

*Appendix 1: Municipal borehole status report  
(August 2007)*

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**BITOU MUNICIPALITY  
GROUNDWATER MANAGEMENT AND  
ARTIFICIAL RECHARGE FEASIBILITY STUDY**

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

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<b>Bh No.</b>	<b>Borehole Site Status</b>	<b>Monitoring Equipment</b>	<b>Recommendations</b>
<p><b>Bh 3A</b></p> <p>Municipal monitoring borehole</p>	<p><b>General Security</b> As for Bh3</p> <p><b>Borehole Enclosure</b> As for Bh3</p> <p><b>Borehole Closure</b> Not closed. The hole is now blocked after it was cleared recently. This time the blockage is at about 19,5mbgl.</p> <p><b>Contamination risk</b> <b>High.</b> Having an open borehole within 5m of the town's highest-yielding production borehole poses <b>a serious health risk.</b> Groundwater and Borehole 3 can easily be polluted at this site (Bh 3 is pumped untreated into the reservoir supplying Kwanokuthula).</p>	<p><b>Water Levels</b> None</p> <p><b>Comment</b> 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.</p>	<ol style="list-style-type: none"> <li>1. Re-open the borehole.</li> <li>2. Disinfect borehole with chlorine.</li> <li>3. Immediately secure borehole to DWAF specifications.</li> <li>4. Install HDPE 40mm CI 10 P-tube to bottom of hole.</li> </ol> <p><b>The above-mentioned items are URGENT for both health and groundwater monitoring purposes.</b></p>
<p><b>Bh 4</b></p> <p>Municipal production borehole</p>	<p><b>General Security</b> Fair, gate locked but broken.</p> <p><b>Borehole Enclosure</b> Filled with litter and muck.</p> <p><b>Borehole Closure</b> The casing fortunately stands +/- 500mm above ground level, preventing ingress of the surrounding filth.</p> <p><b>Headwork</b> Inadequate.</p> <p><b>Contamination risk</b> 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.</p>	<p><b>Water Levels</b> Pump installed, cables have been cut. Solinst F300/M100 LT datalogger installed, serial no: 61023230</p> <p><b>Water Meter</b> None.</p> <p><b>Sampling Tap</b> None.</p>	<ol style="list-style-type: none"> <li>1. Repair gate.</li> <li>2. Lock gate with keyed-alike lock to enable convenient authorised access to enclosure.</li> <li>3. Clean and clear enclosure.</li> <li>4. Install drainage as required.</li> <li>5. Install water meter at least 600mm above ground level.</li> <li>6. Install water sampling point.</li> <li>7. Erect signage explaining the function of the borehole.</li> </ol> <p><b>The gate must be repaired urgently for security of the logger.</b></p>

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

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

**PRIVATE PRODUCTION BOREHOLE**

<b>Bh Golf Course</b>  Private production borehole	<b>General Security</b> OK. In fairly inaccessible area. <b>Borehole Enclosure</b> None <b>Borehole Closure</b> OK <b>Contamination risk</b> Low	<b>Water Meter</b> Below ground.  <b>Sampling Tap</b> None.	<ol style="list-style-type: none"> <li>1. Raise water meter to be above ground level.</li> <li>2. Install water sampling point.</li> </ol>
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### PRIVATE MONITORING BOREHOLES

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

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

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*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**

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# Executive Summary

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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.

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## 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)		
<b>Bh 2</b>	<b>31-10-2006</b>	<b>7.2*</b>		<b>118</b>		<b>19.3</b>	<b>1.0</b>
<b>Bh 3</b>	02-07-1992		6.3		128		
	17-03-2005	6.15		120		22.7	
	14-12-2005	6.3	6.1	123	133		
	<b>31-10-2006</b>	<b>6.2</b>		<b>127</b>		<b>19.4</b>	<b>4.9</b>
	22-07-2007		6.1		132		
<b>Bh 6</b>	14-07-1992	5.85	6.2		130		
	25-08-2005	6.6		94			
	14-12-2005	6.8	6.1	106	115		
	<b>31-10-2006</b>	<b>7.8</b>		<b>66</b>		<b>20.2</b>	<b>7.3</b>
<b>NH</b>	22-06-1998		5.8		61		
	14-12-2005		6.2		44		
	<b>31-10-2006</b>	<b>6.6</b>		<b>44</b>		<b>19.2</b>	<b>5.2</b>

\*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  $0.5\text{ }^{\circ}\text{C}/100\text{ m}$ , while only at the unused borehole, Bh 2, the gradient approaches  $1\text{ }^{\circ}\text{C}/100\text{ m}$  (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 ( $\approx Eh$ ) 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 <sub>3</sub>	-2.70	-1.41	-3.24
Calcite	CaCO <sub>3</sub>	-2.55	-1.26	-3.09
Dolomite	CaMg(CO <sub>3</sub> ) <sub>2</sub>	-4.94	-2.28	-5.72
Fe(OH) <sub>3</sub> (a)	Fe(OH) <sub>3</sub>	1.31	0.83	2.54
Goethite	FeOOH	7.00	6.55	8.22
Haematite	Fe <sub>2</sub> O <sub>3</sub>	15.97	15.08	18.42
Chalcedony	SiO <sub>2</sub>	-0.16	-0.18	-0.37
Quartz	SiO <sub>2</sub>	0.27	0.24	0.06
SiO <sub>2</sub> (a)	SiO <sub>2</sub>	-1.02	-1.04	-1.22
Talc	Mg <sub>3</sub> Si <sub>4</sub> O <sub>10</sub> (OH) <sub>2</sub>	-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 Horizon 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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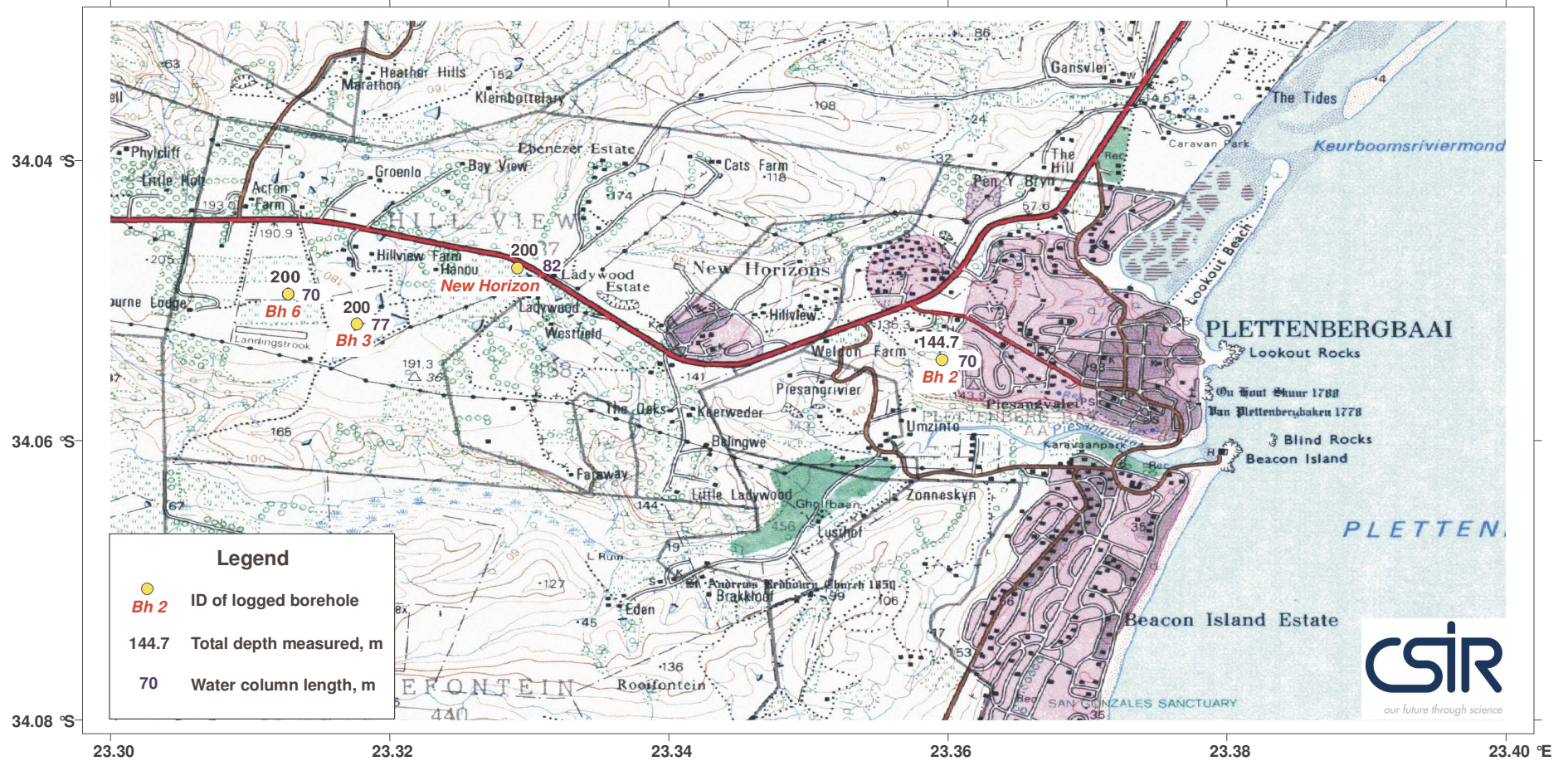


Figure 1: Location of logged boreholes, measured depth, and water column available for logging  
(Base map 3423AB obtained from Surveyor General)

