ASSESSMENT OF THE WATER LEVEL RISE IN STERKFONTEIN CAVES, CRADLE OF HUMANKIND WORLD HERITAGE SITE, GAUTENG PROVINCE

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ASSESSMENT OF THE WATER LEVEL RISE IN STERKFONTEIN CAVES, CRADLE OF HUMANKIND WORLD HERITAGE SITE, GAUTENG PROVINCE

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SUMMARY

Available historical and recent hydrogeological data and information that informs the response of the Sterkfontein Cave water level and chemistry has facilitated an assessment of the water level rise observed in the cave system. More specifically, the assessment provides the context within which this phenomenon is occurring, and in particular to the concern that it is due to the impact of acid mine drainage emanating from the Western Basin of the Witwatersrand Gold Field. The outcome of the assessment is synthesized as follows.

- The phenomenon is not constrained to Sterkfontein Caves alone. It has been observed in at least 19 boreholes in the wider dolomitic (karst) environment both upstream and downstream of the Sterkfontein Caves, demonstrating the extent of the shared groundwater environment.

- The phenomenon is not a recent event. It dates back to at least mid-2007, if not *ca.* 2005, in the wider expanse of the karst environment.

- The magnitude of groundwater level rise observed in 19 boreholes between early- to mid-2007 and early- to mid-2010 ranges from 0.37 to 6.64 m, with mean and median values of ~2.4 and ~2.0 m respectively. The rise in the Main Lake water level in Sterkfontein Caves amounted to ~1.9 m in this period, and more recently (in June 2011) had reached a height of ~2.8 m above the October 2007 level.

- The chemistry of the cave water shows little discernible impact from mine water over a time span of ~10 years, revealing very little variation in chemical composition between four sampling events bracketed by the period April 2001 and January 2011. The most recent iron (Fe) and manganese (Mn) levels in the cave water were below the respective detection limits of 0.020 mg Fe/L and 0.005 mg Mn/L. The nitrate value of 9.3 mg N/L associated with the January 2011 water sample, however, indicates a measure of nutrient contamination.

- The chemistry of the cave water differs from that of groundwater discharged by the downstream Zwartkrans Spring in regard to both inorganic and isotope (^{2}H, ^{3}H and ^{18}O) composition. This suggests that the Sterkfontein Caves do not lie in the main flowpath (thalweg) of groundwater discharge through the Zwartkrans Compartment toward the Zwartkrans Spring.

- The almost 3 m rise in cave water level in the last 2 years (late-2009 to late-2011) is still within the range (2 to 3 m) of perceived most aggressive carbonate re-solution that defines the more recent speleogenetic evolution of the cave system suggested by Martini et al. (2003).

In light of this assessment, it is concluded that the water level rise observed in Sterkfontein Caves is not directly attributable to the "…… *uncontrollable decant of Acid Mine Drainage within the West Rand Basin*." If it were, then this cause would also be reflected in the chemical composition of the cave water. This is not the case. This observation, however, is no reason for complacency, and authorities such as the Department of Water Affairs and the Management Authority of the Cradle of Humankind World Heritage Site (COH WHS) should continue their observational vigilance of the patterns and trends that characterize the dynamic response of the water resource environment in the COH WHS to a variety of threats. This is equally relevant for the fossil sites in the area and the numerous groundwater users (and uses) that depend on this resource for their existence.

ACKNOWLEDGEMENT

The Council for Scientific and Industrial Research (CSIR) acknowledges with gratitude the permission granted by the Management Authority of the Cradle of Humankind World Heritage Site (COH WHS) to use the data and information generated by the recently completed study under the title "*Situation Assessment of the Surface Water and Groundwater Resource Environments in the Cradle of Humankind World Heritage Site*" in the compilation of this assessment report. This study has significantly advanced the understanding of the inter-related surface water and groundwater resource environments in the COH WHS. It has also defined the basis and framework for the development of an "*Environmental Monitoring System and Monitoring System Manual for the Water Resources of the Cradle of Humankind World Heritage Site*". Without this reference and source material, the compilation of this assessment report would not have been possible in the short time frame (one week) afforded the CSIR.

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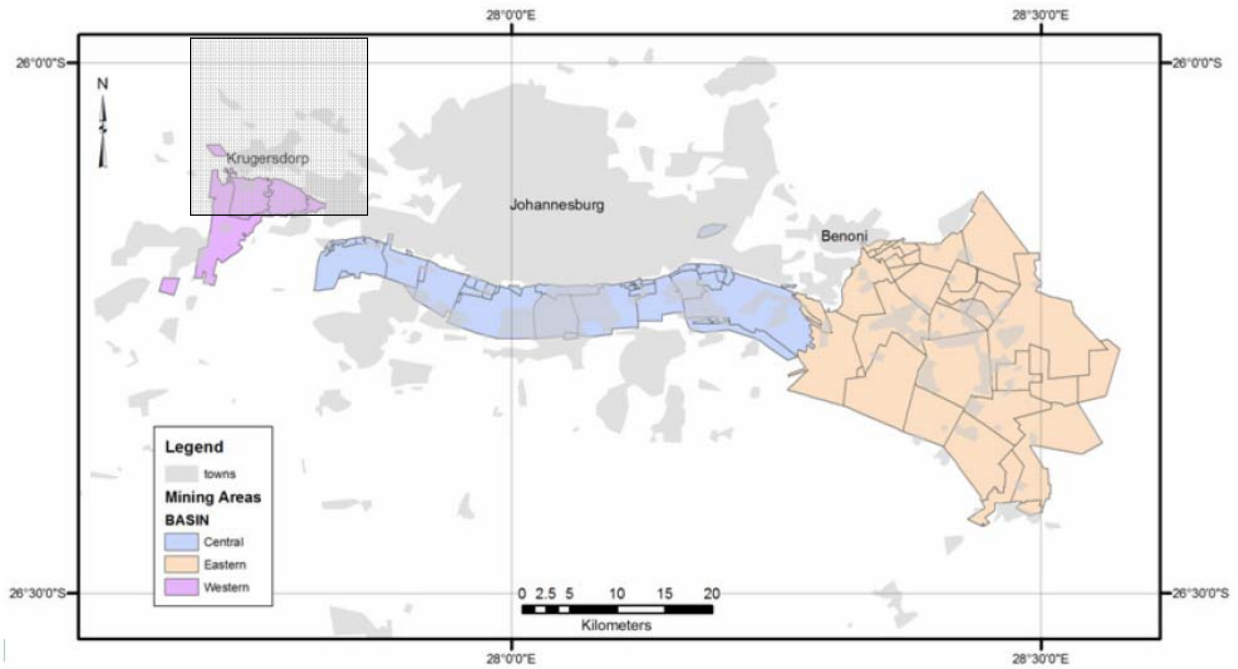
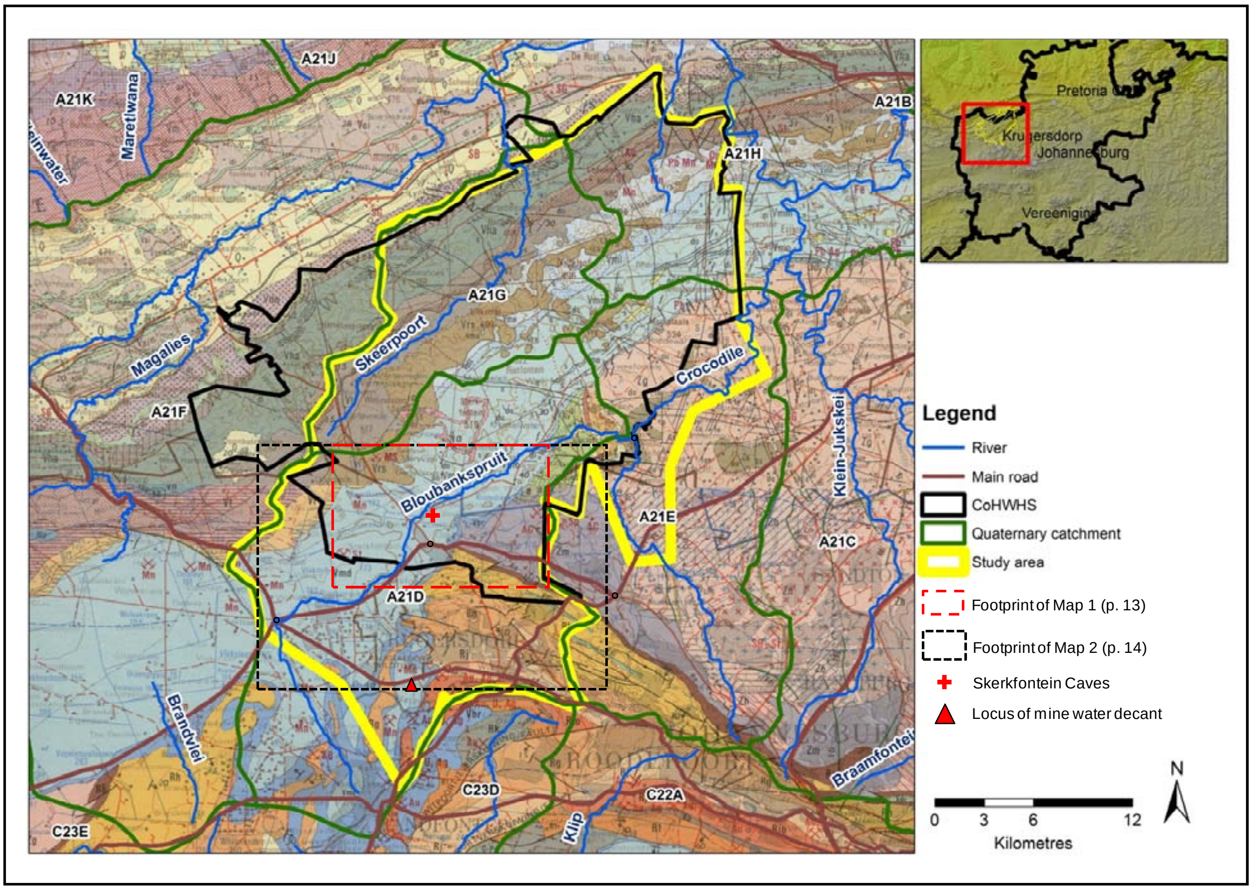
SYMBOLS, ACRONYMS AND ABBREVIATIONS

