Borehole Enclosure** Not enclosed. **Borehole Closure** Base plate installed, adequate until pump is re-installed. **Headwork** Good **Contamination risk** Low	**Water Levels** None **Water Meter** Not found **Sampling Tap** Not found **Comment** If the borehole is not to be put back into production, the hole should be secured and used for monitoring purposes.	1. The equipment should be secured and or removed from site. 2. The 92m of 65mm stainless steel rising main lying alongside the borehole should be removed to safe storage.

PRIVATE PRODUCTION BOREHOLE

Bh Golf Course Private production borehole	**General Security** OK. In fairly inaccessible area. **Borehole Enclosure** None **Borehole Closure** OK **Contamination risk** Low	**Water Meter** Below ground. **Sampling Tap** None.	1. Raise water meter to be above ground level. 2. Install water sampling point.

PRIVATE MONITORING BOREHOLES

Bh No.	Borehole Site Status	Monitoring Equipment	Recommendations
Bh SG3 Private monitoring borehole	**General Security** Poor. Construction work in progress around open borehole. **Borehole Enclosure** None **Borehole Closure** None **Contamination risk** High, unprotected open hole.	**Water Levels** None.	1. Negotiate with owner to install DWAF cap as interim security. **Urgent.**
Bh DW1 Private monitoring borehole	**General Security** Poor. DWAF borehole cap was removed when drillers cleaned hole. **Borehole Enclosure** None, not required. **Borehole Closure** Poor. **Contamination risk** Low.	**Water Levels** P-tube inadequately and incorrectly installed.	1. Install P-tube correctly. Attach P-tube to inside of top of casing, and secure adequately. 2. Replace DWAF cap which was on the borehole. 3. Install Solinst F100/M30 LT Data Logger Serial No: 51024112 when P-tube has been correctly installed.
Bh RD1 Private monitoring borehole	**General Security** Poor, but in inaccessible place. Open at ground level. **Borehole Enclosure** None **Borehole Closure** None **Headwork** Hand-removable pump. **Contamination risk** Fair. Unprotected open hole in a place where few people go.	**Water Levels** None	1. Negotiate with owner to modify casing to enable installation of DWAF cap.

Appendix 2: Down-hole logging report
by
Dr G Tredoux, CSIR

Strategy Development: A National Approach to Implement Artificial Recharge as Part of Water Resource Planning

DOWN-THE-HOLE HYDROGEOCHEMICAL LOGGING OF BOREHOLES FOR ARTIFICIAL GROUNDWATER RECHARGE PILOT STUDY AT PLETTENBERG BAY

by
G. Tredoux

Report prepared for

GROUNDWATER AFRICA

P O Box 162

7603 Lynedoch

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Project Number:	JWG0004
Contact Details:	CSIR Natural Resources and the Environment PO Box 320 Stellenbosch 7599

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our future through science

Executive Summary

Plettenberg Bay has to cope with widely varying seasonal demands. The conjunctive use of surface and groundwater resources is already in place. Hence, artificial groundwater recharge of surplus surface water seems to provide an attractive management solution for more effectively balancing the water supply with the varying seasonal demand. The feasibility of artificial groundwater recharge has to be established through a desk study followed by field studies of the available aquifers and their ability to accept and store water. Water quality considerations pertaining to the recharge water and the ambient groundwater play a critical role in artificial groundwater recharge. When groundwater is abstracted hydrochemical changes take place and conditions within the aquifer can only be determined *in situ.* The objectives of such down-the-hole hydrochemical logging are to:

- Determine hydrochemical parameters in situ, i.e. in the subsurface for obtaining a good indication of the actual pH, oxidation-reduction conditions and other parameters in the aquifer;
- Evaluate trends with depth and associated aquifer characteristics;
- Interpret the implications of the conditions in the aquifer for artificial groundwater recharge

Down-the-hole hydrochemical logging was carried out at three production boreholes (Bh 3, Bh 6, and New Horizon) and one monitoring borehole (Bh 2). Significant variations were found with depth as well as large differences between the individual boreholes. It was also attempted to put the down-the-hole readings into context with regard to the analytical data recorded at the well head and in the laboratory.

It was concluded that the down-the-hole hydrochemical logging of the boreholes confirmed groundwater stratification in all boreholes. The salinities, as indicated by the EC values, vary from borehole to borehole, and to some extent also with depth and time. The down-the-hole logging data also do not always correspond to the analytical data obtained from water samples during abstraction. Longer term evaluation of the salinity will help to unravel the interrelationships between the various boreholes in the aquifer.

Water temperatures revealed critical information about the aquifer and various interrelationships between boreholes.

The corrosive nature of the water was confirmed and the need for plastic borehole casings and other corrosion resistant materials was underlined.

It was also concluded that injection of well-oxygenated water into the aquifer will reduce the iron content in the abstracted water. This may be an important benefit of the artificial recharge by borehole injection.

It was recommended that the groundwater temperature – pumping relationships are investigated at all boreholes. Water level trends should be compared with pumping regimes and rainfall patterns.

Down-the-hole logging should be repeated after longer periods of abstraction for determining the trends with time. Together with the continuous logging of water levels and temperature this would confirm the flow regime in the aquifer.

Contents

1. INTRODUCTION 1

2. GEOLOGY 2

3. HYDROCHEMICAL DEPTH PROFILES 2

3.1 Water level elevations 3
3.2 Down-the-hole hydrochemical logs 3
3.3 Comparison of down-the-hole data with well head measurements 5
3.4 Electrical conductivity (EC) 6
3.5 pH 6
3.6 Temperature 7
3.7 Oxidation-reduction potential (ORP) 7
3.8 Dissolved oxygen (DO) 7

4. HYDROCHEMISTRY 7

4.1 Stability diagrams 8

5. DISCUSSION 9

6. CONCLUSIONS 11

7. RECOMMENDATIONS 12

8. REFERENCES 12

Appendix A	Down –the-hole hydrochemical logging data

Tables

Table 1 List of boreholes logged hydrochemically 2

Table 2 Comparison of hydrochemical down-the-hole logs to well head measurements 6

Table 3 Concentrations of Fe-species expected in solution at boreholes Bh 3, Bh 6 and New Horizon at equilibrium conditions 8

Table 4 Mineral equilibria and saturation indices 9

Figures

1.	Location of logged boreholes, measured depth, and water column available for logging
2.	Water level elevation at logged boreholes (31 October 2006) with inferred water level contours
3.	Down-the-hole hydrochemical profiles in borehole Bh2 at Plettenberg Bay
4.	Down-the-hole hydrochemical profiles in borehole Bh3 at Plettenberg Bay
5.	Down-the-hole hydrochemical profiles in borehole Bh6 at Plettenberg Bay
6.	Down-the-hole hydrochemical profiles in borehole “New Horison” at Plettenberg Bay
7.	Average values of electrical conductivity, pH, temperature, and dissolved oxygen of logged boreholes for the water column, except for Borehole 2 where values represent only the lower part of the water column
8.	Comparison of electrical conductivity profiles in the Plettenberg Bay boreholes
9.	Comparison of pH profiles in the Plettenberg Bay boreholes
10.	Comparison of water temperature profiles in the Plettenberg Bay boreholes
11.	Comparison of water temperature gradient profiles in the Plettenberg Bay boreholes (smoothed 7-reading moving average)
12.	Comparison of oxidation-reduction potential profiles in the Plettenberg Bay boreholes
13.	Comparison of dissolved oxygen profiles in the Plettenberg Bay boreholes
14.	Eh-pH diagram showing stability fields for ferrous and ferric hydroxide in solution (at 25 °C)
15.	Eh-pH diagram for ferrous and ferric ions in solution showing stability fields for magnetite and haematite (at 25 °C)
16.	Groundwater temperatures measured during down-the-hole logging on 2006-10-31 compared with recorded values of the loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon
17.	Water level responses recorded by loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon during abstraction from borehole Bh 3
18.	Water level and temperature trends recorded by loggers in boreholes Bh 3 and Bh 6 during abstraction from borehole Bh 3

1. INTRODUCTION

The Plettenberg Bay area suffers the widespread problem of coastal towns having to deal with widely varying seasonal demands. As the water supply is obtained both from surface and groundwater resources the conjunctive use of both resources is already a reality. Artificial groundwater recharge of surplus surface water, therefore, seems to provide an attractive management solution for more effectively balancing the water supply with the varying seasonal demand. The fact that groundwater resources are being exploited will allow the design of an artificial groundwater recharge scheme largely making use of existing infrastructure.

The feasibility of artificial groundwater recharge of any particular aquifer needs to be approached from various angles. For this purpose an initial desk study is needed to determine whether a reliable source of good quality water is available for recharging the aquifer. At the same time, it is just as important to get an indication of the available aquifers and their ability to accept and store water. Such a study should also attempt to address the question of potential losses of water from the aquifer. Depending on the extent of available historical groundwater monitoring data, e.g. water levels and abstraction volumes, the aquifer characteristics can be determined with greater or lesser certainty. Further water level observations or pumping tests may be needed to enhance the certainty of success before proceeding with the evaluation of the planned artificial groundwater recharge scheme and eventual pilot scale testing.

Water quality considerations are part and parcel of any water supply scheme and due to the critical role thereof in artificial groundwater recharge it will be incorporated in the actions listed above. Again, the more analytical data that are available the better the confidence in the results of the desk study. For artificial groundwater recharge, water quality needs to be considered in its broadest sense.

Objectives of hydrochemical logging:

- Determine hydrochemical parameters *in situ*, i.e. in the subsurface for obtaining a good indication of the actual pH, oxidation-reduction conditions and other parameters in the aquifer;
- Evaluate trends with depth and associated aquifer characteristics;
- Interpret the implications of the conditions in the aquifer for artificial groundwater recharge

Solute chemistry and mineral stability relationships in groundwater systems may be described in terms of the controlling variables Eh and pH (Stumm and Morgan, 1970). The pH reflects the acid-base status while the Eh of natural water depends on the combination of oxidation-reduction couples present in the water. Chemical equilibria in groundwater establish themselves at a specific temperature and pressure. Changes in temperature and pressure will cause a shift in the concentrations of reactants and products as a new equilibrium condition is established. This affects a number of physico-chemical parameters in groundwater, including pH, Eh and dissolved gases. It is commonly accepted that such parameters have to be measured at the well head. However, even though such measurements approach the true hydrochemistry more closely, they still do not allow determination of the actual groundwater composition in the aquifer. As a consequence of large improvements in sensor technology, much more reliable measurements are presently possible down a borehole, at much higher pressures and higher temperatures, than were possible even at the surface two decades ago. Hence, down-the-hole physico-chemical logging of the water column can also serve as an important tool in estimating the potential hydrochemical interactions due to artificial groundwater recharge.

This investigation concentrated on boreholes in the Peninsula Formation of the Table Mountain Group as this is the main source of groundwater in the area and also the prime target for artificial groundwater recharge (Murray, 2006). The apparent presence of high concentrations of iron in the groundwater as witnessed by the brown deposits on the equipment at most boreholes raised concerns regarding borehole clogging, both with regard to abstraction and injection.

2. GEOLOGY

The Peninsula Formation of the Table Mountain Group (TMG) attains a thickness of 550 m in the type area in the Cape Peninsula where the full succession is exposed against Table Mountain (De Beer, 2002). It comprises a succession of coarse-grained, white quartz arenite with scattered small pebbles and discrete thin beds of small-pebble, matrix-supported conglomerate. In the north, at Clanwilliam, the formation reaches a thickness of 1800 m but it is reportedly much thicker in the Eastern Cape (De Beer, 2002). At Plettenberg Bay, the total thickness of the TMG is approximately 3000 m and the production boreholes are all completely contained in the Peninsula Formation.

The logged borehole locations are shown in Figure 1. Borehole Bh 6 is located the furthest west with boreholes Bh 3 and New Horizon some distance further east. The elevations of these three boreholes range from approximately 195 m to 183 m above sea level. Borehole Bh 2, which is situated several kilometres further east, is at a somewhat lower elevation of about 141 m above sea level. The measured depths are shown in the Figure 1. Of the three new boreholes, only at borehole New Horizon the measured depth of 200 m was different to the drilled depth of 250 m. In all cases the boreholes presently extend to a depth just below sea level.

From a geochemical perspective the aquifer matrix will be relatively inert and with the absence of limestone and calcrete the calcium content of the groundwater is very low.

3. HYDROCHEMICAL DEPTH PROFILES

A total of four boreholes were selected for logging, three of which are production boreholes. A fifth private borehole, southeast of the New Horizon borehole, was investigated for logging but it emerged that the borehole was filled with sand from just below the water table. Boreholes in the Skoongesig housing development were also visited but ruled out as those in the Table Mountain Group aquifer were equipped while the Enon borehole was inaccessible. Figure 1 shows the location of the boreholes subjected to down-the-hole hydrochemical logging. These boreholes all belong to the Bitou Municipality and with the exception of Bh 2 are used for water supply to the Greater Plettenberg Bay area, including Kwanokathule. The borehole pumps were removed for maintenance purposes and this provided the ideal opportunity for the hydrochemical logging. The details of the boreholes and the logging operation are given in Table 1. The total depth and the length of the water column at each borehole are presented in the table and shown in Figure 1. Borehole Bh 2 has a steel casing of unknown length which is severely corroded. All the other production boreholes are equipped with plastic casings.

Table 1 List of boreholes logged hydrochemically

Borehole ID	Date	Time	Borehole collar elevation (m)	Total depth (m)	**Water level depth (m)	Water level elevation (m)
Bh 2	31/10/2006	14:00	140.899	144.7	77.75	63.15
Bh 3	31/10/2006	10:00	188.586	200	123.00	65.59
Bh 6	31/10/2006	11:50	194.977	200	129.59	65.39
New Horizon	31/10/2006	15:30	182.664	*200	118.32	64.34

Notes: *Borehole "New Horizon" drilled to 250 m was filled with sand to 200 m depth
**Water level data for 31 October 2006

3.1 Water level elevations

The water level elevations at the logged boreholes are shown in Figure 2 as determined on 31 October 2006 at the time of logging. The purpose was to establish what is possible with regard to groundwater flow and to tie this to the salinity and chemical composition of the various boreholes. It is evident that the highest water level elevation of 65.6 m was found at Bh 3, which was some 0.2 m higher than at the nearby borehole Bh 6 located further westwards and more than a metre higher than at New Horizon located to the east. The water level at borehole Bh 2 several kilometres further east and less than 2 km from the sea is still 63 m above sea level despite a 50 m drop in the surface elevation. The inferred water level contours shown in Figure 2 seem to indicate an eastward gradient. However, it is doubtful that the water would be flowing directly eastwards from borehole Bh 3 to Bh 2 when considering the hydrochemistry of the groundwater at the various points.

3.2 Down-the-hole hydrochemical logs

The hydrochemical log for each individual borehole is shown in Figures 3 to 8.

Borehole Bh 2

This borehole is located next to a road in an area where the infrastructure for a new housing development was constructed. At the time of logging the area was still undeveloped.

The borehole was intended as a production borehole and is equipped with a steel casing but the borehole is not in use. It serves as a monitoring borehole and hence a water level and temperature logger was installed for recording longer term trends. When the equipment was removed for down-the-hole logging it was found that everything was covered in rust showing that the casing was extremely corroded, thus providing graphic proof of the corrosiveness of the groundwater.

The hydrochemical logging results are shown in Figure 3. No geological details were available for the borehole and no information on the borehole construction could be obtained but it was assumed that the lower part of the casing was screened. From the results it is evident that very few of the parameters follow any expected trends. Only the temperature profile seemed to be consistent with an increase in temperature with depth at a rate of approximately 1 °C per 100 m depth. This confirms that there is practically no vertical movement of water in the borehole. Most of the parameters showed a significant change at about 92 m depth. The salinity increased by about 15 mS/m, the pH decreased from 10.5 to about 7, the oxidation-reduction potential decreased from 370 mV to about 100 mV, while the dissolved oxygen reached a minimum of about 0.2 mg/L, but increased at greater depth. It is very likely that groundwater is flowing horizontally through the borehole approximately between 92 and 100 m depth, either through a slotted section or a corroded casing. If this is correct, the temperature of this water is not significantly different to that in the borehole as there is only a slight deviation in the slope of the graph at that point. The extreme pH value (>10) found just below the water level indicates a highly active corrosion process at this depth consuming all the dissolved oxygen, including that being dissolved at the water table in the borehole and it is concluded that the borehole casing will soon disintegrate totally.

Borehole Bh 3

Borehole Bh 3 has its major fracture zones at 174 – 178 m and 183 – 189 m depth and the casing was slotted from 160 – 200 m (Figure 4). In contrast to Bh 2 the casing of Bh 3 and all the other production boreholes consist of high density PVC and are therefore not attacked by the corrosive groundwater.