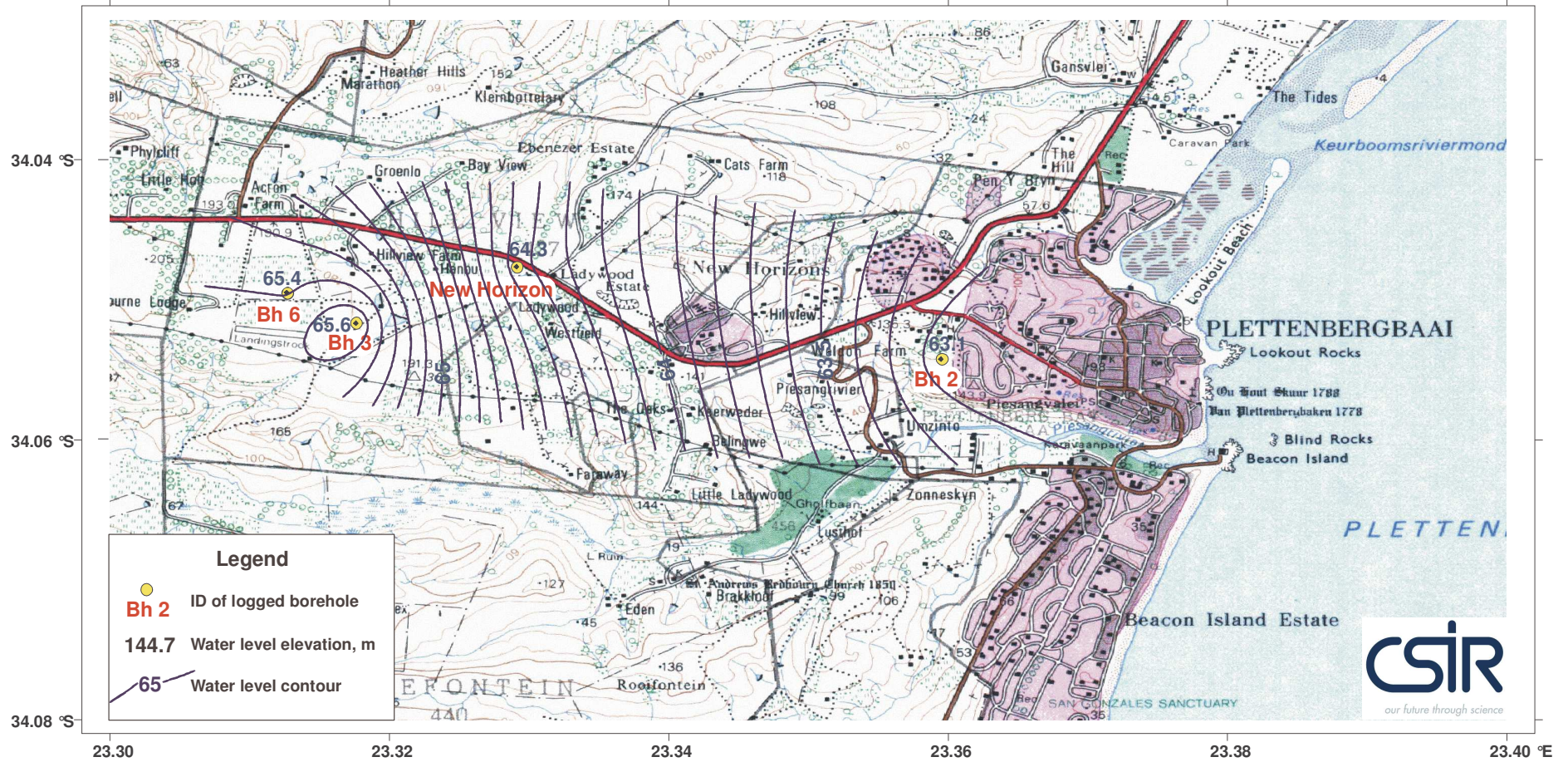


Figure 2: Water level elevation at logged boreholes (31 October 2006) with inferred water level contours

(Base map 3423AB obtained from Surveyor General)

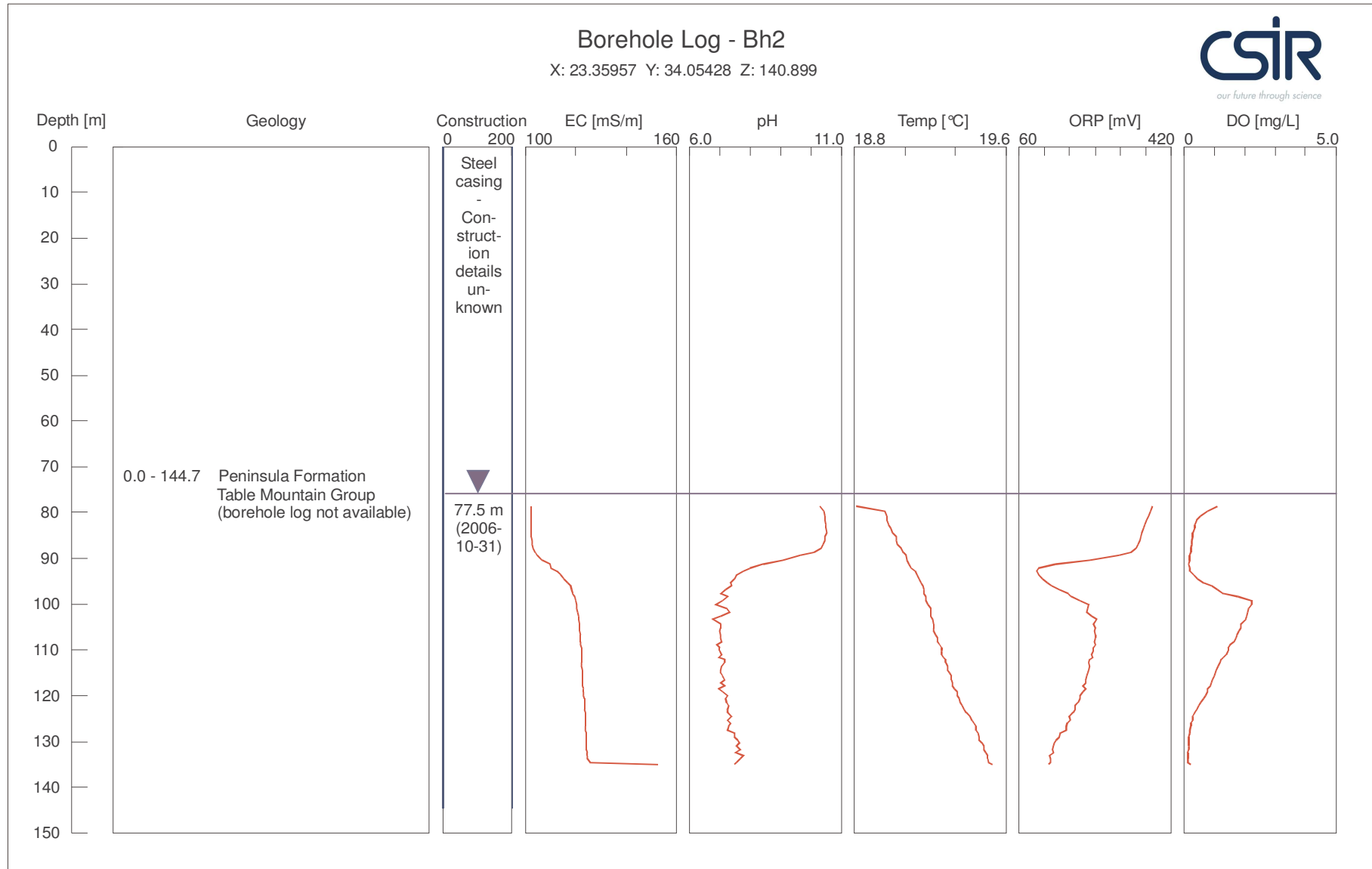


Figure 3: Down-the-hole hydrochemical profiles in borehole Bh2 at Plettenberg Bay