~	approximately
<	less than
%	per cent (parts per hundred)
‰	per mil (parts per thousand)
%ile	percentile
^{2}H	deuterium
^{3}H	tritium
^{18}O	oxygen-18
AMD	acid mine drainage/decant/discharge
amsl	above mean sea level
bc	below collar
bgl	below ground level
BRI	Black Reef Incline
bs	below surface
ca.	*circa* (about)
Ca	calcium
Cl	chloride
COH WHS	Cradle of Humankind World Heritage Site
CSIR	Council for Scientific and Industrial Research
DWA	Department of Water Affairs (formerly Department of Water Affairs & Forestry; DWAF)
EC	electrical conductivity
e.g.	*exempli gratia* (for example)
Fe	iron
FSE	Federation for a Sutainable Environment
HCO_3	bicarbonate
HDS	high density sludge
i.e.	*id est* (that is to say)
JFA	Johan Fourie and Associates (Consultancy)
JNNR	John Nash Nature Reserve
K	potassium
m	metre(s)
MA	Management Authority
Ma	million years
MAP	mean annual precipitation
meq/L	millequivalent(s) per litre
Mg	magnesium
mg/L	milligram(s) per litre
mm	millimetre(s)
m/month	metre(s) per month
Mn	manganese
mS/m	milliSiemens per metre
Na	sodium
N	nitrate
p.	page
pp.	pages
RU	Rand Uranium
SO_4	sulphate
TU	tritium unit(s) [1 TU = 1 tritium in 10^{18} hydrogen atoms]
WBTWG	Western Basin Technical Working Group
WMA	water management area
WWTW	wastewater treatment works

REGIONAL PLACEMENT OF THE STUDY AREA



Geographic location of the three mining basins (Western, Central and Eastern) that collectively define the Witwatersrand Basin formed by the Witwatersrand Gold Field. Western Basin and footprint of study area (shaded) at upper left.



Location of the study area extending to the north of the Western Basin. Base map shows geology as per the published 1:250 000 scale geological maps 2526 Rustenburg (1981) and 2626 West Rand (1986). Principal drainage pattern is to the north-east and north.

1 INTRODUCTION

On 06/10/2011, the Department of Water Affairs (DWA) requested the Council for Scientific and Industrial Research (CSIR) to assess and evaluate the circumstances that inform the water level rise observed in the Sterkfontein Caves. The request followed concerns raised by the Federation for a Sustainable Environment (FSE) in email correspondence dated 05/10/2011 directed at the DWA. The correspondence posits the inference that the water level rise in Sterkfontein Caves is attributable to the "…… *uncontrolled decant of Acid Mine Drainage within the West Rand Basin.*"

2 BACKGROUND DISCUSSION

It is known that the water level in the Sterkfontein Caves has been the subject of considerable debate and at least some confusion in the comparatively recent past. To resolve any possible confusion, the water level in question is that associated with the so-called Main Lake (after Martini et al., 2003), which is the most readily accessible water body in the cave system. The rise in the level of this water body has necessitated that Maropeng re-direct the tourist route through the caves.

A Western Basin Technical Working Group (WBTWG) meeting held on 28/02/2007 at the Rand Uranium Office Complex in Randfontein was informed that the Zwartkrans Spring was dry, and that any flow in this vicinity represented surface runoff. This was in response to a query regarding the level of groundwater in the Sterkfontein Caves (reportedly 1436 m amsl) vis-à-vis the elevation of the spring (reportedly 1439 m amsl). These circumstances were put forward as evidence that the water level in Sterkfontein Caves could not rise more than 3 m, i.e. up to the level of 1439 m amsl at which the dolomitic Zwartkrans Compartment would overflow via the spring. These circumstances would then also explain the reported drying up of the Zwartkrans Spring. The owner of the Zwartkrans Spring property, however, has confirmed that the Zwartkrans Spring has never stopped flowing in the 31-year period that she has lived on the property (H. Roos, personal communication). The following circumstances, arrived at from an analysis of availablel relevant information, are considered to more closely reflect the true situation.

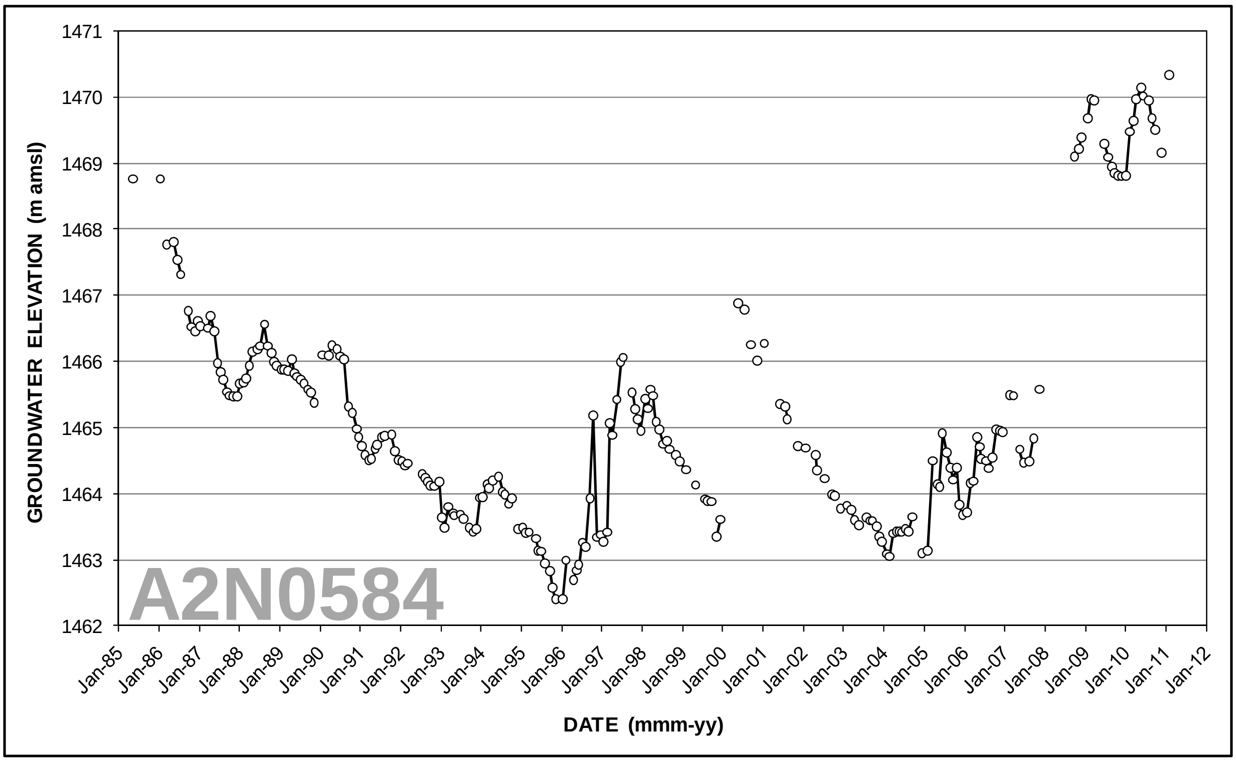
A re-survey on 12/12/2007 of the benchmark in Sterkfontein Caves from which the Main Lake water level is derived, placed it an elevation of 1437.94 m amsl compared to the previous elevation of 1452.37 reported by JFA (2006). The difference of 14.43 m, when applied to the Main Lake water level of 1450.88 also reported by JFA (2006), returned a water level of 1436.5 m amsl, i.e. in agreement with that reported to the WBTWG meeting mentioned above. This compares favourably with both the reported groundwater level elevation of 1437.5 m amsl (JFA, 2006) in the nearby monitoring borehole SF1 (**Map 1**), and the surface elevation of the Zwartkrans Spring which is placed at ~1432 m amsl [Hobbs (Ed.), 2011].