A characteristic of the logging results is the constant electrical conductivity (EC) which varied by only 0.2 mS/m of the full depth of the water column. Similarly, the dissolved oxygen (DO) remained essentially constant at about 5 mg/L. This means the water is fairly well-aerated throughout the water column with the DO at about 5 mg/L. In contrast, the graphs for pH, temperature, and oxidation-reduction potential all show a change in the slope of the respected graphs from a point near the top of the slotted casing. This indicates the flow of water from the aquifer through the borehole. This water seems to enter the borehole near the bottom with the flow possibly having a slight vertical flow component in view of the increase in temperature gradient at about 180 m depth. The water is slightly warmer than that entering at about 168 m. Hence the initial decrease in the temperature gradient. Alternatively the constant EC may indicate groundwater flowing slowly vertically down the borehole as the temperature gradient is lower than it should be. This can be checked by camera logging to ascertain the existence of any holes in the borehole casing.

Borehole Bh 6

As in the case of production borehole Bh 3, the geological log for borehole Bh 6 indicates that the fracture zone is at about 174 to 180 m depth (Figure 5). However, compared to Bh 3, the down-the-hole log for Bh 6 shows significant deviations from the expected patterns. For example, the lowest salinity is found at the bottom of the slotted casing at the depth of the fracture zone. This is also the depth at which the pH reaches its highest value and the temperature is at its lowest. The temperature graph does not at all resemble the general increase in temperature with depth found in most boreholes. The oxidation-reduction potential increases gradually with depth which is in contrast with the dissolved oxygen concentration which is slightly lower at depth.

From the logs it would seem that the water flowing through the borehole at the bottom of the screen opposite the main fracture zone has a lower salinity (EC), a higher pH, a lower temperature, a higher ORP, and a slightly lower DO than the rest of the water column in the borehole. The question then remains how the water column in the borehole remains slightly warmer (and slightly more saline) than the water flowing through the borehole at depth. One possibility could be that the temperature (and EC) of the water entering the borehole varies from time to time. The lower temperature of the water at the bottom of the screened section means that this water is coming from a shallower depth below surface.

The log clearly shows that there is groundwater flow through the borehole opposite the fracture zone. It is assumed that the groundwater would mainly be drawn from this depth when pumping.

Borehole New Horizon

The total depths of the boreholes as shown in Table 1 refer to the measurement at the time of logging. According to the drilling logs, the New Horizon (NH) borehole was drilled to 250 m. However, the depth measured at logging was only 200 m. Apparently the borehole was backfilled with sand to 200 m after drilling.

The electrical conductivity (salinity) of the New Horizon borehole is very low at 44 mS/m and very constant with depth (Figure 6). The major water strike was at 165 m but this does not reflect in the EC log. The pH is the only parameter that shows a trend which seems to relate to the major water strike. The pH reaches its highest value approximately at this depth. Temperature on the other hand, shows an inflection at 185 m with the temperature increasing very slowly up to this point but then rising faster over the next ten metres. This may indicate that the water entering the borehole equilibrated its temperature with rocks at a shallower depth where it is cooler, keeping the temperature gradient low. The ORP increases with depth but the reason for the increase is not immediately evident. Dissolved oxygen remains fairly constant at relatively high levels over the whole of the water column. Only close to the surface the DO is lower. This may indicate the effect of the iron oxides that coated all the pipes and the pump.

3.3 Comparison of down-the-hole data with well head measurements

In an attempt to determine the relevance of the down-the-hole measurements "representative" readings were selected for comparison with well head and laboratory analyses. The results of this comparison are shown in Table 2. In the case of Bh 2 no analytical or well head data were available but in the case of boreholes Bh 3 and NH a relatively good correlation was obtained. Only the temperature at BH 3 deviated significantly with the pumped water being warmer but that could be due to the heat generated by the electric motor of the pump. At borehole Bh 6, however, the down-the-hole data did not fit the other data at all. This begs the question of variability of the water quality at borehole Bh 6 as it varied over a very wide range. The field and laboratory values were also not consistent over time.

The "representative" values measured down-the-hole were plotted geographically for the four boreholes in Figure 7. Boreholes Bh 3 is located relatively near to Bh 6 but the chemical characteristics are quite different with the salinity twice as high at Bh 3 than at Bh 6. The pH, DO, and temperature of the water are also different. On the other hand, the laboratory analytical results for July 1992 and December 2005 did not differ very much and the relative chemical composition was similar for these two boreholes. In the case of the boreholes Bh 3 and New Horizon the salinity also differ significantly but the other parameters recorded during logging are more similar. In the case of New Horizon also the chemical analytical results differed significantly between June 1998 and December 2005 but the salinity at the latter date was exactly the same as during the down-the-hole logging. At Bh 2, located further down-gradient, closer to the sea the characteristics are more similar to Bh 3 except for the dissolved oxygen that was consumed by the oxidation (rusting) of the casing. Overall, it would seem that the boreholes do not have coherent chemical and physical characteristics that would be indicative of a single water body. In addition, the chemistry seems to be changing with time at least at some of the boreholes.

Table 2 Comparison of hydrochemical down-the-hole logs to well head measurements

Borehole ID	Date	pH		Electrical Conductivity		Temperature °C	Dissolved oxygen mg/L
		(Field)	(Lab)	(Field)	(Lab)		
Bh 2	**31-10-2006**	**7.2***		**118**		**19.3**	**1.0**
Bh 3	02-07-1992		6.3		128		
	17-03-2005	6.15		120			
	14-12-2005	6.3	6.1	123	133	22.7	
	31-10-2006	**6.2**		**127**		**19.4**	**4.9**
	22-07-2007		6.1		132		
Bh 6	14-07-1992	5.85	6.2		130		
	25-08-2005	6.6		94			
	14-12-2005	6.8	6.1	106	115		
	31-10-2006	**7.8**		**66**		**20.2**	**7.3**
NH	22-06-1998		5.8		61		
	14-12-2005		6.2		44		
	31-10-2006	**6.6**		**44**		**19.2**	**5.2**

*Note: Data in bold refer to down-the-hole logging “midpoint” values in screened part of borehole

In the paragraphs below the characteristics as measured in the down-the-hole logs for the four boreholes are compared in order to gain further insight into the nature of the aquifer and the groundwater found in the area. For comparison purposes the depths are given as the elevation in metres above mean sea level.

3.4 Electrical conductivity (EC)

The borehole New Horizon (NH) has the lowest electrical conductivity and, therefore, also the lowest salinity (Figure 8) while borehole Bh 3 has the highest EC. At both these boreholes the EC remained constant over the whole depth of the water column. This would seem to indicate that the groundwater is essentially derived from one fracture with a consistent water quality. At the time of logging, borehole Bh 6 had a relatively low salinity over the full water column with even lower salinity at the bottom. In contrast, borehole Bh 2 had a slightly lower salinity at the top, possibly in the part of the borehole with solid casing with salinity comparable to that of Bh 3 at depth. When analysing a pumped sample from Bh 6 the salinity was higher than at the time of logging.

Generally, the salinity in an aquifer increases along the flow path and with borehole Bh 2 being the furthest “down-gradient” it would be expected that the salinity would reach the highest value of all the logged boreholes. This is not really the case and it would seem that the groundwater body or bodies in the area needs closer definition.

3.5 pH

Boreholes Bh 3, NH, and Bh 6 show relatively consistent values over the length of the water column (Figure 9). Whereas Bh 3 has a low pH Bh 6 has a much higher pH value. Even borehole Bh 2, which shows anomalous pH values near surface, has a lower pH at depth. The reason for the high pH at Bh 6 is unknown, and it is noteworthy that the salinity of the borehole was higher when analysed on a pumped sample, while the pH was lower.

3.6 Temperature

The three production boreholes, Bh 3, Bh 6, and NH, all show a relatively similar increase in temperature with depth (Figure 10). Borehole Bh 2 has a totally anomalous temperature profile in addition to the fact that the temperature is approximately one degree higher than at the other three boreholes in the upper part of the water column, i.e. mostly the “stagnant” water above the well screen. It would seem that lower temperature water passes through the bottom part of the slotted casing. This water also has a lower EC and higher pH (Figure 5).

The temperature gradients (dT/dx, where x is the depth in m) in the four boreholes was calculated and the smoothed 7-reading average is shown in Figure 11 to eliminate most of the noise. The gradient is positive in all cases except in borehole 6 where a negative gradient prevails at a depth greater than 150 m but particularly below 170 m (approximately 30 m above sea level). It would seem that based on the measurements at these boreholes the temperature gradient in the area, at least over the first 60 to 70 m, is relatively low at about 0.5 °C/100 m, while only at the unused borehole, Bh 2, the gradient approaches 1 °C/100 m (Figure 11). This could be an indication that the flux of cool recharge water through the rock matrix is such that the water does not attain equilibrium with the temperature of the rocks.

3.7 Oxidation-reduction potential (ORP)

Boreholes Bh 3, Bh 6, and NH have comparable ORP values, which converge near a depth equivalent to sea level while that of borehole Bh 2 is anomalous and decreases with depth (Figure 12). The extreme corrosion of the steel casing of Bh 2 is considered to be the main cause of the lower ORP at this borehole.

It is also noteworthy that the lower pH water has higher ORP values with the exception of Bh 2, which has the highest ORP at extremely high pH and a lower ORP at lower pH (see Figures 9 and 12).

3.8 Dissolved oxygen (DO)

Boreholes Bh 3 and New Horizon have similar levels of dissolved oxygen (Figure 13). In contrast, borehole Bh 6 has a much higher level, nearly anomalously high compared to other logged boreholes. This needs to be confirmed. Borehole Bh 2 is low in dissolved oxygen compared to the other three boreholes and based on the extensive corrosion of the borehole casing this is considered plausible.

4. HYDROCHEMISTRY

The main aim of the hydrochemical logging of the boreholes was to determine the potential risk of unwanted chemical reactions when injecting (treated?) surface water with different hydrochemical characteristics into the aquifer. Based on the logging results the overall conclusion is that the water is well-oxygenated and the introduction of surface water, which is naturally saturated with oxygen at atmospheric pressure, should not disturb the chemical equilibria significantly. However, to some extent a change in pH may play a role, depending on the buffer capacity of the different waters.

4.1 Stability diagrams

As the presence of iron in the groundwater was clearly evident from the deposits on the borehole equipment, it was considered important to determine the stability fields for the various iron species using the logging results. The stability fields are defined using the various chemical reaction constants and the pH and oxidation-reduction potential (≈ Eh) of the "solution" (see Figures 14 and 15). In these graphs the corresponding pH and ORP values were plotted for all measurements down the borehole. From Figure 14 it is evident that iron will be mainly in the ferric form at all boreholes at all depths. Borehole Bh 2 shows a trend moving closer to the ferrous stability field at depth but does not cross the boundary.

Further evaluation in terms of equilibria with the iron minerals (Figure 15) confirms that the iron in "solution" will be within the stability field of haematite at all boreholes. This means that if the iron concentration in solution is high enough haematite will be precipitated. These data were also confirmed analytically in order to determine the quantities of iron species that could be present in solution.

For calculating the data in Tables 3 and 4, the analytical data for 14 December 2005 were used (Murray, 2006) together with the down-the-hole logging data for pH, oxidation-reduction potential (ORP), temperature, and dissolved oxygen. Due to the high ORP and the significant presence of dissolved oxygen the iron is largely in the ferric (oxidised) form and mainly in the form of hydroxyl complexes and partly already in the form of the zero valent ferric hydroxide ($Fe(OH)_3$). Ferric hydroxide is relatively insoluble and, therefore, precipitates easily as can be observed, especially at borehole New Horizon where all riser pipes and other equipment are heavily coated with iron oxide. The total iron concentration in Table 3 is the value determined by analysis, which is assumed to be that of a sample filtered at sampling.

Table 3 Concentrations of Fe-species expected in solution at boreholes Bh 3, Bh 6 and New Horizon at equilibrium conditions

Oxidation state	Borehole 3		Borehole 6		Borehole New Horizon	
	Fe-species	**mg/L as Fe***	**Fe-species**	**mg/L as Fe**	**Fe-species**	**mg/L as Fe**
Ferric (Fe^{3+})	$Fe(OH)_2^+$	0.0486	$Fe(OH)_3$	0.0041	$Fe(OH)_2^+$	0.4895
	$Fe(OH)_3$	0.0109	$Fe(OH)_2^+$	0.0007	$Fe(OH)_3$	0.1802
	$FeOH^{2+}$	0.0001	$Fe(OH)_4^-$	0.0002	$FeOH^{2+}$	0.0006
					$Fe(OH)_4^-$	0.0006
All Fe^{3+}		0.0596		0.0050		0.6709
Ferrous (Fe^{2+})	Fe^{2+}	0.0004	Fe^{2+}	0.0000	Fe^{2+}	0.0186
					$FeSO_4$	0.0005
					$FeHCO_3^+$	0.0002
					$FeCl^+$	0.0001
All Fe^{2+}		0.0004		0.0000		0.0194
Total Fe		0.0600		0.0050		0.6903

*Note: All Fe-complex species are expressed as an equivalent quantity of Fe

Based on the chemical analytical data mineral equilibria were calculated for the iron minerals as well as carbonate and certain silicate minerals. The results are presented in Table 4. The saturation index for a mineral is defined as "0" at equilibrium between the mineral and the chemical species in solution. When the index is negative it denotes that the solution is under saturated with respect the mineral while a positive index denotes super saturation. The magnitude of the number is not directly related to the extent of under or over saturation.

From the results it is evident that in all cases the groundwater is under saturated with respect to the carbonate minerals. In general this means that the water will be corrosive as raw water is generally treated at the water treatment works to have a slight over saturation with respect to calcite before distribution. The raw borehole water therefore needs to be transported to the treatment works in plastic pipes or suitably lined cement pipes that would not be subject to corrosion.

With respect to the iron minerals, it is evident that the groundwater from all three boreholes is supersaturated to these. This confirms the fact established in Figure 15.

Due to the quartzitic nature of the aquifer it is expected that the water would be close to saturation with regard to quartz. The slightly different composition of the water from Bh 6 brings it close to saturation with respect to talc, a magnesium silicate.

Table 4 Mineral equilibria and saturation indices

Phase	Formula	Bh 3	Bh 6	New Horizon
Aragonite	$CaCO_3$	-2.70	-1.41	-3.24
Calcite	$CaCO_3$	-2.55	-1.26	-3.09
Dolomite	$CaMg(CO_3)_2$	-4.94	-2.28	-5.72
$Fe(OH)_3$(a)	$Fe(OH)_3$	1.31	0.83	2.54
Goethite	FeOOH	7.00	6.55	8.22
Haematite	Fe_2O_3	15.97	15.08	18.42
Chalcedony	SiO_2	-0.16	-0.18	-0.37
Quartz	SiO_2	0.27	0.24	0.06
SiO_2(a)	SiO_2	-1.02	-1.04	-1.22
Talc	$Mg_3Si_4O_{10}(OH)_2$	-8.53	-0.12	-8.74

5. DISCUSSION

The predominance of iron oxide deposits on all the pumping equipment at the production boreholes confirms the presence of appreciable iron concentrations in the groundwater. Based on the down-the-hole measurements and stability calculations it would seem that only very small concentrations of the iron are in ionic form, mostly as ferric complexes and it is evident that these will eventually be precipitated as the saturation indices for haematite and others are exceeded. This may eventually cause clogging of the well screens in the abstraction boreholes. It would seem that clogging of the injection boreholes by injecting oxygen-rich surface water into the aquifer will not be a serious problem as the groundwater itself is also aerobic which means that the iron should be relatively immobile. This raises the question as to the reason for the mobility of the iron and whether conditions in the aquifer are different to those measured in the boreholes during logging. Nevertheless, injecting water that is (super-) saturated with oxygen (or air) into the boreholes (especially New Horizon) should be beneficial as it will assist in keeping the iron in an oxidised form which will diminish its mobility, actually fixing the iron in the aquifer matrix.

In the evaluation of the results a number of unanswered questions remained. In order to investigate the possibility of various water bodies potentially existing in the aquifer, as well as the interaction between nearby boreholes during pumping, data were analysed which were obtained by longer term logging of water levels and temperatures. From 23 November 2006 to 5 February 2007 groundwater temperatures were logged together with the water levels in the production boreholes and Bh 2. These data are plotted in Figure 16 together with the measurements taken on 31 October 2005 during the down-the-hole hydrochemical logging of the boreholes.

The “representative” temperature for borehole Bh 2 was taken as 19.3 °C but should possibly rather be 19.1 °C as this is the temperature at 92 m depth where the inflow is occurring. The probe was placed at the bottom of the borehole where the temperature was 19.6 °C and as it was possibly in the borehole “sump”, the temperature remained constant. It is recommended that the probe be placed at a depth of 92 m below surface for future logging of water levels and temperature.

Borehole Bh 3 was pumped for short intervals during the observation period. The probe was placed below the pump in or near the sump of the borehole. The “representative” temperature from the logging agreed quite well with the recorded temperature which also remained constant except at the times the pump was turned on or off. This is explored in more detail in Figure 18 below.