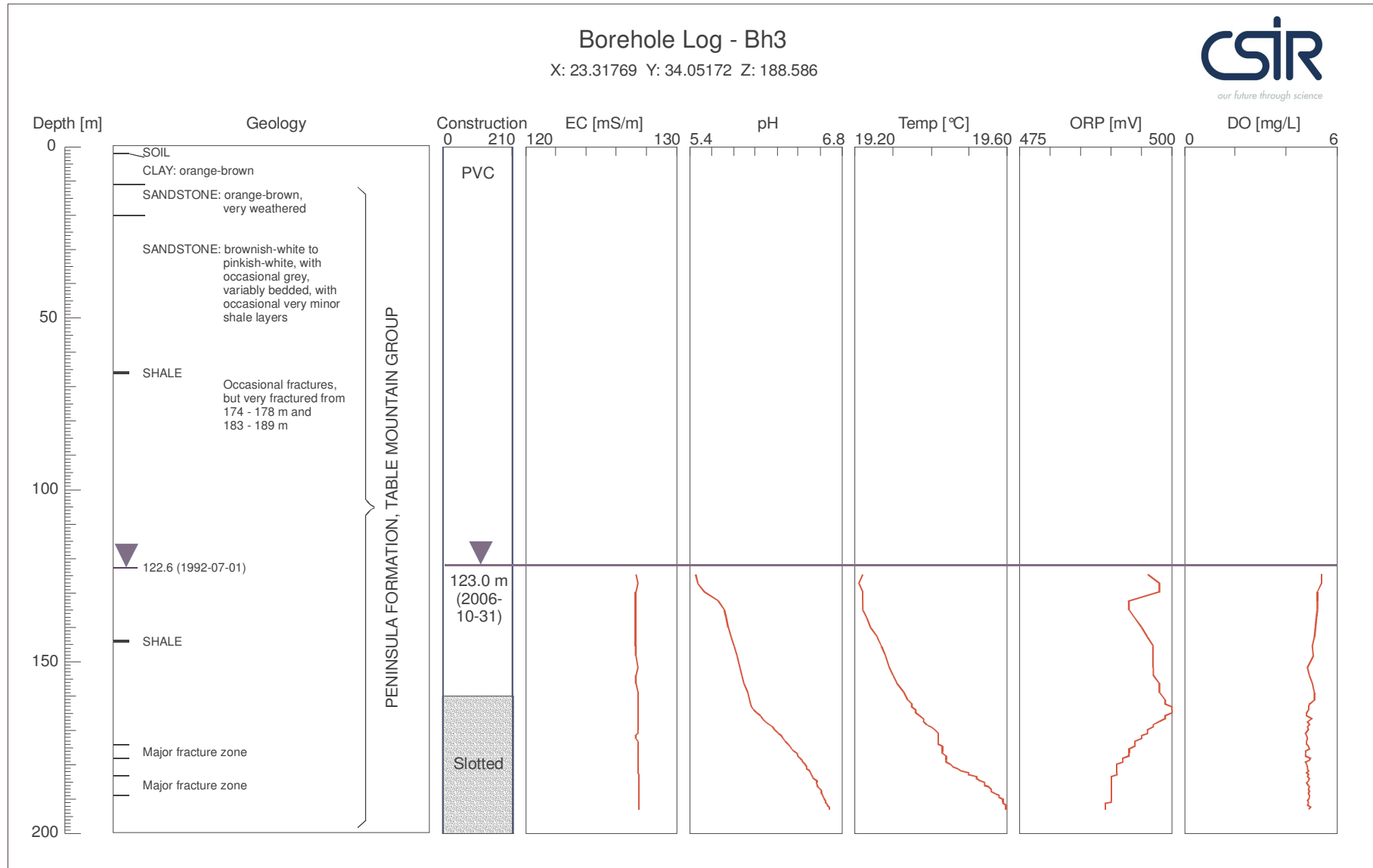


Figure 4: Down-the-hole hydrochemical profiles in borehole Bh3 at Plettenberg Bay

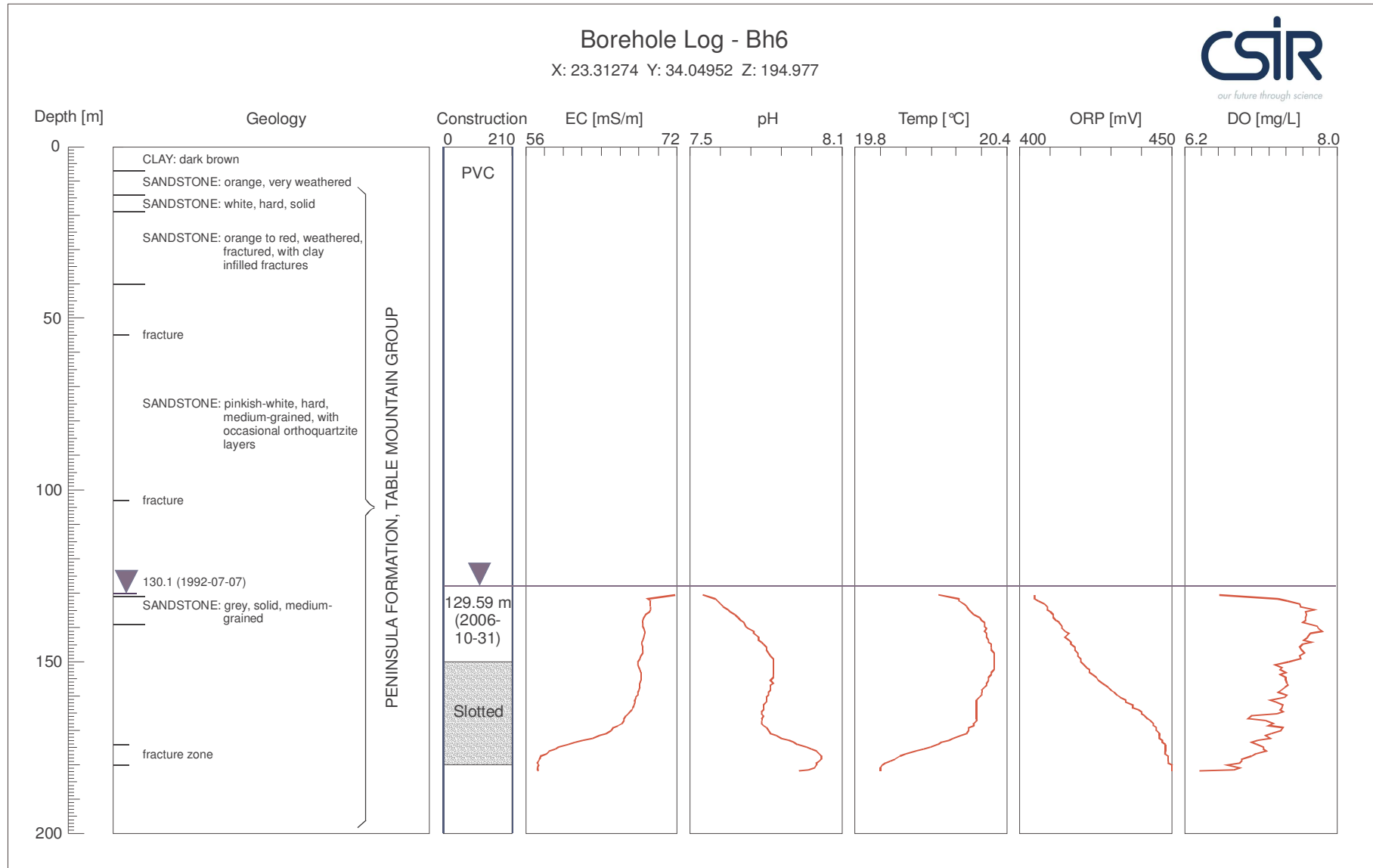


Figure 5: Down-the-hole hydrochemical profiles in borehole Bh6 at Plettenberg Bay

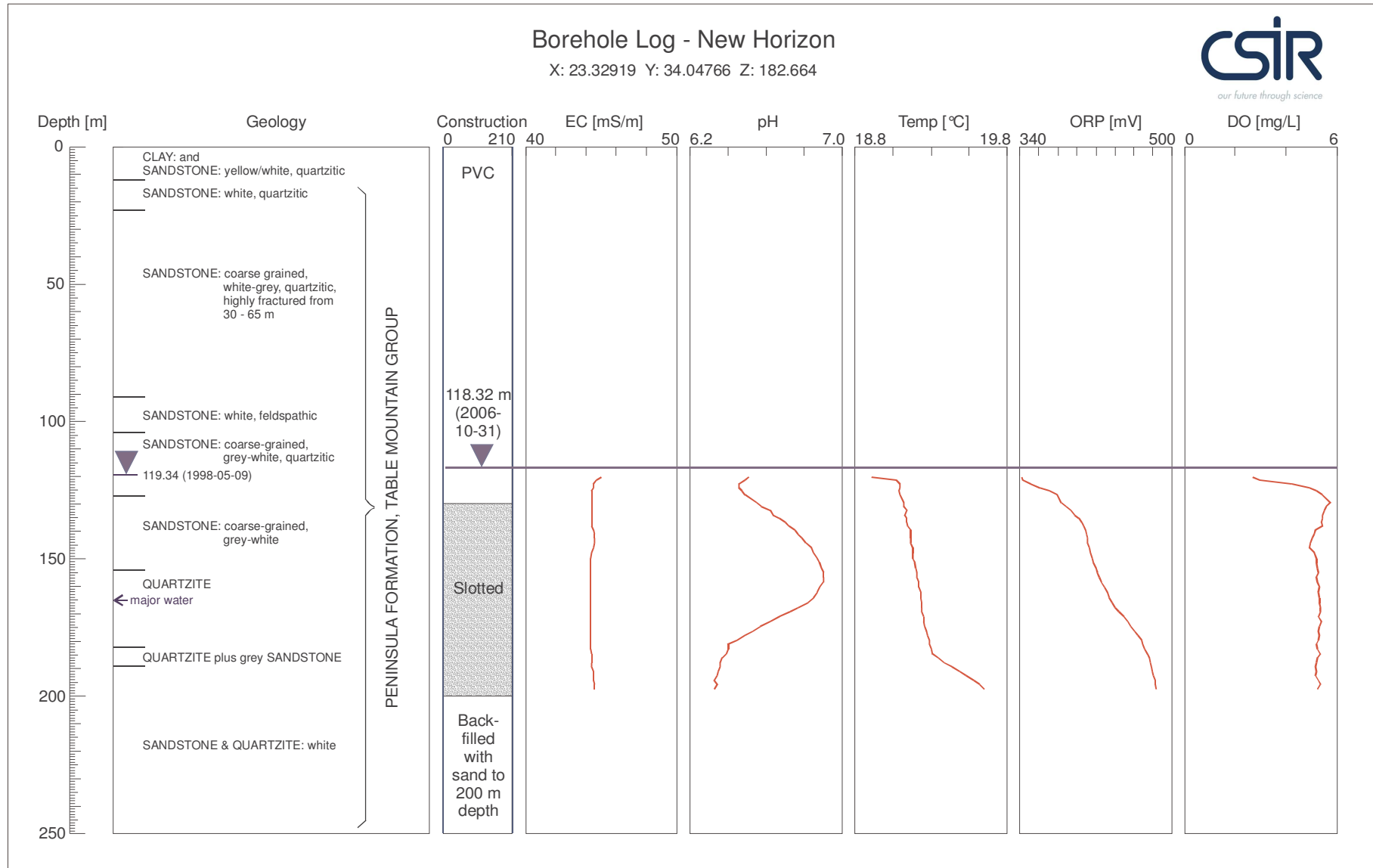


Figure 6: Down-the-hole hydrochemical profiles in borehole "New Horizon" at Plettenberg Bay