A rest water level measurement in borehole SF1 on 01/10/2007 returned a value of 17.4 m bc (below collar) which, for an interpolated surface elevation of 1454 m amsl, gives a potentiometric level of 1436.6 m amsl. This closely resembles that of the Main Lake water level, and suggests that the groundwater rest level in SF1 and the caves represents a single potentiometric surface. This suggestion is shared by Krige (2009; 2010) following a revision of earlier reports by Krige and Van Biljon (2006; 2010). In practical terms, this indicates that the caves share the same aquifer as the nearby borehole SF1, and which is drained by the Zwartkrans Spring. Martini et al. (2003) report earlier similar discrepancies in elevation (up to 9 m) between various water bodies (up to 30 reported 'static' pools) inside the cave system, but conclude that more recent measurements suggest elevation differences in the order of decimetres (tens of centimetres) rather than metres.

The above circumstances bring into question the relationship with the channel of the Bloubank Spruit north of (opposite) the Sterkfontein Caves, which is placed at an elevation of ~1440 m amsl [Hobbs (Ed.), 2011], compared to the 1445 m amsl attributed to it by JFA (2006). The elevation difference of ~3 m between the surface drainage and the October 2007 groundwater level does not necessarily imply that the surface and groundwater systems are in direct hydraulic continuity, since it has been shown by Hobbs and Cobbing (2007) that the potentiometric surface (water table) upstream of the Oaktree area (and therefore the caves) was separated from the overlying surface drainage (the Riet Spruit) by 12 to 30 m. This difference has subsequently decreased significantly as a consequence of recharge of the karst aquifer. These circumstances are reflected in **Table1**, which presents the results of water level measurements carried out in 19 boreholes in 2006/07 and 2010, respectively. The long-term record of more continuous water level measurements carried out in DWA monitoring boreholes in the Zwartkrans Compartment lend further support to the data presented in **Table 1**. Examples in this regard are shown in **Figure 1**.

Table 1. Comparison of historical and recent depth to groundwater level in the study area. Station positions are shown in **Maps 1** and **2**.

Station	**Historic Water Level**			**Recent Water Level**			**Difference (m bc)**
	Date	**Depth (m bc)**	**Elevation (m amsl)**	**Date**	**Depth (m bc)**	**Elevation (m amsl)**	
SW1	09/12/2005	18.00	1441	11/02/2010	11.36	1448	+6.64
A2N0594	25/01/2006	74.00	1439	08/02/2010	73.43	1440	+0.57
DRP15	30/07/2006	59.00	1416	02/12/2009	58.63	1417	+0.37
ZW1	30/07/2006	29.64	1438	17/02/2010	27.64	1440	+2.00
A2N0600	30/07/2006	25.06	1438	17/02/2010	23.03	1440	+2.03
BolandB1	30/07/2006	22.15	1438	17/02/2010	21.77	1438	+0.38
SF1	01/10/2007	17.43	1437	17/02/2010	16.13	1438	+1.30
				09/06/2010	15.54	1438	+1.89
GB1	30/07/2006	20.36	1444	11/02/2010	17.64	1447	+2.72
MB1	30/07/2006	15.07	1435	13/05/2010	13.79	1436	+1.28
VW1	30/07/2006	13.94	1445	06/05/2010	9.71	1449	+4.23
HW1	30/07/2006	8.00	1410	13/05/2010	6.09	1412	+2.09
SWBH1	30/07/2006	28.00	1417	13/05/2010	27.30	1418	+0.70
SBH1	30/07/2006	22.26	1415	13/05/2010	21.18	1416	+1.08
A2N0584	08/02/2007	25.71	1466	16/02/2010	21.78	1469	+3.93
CSIR34	13/02/2007	35.10	1470	14/04/2010	33.99	1471	+1.11
CSIR8	13/02/2007	28.42	1447	14/04/2010	24.28	1451	+4.14
A2N0586	08/03/2007	26.96	1460	16/02/2010	21.98	1465	+4.98
CSIR57	08/03/2007	12.32	1461	16/02/2010	7.06	1466	+5.26
A2N0598	16/05/2007	63.22	1480	09/06/2010	61.14	1482	+2.08
Statistical analysis						n	19
						Minimum value	0.37
						5%ile value	0.38
						Mean value	2.42
						Median value	2.03
						95%ile value	5.40
						Maximum value	6.64



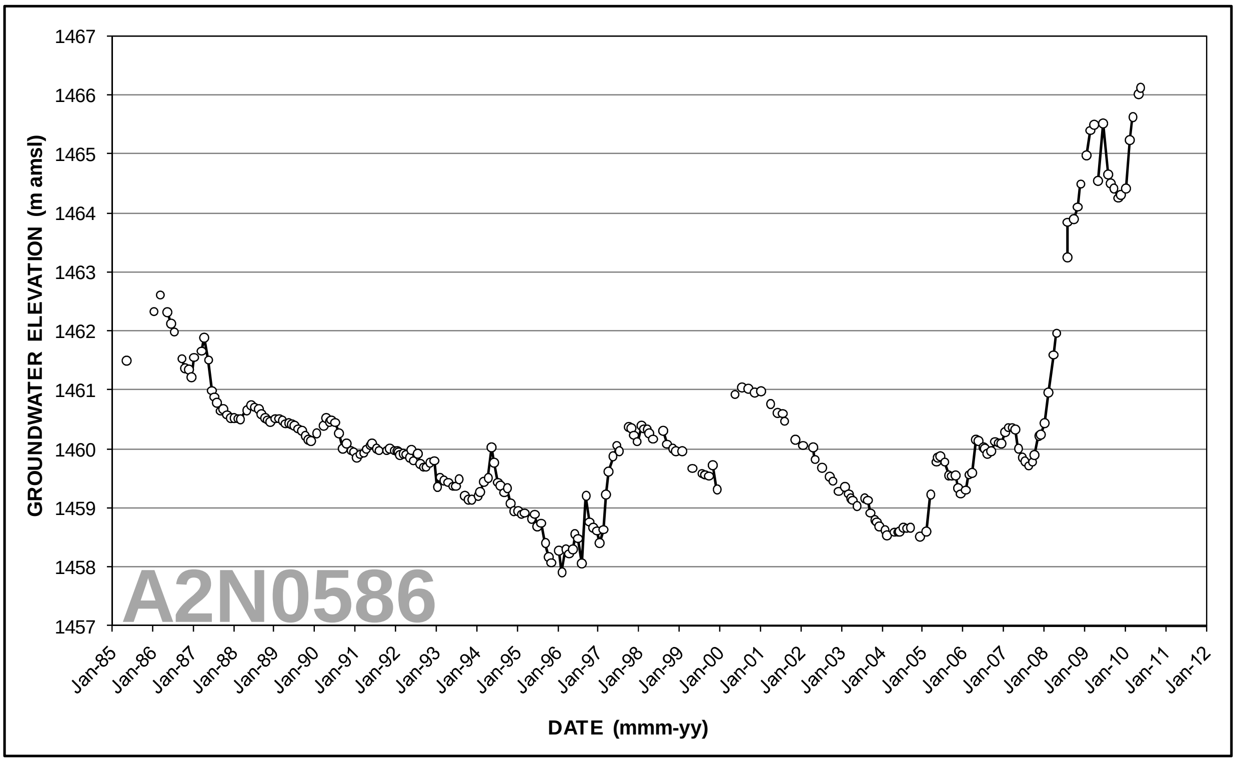


Figure 1. Hydrographs of two DWA long-term water level monitoring boreholes (stations A2N0584 and A2N0586) upstream of Sterkfontein Caves. See **Maps 1** and **2** for positions of these stations.