Borehole Bh 6 had a temperature slightly higher than 20 °C over most of its depth. Only towards the bottom of the borehole the temperature dropped just below 19 °C. Considering the temperature recorded, it is assumed that the sensor was located close to the bottom of the borehole. During logging the present depth of the borehole was found to be about 180 m, i.e. practically at the bottom of the screen which means that the sump may be filled with sand. For this reason it is assumed that a probe at the bottom of the hole will still react to temperature changes due to changing inflow of water.

The New Horison borehole had a temperature of 19.2 °C at a depth of 150 to 160 m below surface. The water level and temperature probe showed a similar temperature over the period of observation (Figure 16). It is assumed that the probe was placed approximately at this depth. Only at the beginning of the period there was a small rise in temperature of just more than one degree but subsequently it remained constant. Further observations with the probe placed opposite the well screen will be needed to establish whether there are temperature trends which may be related to water movement in the aquifer.

The detailed water level responses recorded by the loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon over the period 23 November 2006 to 5 February 2007 are shown in Figure 17. This period includes three brief abstraction episodes at borehole Bh 3 at the end of each month from November to January. The exact rest water level before pumping started at Bh 3 is unknown but it is evident that after a shorter pumping period the recovery of the water level in January 2007 was higher than in December 2006 when abstraction continued for a slightly longer period. The graph also shows that at borehole Bh 6 there was a small but definite response in the water level amounting to nearly 0.2 m each time the pump at borehole Bh 3 was either started or stopped. The fact that the water level rose when the abstraction began and dropped when it stopped is contrary to the expectation and cannot be explained at this stage. It is also noteworthy that all the boreholes show very similar short term fluctuations over the whole period. The cause is unknown but it could either be related to earth tides or incorrect barometric compensation or both or another reason. Longer term comparison of the water level trends with the pumping regimes as well as the rainfall patterns will help to interpret the longer term water level responses and trends, e.g. the gradual decline in the water level at borehole Bh 2 over the period from 10 December 2006 to 31 January 2007.

Figure 18 shows that when the pump is switched off the temperature in production borehole Bh 3 rises by 0.7 to 0.9 °C during the water level recovery phase and this is ascribed to the heat developed in the electric motor of the submersible pump. Most of this heat is dissipated quickly except for the last 0.1 degree which takes approximately two days to disappear completely. It is noteworthy that the temperature recorded at the bottom of borehole Bh 6, at a distance of some 600 m, also responded when the pump in borehole Bh 3 was turned on and off. Together with the water level response this would indicate that there is a hydraulic link between boreholes Bh 3 and Bh 6 despite the difference in water quality.

6. CONCLUSIONS

The down-the-hole hydrochemical logging of the boreholes identified a degree of groundwater stratification in all boreholes. The stratification and flow through the boreholes were often displayed by different parameters. Hence all parameters, electrical conductivity (EC), temperature, pH, oxidation-reduction potential, and dissolved oxygen, need to be considered when evaluating the relationships in the aquifer.

The salinities, as indicated by the EC values, vary from borehole to borehole, and to some extent also with depth and time. The down-the-hole logging data also do not always correspond to the analytical data obtained from water samples during abstraction. Longer term evaluation of the salinity will help to unravel the interrelationships between the various boreholes in the aquifer. At this stage the low salinity of the New Horizon borehole does not fit into the general pattern. It is possible that the groundwater at New Horizon is derived from another recharge area.

Water temperatures reveal a lot about the aquifer and interrelationships/hydraulic linkages, as well as recharge. The small but immediate temperature and water level responses at Bh 6 on abstraction from Bh 3 indicate that there is a direct hydraulic link between these two boreholes despite the water quality differences.

The water is corrosive and steel casings and other susceptible materials will be corroded by the raw water. This is demonstrated by the extreme corrosion at borehole Bh 2. All boreholes should be equipped with plastic casings.

In view of the high oxygen levels in the groundwater, the iron in the groundwater is mainly held in “solution” as hydroxide and hydroxyl complexes. Ferric hydroxide is a transitory compound that in itself is unstable and will deposit with time as haematite. Borehole New Horizon has the highest iron content. It may be possible to inject oxygenated water into the boreholes which may cause the iron to precipitate in the aquifer matrix or at least prevent its dissolution. This may be an important benefit of the artificial recharge by borehole injection. Once abstraction is resumed and the iron starts to rise to unacceptable levels a further injection cycle will be needed.

7. RECOMMENDATIONS

It is recommended that:

The groundwater temperature – pumping relationships are investigated at all boreholes by longer term continuous recording of these parameters. For this purpose the water level and temperature loggers should be placed at the following depths:

- Bh 2 at 92 m
- Bh 3 at 175 m
- Bh 6 at 188 m
- Bh New Horizon at 165 m;

Water level trends are compared with pumping regimes and rainfall patterns;

Down-the-hole logging should be repeated after longer periods of abstraction for determining the trends with time. Together with the continuous logging of water levels and temperature this would confirm the flow regime in the aquifer, which will contribute to a better understanding of the aquifer characteristics and flow patterns.

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Figures

Figure 1: Location of logged boreholes, measured depth, and water column available for logging 14

Figure 2: Water level elevation at logged boreholes (31 October 2006) with inferred water level contours 15

Figure 3: Down-the-hole hydrochemical profiles in borehole Bh2 at Plettenberg Bay 16

Figure 4: Down-the-hole hydrochemical profiles in borehole Bh3 at Plettenberg Bay 17

Figure 5: Down-the-hole hydrochemical profiles in borehole Bh6 at Plettenberg Bay 18

Figure 6: Down-the-hole hydrochemical profiles in borehole "New Horison" at Plettenberg Bay 19

Figure 7: Average values of electrical conductivity, pH, temperature, and dissolved oxygen of logged boreholes for the water column, except for Borehole 2 where values represent only the lower part of the water column 20

Figure 8: Comparison of electrical conductivity profiles in the Plettenberg Bay boreholes 21

Figure 9: Comparison of pH profiles in the Plettenberg Bay boreholes 22

Figure 10: Comparison of water temperature profiles in the Plettenberg Bay boreholes 23

Figure 11: Comparison of water temperature gradient profiles in the Plettenberg Bay boreholes (smoothed 7-reading moving average) 24

Figure 12: Comparison of oxidation-reduction potential profiles in the Plettenberg Bay boreholes 25

Figure 13: Comparison of dissolved oxygen profiles in the Plettenberg Bay boreholes 26

Figure 14: Eh-pH diagram showing stability fields for ferrous and ferric hydroxide in solution (at 25 °C) 27

Figure 15: Eh-pH diagram for ferrous and ferric ions in solution showing stability fields for magnetite and haematite (at 25 °C) 28

Figure 16: Groundwater temperatures measured during down-the-hole logging on 2006-10-31 compared with recorded values of the loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon 29

Figure 17: Water level responses recorded by loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon during abstraction from borehole Bh 3 30

Figure 18: Water level and temperature trends recorded by loggers in boreholes Bh 3 and Bh 6 during abstraction from borehole Bh 3 31

Appendix A	Down-the-hole hydrochemical logging data

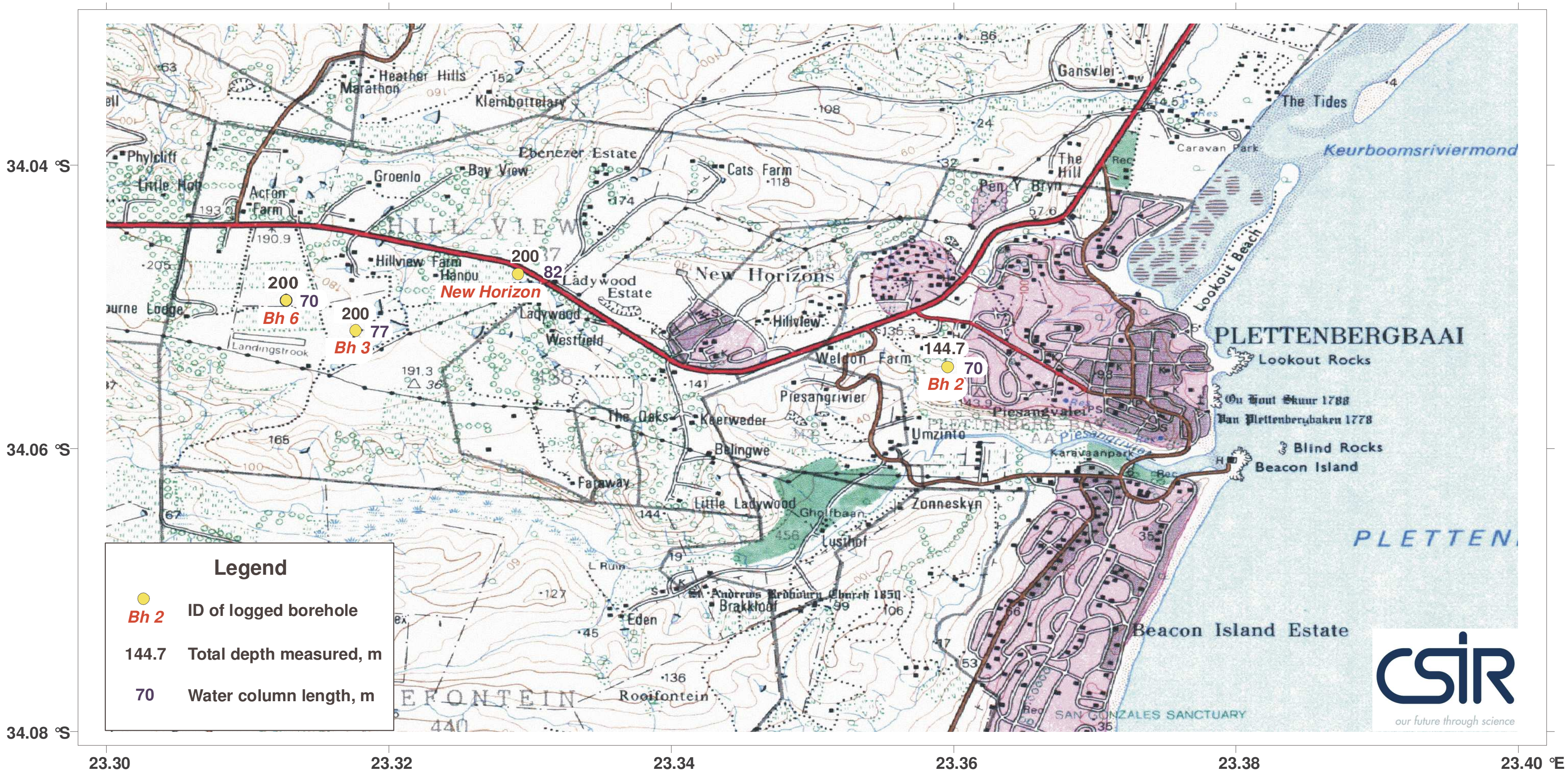

Figure 1: Location of logged boreholes, measured depth, and water column available for logging

(Base map 3423AB obtained from Surveyor General)

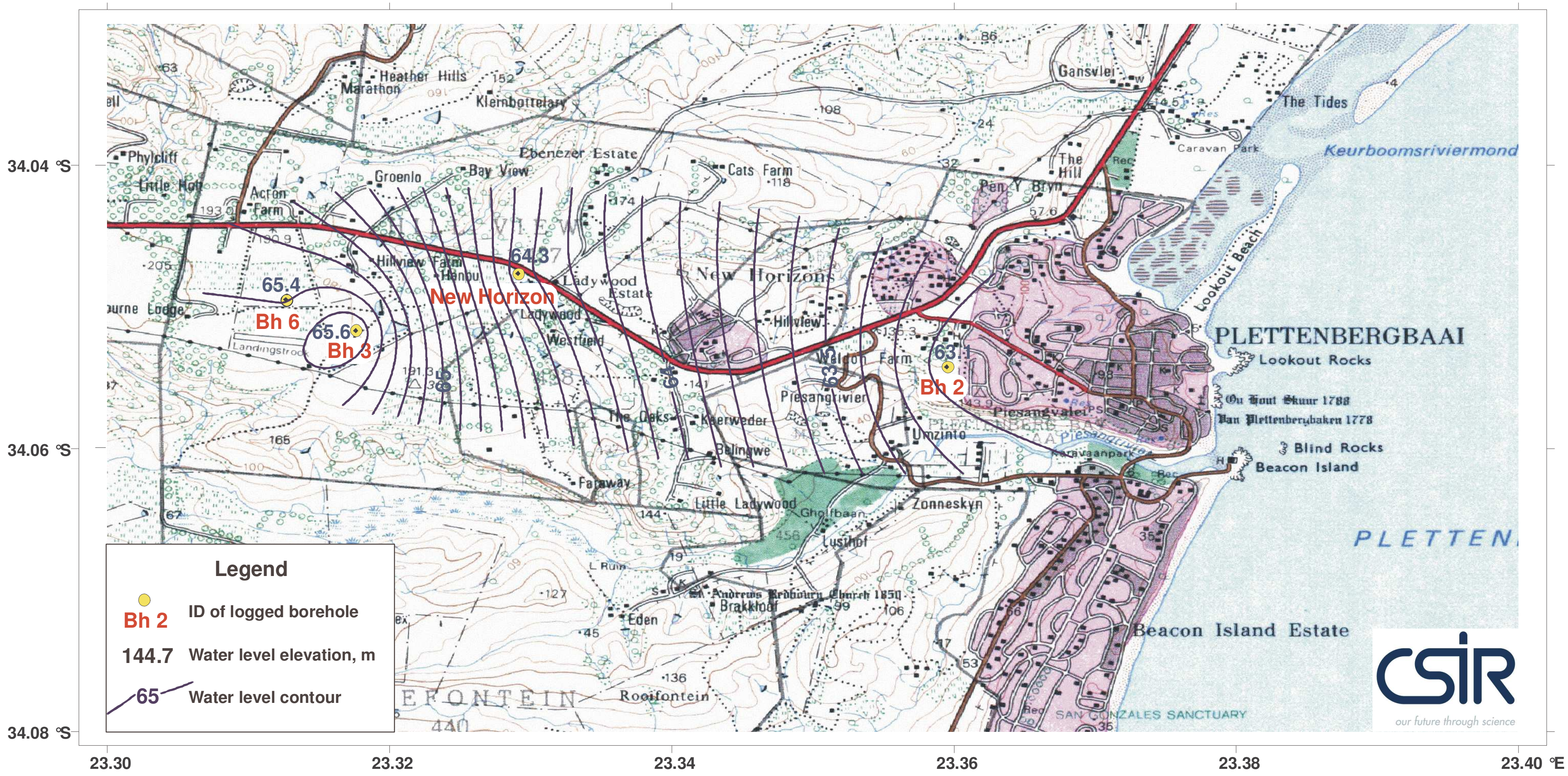

Figure 2: Water level elevation at logged boreholes (31 October 2006) with inferred water level contours

(Base map 3423AB obtained from Surveyor General)

