PROJECT TITLE

SURFACE WATER AND GROUNDWATER RESOURCES MONITORING, CRADLE OF HUMANKIND WORLD HERITAGE SITE, GAUTENG PROVINCE, SOUTH AFRICA

REPORT TITLE

WATER RESOURCES STATUS REPORT FOR THE PERIOD APRIL TO SEPTEMBER 2015

AUTHOR

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SUMMARY

The Management Authority (MA) of the Cradle of Humankind World Heritage Site (COH WHS) commissioned project BIQ005/2008 to develop a water resources monitoring programme for the property. The outcome of this project was documented in a comprehensive situation assessment report dated March 2011, and resulted in the implementation of a water resources monitoring programme for the property. The outcomes of the programme are reported bi-annually in water resources status reports. This document represents the 7th such report. It covers the period April to September 2015 and, as such, represents a mid-term monitoring report and deliverable in the timeframe of the MAs financial year according to which annual contracts are managed.

A notable event in the timeframe of this report is the unveiling of the *Homo naledi* remains at Maropeng on 10 September 2015. The site of these remains, the Rising Star cave system, has specific relevance for its position in the hydrogeologic landscape of the COH. This exemplifies the fact that an assessment of impacts on the water resources environment of the COH property must necessarily consider both a holistic view and a specific focus on those resources that are at greatest risk from an impact. In the context of the COH property, impacts are necessarily focussed on wastewater sources of which acid mine drainage rising in the Western Basin, and municipal effluent discharged from the Percy Stewart Wastewater Treatment Works, are of primary concern. The outcome of monitoring activities as documented in this report consolidates the conceptual hydrophysical and hydrochemical model originally developed for the property in the situation assessment report and refined in the subsequent bi-annual water resources status reports. The results reveal the following responses in the hydro-environment.

- The 2014–’15 wet (summer) season is the driest since 2008–’09, experiencing ~15% less than the next lowest (2011–’12) season. These circumstances have translated into a below average recharge of the mine void, resulting in a reduced mine water discharge (decant) on surface that has assisted in reversing the negative impacts driven by the very wet 2013–’14 summer season. This situation was maintained through the 2014–’15 dry (winter) season.

- The 2014–’15 hydrological year produced a similar runoff (~35 Mm^3) as the 2012–’13 hydrological year (~33 Mm^3), which is roughly 42% greater than the long-term (whole record) median discharge of ~24 Mm^3/a. It remains to be seen what the coming 2015–’16 wet season, which it is forecast will experience the effects of a severe El Niño Southern Oscilation (ENSO) event, will produce.

- The return to ‘more normal’ pre-2010 discharge water quality in the downstream receiving hydrologic environment observed in the previous reporting period has continued into the current reporting period. This is reflected in electrical conductivity values of ~300 mS/m, near-neutral pH values, and sulphate values of ~2000 mg/L.

- Faecal coliform counts continue to reflect unacceptably high levels (median of 310 cfu/100 mL) in the lower reaches of the Bloubank Spruit system, highlighting the poor performance of the Percy Stewart Wastewater Treatment Works as the primary source located further upstream.

- The groundwater elevation continues to show the greatest decline in the south-western portion of the property (the Zwartkrans Compartment) where the allogenic recharge component is

greatest. This is exemplified by the Main Lake water level in Sterkfontein Caves, which has dropped by ~0.8 m since the maximum in the ~30-year period of monitoring was reached in July 2014.

- A comparison of the TDS loads delivered by major drainages to Hartbeespoort Dam in the last six hydrological years, with those delivered in the periods 1979–’80 to 2008–’09 (which defines the period of negligible mine water impact) and 1979–’80 to 2014–’15 (which defines the whole record including the period of greatest mine water impact and exceptionally high runoff), reveals moderate impacts from mine water at a subregional scale, and slight impacts at a regional scale. This is attributed to the contribution of good to excellent quality dolomitic groundwater from high-yielding karst springs that rise on the COH property. Their bias in favour of the mine water receiving Bloubank Spruit naturally acts to reduce a mine water impact in a subregional context, whereas their moderating influence at a regional scale is muted by the much greater loads contributed by the larger Jukskei and Hennops rivers.