Using data from **Table 1** that is specific to the Sterkfontein Caves, it is evident that by 09/06/2010 the water level in borehole SF1 had risen ~1.9 m from its 01/10/2007 depth of ~17.4 m bc. This places the water table elevation in June 2010 at ~1438 m amsl, which is only some 2 m below the ~1440 m amsl of the Bloubank Spruit channel. The difference can be expected to be even less as the river-bed elevation approaches that of the Zwartkrans Spring, these surfaces coinciding in proximity to the spring. Under these circumstances, it is probable that groundwater also 'resurfaces' in the channel of the Bloubank Spruit upstream of the Zwartkrans Spring. Observations that support this hypothesis are presented and discussed by Hobbs (Ed.) (2011).

Further informative aspects of the Main Lake water level reported by Martini et al. (2003) are the following.

- The indication that the cave was already dewatered at 20 to 25 m above the present water level, i.e. between an elevation of 1456 and 1461 m amsl, some 3.3 Ma[1] ago. In terms of the present landscape, this implies that the valley to the north of the caves would have been under water to a depth of 15 to 20 m. Further, that the water level decline was irregular, being punctuated by temporary rises as indicated by re-solution of calcified deposits ~12 m above the current (presumably *ca.* 2003) water level[2], and speleothems corroded up to 6 m above this level.

- The observation that the *ca.* 2003 Main Lake water level fluctuation was within a range of ~2 m, and varied gradually in response to a prior rainfall pattern. Further, that speleothems (flowstone and stalactites) were corroded in the interval of roughly 3 to 6 m above the current (*ca.* 2003) water level, and that no speleothems occur below 2-3 m above this level in the vicinity of the Main Lake. The latter observation indicates that this interval is the most aggressive in terms of carbonate re-solution, at least in the more recent speleogenesis of the cave system. This observation also accords with the evaluation of the ambient potentiometric (water level) response pattern (**section 4**).

3 RAINFALL TREND

It is common cause that the rainfall experienced in the region (and beyond) in the last two summer seasons has been above average. This is evident in the monthly precipitation record (**Figure 2**) of the Rand Uranium (RU) rainfall stations located at the High Density Sludge (HDS) mine water treatment plant and the Black Reef Incline (BRI) mine water decant position. For the period October 2008 to July 2011, **Figure 2** reveals the excessively wet 2009-'10 and 2010-'11 summer rainfall seasons. The total rainfall in each of these seasons amounted to 676 and 761 mm at the HDS station, and 622 and 597 mm at the BRI station, respectively. These values equate to the mean annual precipitation (MAP) value of 714 mm reported for quaternary catchment A21D[3] [Hobbs (Ed.), 2011].

4 GROUNDWATER LEVEL TREND

Figure 1 indicates that the groundwater level in the karst aquifer upstream of the caves, as recorded in the DWA monitoring boreholes A2N0584 and A2N0586 (amongst others), already started to rise in early-2005, and more sharply during 2007.

[1] Million years.
[2] Unfortunately Martini et al. (2003) do not report an absolute elevation for the cave water level in their paper.
[3] The Bloubank Spruit system drains this quaternary basin in the Crocodile (West) and Marico WMA.

The installation of a continuous water level monitoring device in the cave lake by the DWA in May 2005 yields information on the Main Lake water level response pattern to July 2007. The recorded pattern is shown in **Figure 3**. It reveals three periods of steady decline at a rate of between 0.08 and 0.06 m/month, the latter occurring after an upward 'adjustment' of ~0.5 m in the 2006-'07 summer.

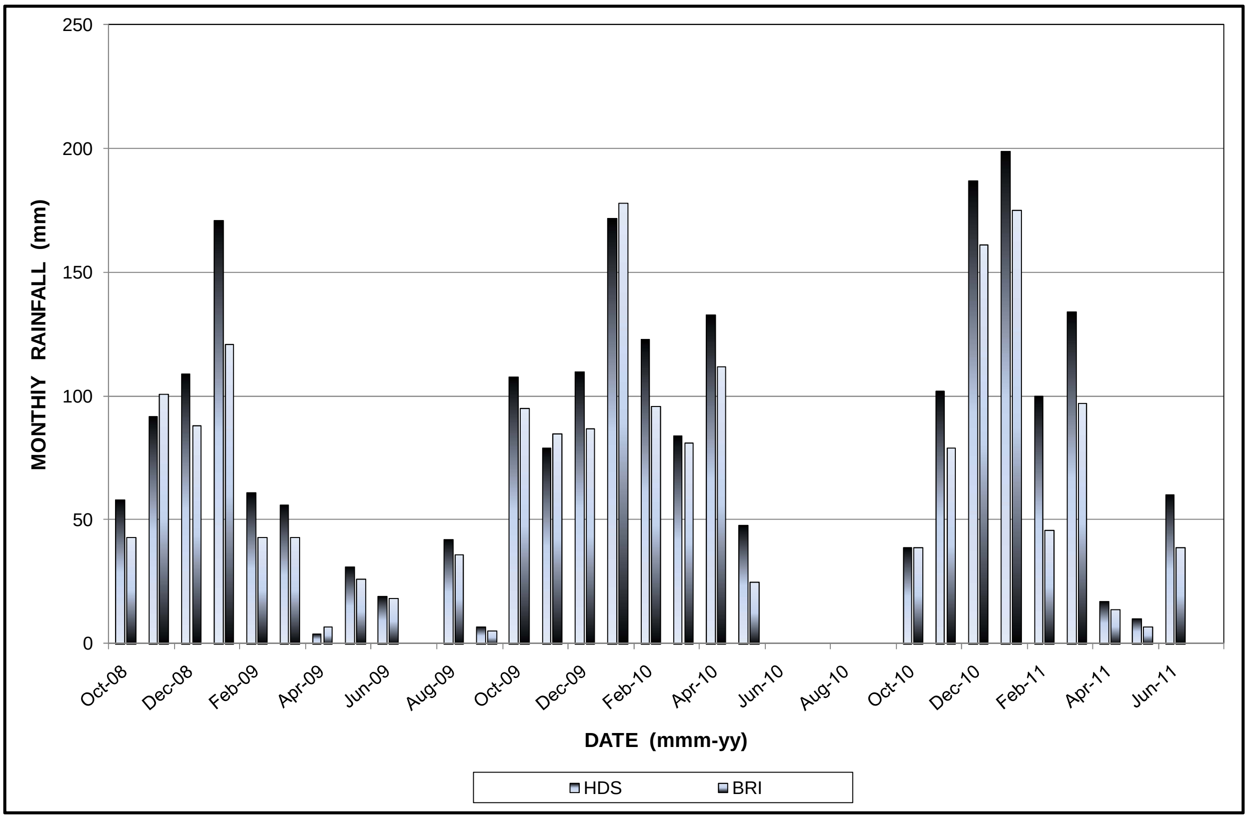


Figure 2. Monthly precipitation recorded at the Rand Uranium HDS and BRI rainfall monitoring stations (separation distance ~2200 m) in the period October 2008 to July 2011.