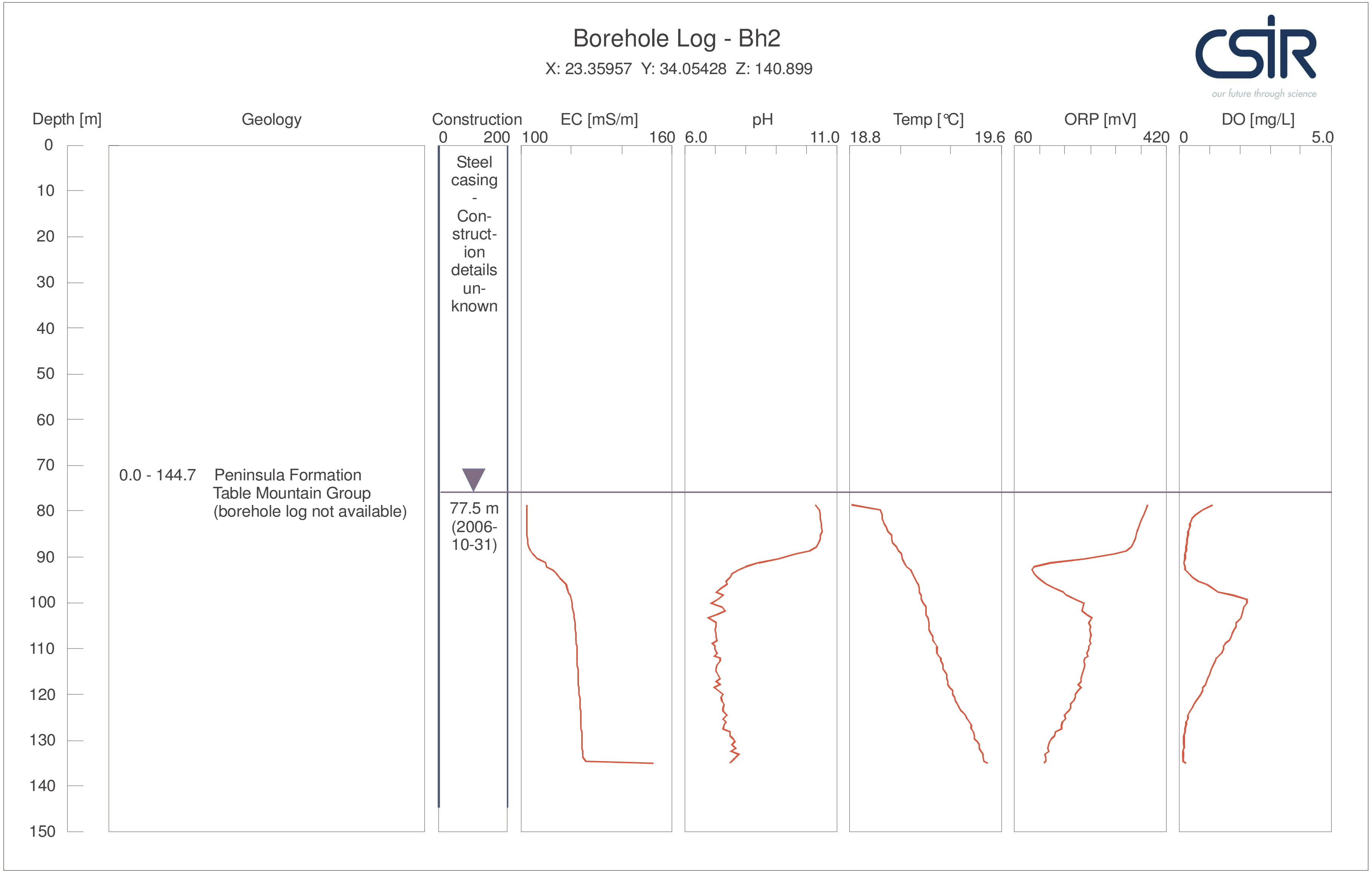

Figure 3: Down-the-hole hydrochemical profiles in borehole Bh2 at Plettenberg Bay

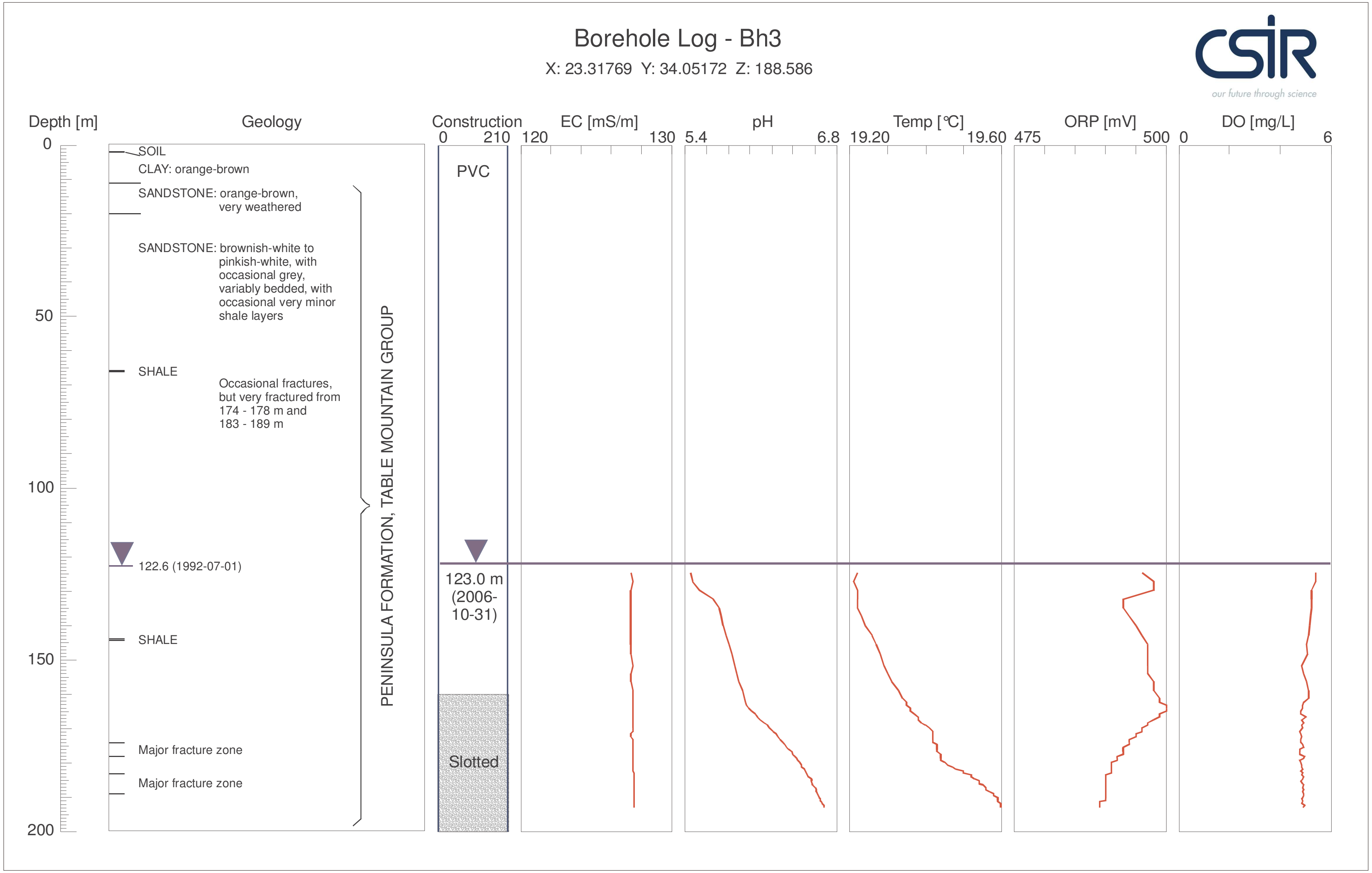

Figure 4: Down-the-hole hydrochemical profiles in borehole Bh3 at Plettenberg Bay

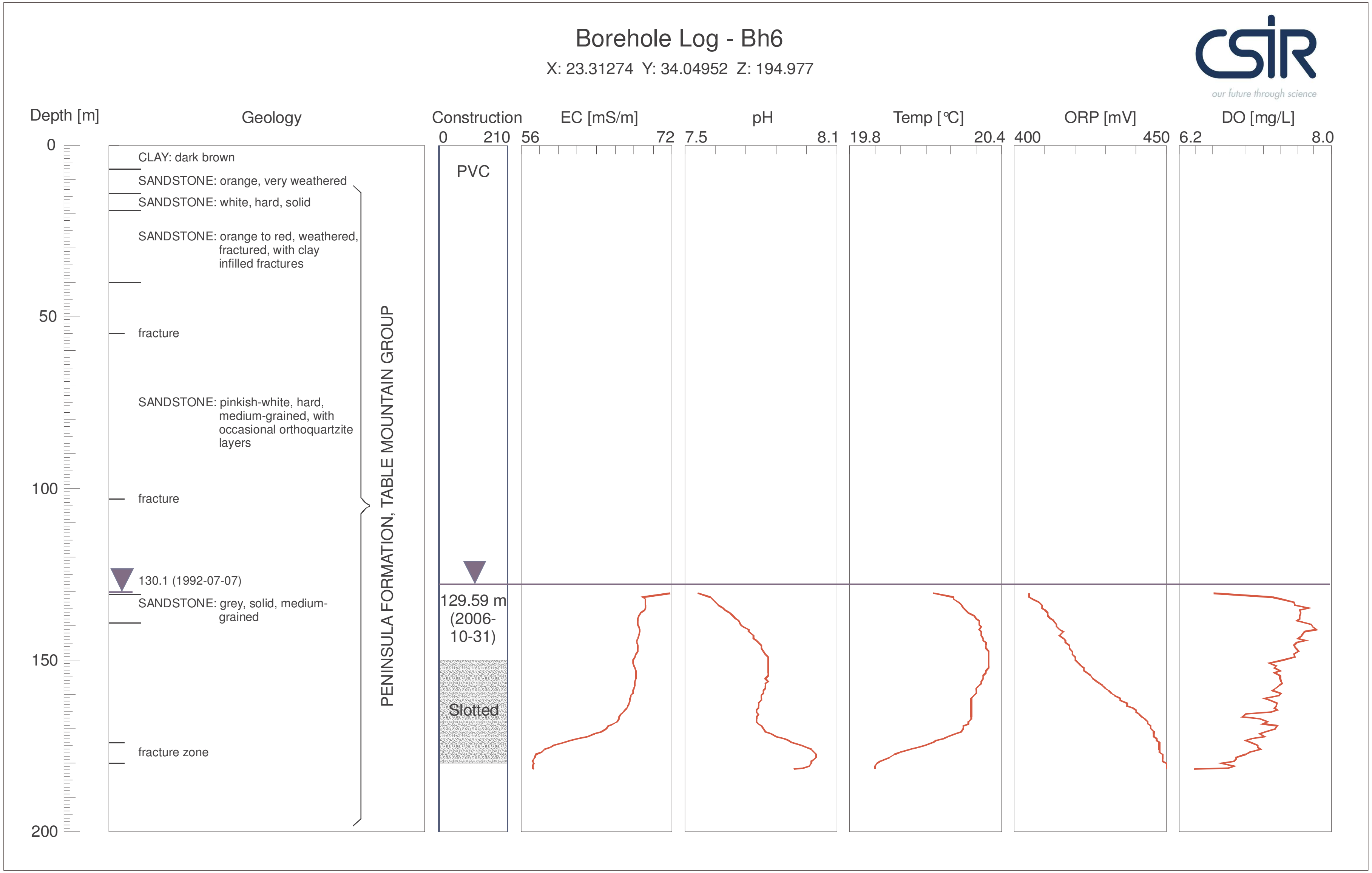

Figure 5: Down-the-hole hydrochemical profiles in borehole Bh6 at Plettenberg Bay

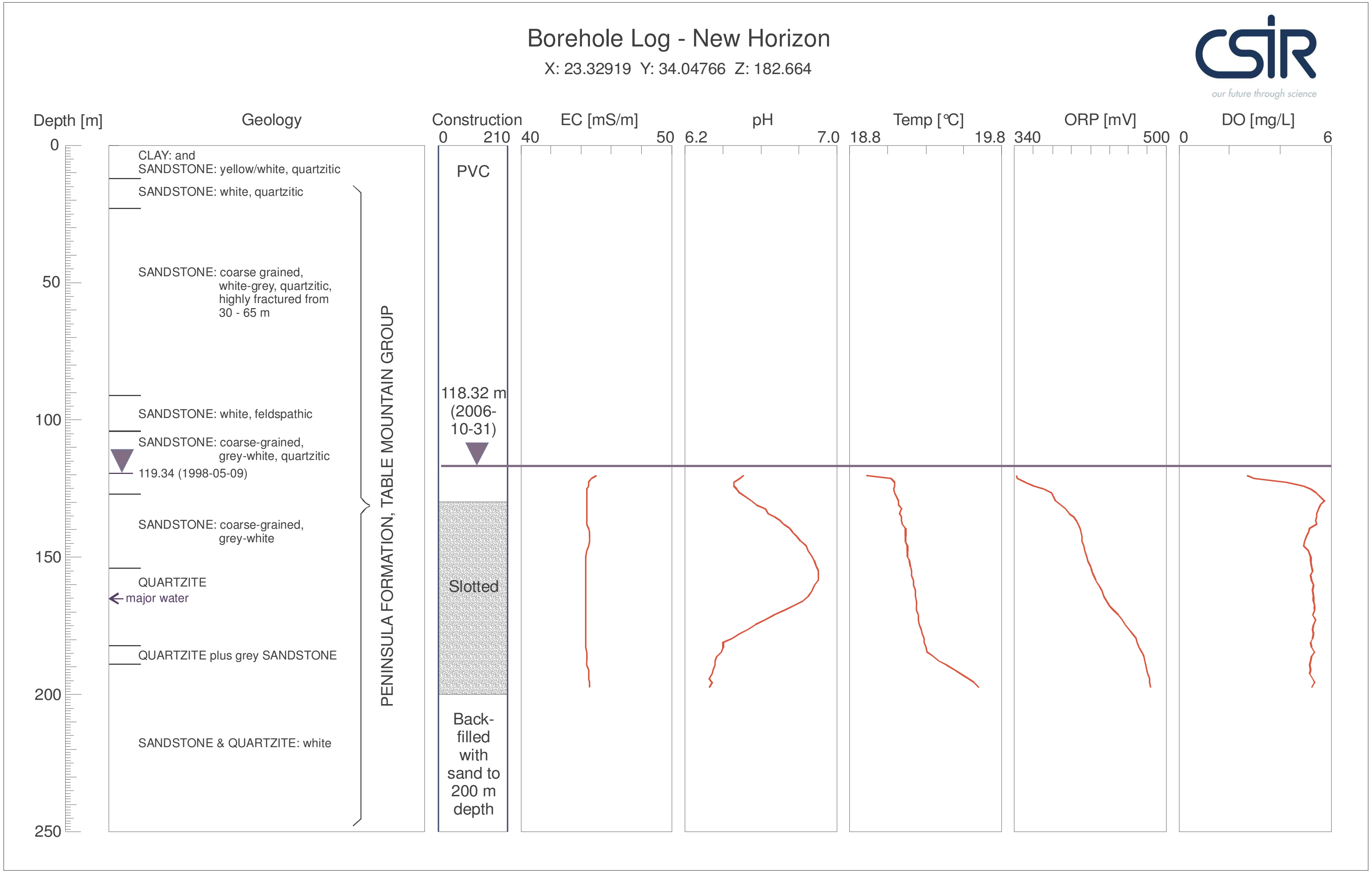

Figure 6: Down-the-hole hydrochemical profiles in borehole “New Horison” at Plettenberg Bay

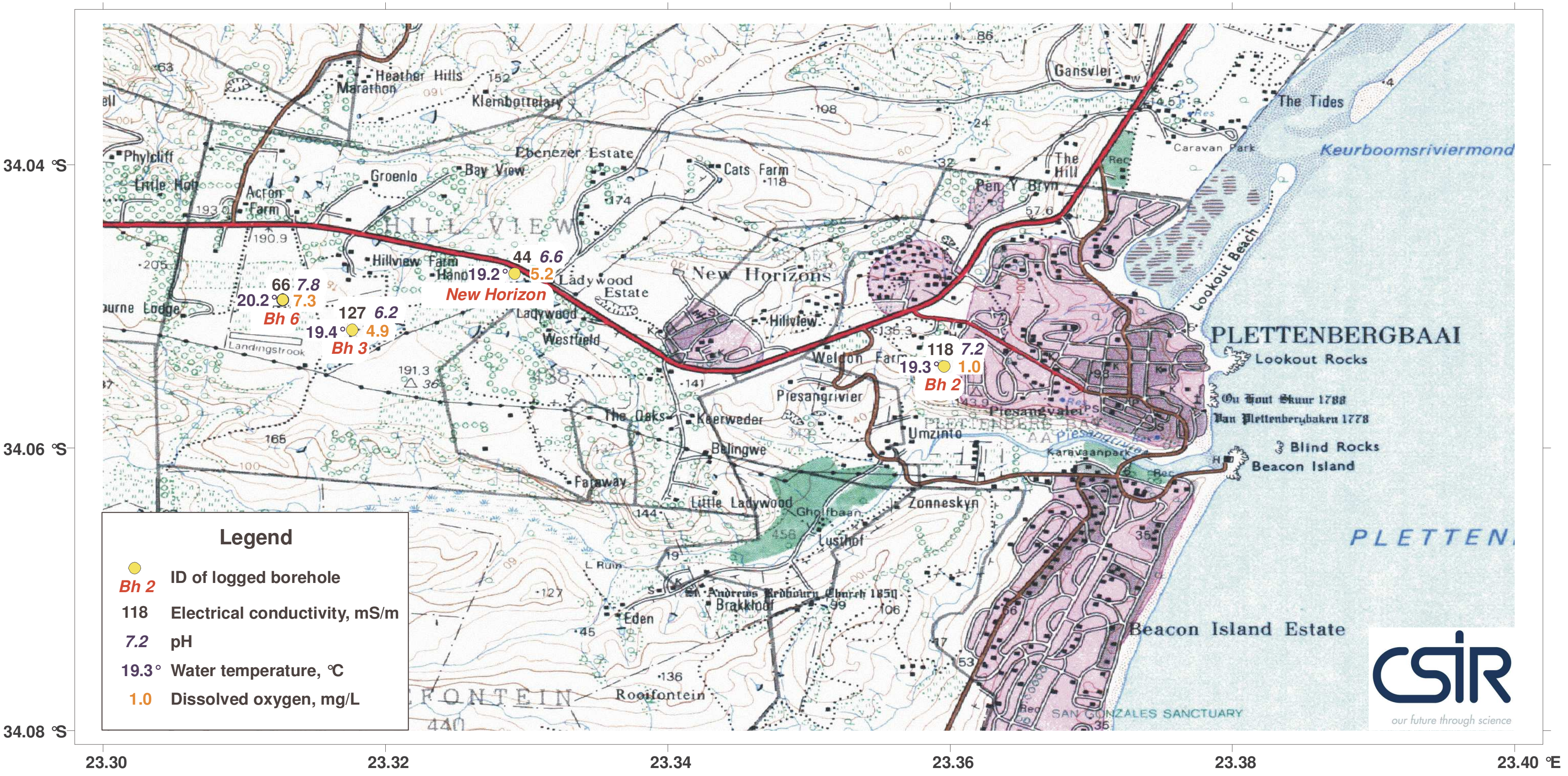

Figure 7: Average values of electrical conductivity, pH, temperature, and dissolved oxygen of logged boreholes for the water column, except for Borehole 2 where values represent only the lower part of the water column