It is concluded that the water resources monitoring results documented in this report confirm the conceptual hydrophysical and hydrochemical model developed for the COH WHS in the situation assessment report. As with previous water resources status reports, it has not revealed any major inconsistencies, nor has it exposed significant flaws that might question the water resources situation assessment and monitoring programme as originally formulated. This is especially encouraging in the light of the recent global focus on the Rising Star site resulting from the *Homo naledi* fossil find, which elevates any environmental impact in the vicinity beyond measure.

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Annexure C	**Recent water chemistry associated with the major karst springs in the Cradle of Humankind**

SYMBOLS, ACRONYMS & ABBREVIATIONS

~	approximately
>	greater than
<	less than
%	per cent (parts per hundred)
%ile	percentile
°C	degree(s) Centigrade
Δh	change in head
a_h	hydrological year
AMD	acid mine drainage
amsl	above mean sea level
bc	below collar
BRI	Black Reef Incline
bs	below surface
ca.	circa (about)
cfu	coliform forming units
COH WHS	Cradle of Humankind World Heritage Site
CoV	coefficient of variation
DWS	Department of Water & Sanitation [formerly the Department of Water Affairs (DWA)]
EC	electrical conductivity
ENSO	El Niño Southern Oscilation
HDS	high density sludge
kg	kilogram(s)
km	kilometre(s)
L/d	litre(s) per day
L/s	litre(s) per second
L/s/km	litre(s) per second per kilometre
m	metre(s)
MA	Management Authority
meq/L	milliequivalent(s) per litre
mg/L	milligram(s) per litre

ML/d	megalitre(s) per day
mm	millimetre(s)
m^3/s	cubic metre(s) per second
Mm^3	million cubic metre(s)
Mm^3/a	million cubic metres per annum
MPN	most probable number
mS/m	milliSiemens per metre
n	count
n.s.	not specified
pp	pages
REGM	Randfontein Estates Gold Mine
RU	Rand Uranium (earlier owner of the original REGM)
SD	standard deviation
SDM	synoptic discharge measurement
SG	Sibanye Gold (current owner of the original REGM)
SOC	State of Conservation
TCTA	Trans-Caledon Tunnel Authority
TDS	total dissolved solids
UNESCO	United Nations Educational, Science and Cultural Organisation
WHC	World Heritage Committee
WWTW	wastewater treatment works

1 INTRODUCTION, BACKGROUND & CONTEXT

The Management Authority (MA) of the Cradle of Humankind World Heritage Site (COH WHS) commissioned project BIQ005/2008 to develop a water resources monitoring programme for the property (**Figure 1**). This delivered a situation assessment of the surface water and groundwater resource environments (Hobbs, 2011a) that redefined the understanding of especially the geometry of the hydrogeologic environment. Subsequent monitoring activities have generated new data and additional insight that are documented in bi-annual water resources status reports (Hobbs, 2012; 2013a; 2013b; 2014a; 2014b; 2015a). This document represents the seventh such report, which covers the mid-term period April to September 2015.