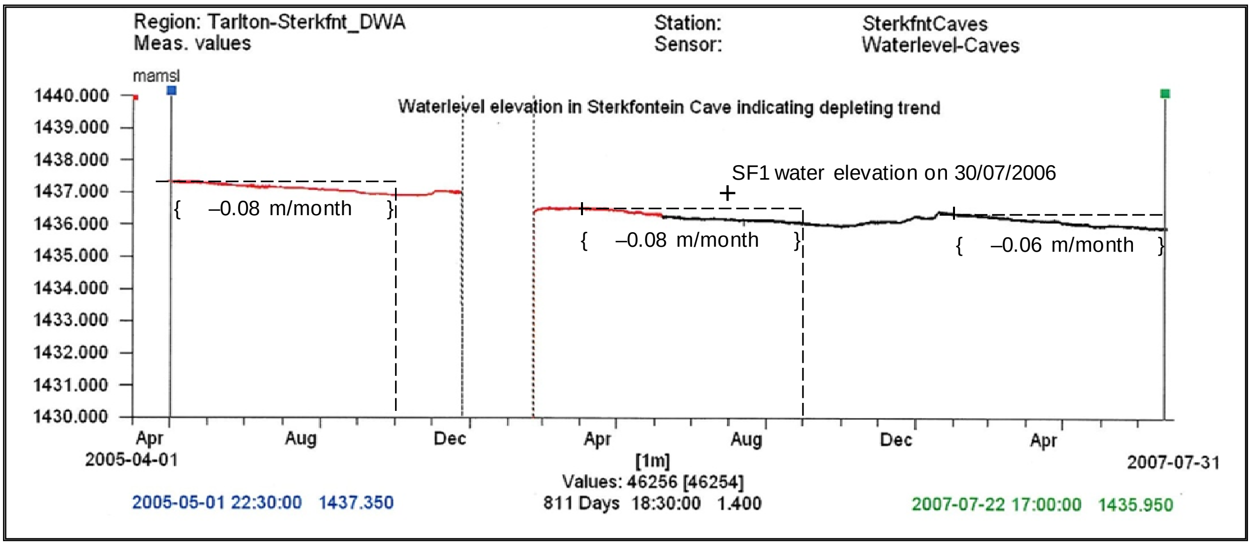


Figure 3. Continuous groundwater level response pattern in Sterkfontein Caves over a period of 27 months. (Use of image courtesy of E. van Wyk, DWA).

A water level measurement in borehole SF1 on 14/01/2011 indicated a further rise of ~0.7 m since 09/06/2010, for a total rise of ~2.6 m between October 2007 and January 2011, increasing to ~2.8 m with a further rise of ~0.2 m being manifested in the 5-month period January 2011 to 28/06/2011. The rates of rise in the three periods 17/02/2010 – 09/06/2011, 09/06/2010 – 14/01/2011 and 14/01/2011 – 28/06/2011 amount to ~0.15, ~0.09 and ~0.04 m/month respectively. The associated trend is shown in **Figure 4**, which also suggests the cave lake water level rise started between late-2007 and late-2009, most probably closer to the latter.

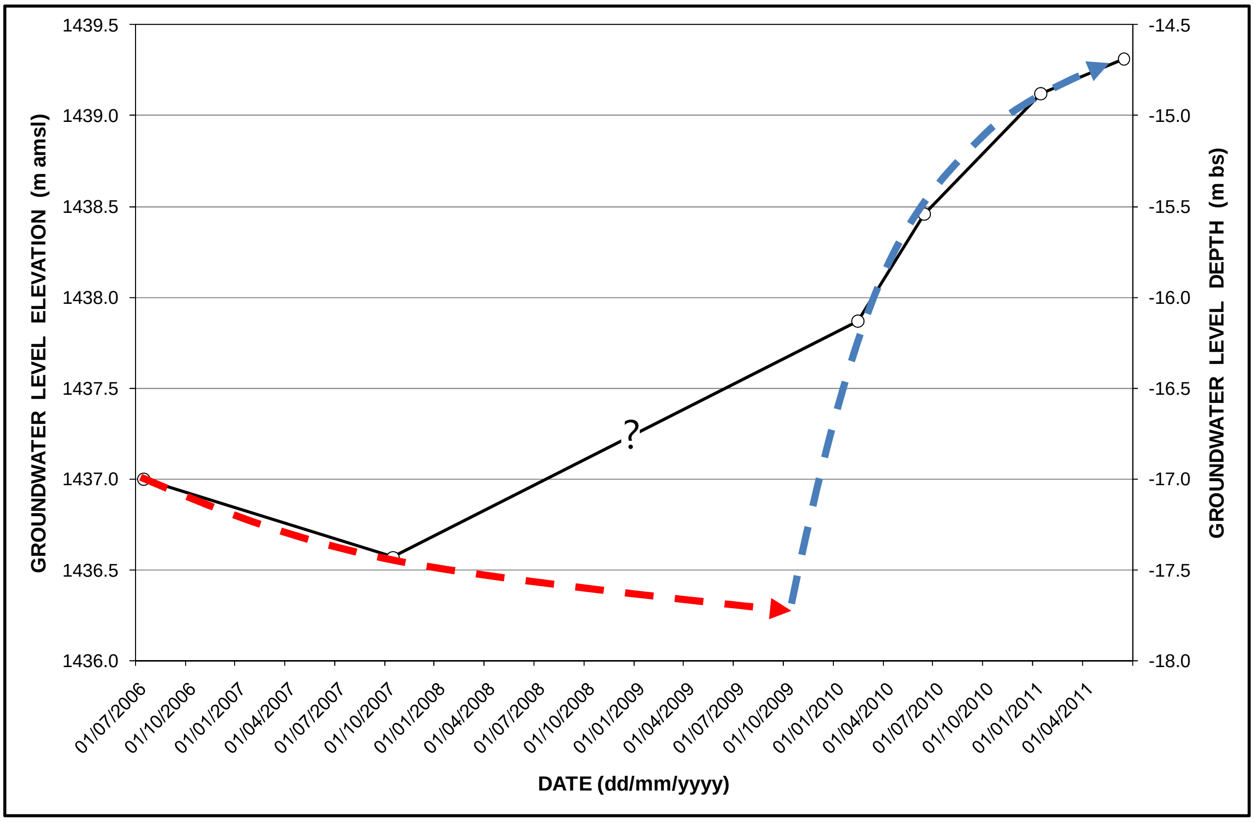


Figure 4. Recent groundwater level response pattern in borehole SF1 that serves as a proxy for the Main Lake water level in Sterkfontein Caves. The declining (red) and rising (blue) arrows indicate the more probable water level trend.

In sympathy with the observed rise in water levels in the study area in the more recent past, i.e. the 2009-'10 and 2010-'11 hydrological years [Hobbs (Ed.), 2011], a similar response is observed in the Sterkfontein Caves. In mid-May 2010, cave guide K. Mangole (personal communication) estimated a rise of ~1 to 2 feet (0.3 to 0.6 m) since late-2009. This is in good agreement with the ~0.6 m rise observed in the nearby borehole SF1 between 17/02/2010 and 09/06/2010 [Hobbs (Ed.), 2011], and the ~0.4 m rise in borehole MB1 (**Map 1**) between 18/02/2010 and 13/05/2010.

The projected 'final' Main Lake water level elevation of ~1439.5 m amsl approaches the 1440 m amsl assigned to the Bloubank Spruit channel north of the site. This observation suggests that the cave water level reaches equilibrium at an elevation of ~1440 m amsl (equivalent to a depth of ~14.5 m below surface in borehole SF1) when the karst water table intersects the stream channel of the Bloubank Spruit located to the north. If so, then the maximum possible rise of ~3 m agrees well with the zone of perceived most aggressive carbonate re-solution that defines the more recent speleogenetic evolution of the cave system as observed by Martini et al. (2003) (**section 2**).

The water level decline in the early part of the SF1 record shown in **Figure 4** reflects a rate of fall of 0.03 m/month. This is roughly half the rate of 0.06 to 0.08 m/month reflected in the three earlier periods demarcated in **Figure 3** for the Sterkfontein Caves water level. Also shown in **Figure 3** is the SF1 groundwater level elevation on 30/07/2006, which shows a <1 m discrepancy with that of the contemporaneous cave lake water level elevation. The datum for the cave lake water level is a surveyed elevation (Krige, 2009), and must therefore be regarded as accurate to <0.1 m resolution. This is supported by the elevation values reported to the second decimal in **section 2**. By comparison, the SF1 datum is a surface elevation interpolated from the 1:10 000 scale orthophoto map 2627BA5 Sterkfontein (2nd ed., 1987). With a contour interval of 5 m, an interpolation accuracy of ±1 m is feasible with knowledge of the landscape.

Drilling information provided by DWA borehole GP00313 (**Figure 8**) located ~900 m to the north-west across the valley of the Bloubank Spruit from Sterkfontein Caves yielded some insight into the physical subsurface environment. This borehole intersected very weathered to decomposed and cavernous dolomite down to its completion depth of 37 m bs, i.e. 17 m below the water table depth of ~20 m bs (1440 m amsl). The most substantial cavity was encountered in the interval from 17 to 32 m bs (1443 to 1425 m amsl) This places the depth of circulation at least 7 m below the elevation of Zwartkrans Spring, and closer to 15 m below the recent Main Lake water level of ~1439 m amsl (**Figure 4**).