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(Base map 3423AB obtained from Surveyor General)

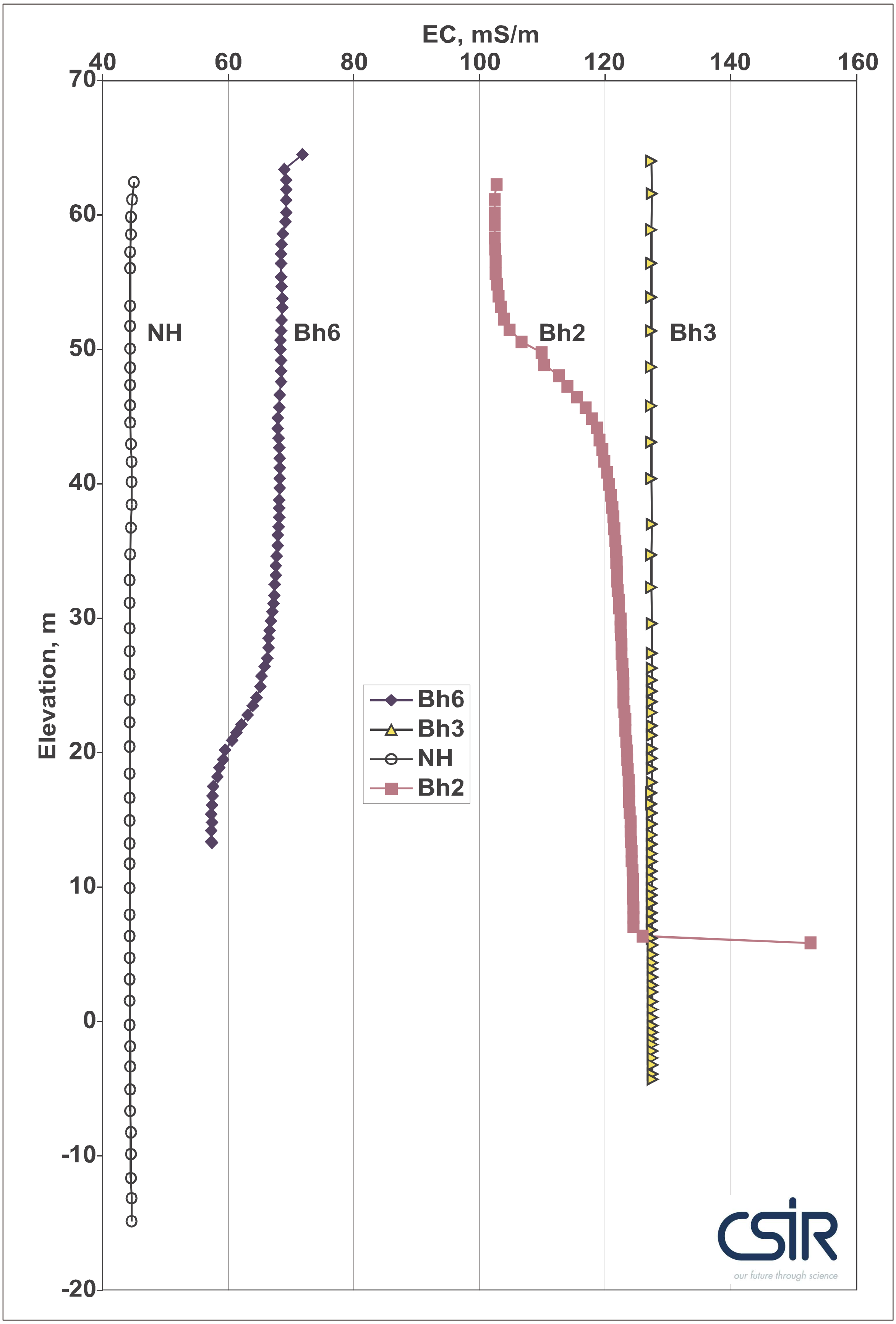

Figure 8: Comparison of electrical conductivity profiles in the Plettenberg Bay boreholes

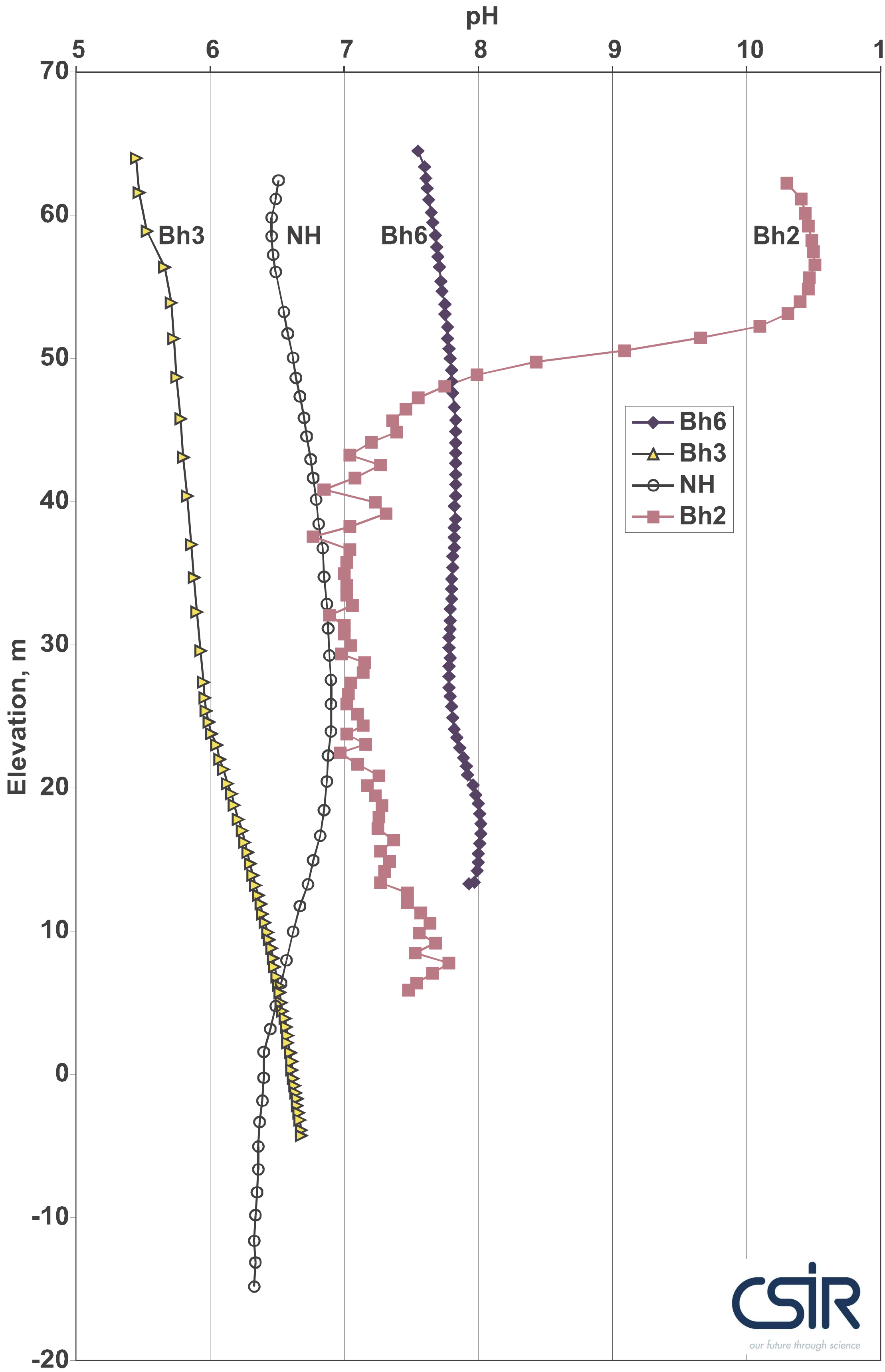

Figure 9: Comparison of pH profiles in the Plettenberg Bay boreholes

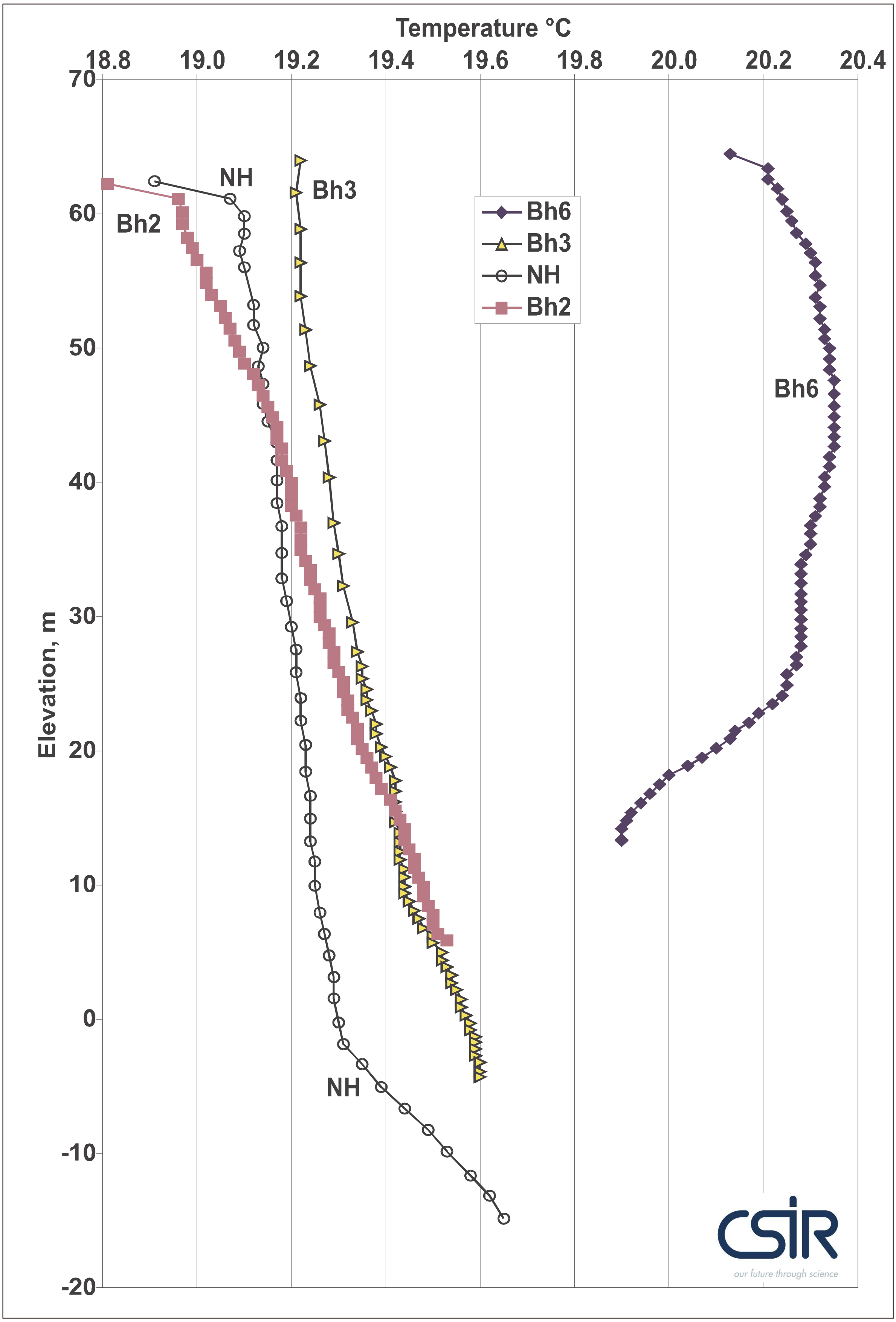

Figure 10: Comparison of water temperature profiles in the Plettenberg Bay boreholes

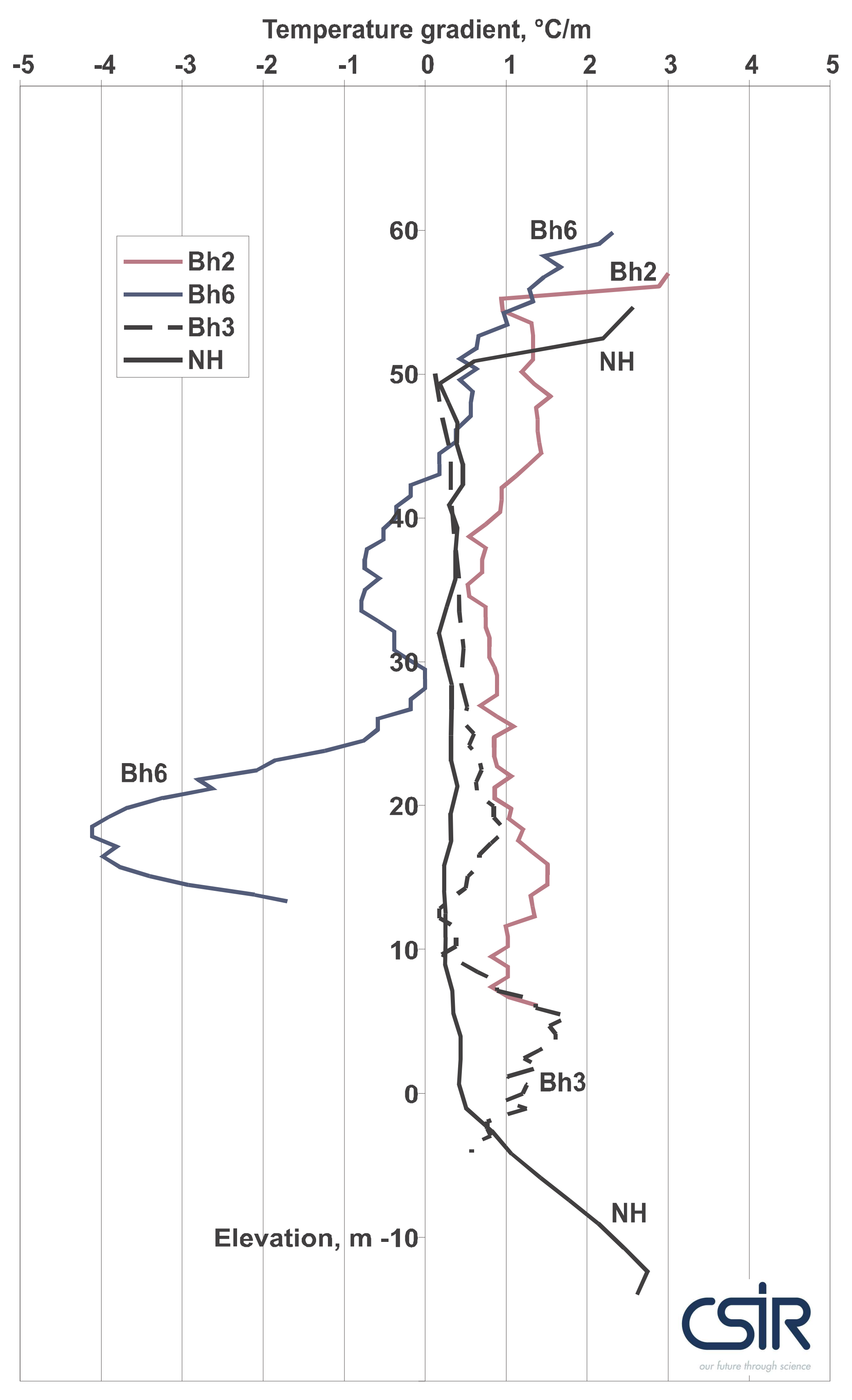

Figure 11: Comparison of water temperature gradient profiles in the Plettenberg Bay boreholes (smoothed 7-reading moving average)