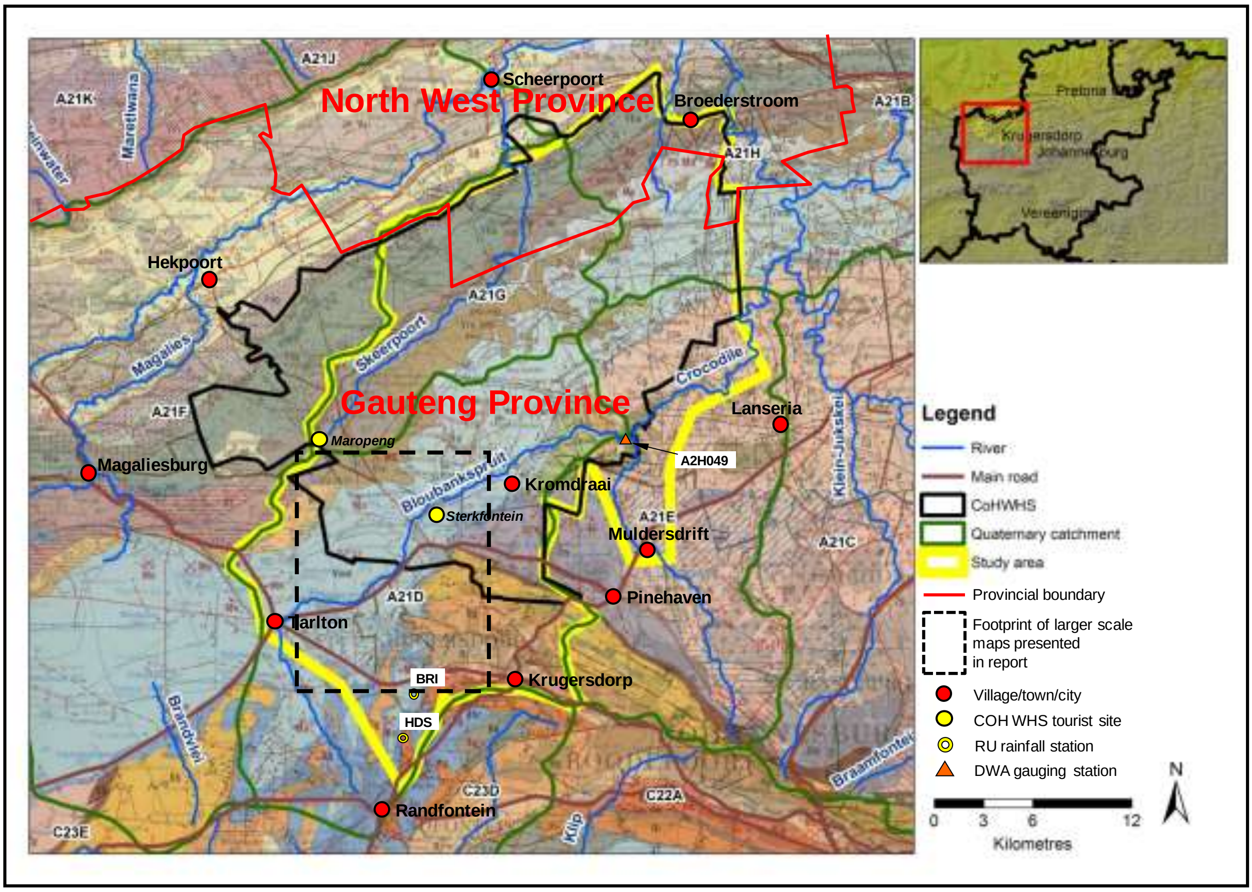


Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

2 TIMELINE OF KEY EVENTS

It is considered appropriate to contextualise the material presented and discussed in this report in terms of an updated timeline of key events relevant to the reporting period. The timeline presented in **Figure 2** begins with the inscription of the COH property as a World Heritage Site in 1999. The most recent landmark event on the timeline is the unveiling of the *Homo naledi* remains at Maropeng on 10 September 2015. This find has generated a considerably greater focus on the COH internationally, and places an even greater burden on the water resources monitoring programme to deliver a rigorous and robust evaluation of impacts on the receiving surface and subsurface water resources.