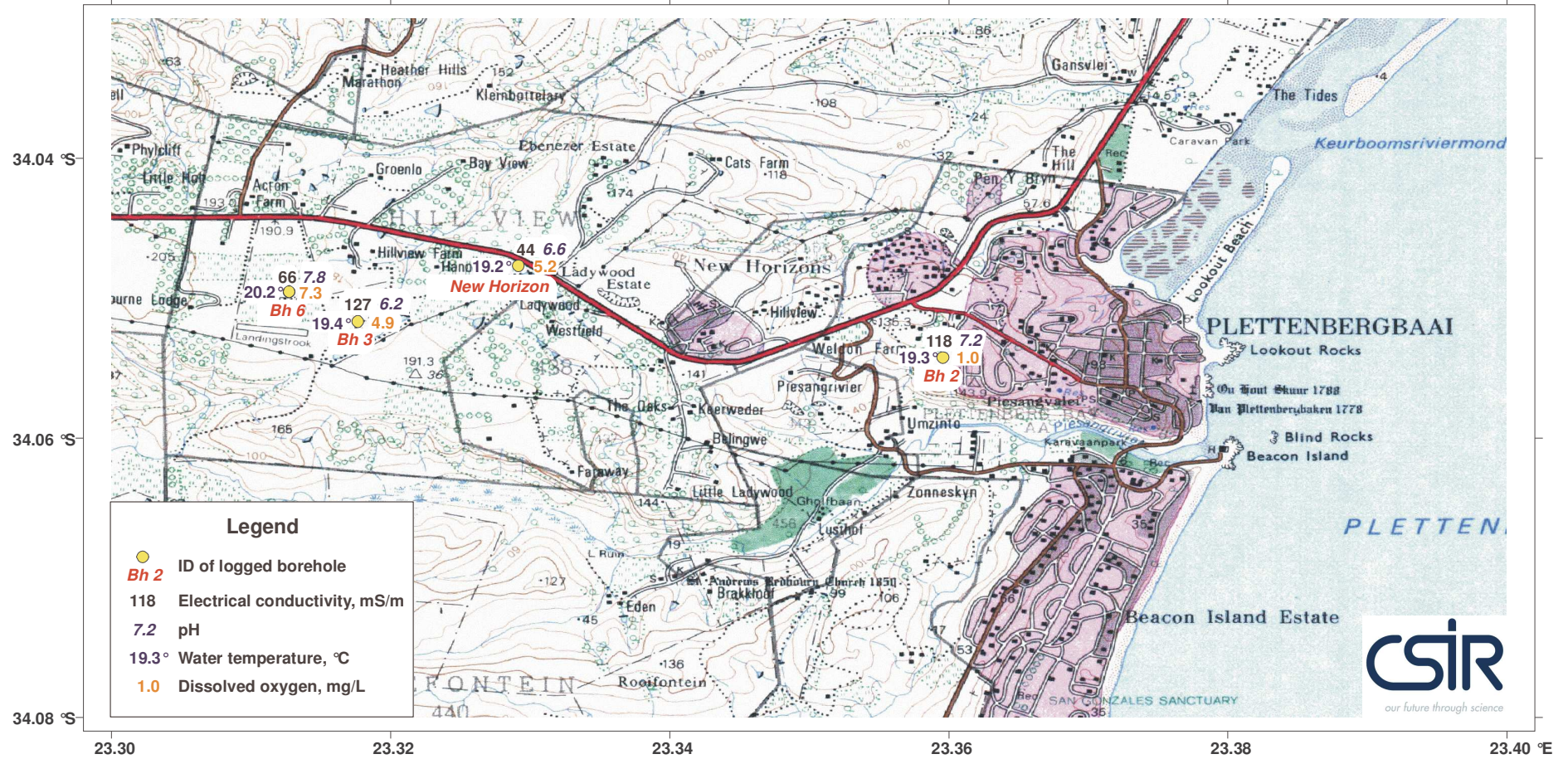


Figure 7: Average values of electrical conductivity, pH, temperature, and dissolved oxygen of logged boreholes for the water column, except for Borehole 2 where values represent only the lower part of the water column

(Base map 3423AB obtained from Surveyor General)

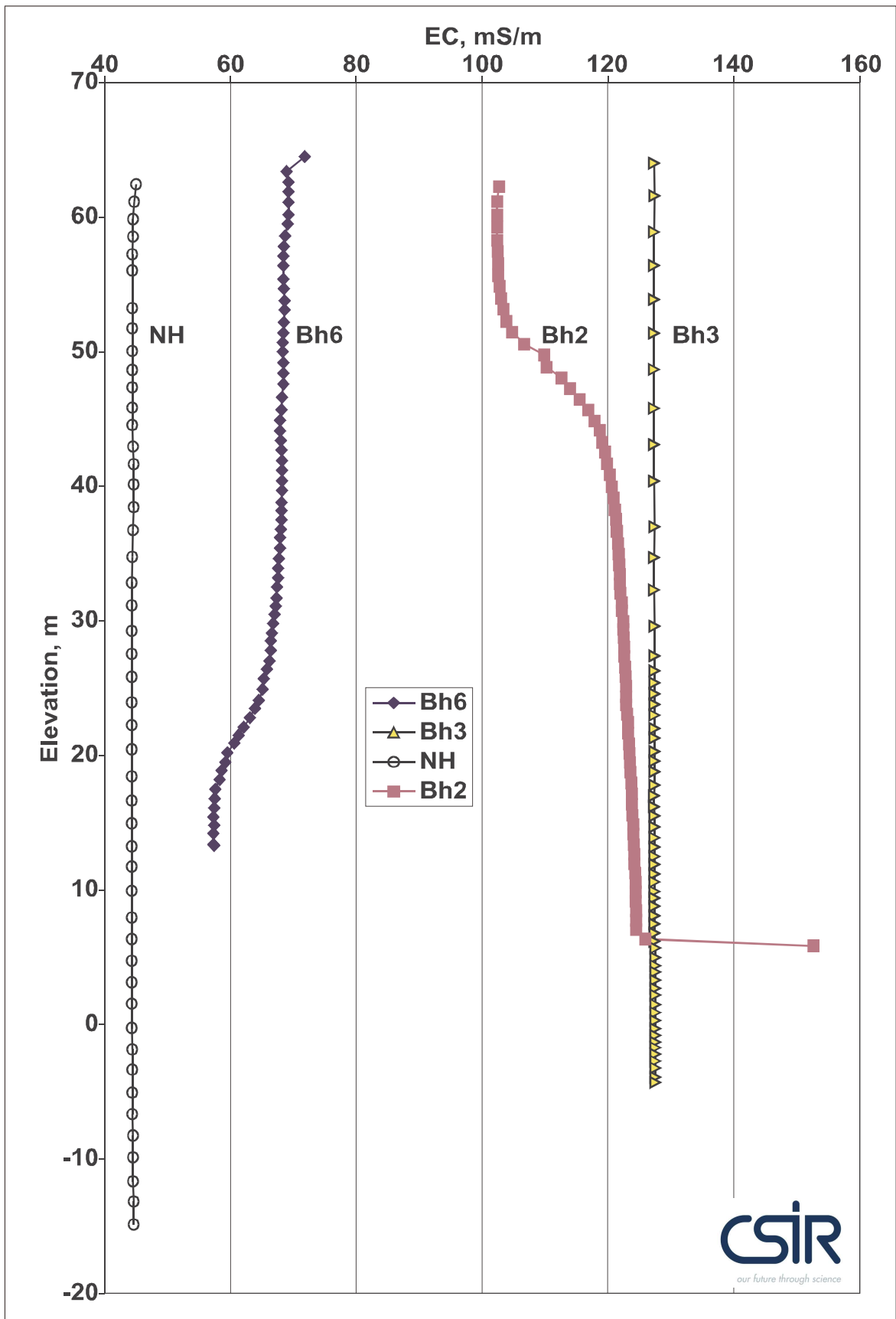


Figure 8: Comparison of electrical conductivity profiles in the Plettenberg Bay boreholes