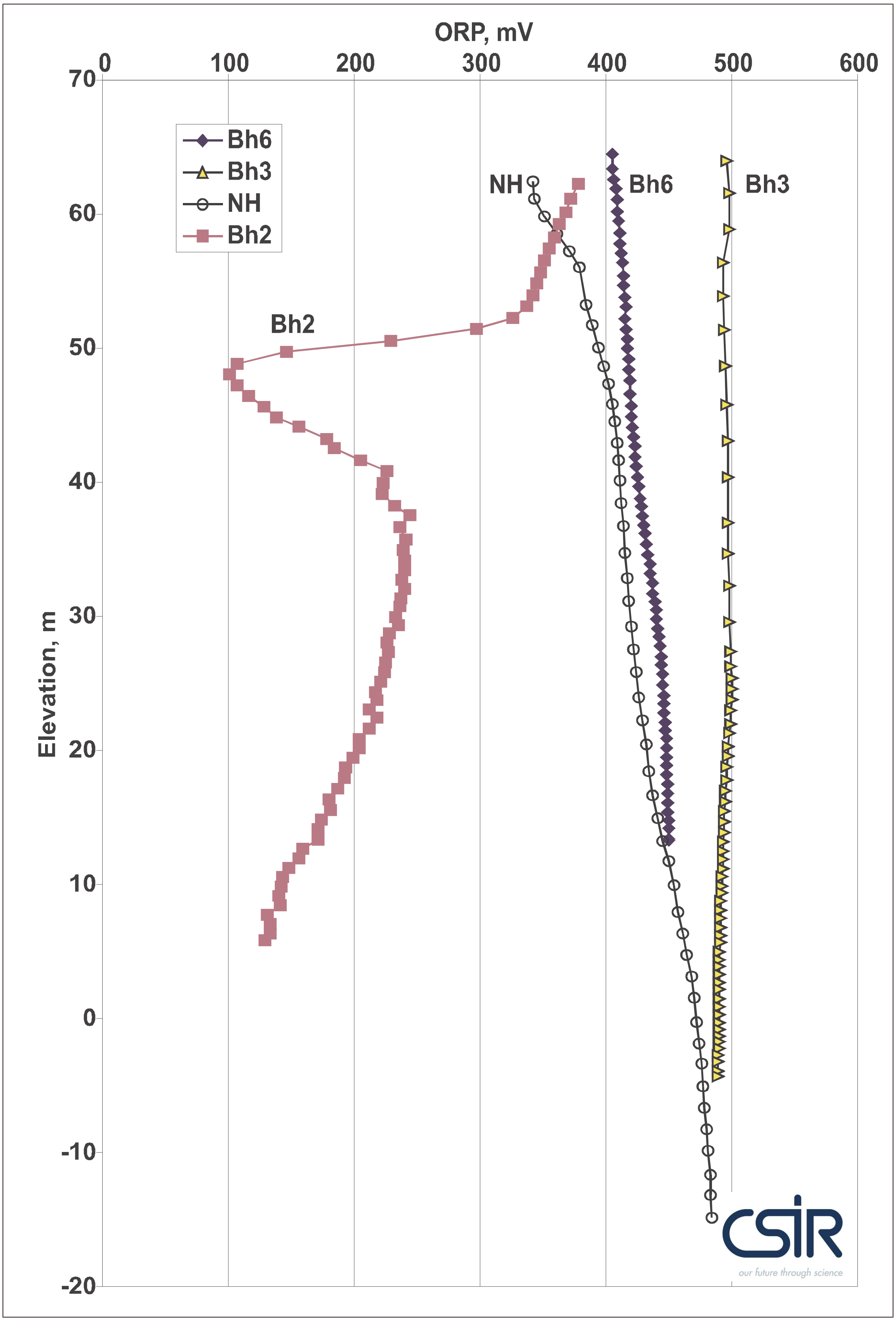

Figure 12: Comparison of oxidation-reduction potential profiles in the Plettenberg Bay boreholes

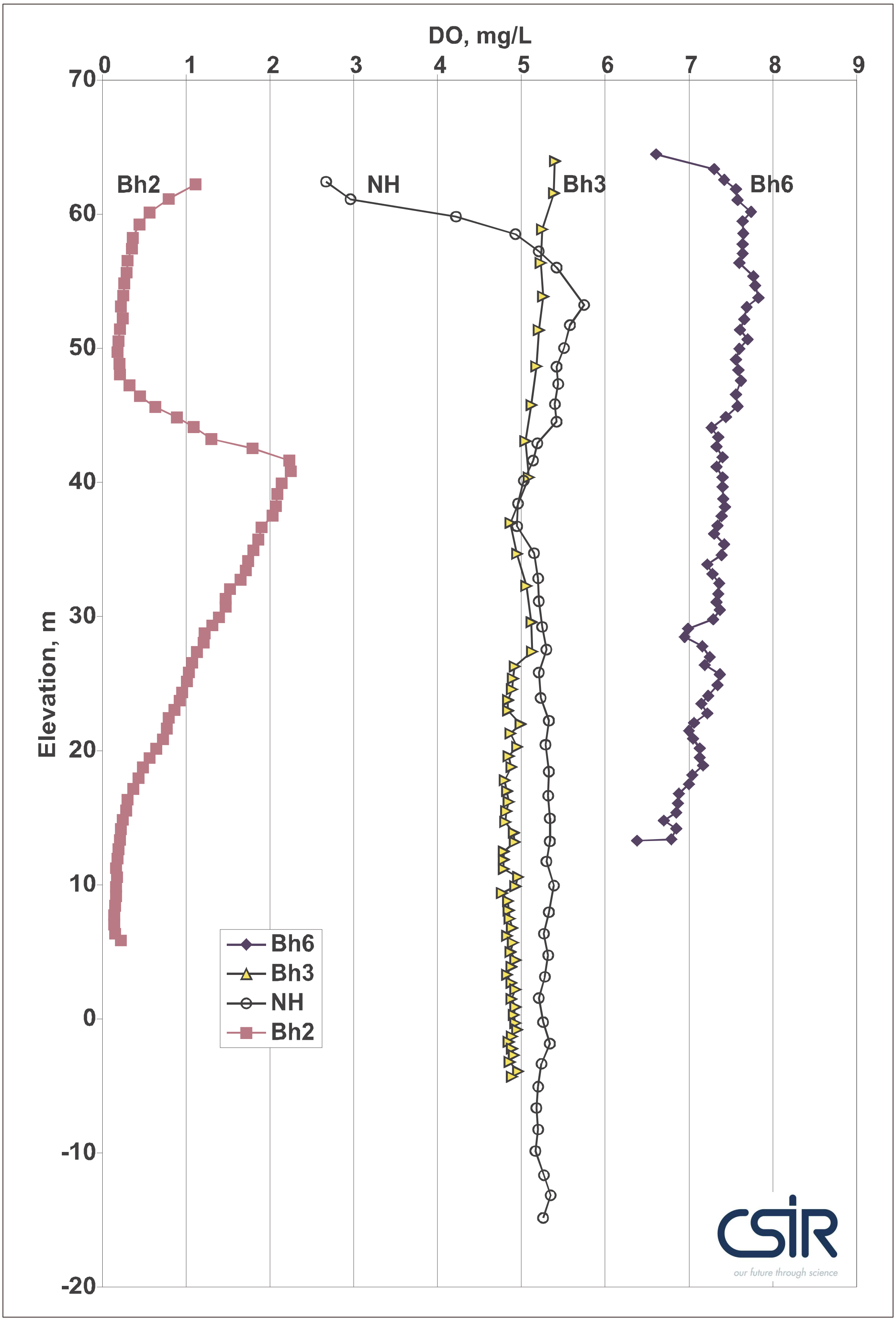

Figure 13: Comparison of dissolved oxygen profiles in the Plettenberg Bay boreholes

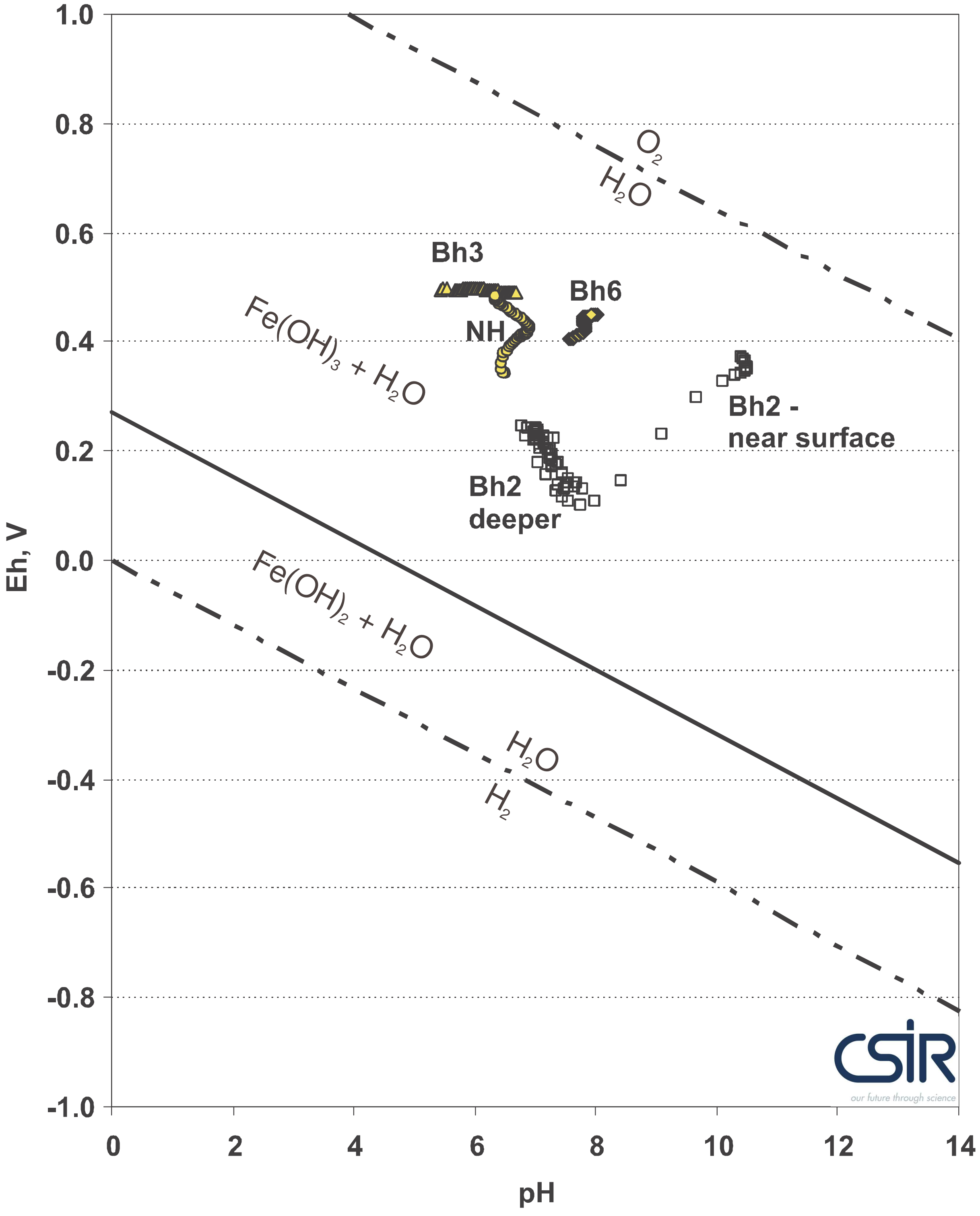

Figure 14: Eh-pH diagram showing stability fields for ferrous and ferric hydroxide in solution (at 25 °C)

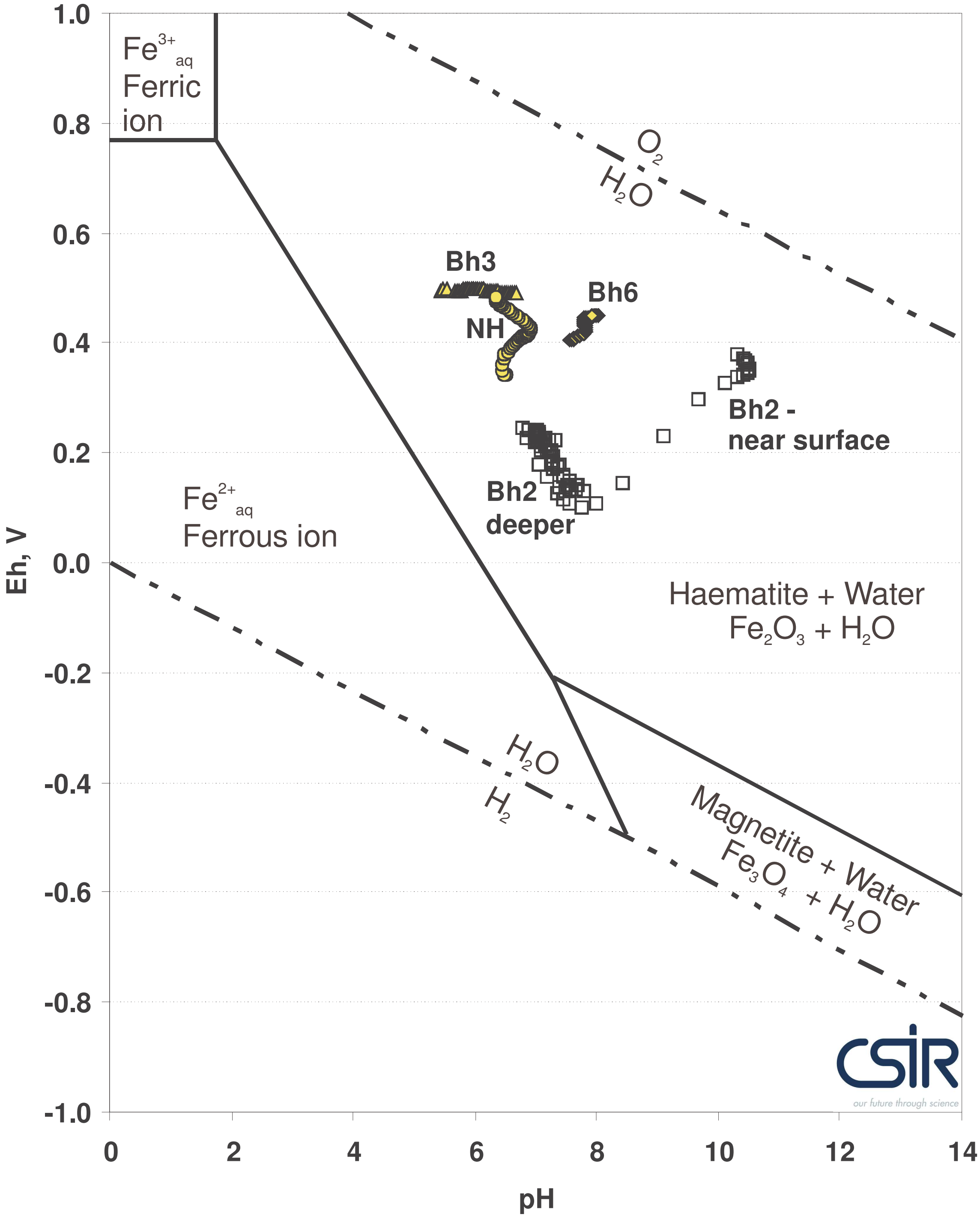

Figure 15: Eh-pH diagram for ferrous and ferric ions in solution showing stability fields for magnetite and haematite (at 25 °C)