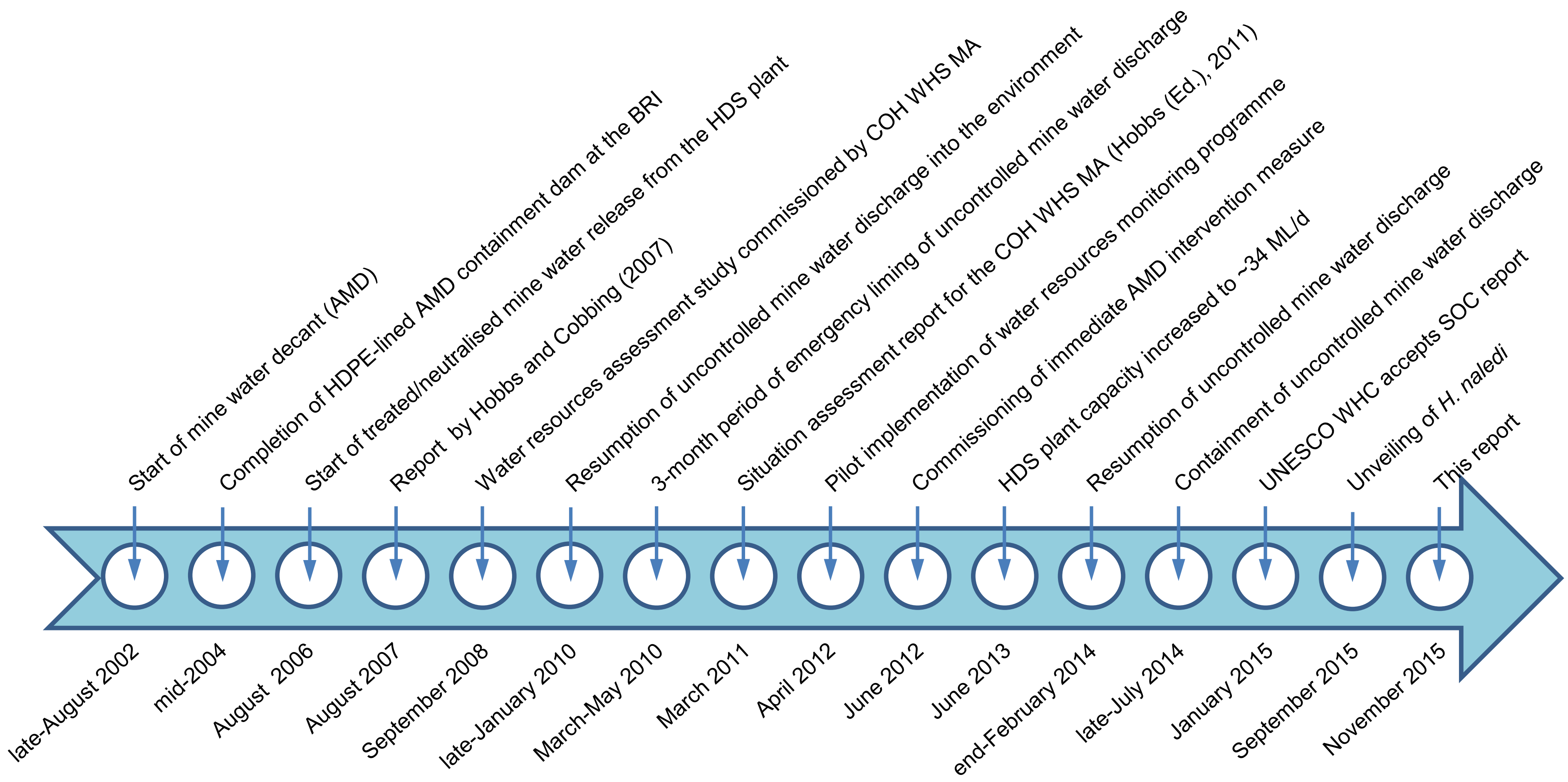


Figure 2 Updated timeline of events relevant to this report

3 RAINFALL

The monthly precipitation record for the period October 2008 to September 2015 of the Sibanye Gold (SG) rainfall station HDS (**Figure 3**) reveals the wetter than normal 2010–'11 and 2013–'14 summer rainfall seasons (**Figure 4**) and, by comparison, the drier than normal 2014–'15 summer. Of relevance to the current reporting period is the rainfall experienced in July (~28 mm) and September (~38 mm), rendering the 2014–'15 winter the wettest since 2009. The significance of especially the latter event is discussed in **Section 5.3**.

Also shown in **Figure 3** and **Figure 4** are the contemporary rainfall data recorded by the DWS cumulative gauging station located at Sterkfontein Caves. Data for the period June 2010 to September 2015 were provided by the DWS. The common monthly rainfall record (n = 64) for the HDS and Sterkfontein Caves stations indicates a good correlation ($R^2 = 0.90$) (**Figure 5**).

Figure 5 confirms earlier observations (Hobbs, 2012; 2013a; 2013b; 2014a; 2014b; 2015a) that monthly rainfall to the north of the continental divide is generally ~10–15% less than that measured on the divide.

The ~66 mm of rainfall experienced in the latter part of the 2014–'15 winter appears to have had little influence on the volume of mine water rising in the locus of decant. This has remained considerably reduced since mid-2014, with mine water management efforts successfully containing and treating this water, and maintaining the curtailed discharge of raw mine water into the environment. It remains to be seen what the coming 2015–'16 wet season, which it is forecast will experience the effects of a severe El Niño Southern Oscilation (ENSO) event, will produce.