Groundwater level depth measurements *ca.* mid- to late-2010 in three boreholes indicate that the groundwater gradient in the valley of the Bloubank Spruit to the north of Sterkfontein Caves amounted to 0.003 in a north-easterly direction. This is equal to a fall of 0.3 m per 100 m, or an even less readily discernible fall of 0.15 m per 50 m. These circumstances provide the context for the "*apparently static*" nature of pools in the cave system (Martini et al., 2003).

5 GROUNDWATER CHEMISTRY TREND

It might be expected that if the water level rise in Sterkfontein Caves is attributable to the "…… *uncontrollable decant of Acid Mine Drainage within the West Rand Basin*.", then this would also be reflected in the cave water chemistry.

Holland et al. (2009) report comparatively recent SO_4 and Cl concentrations of 154 and 55 mg/L respectively for groundwater sourced from a borehole (presumably SF1) near the Sterkfontein Caves. This is put forward as "……… *undoubtedly indicating anthropogenic impacts*." These values agree with the averages of 147 mg SO_4/L and 66 mg Cl/L for three boreholes (CSIR7, CSIR8 and CSIR9) in the upstream Oaktree area (Hobbs and Cobbing, 2007), and raise concern for the quality of the cave water.

A more complete comparison of earlier cave water chemistry with the present is provided by the analyses of April 2001 (from Rand Uranium records), 29/04/2005 (from DWA records) and 13/05/2010 and 14/01/2011. This comparison is made in **Figure 5** (which also shows the 29/04/2005 analysis result for Koelenhof Cave groundwater and the 13/05/2010 result for Zwartkrans Spring water) and in **Figure 6**. The similar chemical composition of the cave waters is readily apparent in **Figure 5**. Also notable and significant is the very similar composition of the two more recent Sterkfontein Caves water samples, and the higher laboratory EC value of 74 mS/m associated with the April 2001 water sample from this source.

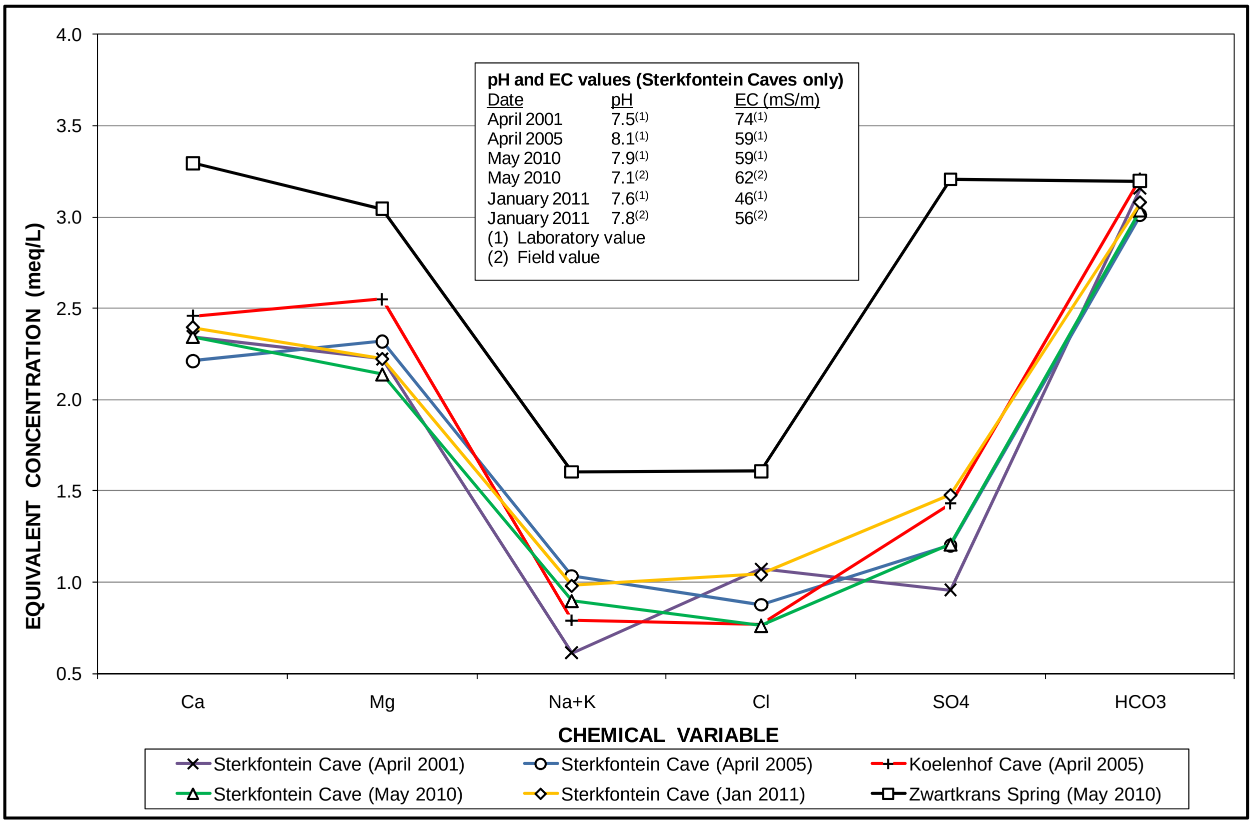


Figure 5. Graphic comparison of historical and recent Sterkfontein Caves groundwater chemistry.

The 22% increase in SO_4 concentration from 1.21 meq/L (58 mg/L) in May 2010 to 1.48 meq/L (71 mg/L) in January 2011 indicates a slight measure of deterioration associated with the cave water that is not reflected in either the contemporaneous field EC values of 62 and 56 mS/m, or the field pH values of 7.1 and 7.8, respectively. A similar increase (26%) in SO_4 concentration from 0.96 meq/L (46 mg/L) in April 2001 to 1.21 meq/L (58 mg/L) in April 2005 is also evident in **Figure 5**. These "changes" are hardly evident in **Figure 6.**

Included in the January 2011 chemical analysis of the cave water were nitrate (9.3 mg N/L), iron (<0.020 mg Fe/l) and manganese (<0.005 mg Mn/L). The very low Fe and Mn concentrations indicate no discernible impact from a mine water source. The nitrate concentration, however, suggests a measure of contamination by nutrient-rich water. Possible sources of such water include the following:

- upstream agricultural land use practices — the Oaktree area supports extensive irrigated agriculture that includes maize, vegetables and tunnel farming (of cut-flowers) using groundwater drawn locally from the karst aquifer;
- municipal wastewater effluent — the discharge from Mogale City's Percy Stewart Wastewater Treatment Works (WWTW, **Map 2**) imposes a median SO_4 concentration of ~160 mg/L in the receiving Blougat Spruit [Hobbs (Ed.), 2011], an upper tributary of the Bloubank Spruit;
- on-site sanitation facilities on the numerous smallholdings in the Oaktree area — this area is not served by the Mogale City Local Municipality sewerage system; and possibly even
- the sanitation facility serving the Sterkfontein Caves Visitors Centre which, until recently, comprised a septic tank system — this was replaced with a much more environment-friendly self-contained bioreactor system (M. Fouche, personal communication) in January 2011.

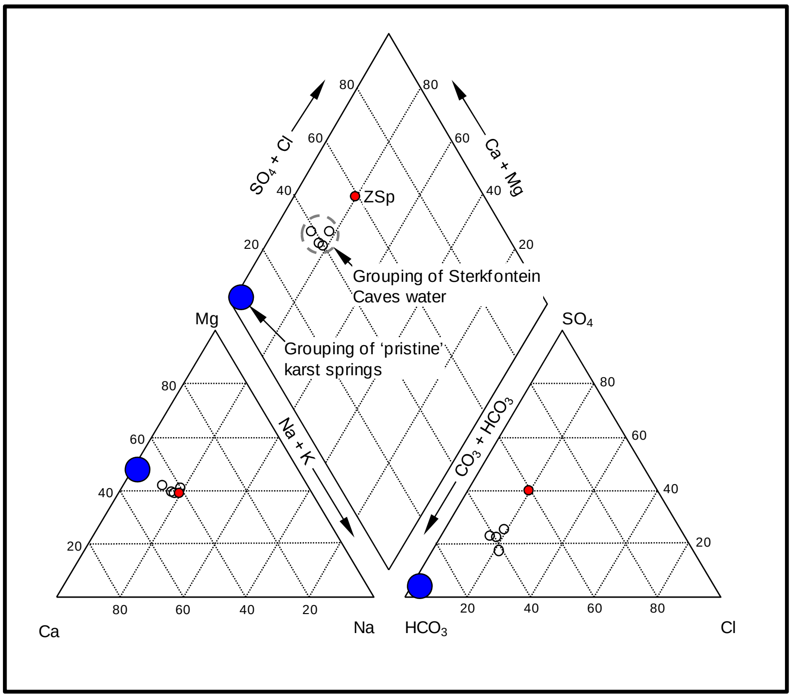


Figure 6. Piper diagram of historical and recent Sterkfontein Caves water chemistry compared to 'pristine' karst groundwater and *ca.* May 2010 Zwartkrans Spring (ZSp) water.