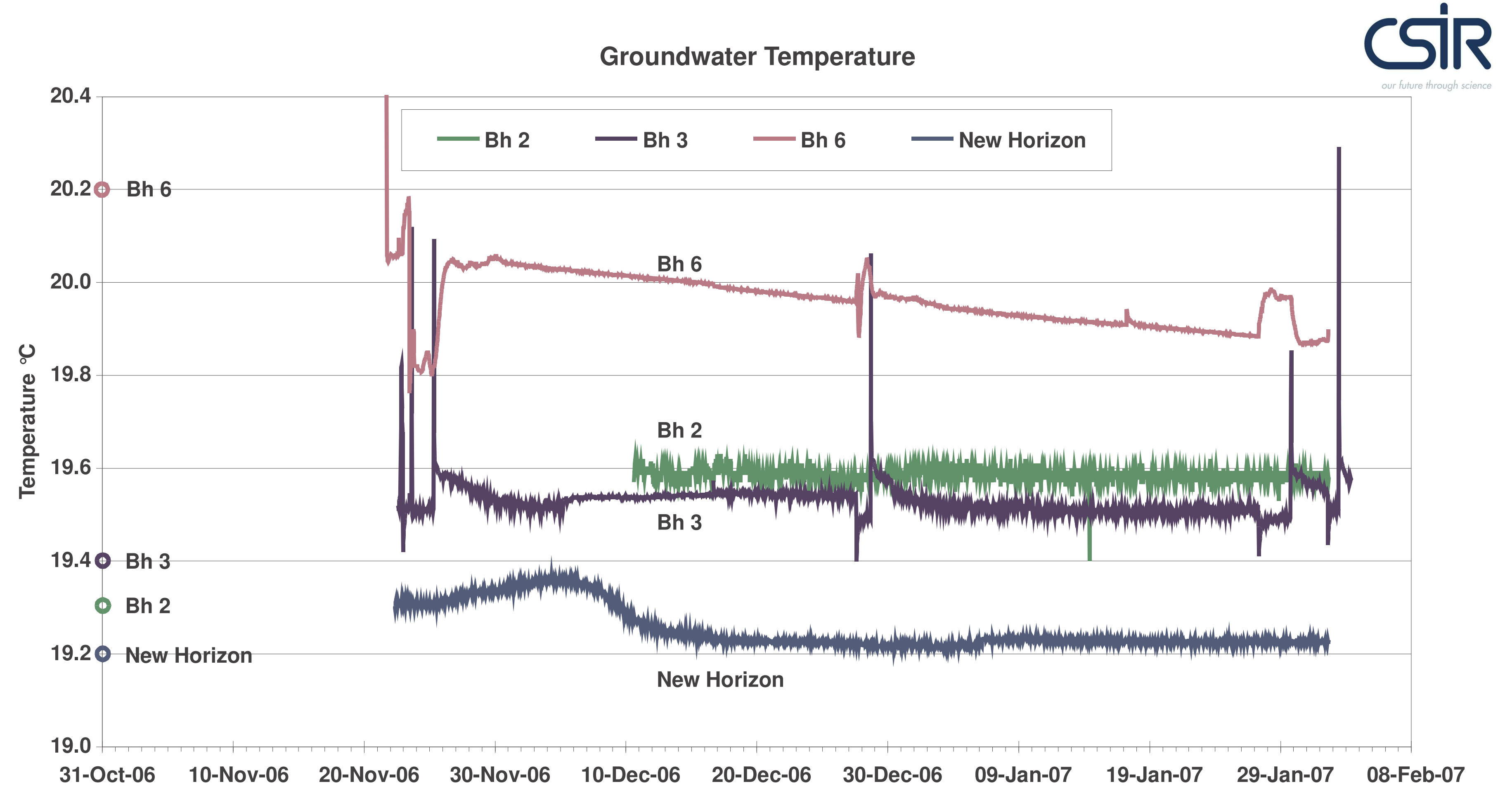

Figure 16: Groundwater temperatures measured during down-the-hole logging on 2006-10-31 compared with recorded values of the loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon

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(Data from DWAF via Groundwater Africa)

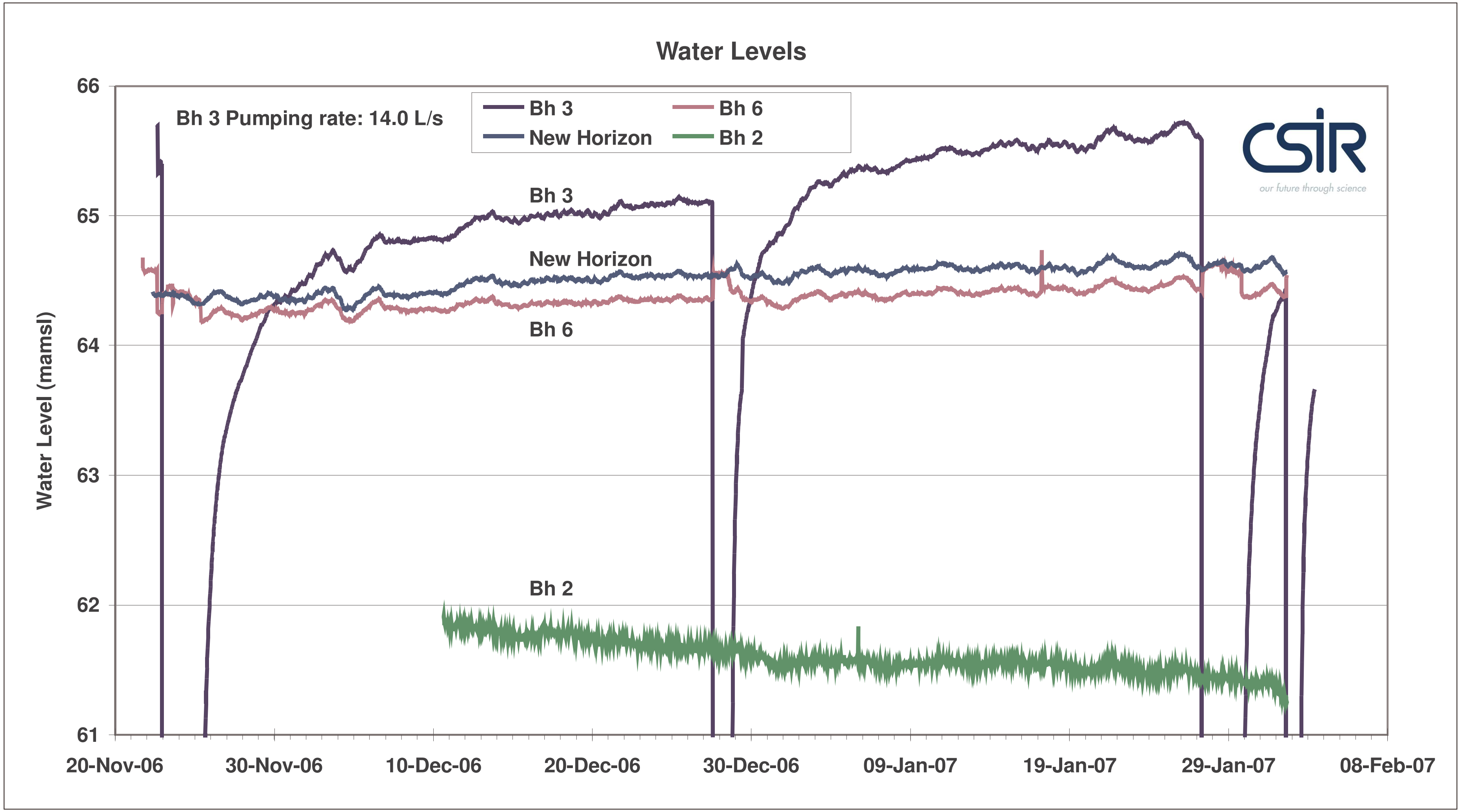

Figure 17: Water level responses recorded by loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon during abstraction from borehole Bh 3

(Data from DWAF via Groundwater Africa)

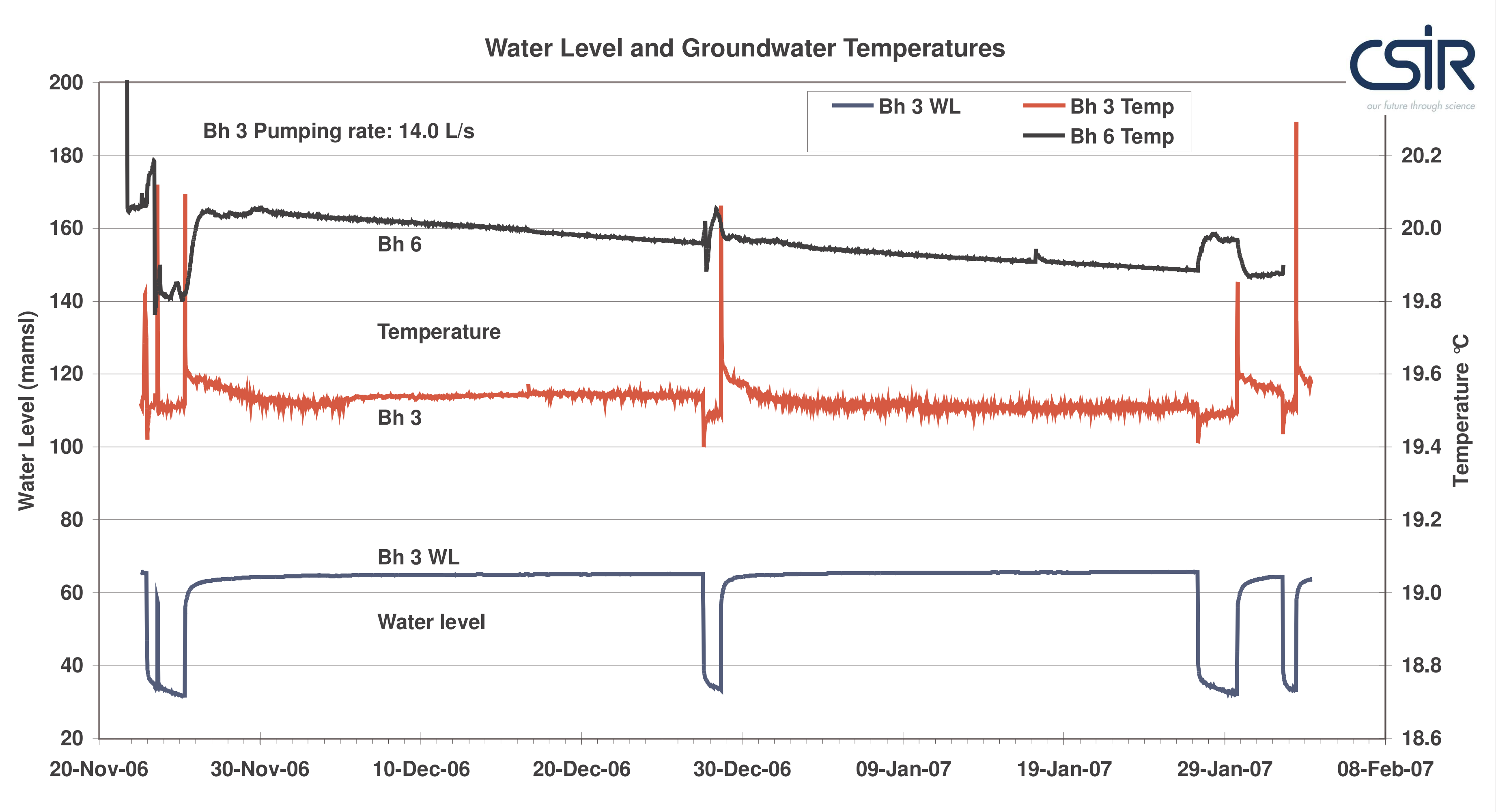

Figure 18: Water level and temperature trends recorded by loggers in boreholes Bh 3 and Bh 6 during abstraction from borehole Bh 3

(Data from DWAF via Groundwater Africa)

APPENDIX A: Down-the-hole hydrochemical logging data

Borehole No 2 Logged 31/10/2006 14:00						
Depth m	EC mS/m	pH	Temp ℃	Eh mV	DO mg/L	DO %
78.7	102.7	10.30	18.81	378	1.11	13.0
79.8	102.4	10.41	18.96	372	0.79	9.2
80.8	102.4	10.44	18.97	368	0.56	6.6
81.7	102.4	10.46	18.97	363	0.44	5.2
82.7	102.4	10.49	18.98	359	0.36	4.2
83.5	102.5	10.50	18.99	355	0.35	4.1
84.4	102.6	10.51	19.00	351	0.30	3.6
85.3	102.6	10.47	19.02	348	0.29	3.4
86.1	102.8	10.46	19.02	345	0.26	3.0
87.0	103.0	10.40	19.03	342	0.25	3.0
87.8	103.4	10.31	19.05	337	0.22	2.6
88.7	103.9	10.10	19.06	326	0.24	2.8
89.5	104.8	9.66	19.07	297	0.21	2.5
90.4	106.7	9.09	19.08	229	0.19	2.2
91.2	109.9	8.43	19.09	146	0.18	2.2
92.1	110.3	7.99	19.10	107	0.20	2.3
92.9	112.6	7.75	19.12	101	0.21	2.5
93.7	114.0	7.55	19.13	107	0.32	3.7
94.5	115.5	7.46	19.14	116	0.45	5.3
95.3	116.9	7.36	19.15	128	0.63	7.5
96.1	117.9	7.39	19.16	138	0.89	10.5
96.8	118.7	7.20	19.17	156	1.09	12.8
97.7	119.1	7.04	19.17	178	1.30	15.3
98.4	119.6	7.27	19.18	184	1.79	21.2
99.3	119.9	7.08	19.18	205	2.23	26.3
100.1	120.3	6.85	19.19	226	2.25	26.6
101.0	120.6	7.23	19.20	223	2.14	25.3
101.8	120.9	7.31	19.20	222	2.09	24.5
102.7	121.1	7.04	19.20	232	2.07	24.5
103.4	121.3	6.77	19.21	244	2.03	23.9
104.3	121.4	7.04	19.22	236	1.90	22.4
105.2	121.6	7.02	19.22	241	1.86	22.0
106.0	121.7	7.00	19.22	239	1.80	21.3
106.8	121.8	7.02	19.23	240	1.74	20.5
107.5	121.9	7.02	19.24	240	1.71	20.2
108.2	121.9	7.06	19.24	238	1.65	19.5
108.9	122.0	6.89	19.25	240	1.52	18.0
109.6	122.2	7.00	19.26	237	1.47	17.4
110.2	122.2	7.00	19.26	236	1.47	17.3
111.0	122.4	7.05	19.26	233	1.39	16.4
111.6	122.4	6.98	19.27	235	1.31	15.5
112.2	122.5	7.15	19.28	228	1.22	14.4
112.9	122.6	7.14	19.28	226	1.21	14.4
113.6	122.6	7.05	19.29	227	1.13	13.4
114.4	122.7	7.03	19.29	225	1.07	12.7
115.1	122.8	7.02	19.30	224	1.03	12.2
115.8	122.9	7.10	19.31	221	1.01	11.9
116.6	122.9	7.14	19.31	217	0.95	11.2
117.2	122.9	7.02	19.32	218	0.92	10.9

Borehole No 2 Logged 31/10/2006 14:00						
Depth m	**EC mS/m**	**pH**	**Temp °C**	**Eh mV**	**DO mg/L**	**DO %**
117.9	123.0	7.16	19.32	212	0.86	10.2
118.5	123.2	6.97	19.33	218	0.79	9.4
119.3	123.2	7.10	19.34	212	0.77	9.1
120.1	123.3	7.26	19.34	204	0.72	8.5
120.8	123.4	7.17	19.35	204	0.64	7.6
121.5	123.5	7.23	19.36	199	0.56	6.6
122.2	123.6	7.28	19.37	193	0.48	5.7
123.0	123.7	7.26	19.38	192	0.43	5.0
123.8	123.8	7.25	19.39	187	0.37	4.4
124.6	123.8	7.37	19.41	180	0.30	3.6
125.4	123.9	7.27	19.42	181	0.28	3.3
126.1	124.0	7.34	19.43	174	0.24	2.8
126.8	124.0	7.30	19.44	171	0.22	2.7
127.6	124.1	7.27	19.44	171	0.21	2.4
128.3	124.2	7.47	19.45	159	0.19	2.3
129.0	124.2	7.47	19.46	156	0.18	2.1
129.7	124.3	7.57	19.46	148	0.16	1.9
130.4	124.4	7.64	19.47	143	0.17	2.0
131.1	124.4	7.56	19.48	142	0.16	1.9
131.8	124.4	7.68	19.48	140	0.16	2.0
132.5	124.5	7.53	19.49	141	0.15	1.8
133.2	124.5	7.78	19.50	131	0.14	1.7
133.9	124.5	7.66	19.50	133	0.14	1.7
134.6	125.9	7.54	19.51	133	0.15	1.7
135.1	152.7	7.48	19.53	129	0.22	2.6