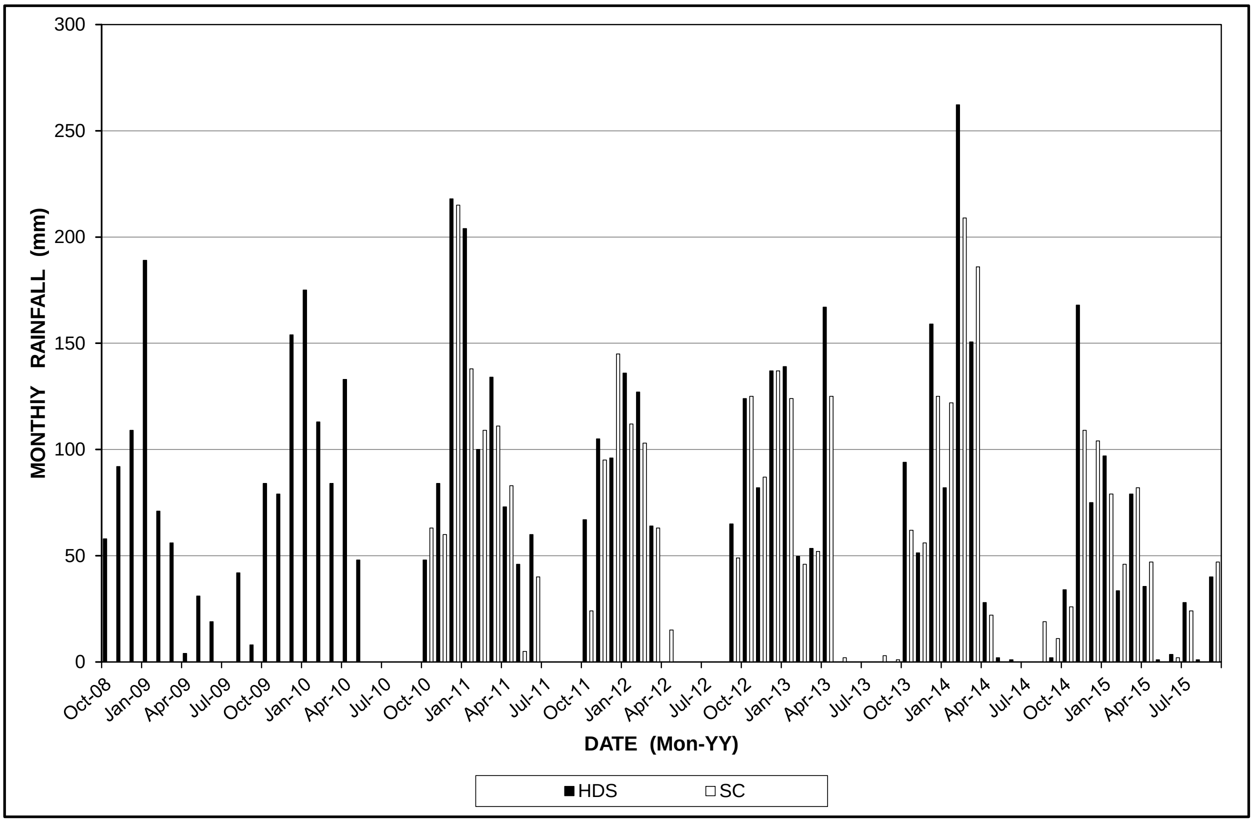


Figure 3 Monthly precipitation at the SG rainfall monitoring station HDS and the available contemporary record for the Sterkfontein Caves station in the period October 2008 to September 2015