The different chemical composition of the Zwartkrans Spring water, which reflects a contrasting Ca-SO_4 composition compared to the CaMg-HCO_3 character of the Sterkfontein Caves water, is equally evident. The comparison of the Sterkfontein Caves water chemistry with that of 'pristine' karst springs in the COH WHS is shown in **Figure 6**. The Piper diagram indicates that this difference is primarily associated with the anionic composition (SO_4, Cl and HCO_3) of the dolomitic groundwater.

The installation of a continuous electrical conductivity (EC) monitoring device in the Main Lake by the DWA in May 2005 yields information on the cave water salinity response in the recent past. This pattern is shown in **Figure 7**, and reveals an initial EC value of ~47 mS/m, followed after a hiatus of some 32 weeks by a notably higher value of ~60 mS/m. An analysis of the cave water sampled on 29/04/2005 (as sourced from the DWA records), i.e. within a month of installation of the monitoring device, returned an EC value of 59 mS/m (**Figure 5**). As shown in **Figure 7**, this suggests that the early salinity record might be in error by an 'under-reading' of ~12 mS/m. If so, then the salinity of the cave water has not changed much between mid-2005 and the present, a period of some five years. Recent field EC values of 62 and 56 mS/m (in May 2010 and January 2011) for the cave water confirm the pattern described by the continuous DWA record. The salinity monitoring device has become inaccessible since *ca.* mid-2010 due to the rise in the Main Lake water level.

The similar chemical composition of Sterkfontein Caves water reflected in **Figures 5** and **6**, despite the difference of some ten years between analyses, mimics the situation sketched by the salinity record (**Figure 7**). Also encouraging are the results of stable isotope (^2H and ^{18}O) and radioactive isotope (^3H) analyses carried out on cave water in the recent past. The comparative data tabulated below indicate very little difference in the span of one year between relatively recent analyses.

Date	δ^2H	$\delta^{18}O$	^3H
28/05/2009	–19.8‰	–3.53‰	1.3 ± 0.3 TU
13/05/2010	–20.3‰	–3.55‰	not analysed

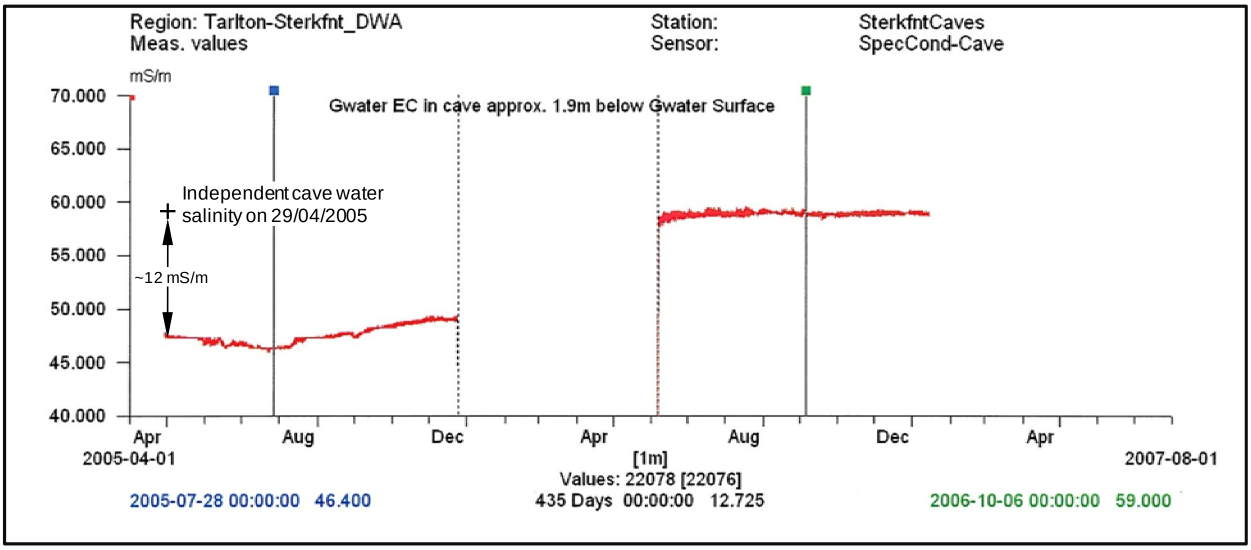


Figure 7. Continuous electrical conductivity response pattern in Sterkfontein Cave water over a period of 27 months. (Use of image courtesy of E. van Wyk, DWA).

A comparison of the May 2009 cave water tritium (^{3}H) value of 1.3 ± 0.3 TU (tritium units) with that obtained in July 2009 for the Zwartkrans Spring (2.4 ± 0.3 TU) reflects a significant difference of 1.1 ± 0.6 TU. The higher value associated with the spring water indicates an isotopically "lighter" water that suggests a stronger evaporative signature associated with this groundwater compared to that associated with the cave water. The most plausible explanation for this situation is that the Sterkfontein Caves do not lie in the main flowpath (thalweg) of groundwater discharge through the Zwartkrans Compartment toward the Zwartkrans Spring. Similarly, Groenewald (2010) refers to the Sterkfontein Caves as occupying a low energy groundwater system, and Martini et al. (2003) refer to the "…..*apparently static*……" pools in the cave system.

6 CONCLUSION

Available historical and recent hydrogeological data and information that informs the hydrodynamic response of the Sterkfontein Cave water level and chemistry has facilitated an assessment of the water level rise observed in the cave system. More to the point, the assessment provides the context within which this phenomenon is occurring, and in particular to the concern that it is somehow due to the impact of acid mine drainage emanating from the Western Basin. The outcome of the assessment is synthesized as follows.

- The phenomenon is not constrained to Sterkfontein Caves alone. It has been observed in at least 19 boreholes in the wider dolomitic (karst) environment both upstream and downstream of the Sterkfontein Caves, demonstrating the extent of the shared groundwater environment.

- The phenomenon is not a recent event. It dates back to at least mid-2007, if not *ca.* 2005, in the wider expanse of the karst environment.

- The magnitude of groundwater level rise observed in 19 boreholes between early- to mid-2007 and early- to mid-2010 ranges from 0.37 to 6.64 m, with mean and median values of 2.4 and

2.0 m respectively. The rise in the Main Lake water level in Sterkfontein Caves amounted to ~1.9 m in this period, and more recently (in June 2011) had reached a height of ~2.8 m above the October 2007 level.

- The chemistry of the cave water continues to show little discernible impact from mine water. In fact, the chemical composition of the cave water reveals very little variation between the four sampling events bracketed by the period April 2001 and January 2011. The nitrate value of 9.3 mg N/L associated with the January 2011 water sample, however, indicates a measure of nutrient contamination.

- The chemistry of the cave water differs from that of groundwater discharged by the downstream Zwartkrans Spring in regard to both inorganic and isotope (^{2}H, ^{3}H and ^{18}O) composition. This suggests that the Sterkfontein Caves do not lie in the main flowpath (thalweg) of groundwater discharge through the Zwartkrans Compartment toward the Zwartkrans Spring.

- The almost 3 m rise in cave water level in the last 2 years (late-2009 to late-2011) is still within the range (2 to 3 m) of perceived most aggressive carbonate re-solution that defines the more recent speleogenetic evolution of the cave system suggested by Martini et al. (2003).