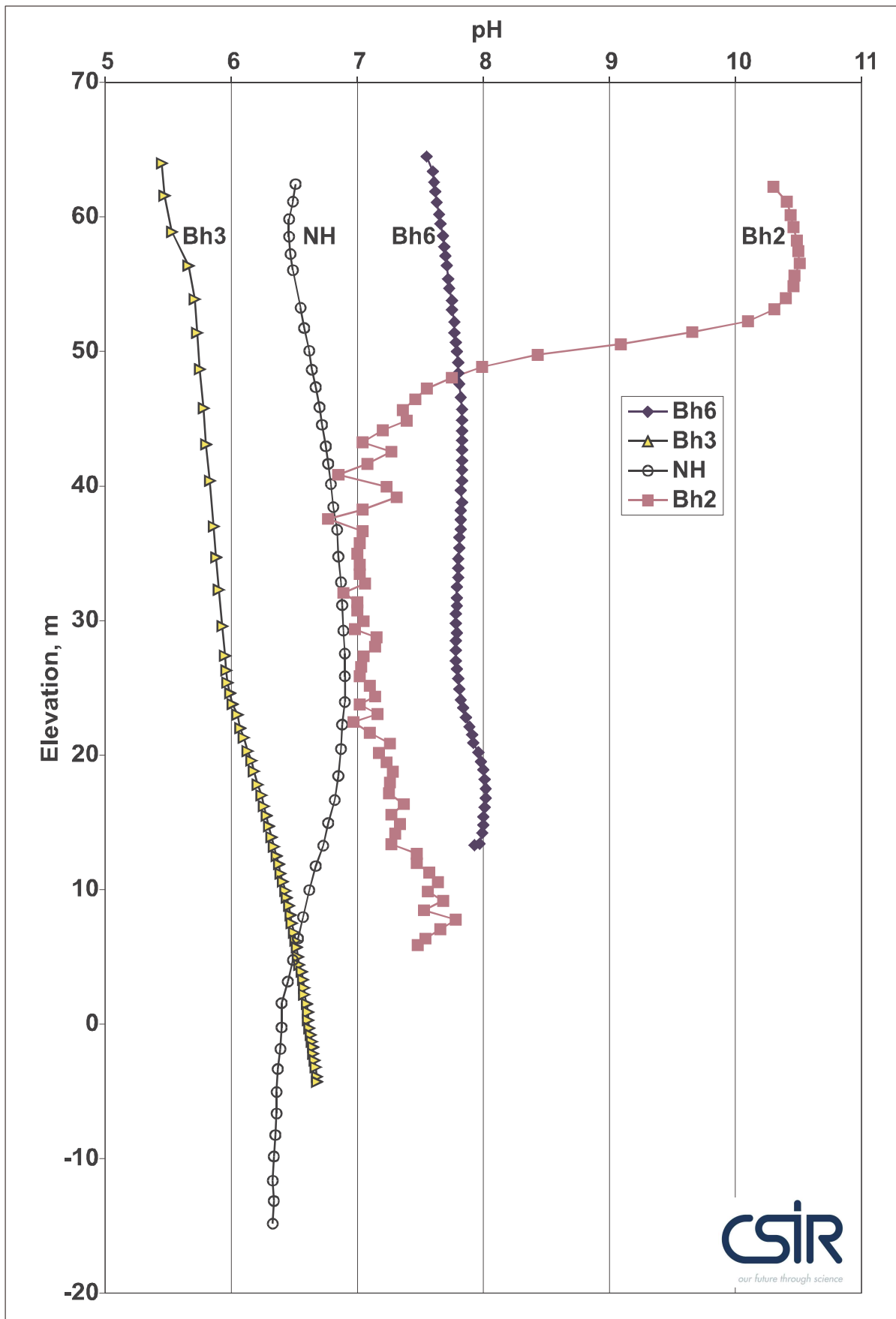


Figure 9: Comparison of pH profiles in the Plettenberg Bay boreholes

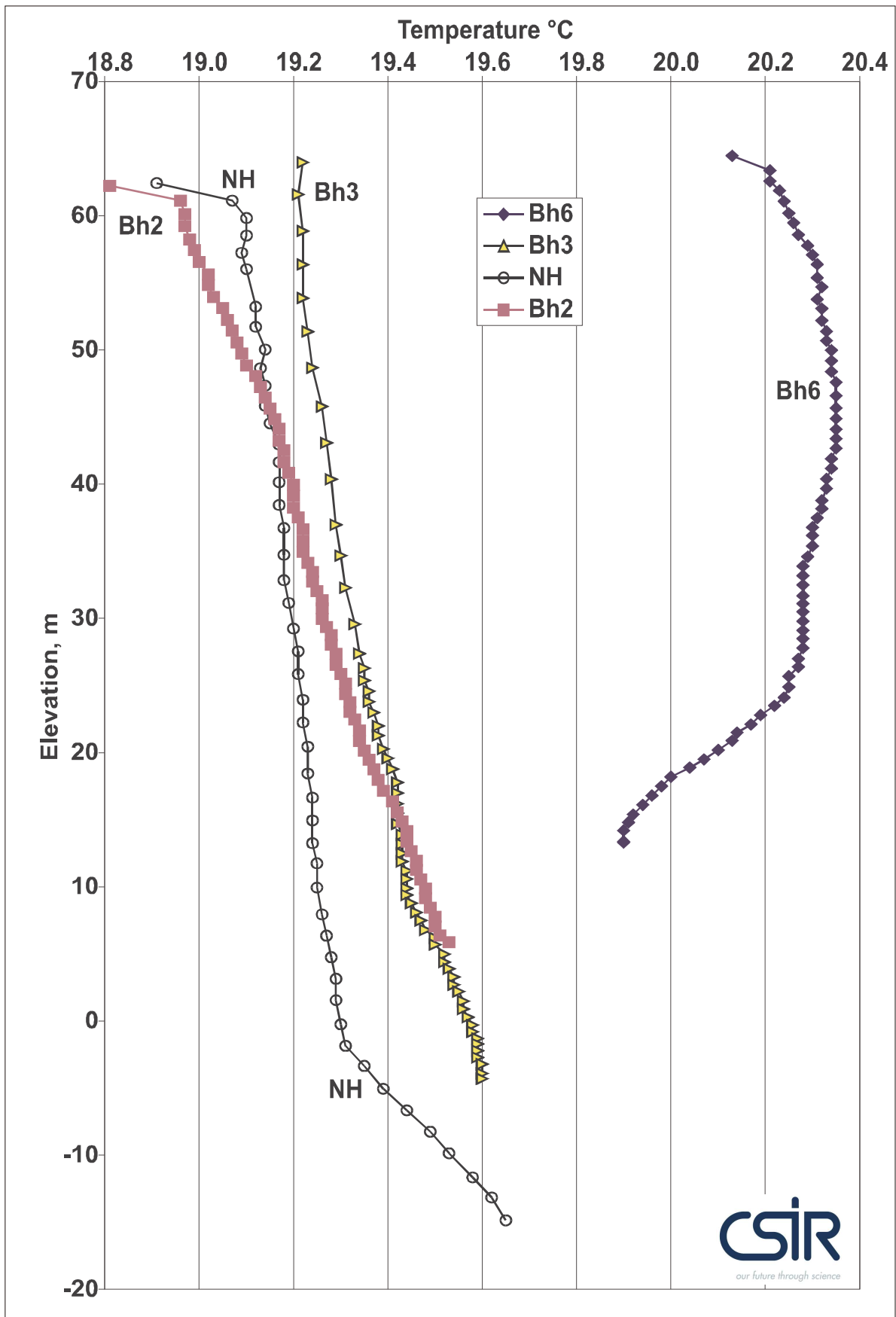


Figure 10: Comparison of water temperature profiles in the Plettenberg Bay boreholes

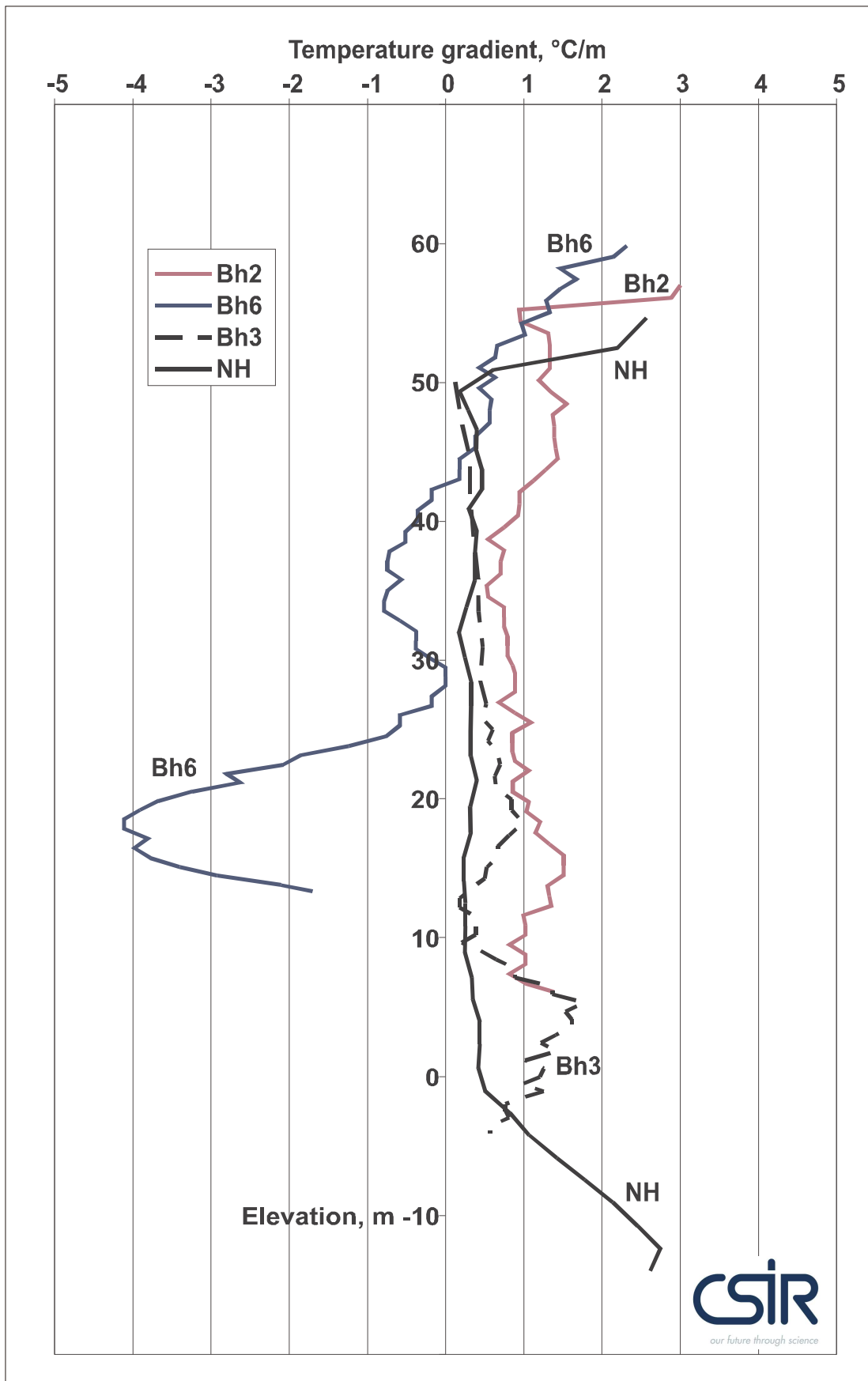


Figure 11: Comparison of water temperature gradient profiles in the Plettenberg Bay boreholes (smoothed 7-reading moving average)