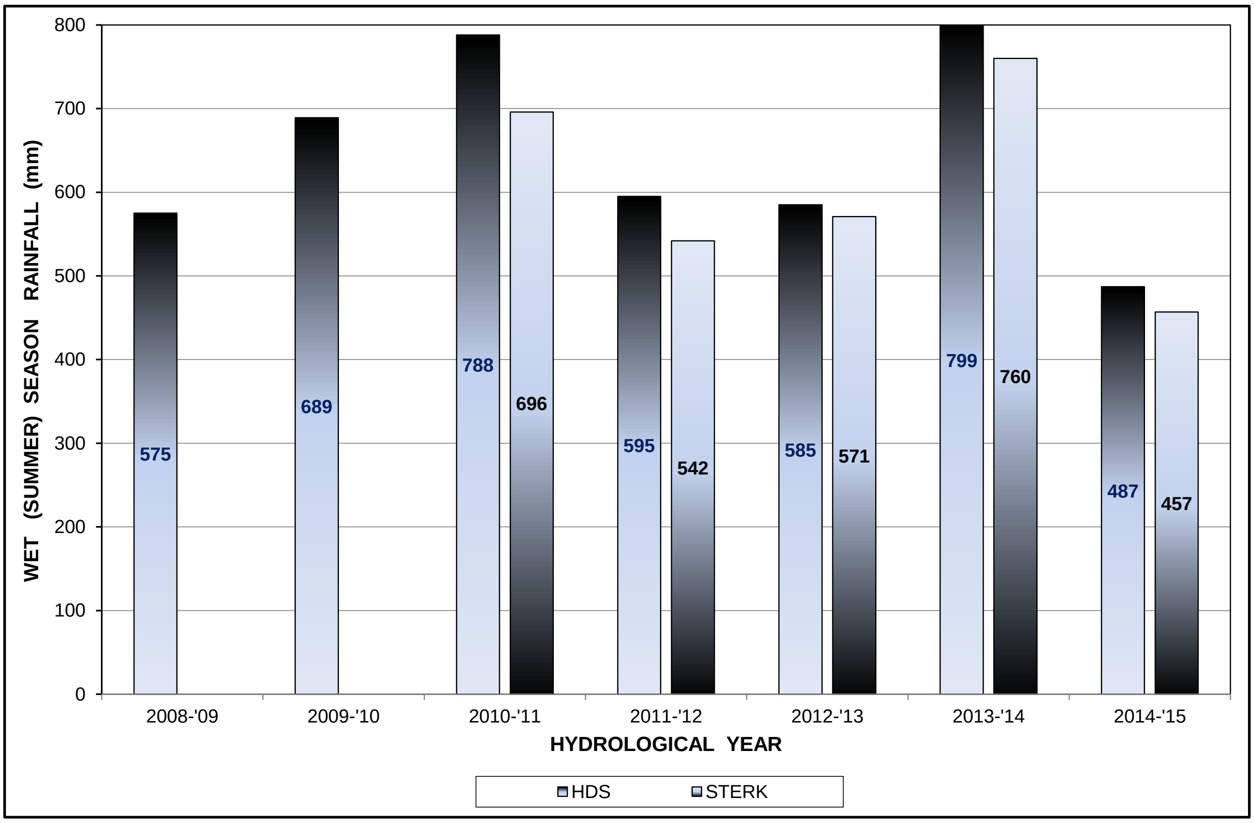


Figure 4 Total wet season (summer) rainfall at the HDS plant in the past seven hydrological years, also showing the comparison with that for the available contemporary Sterkfontein Caves record