In light of this assessment, it is concluded that the water level rise observed in Sterkfontein Caves is not directly attributable to the "…… *uncontrollable decant of Acid Mine Drainage within the West Rand Basin*." If it were, then this cause would also be reflected in the chemical composition of the cave water. This is not the case. This observation, however, is no reason for complacency, and authorities such as the Department of Water Affairs and the Management Authority of the Cradle of Humankind World Heritage Site (COH WHS) should continue their observational vigilance of the patterns and trends that characterize the dynamic response of the water resource environment in the COH WHS to a variety of threats. It is equally important that any and all findings in this regard be communicated to both interested and affected parties and the general public via appropriate channels. The international status of the COH WHS demands nothing less.

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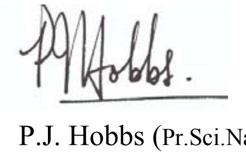

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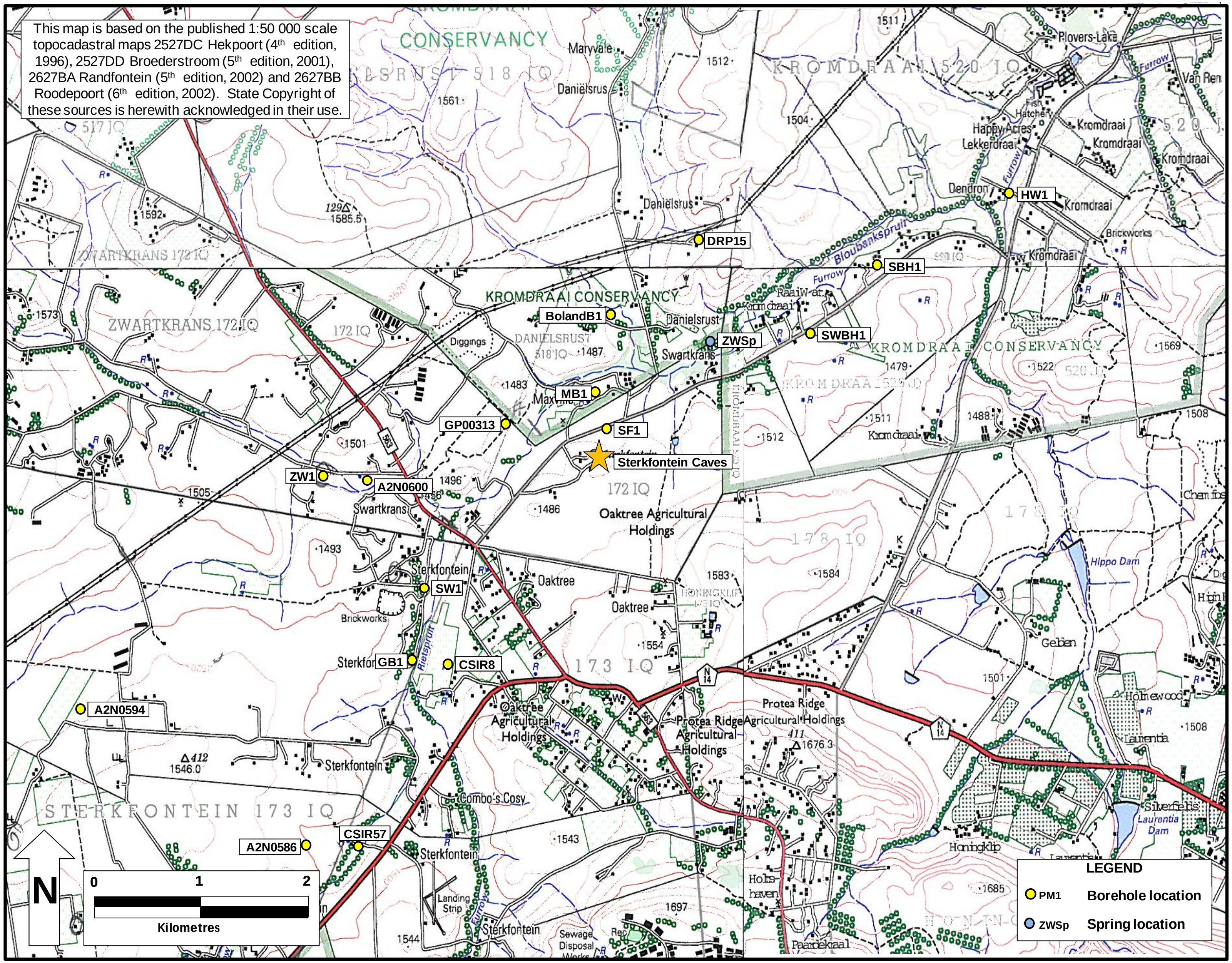
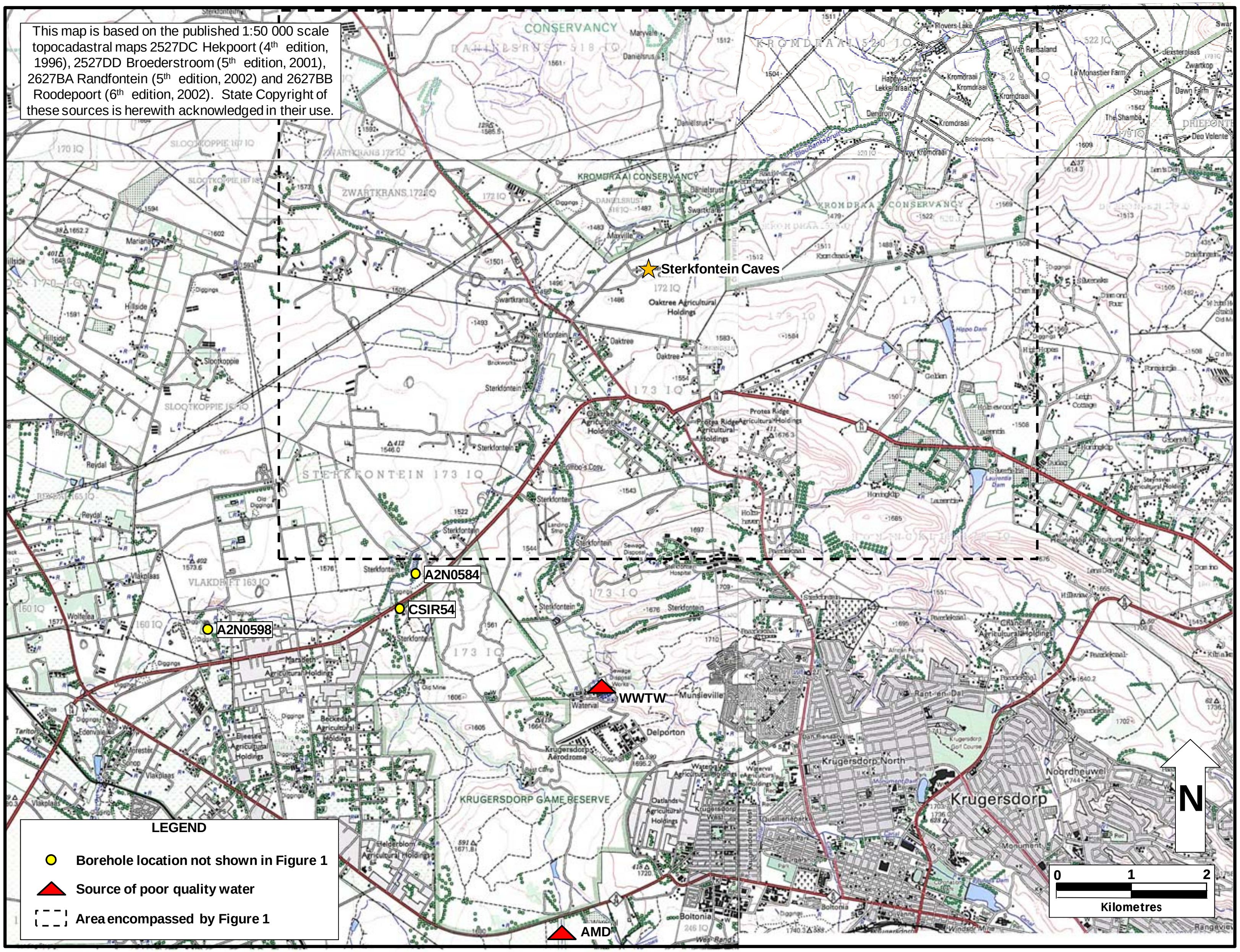
MAP 1. LOCALITY MAP OF STATIONS REFERENCED IN THIS DOCUMENT.



MAP 2. LOCALITY MAP OF STATIONS NOT REFERENCED IN **MAP 1**.



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