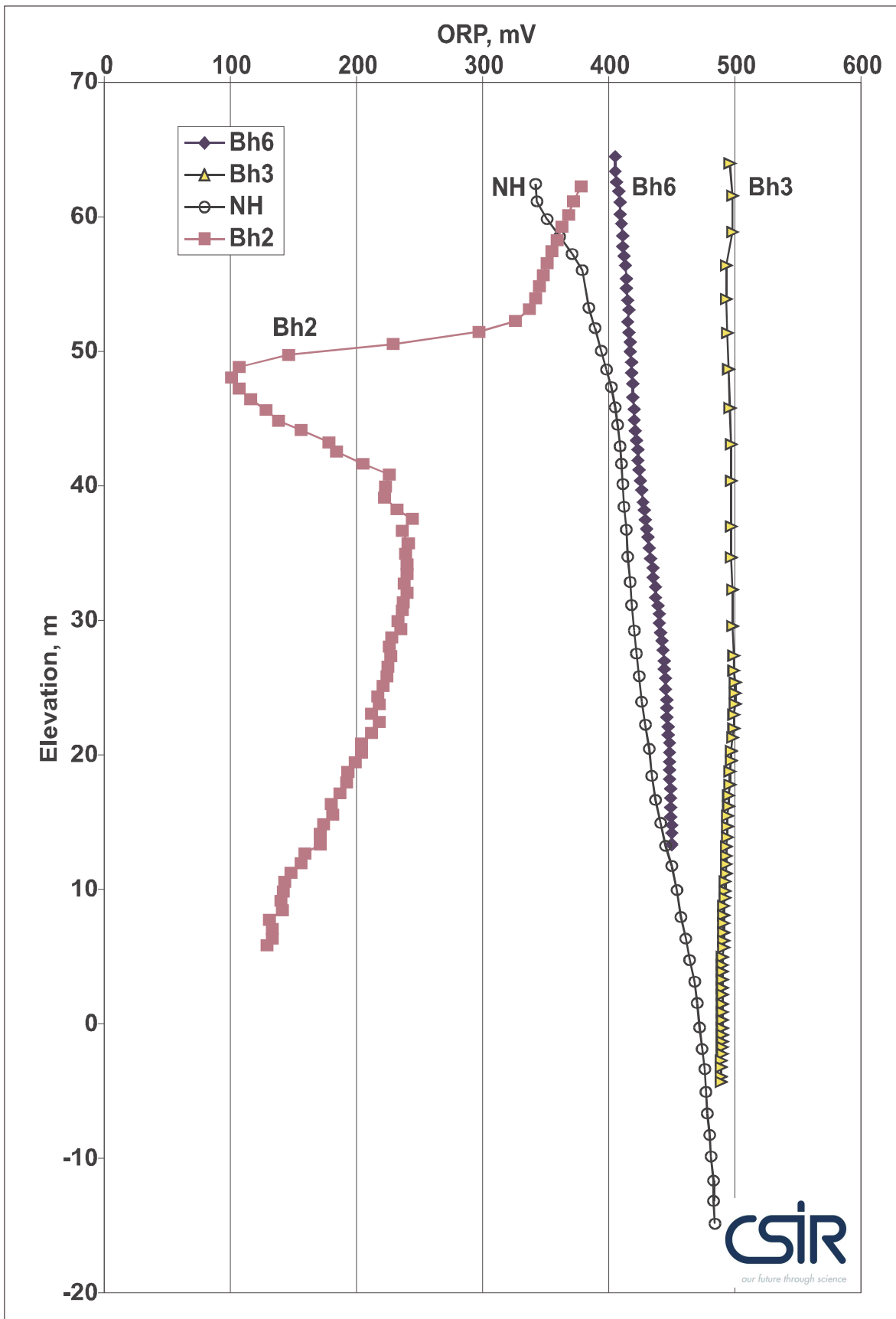


Figure 12: Comparison of oxidation-reduction potential profiles in the Plettenberg Bay boreholes

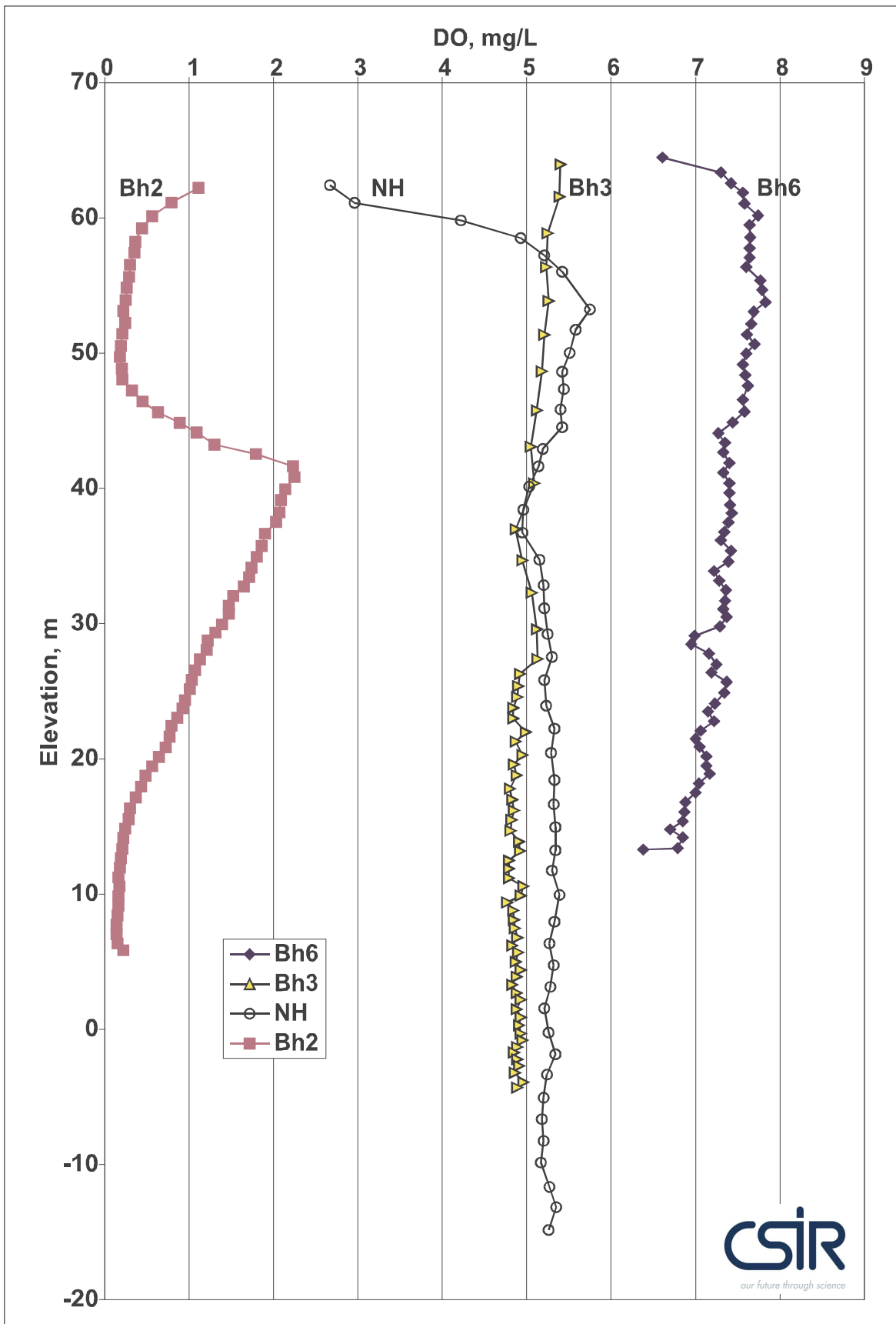


Figure 13: Comparison of dissolved oxygen profiles in the Plettenberg Bay boreholes