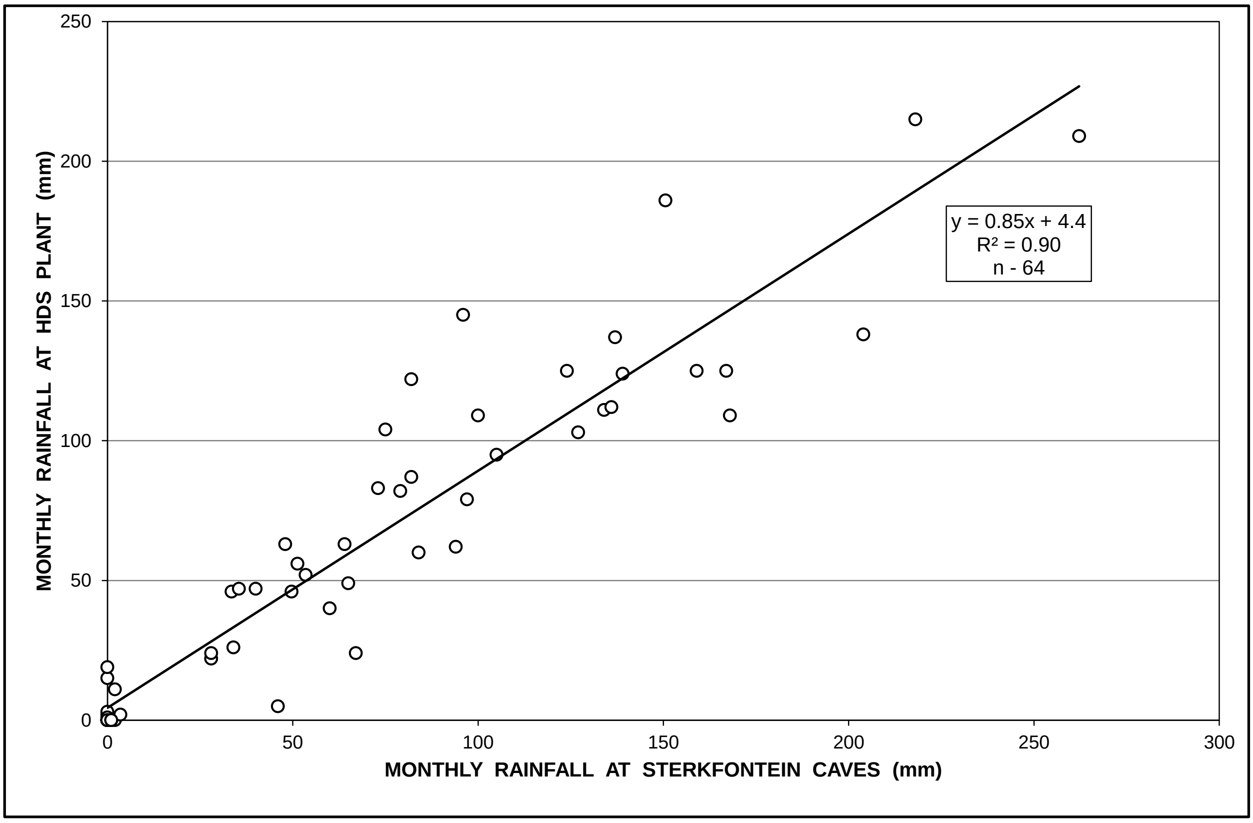


Figure 5 Correlation of monthly rainfall at Sterkfontein Caves with that at the HDS plant in the mine area

4 SURFACE WATER HYDROLOGY

4.1 Physical Hydrology

4.1.1 Surface Water Discharge

The discharge of the Bloubank Spruit system is gauged by the DWS at station A2H049 located ~700 m before the confluence with the Crocodile River (**Figure 1**). The 43-year record of this catchment (quaternary A21D) provides the monthly discharge statistics presented in **Table 1**.

Table 1 Statistical analysis of Bloubank Spruit monthly discharge data gauged at station A2H049 in the period October 1972 to September 2015

Variable	**Month**											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	41	41	42	42	43	43	43	42	43	43	42	42
Minimum	0.682	0.815	0.711	0.721	0.706	0.828	0.886	0.847	0.894	0.939	0.890	0.770
5%ile	0.784	0.846	1.041	1.097	0.898	1.049	1.182	0.986	0.956	0.958	0.914	0.800
Mean	1.847	1.858	2.259	2.696	2.645	2.967	2.399	2.250	2.065	2.038	1.919	1.789
Median	1.556	1.740	1.962	2.419	1.951	2.489	1.985	1.844	1.746	1.640	1.603	1.502
95%ile	3.873	2.961	4.526	5.425	6.424	8.131	5.446	4.911	4.174	4.104	3.659	3.509
Maximum	4.211	4.577	5.900	12.079	10.619	11.351	6.081	5.373	5.166	4.754	4.055	4.342
SD	0.935	0.840	1.117	1.958	1.938	2.236	1.312	1.205	0.982	0.938	0.874	0.888
CoV (%)	50.6	45.2	49.5	72.6	73.3	75.4	54.7	53.6	47.6	46.0	45.6	49.7