Borehole No 3 Logged 31/10/2006 10:00

Depth m	EC mS/m	pH	Temp ℃	Eh mV	DO mg/L	DO %
124.6	127.3	5.45	19.22	496	5.40	63.8
127.0	127.4	5.47	19.21	498	5.39	63.6
129.7	127.3	5.53	19.22	498	5.25	62.0
132.2	127.3	5.66	19.22	493	5.23	61.8
134.7	127.3	5.71	19.22	493	5.26	62.1
137.2	127.3	5.73	19.23	494	5.21	61.6
139.9	127.3	5.75	19.24	495	5.18	61.2
142.8	127.3	5.78	19.26	496	5.12	60.5
145.5	127.3	5.80	19.27	497	5.05	59.7
148.2	127.3	5.83	19.28	497	5.09	60.2
151.6	127.4	5.86	19.29	497	4.87	57.6
153.9	127.3	5.88	19.30	497	4.95	58.5
156.3	127.3	5.90	19.31	498	5.06	59.9
159.0	127.4	5.93	19.33	498	5.12	60.6
161.2	127.4	5.95	19.34	499	5.13	60.7
162.3	127.4	5.96	19.35	499	4.92	58.3
163.2	127.4	5.97	19.35	500	4.90	58.0
164.0	127.4	5.99	19.36	500	4.89	57.9
164.8	127.4	6.01	19.36	500	4.84	57.3
165.6	127.4	6.05	19.37	499	4.84	57.4
166.6	127.4	6.07	19.38	499	4.99	59.1
167.3	127.4	6.10	19.38	498	4.87	57.7
168.3	127.4	6.13	19.39	497	4.95	58.6
169.0	127.4	6.16	19.40	497	4.85	57.5
169.8	127.4	6.18	19.41	496	4.88	57.8
170.8	127.4	6.21	19.42	496	4.80	56.9
171.6	127.3	6.24	19.42	495	4.83	57.3
172.4	127.3	6.26	19.42	495	4.85	57.5
173.1	127.4	6.28	19.42	494	4.82	57.2
173.9	127.4	6.30	19.42	494	4.81	57.1
174.7	127.4	6.32	19.43	494	4.91	58.2
175.4	127.4	6.34	19.43	493	4.92	58.3
176.1	127.4	6.36	19.43	493	4.79	56.8
176.7	127.4	6.38	19.43	493	4.79	56.9
177.4	127.4	6.39	19.44	493	4.79	56.8
178.0	127.4	6.41	19.44	492	4.96	58.8
178.7	127.4	6.43	19.44	492	4.93	58.4
179.2	127.4	6.44	19.44	492	4.77	56.6
179.8	127.4	6.46	19.45	491	4.84	57.4
180.5	127.4	6.47	19.46	491	4.85	57.6
181.1	127.4	6.48	19.47	491	4.86	57.7
181.8	127.4	6.50	19.48	491	4.89	58.0
182.4	127.4	6.51	19.50	491	4.83	57.4
182.9	127.5	6.52	19.50	491	4.90	58.2
183.6	127.5	6.53	19.52	490	4.87	57.8
184.2	127.5	6.54	19.52	490	4.93	58.6
184.7	127.5	6.56	19.53	490	4.88	57.9
185.3	127.5	6.57	19.54	490	4.83	57.4
185.9	127.5	6.58	19.54	490	4.88	58.0
186.4	127.5	6.58	19.55	490	4.93	58.6
187.1	127.5	6.60	19.56	490	4.88	58.0
187.7	127.5	6.61	19.56	490	4.93	58.6

Borehole No 3 Logged 31/10/2006 10:00						
Depth m	**EC mS/m**	**pH**	**Temp °C**	**Eh mV**	**DO mg/L**	**DO %**
188.3	127.5	6.61	19.57	490	4.91	58.4
188.9	127.5	6.62	19.58	490	4.93	58.6
189.4	127.5	6.63	19.58	490	4.95	58.9
189.9	127.5	6.64	19.59	490	4.89	58.1
190.3	127.5	6.65	19.59	490	4.85	57.7
190.8	127.5	6.65	19.59	490	4.89	58.2
191.3	127.5	6.66	19.59	489	4.91	58.4
191.8	127.5	6.67	19.60	489	4.86	57.8
192.5	127.5	6.68	19.60	489	4.96	59.0
192.9	127.5	6.68	19.60	489	4.89	58.1

Borehole No 6 Logged 31/10/2006 11:50

Depth m	EC mS/m	pH	Temp ℃	Eh mV	DO mg/L	DO %
130.5	71.8	7.55	20.13	405	6.61	79.3
131.6	68.9	7.60	20.21	405	7.30	87.7
132.4	69.2	7.61	20.21	406	7.42	89.2
133.1	69.2	7.62	20.23	408	7.56	91.0
133.9	69.2	7.63	20.24	409	7.58	91.1
134.8	69.2	7.65	20.25	409	7.74	93.1
135.5	69.1	7.66	20.26	410	7.64	91.9
136.4	68.7	7.68	20.27	411	7.65	92.1
137.2	68.5	7.69	20.29	411	7.64	91.9
137.9	68.4	7.70	20.30	412	7.64	92.0
138.6	68.4	7.71	20.31	413	7.60	91.6
139.6	68.4	7.72	20.31	414	7.77	93.6
140.3	68.5	7.73	20.32	414	7.79	93.8
141.2	68.6	7.75	20.31	415	7.83	94.4
141.9	68.6	7.75	20.32	416	7.69	92.7
142.8	68.5	7.77	20.32	415	7.66	92.2
143.6	68.4	7.77	20.33	416	7.61	91.7
144.3	68.3	7.78	20.33	417	7.70	92.8
145.0	68.3	7.79	20.34	417	7.60	91.6
145.8	68.4	7.80	20.34	418	7.56	91.1
146.6	68.4	7.80	20.34	418	7.59	91.5
147.4	68.4	7.81	20.35	419	7.62	91.8
148.4	68.2	7.82	20.35	419	7.56	91.1
149.3	68.1	7.83	20.35	420	7.58	91.4
150.1	67.9	7.83	20.35	420	7.44	89.7
150.9	67.9	7.83	20.35	421	7.27	87.7
151.6	68.0	7.83	20.35	422	7.35	88.6
152.3	68.1	7.83	20.35	423	7.33	88.3
153.1	68.2	7.83	20.34	423	7.40	89.1
153.8	68.2	7.83	20.34	424	7.33	88.3
154.6	68.2	7.83	20.33	425	7.40	89.1
155.3	68.2	7.82	20.33	426	7.40	89.2
156.2	68.1	7.83	20.32	427	7.41	89.3
156.8	68.1	7.82	20.32	428	7.43	89.5
157.5	68.1	7.82	20.31	429	7.39	89.0
158.2	68.0	7.82	20.30	430	7.34	88.4
158.8	67.9	7.81	20.30	431	7.30	87.9
159.6	67.9	7.81	20.30	432	7.42	89.3
160.4	67.7	7.80	20.29	433	7.39	88.9
161.1	67.6	7.80	20.28	435	7.22	86.9
161.8	67.6	7.80	20.28	435	7.28	87.6
162.5	67.4	7.79	20.28	437	7.36	88.6
163.3	67.3	7.79	20.28	437	7.35	88.4
163.9	67.2	7.79	20.28	439	7.33	88.2
164.5	67.0	7.78	20.28	440	7.37	88.7
165.2	66.8	7.78	20.28	440	7.29	87.7
165.9	66.6	7.79	20.28	441	6.99	84.2
166.5	66.4	7.78	20.28	442	6.95	83.7
167.2	66.4	7.78	20.28	443	7.16	86.2
168.0	66.2	7.78	20.27	444	7.25	87.3
168.6	65.8	7.79	20.27	444	7.19	86.5
169.3	65.3	7.80	20.25	445	7.37	88.6

Borehole No 6 Logged 31/10/2006 11:50						
Depth m	**EC mS/m**	**pH**	**Temp ℃**	**Eh mV**	**DO mg/L**	**DO %**
170.1	65.1	7.81	20.25	445	7.34	88.3
170.9	64.5	7.82	20.24	446	7.23	86.9
171.5	63.9	7.84	20.22	446	7.15	85.9
172.2	63.1	7.86	20.19	446	7.22	86.7
172.9	62.1	7.89	20.17	447	7.06	84.7
173.5	61.3	7.91	20.14	447	7.00	84.0
174.1	60.6	7.92	20.13	448	7.05	84.6
174.8	59.5	7.96	20.10	448	7.13	85.4
175.5	59.2	7.98	20.07	448	7.13	85.4
176.1	58.6	8.00	20.04	448	7.17	85.8
176.8	58.3	8.01	20.00	448	7.04	84.2
177.5	57.6	8.02	19.98	449	7.00	83.8
178.2	57.5	8.02	19.96	449	6.88	82.3
178.9	57.4	8.01	19.94	449	6.87	82.1
179.6	57.3	8.00	19.92	449	6.85	81.3
180.2	57.4	8.00	19.91	450	6.70	80.0
180.8	57.3	7.99	19.90	450	6.85	81.8
181.6	57.3	7.97	19.90	450	6.79	81.1
181.7	57.4	7.93	19.90	450	6.38	76.2

Borehole New Horizon Logged 31/10/2006 15:30						
Depth m	**EC mS/m**	**pH**	**Temp ℃**	**Eh mV**	**DO mg/L**	**DO %**
120.2	45.0	6.51	18.91	342	2.67	31.2
121.5	44.7	6.49	19.07	343	2.96	34.7
122.8	44.5	6.46	19.10	351	4.22	49.5
124.1	44.5	6.46	19.10	361	4.93	57.9
125.4	44.4	6.47	19.09	371	5.21	61.2
126.6	44.4	6.49	19.10	379	5.42	63.7
129.4	44.4	6.55	19.12	384	5.75	67.5
130.9	44.4	6.58	19.12	389	5.58	65.5
132.6	44.4	6.62	19.14	394	5.51	64.8
134.0	44.4	6.64	19.13	398	5.42	63.7
135.3	44.4	6.67	19.14	402	5.44	64.0
136.8	44.4	6.70	19.14	405	5.40	63.5
138.1	44.4	6.72	19.15	407	5.42	63.7
139.7	44.5	6.75	19.17	409	5.19	61.1
141.0	44.6	6.77	19.17	410	5.14	60.4
142.5	44.6	6.79	19.17	411	5.03	59.2
144.2	44.6	6.81	19.17	412	4.96	58.4
145.9	44.5	6.84	19.18	414	4.95	58.2
147.9	44.4	6.85	19.18	415	5.15	60.6
149.8	44.3	6.87	19.18	417	5.20	61.2
151.5	44.3	6.88	19.19	418	5.21	61.3
153.4	44.3	6.89	19.20	420	5.25	61.8
155.1	44.3	6.90	19.21	422	5.30	62.4
156.8	44.3	6.90	19.21	424	5.21	61.3
158.7	44.3	6.90	19.22	426	5.23	61.6
160.4	44.3	6.88	19.22	429	5.33	62.8
162.2	44.3	6.87	19.23	432	5.29	62.4
164.2	44.3	6.85	19.23	434	5.33	62.8
166.0	44.3	6.82	19.24	437	5.32	62.7
167.7	44.3	6.77	19.24	441	5.34	62.9
169.4	44.3	6.73	19.24	445	5.34	63.0
170.9	44.3	6.67	19.25	450	5.30	62.5
172.7	44.3	6.62	19.25	454	5.39	63.5
174.7	44.3	6.57	19.26	457	5.33	62.8
176.3	44.3	6.53	19.27	461	5.27	62.1
177.9	44.3	6.49	19.28	464	5.32	62.7
179.5	44.3	6.45	19.29	468	5.28	62.2
181.1	44.3	6.40	19.29	470	5.21	61.5
182.9	44.3	6.40	19.30	472	5.26	62.1
184.5	44.4	6.39	19.31	474	5.34	63.0
186.0	44.4	6.37	19.35	476	5.24	61.8
187.7	44.4	6.36	19.39	477	5.20	61.5
189.3	44.4	6.36	19.44	478	5.18	61.2
190.9	44.5	6.35	19.49	480	5.20	61.5
192.5	44.5	6.34	19.53	481	5.17	61.2
194.3	44.5	6.33	19.58	483	5.27	62.5
195.8	44.6	6.34	19.62	483	5.35	63.5
197.5	44.6	6.33	19.65	484	5.26	62.5

Appendix 3: Environmental requirements for artificial recharge - letter from Ashwin West and Mike Luger, Ninham Shand

M E M O R A N D U M

NINHAM SHAND
CONSULTING SERVICES
FOUNDED IN 1932

81 Church Street, Cape Town, 8001
P O Box 1347, Cape Town, 8000
Tel: +27 21 481 2400 / Fax: +27 21 424 5588
E-mail: enviro@shands.co.za
Website: www.ninhamshand.co.za

To:	Dr Ricky Murray		
Of:	Groundwater Africa		
From:	Ashwin West, Environmental Discipline Group		
Date:	24 May 2007	**Reference Number:**	401808/1580
Subject:	Comment on the environmental requirements of the proposed Bitou Municipality Artificial Recharge project		

Dear Ricky

The terms of reference for the Artificial Groundwater Recharge project have reference. As requested, please find below our comments on the likely environmental requirements for the proposed Artificial Recharge project for the Bitou Municipality

Understanding of the scope of the proposed project

It is our understanding the pilot artificial recharge scheme would entail using water from the Keurbooms River, which has been treated to potable standards, to artificially recharge the aquifer in the Kwanokathula area, by pumping the treated water into boreholes 3 and 6 and later abstracting water from these same boreholes. The total volume of water that would be used for recharge is approximately 55 000 m^3 (48 000 m^3 + 10% for losses), injected over the winter period of four to six months. Should this initial pilot scheme prove successful, then the injection volumes would be increased.

The establishment of the pilot recharge scheme will not require the installation of new boreholes, the construction of additional pipelines or new access roads, and will essentially use existing infrastructure. Furthermore, it is understanding that the Bitou Municipality has an existing lawful use (ELU) allowing it to abstract some 326 000 m^3 of groundwater from a range of boreholes located in Kwanokathula, New Horizons and Plettenberg Bay itself. The proposed recharge and subsequent abstraction of groundwater would be within the limits of the Municipality's ELU.

Environmental requirements

We are of the opinion that the proposed project does not trigger the requirements of Regulation 385 and 386 in terms of the National Environmental Management Act (NEMA), for the following reasons:

- The storage of the 48 000 m^3 of water in an underground aquifer is not considered storage in a dam or reservoir (Regulation 386 1(n)).

- The abstraction of groundwater is excess of the General Authorisation (as stipulated by the Department of Water Affairs) would not be an issue in this project, as the proposed abstraction would be within the limits of the Municipality's ELU.
- The transfer of water would not trigger activity 1(n) of Regulation 387, 'the transfer of 20 000 m^3 or more water between water catchments[1] of impoundments per day', since the total volume of water that would be transferred is 48 000 m^3 and would transferred over a period of four to six months.

Should the proposed pilot scheme be increased beyond the current proposed capacity of some 55 000 m^3 per annum, the project may be subject to the requirements of Regulation 386, if the abstraction of water exceeds the Municipality's registered existing lawful groundwater usage (ELU). It is our understanding that the total groundwater ELU for the Bitou Municipality is some 362 000 m^3. It is our opinion that provided the Municipality's total groundwater abstraction (including the reabstraction of artificially recharged water) does not exceed 362 000 m^3 an environmental authorisation should not be required.

However, further to Mr Yakeen Atwaru's[2] email of 20 February 2007 regarding various questions about artificial recharge projects, he has advised that even if a proposed artificial recharge project is not listed in terms of the NEMA EIA Regulations, an EIA process should still be followed in terms of the requirements of Section 28 of NEMA 'General Duty of Care' provisions.

While we agree with this sentiment, we are of the opinion that an EIA process would not be able to add value to the understanding of the potential environmental impacts related to artificial recharge. We therefore propose that we undertake a site visit and compile a report on the risk and reversibility of the proposed project together with a comprehensive monitoring plan. The monitoring plan should include *inter alia* the following aspects:

- Monitoring groundwater levels in the surrounding boreholes;
- Monitoring groundwater quality in terms of the DWAF standards;
- Identification of groundwater dependent ecosystems which should be monitored during the recharge and abstraction periods;
- Identification of areas where the groundwater table is close to the surface, and the identification and monitoring of potential infrastructure that could be undermined due to a raised water table.

We would then host an authority and key stakeholder workshop in order to present the project details and the monitoring plan.

We estimate that we would require approximately 12 person days to address the environmental requirements for this proposed project, which would include undertaking the relevant site visit, compiling the risk and reversibility report, contributing to the monitoring plan, and convening an authority and key stakeholder workshop.

---

[1] The groundwater aquifer in the vicinity of Kwanokathula would be considered a distinct catchment, separate from the Piesangs River catchment. Consequently if the volume of water transferred to the aquifer was to exceed 20 000 m^3 per day then Regulation 387 1(n) would be applicable.

[2] Mr Atwaru, Deputy Director, Western Cape Department of Environmental Affairs and Development Planning, George

I trust that the above comments will be useful in finalising the Bitou Municipality Artificial Recharge Pre-Feasibility Study. Should you have any queries, please contact the undersigned.

Yours sincerely
NINHAM SHAND

ASHWIN WEST (*Pr. Sci. Nat.*)
Principal Environmental Practitioner

MIKE LUGER
Environmental Discipline Group Manager

Appendix 4: DWAF authorisation to conduct artificial recharge tests

REPUBLIC OF SOUTH AFRICA : REPUBLIEK VAN SUID AFRICA
DEPARTMENT OF WATER AFFAIRS : DEPARTEMENT VAN WATERWESE
Private Bag X16, Sanlamhof, 7532
17 Strand Street, Bellville, 7530
Tel: (021) 950 7100 Fax: (021) 950 7224

Enquiries: M C Smart
Reference: 19/4/1/1/K60G
19/4/1/1/J23F

10 July 2007

Groundwater Africa
Box 162
Lyendoch
7603

REQUEST TO CONDUCT INJECTION TESTS IN PLETTENBERG BAY AND PRINCE ALBERT

The Department approves the feasibility testing as requested in your letter of 12 June 2007.

A condition is that DWAF and DEADP are invited to an onsite meeting prior to commencement of testing so that any inputs to the monitoring plan can be made.

pp 10/7/2007.

Chief Director
DWAF
Bellville