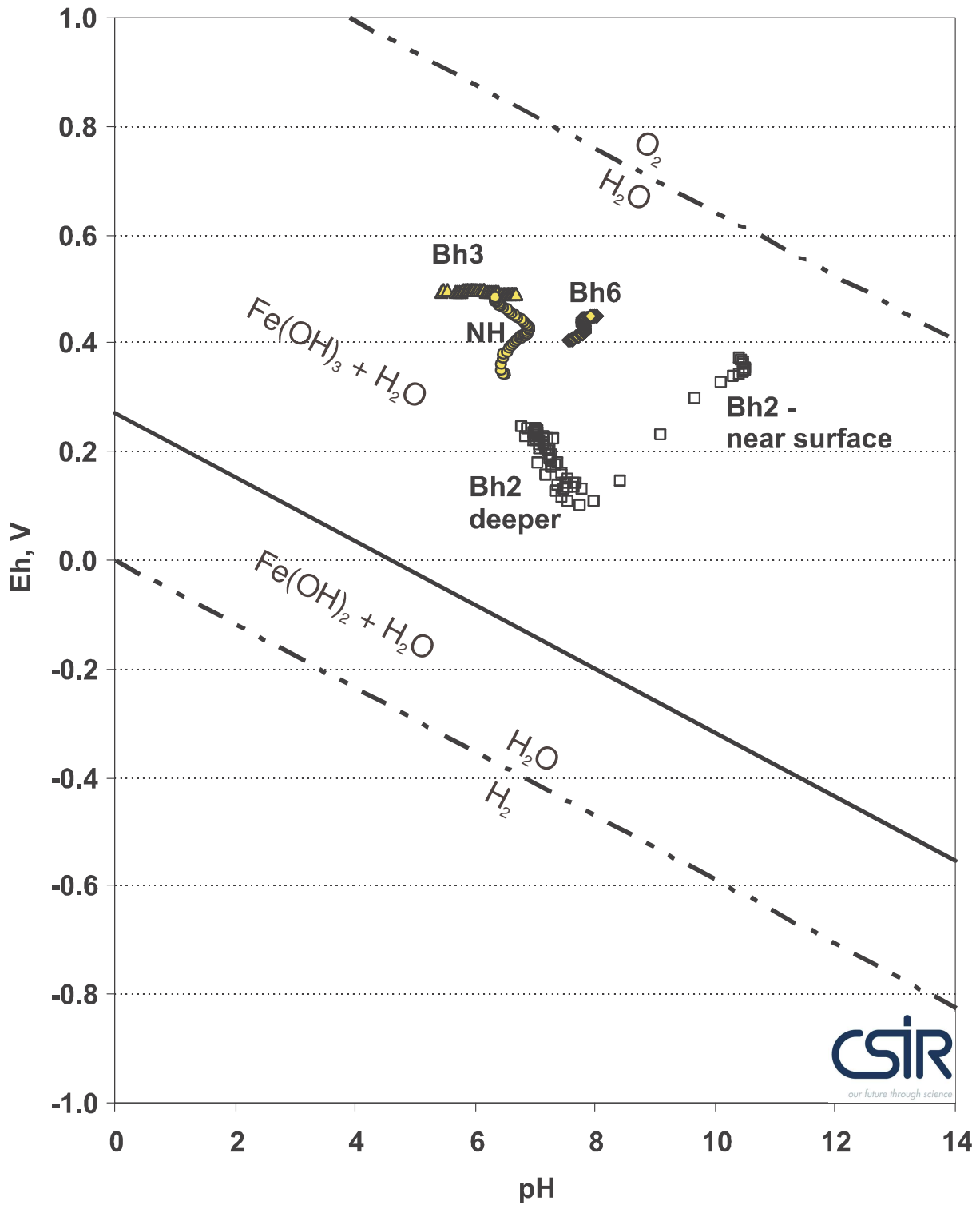


Figure 14: Eh-pH diagram showing stability fields for ferrous and ferric hydroxide in solution (at 25 °C)

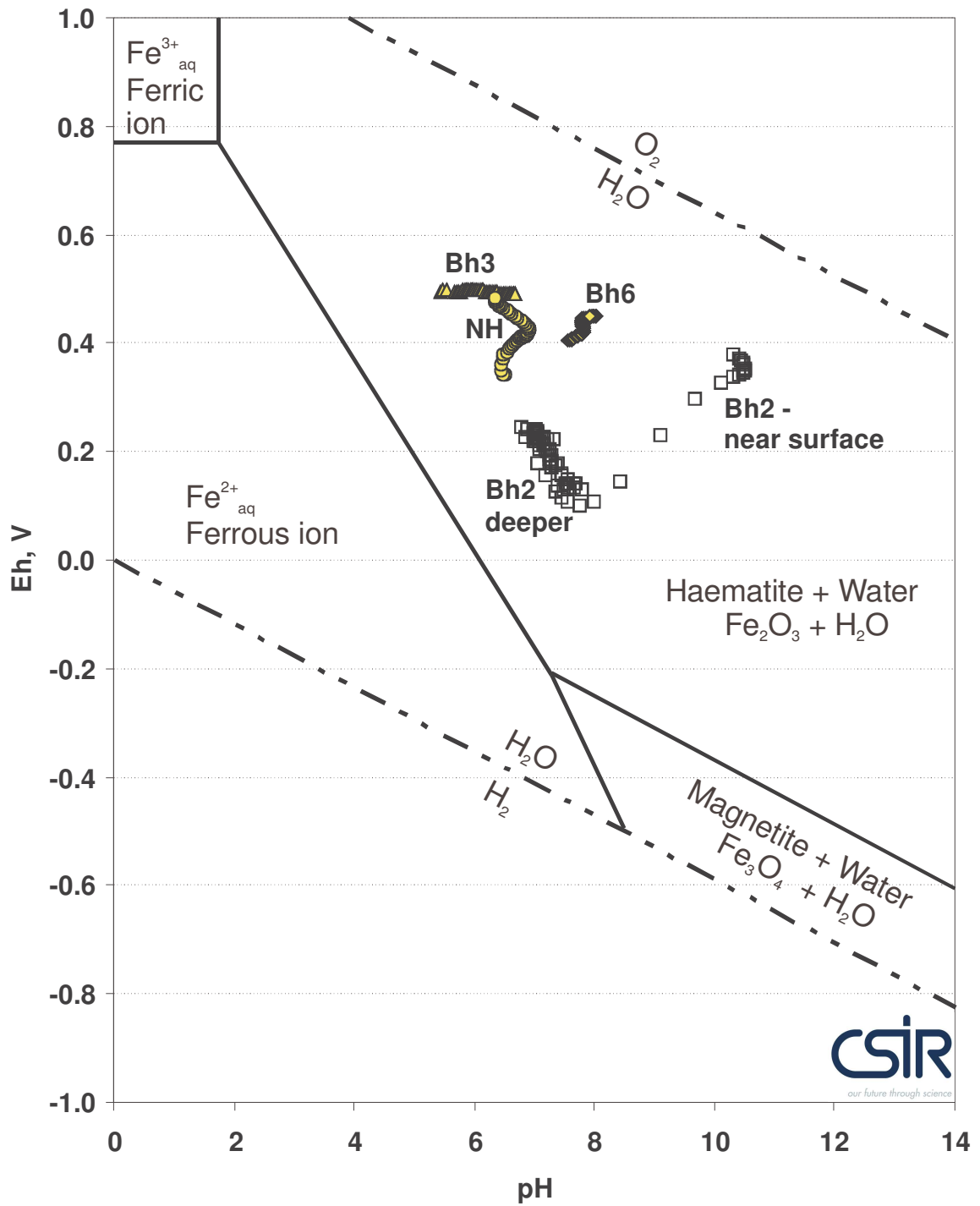


Figure 15: Eh-pH diagram for ferrous and ferric ions in solution showing stability fields for magnetite and haematite (at 25 °C)

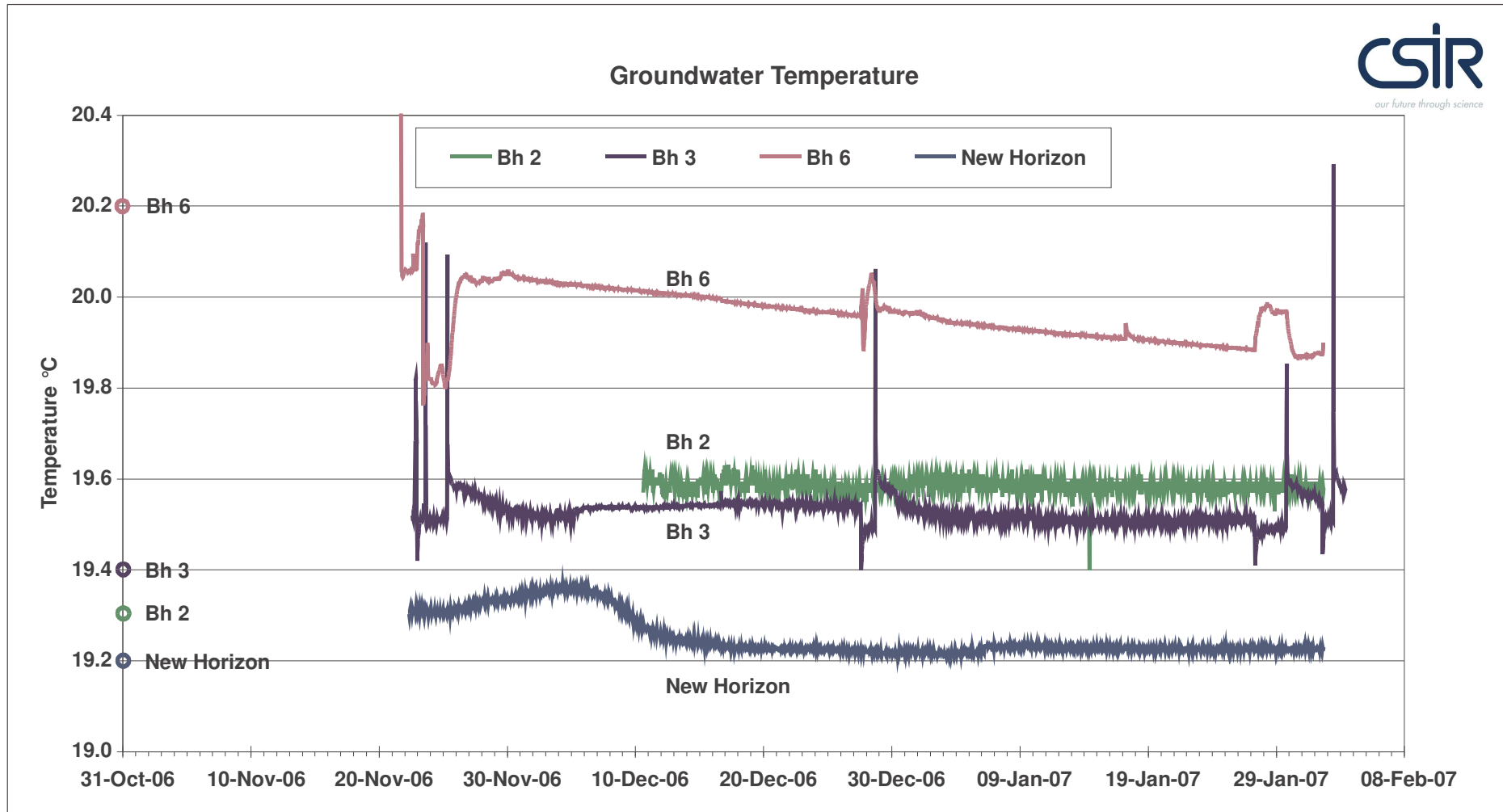


Figure 16: Groundwater temperatures measured during down-the-hole logging on 2006-10-31 compared with recorded values of the loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon

(Data from DWAF via Groundwater Africa)

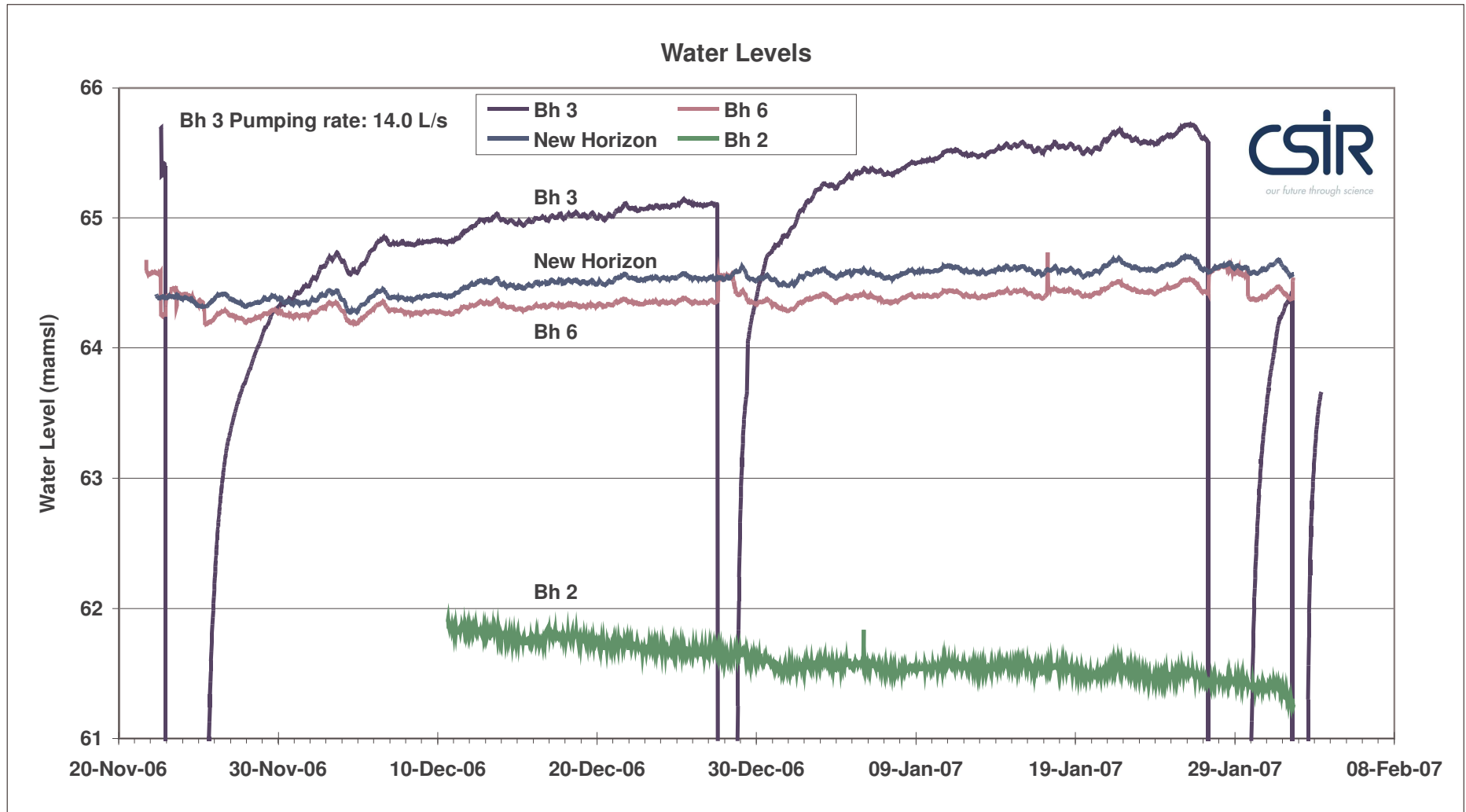


Figure 17: Water level responses recorded by loggers in boreholes Bh 2, Bh 3, Bh 6, and New Horizon during abstraction from borehole Bh 3  
(Data from DWAF via Groundwater Africa)

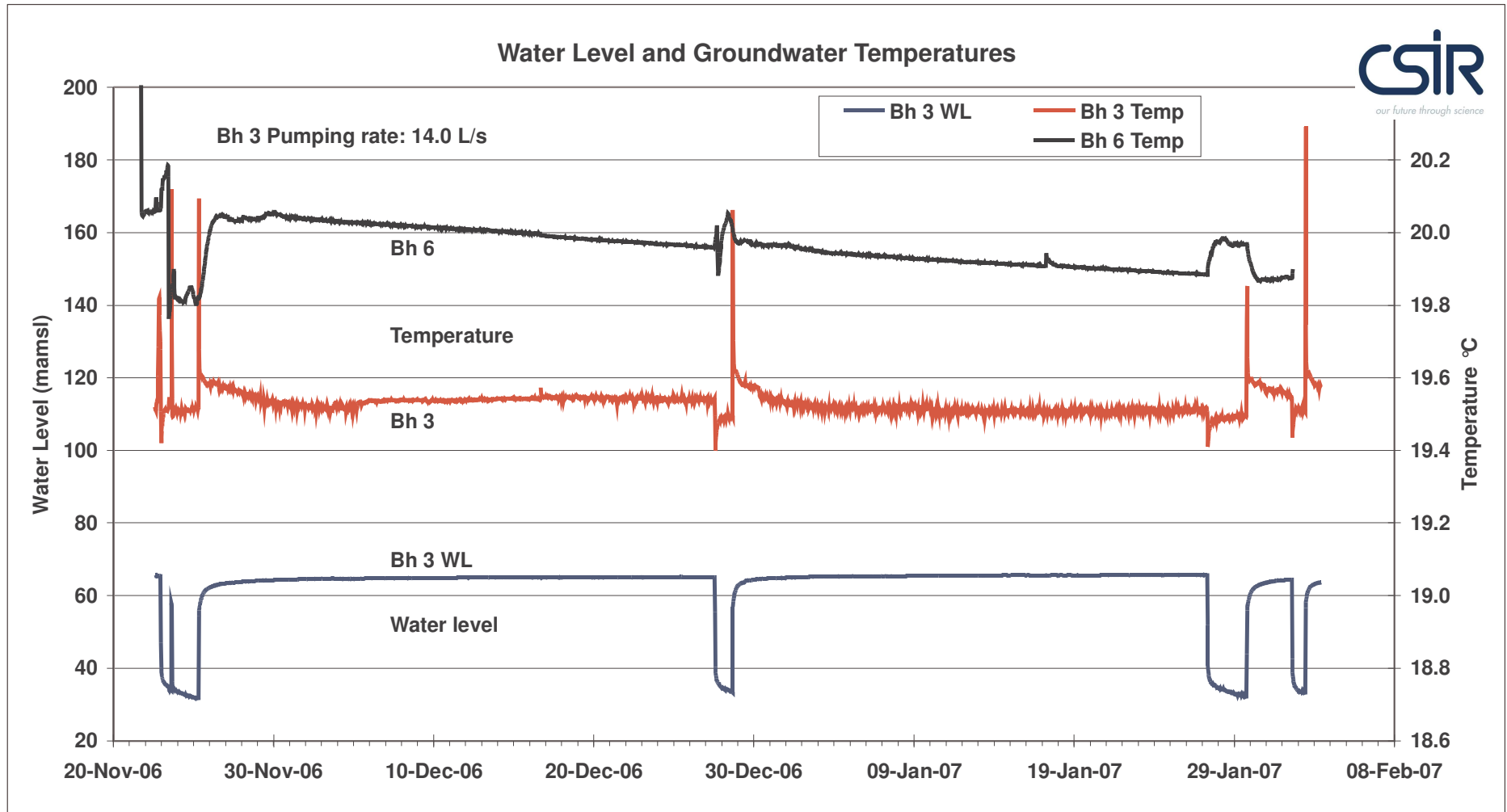


Figure 18: Water level and temperature trends recorded by loggers in boreholes Bh 3 and Bh 6 during abstraction from borehole Bh 3

(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 °C	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 °C	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 °C	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 °C	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 °C	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*

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# MEMORANDUM



**NINHAM SHAND**  
CONSULTING SERVICES

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<b>To:</b>	Dr Ricky Murray		
<b>Of:</b>	Groundwater Africa		
<b>From:</b>	Ashwin West, Environmental Discipline Group		
<b>Date:</b>	24 May 2007	<b>Reference Number:</b>	401808/1580
<b>Subject:</b>	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<sup>3</sup> (48 000 m<sup>3</sup> + 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<sup>3</sup> 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<sup>3</sup> 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<sup>3</sup> or more water between water catchments<sup>1</sup> of impoundments per day', since the total volume of water that would be transferred is 48 000 m<sup>3</sup> and would be 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<sup>3</sup> 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<sup>3</sup>. 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<sup>3</sup> an environmental authorisation should not be required.

However, further to Mr Yakeen Atwaru's<sup>2</sup> 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.

<sup>1</sup> 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<sup>3</sup> per day then Regulation 387 1(n) would be applicable.

<sup>2</sup> 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*

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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  
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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/ym 10/7/2007*

**Chief Director  
DWAF  
Bellville**