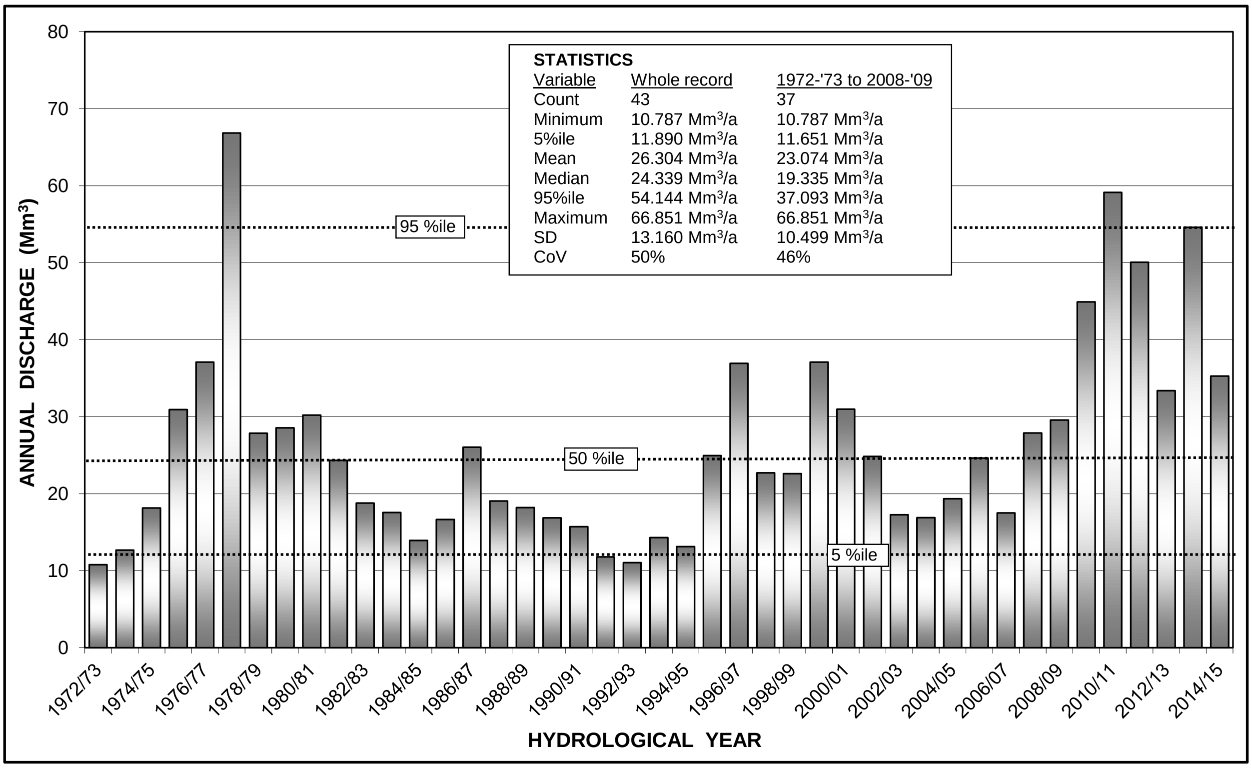
All units are Mm^3 unless otherwise indicated.

Analysis excludes months with missing and station rating exceedance data, but includes unaudited (recent) and estimated data

The discharge per hydrological year shown in **Figure 6** indicates that the 2013–'14 hydrological year witnessed the 3rd highest runoff (54.6 Mm^3) after the 66.9 Mm^3 of the 1977–'78 and the 59.1 Mm^3 of the 2010–'11 hydrological years in the historical record of this catchment. By comparison, the 2012–'13 and 2014–'15 hydrological years produced modest discharges of ~33.4 and ~35.3 Mm^3 respectively, in keeping with respective lower summer (wet season) rainfalls of ~580 and ~470 mm (**Figure 4**).

The instantaneous monthly flow pattern at station A2H049 for the complete record October 1972 to September 2015 is shown in **Figure 7**. This reveals a comparatively constant lowest value of 0.25 m^3/s. Evident in the hydrograph (**Figure 7**) are distinct recession curves following peak discharge events. Station A2H049, however, is not only located a substantial distance (5–10 km) downstream of its principal perennial sources, the ~130 L/s Zwartkrans and ~300 L/s Kromdraai springs, but also receives the discharge of other 'lesser' springs (e.g. the ~60 L/s Plover's Lake and ~3 L/s Aquamine springs) and ephemeral tributaries such as the Honingklip and Tweefontein spruits. These circumstances negate a simple correlation between spring discharge and rainfall.

A closer inspection of the instantaneous flow data record generated at station A2H049 (**Figure 7**) reveals a typical recession curve following the exceptionally high discharge experienced in March 2014. These circumstances, in particular the absence of high monthly discharge rates in the course of the 2014–'15 wet season, account in part for the more recent successful control and management of mine water discharge from the mine area.



STATISTICS

Variable	Whole record	1972-'73 to 2008-'09
Count	43	37
Minimum	10.787 Mm³/a	10.787 Mm³/a
5%ile	11.890 Mm³/a	11.651 Mm³/a
Mean	26.304 Mm³/a	23.074 Mm³/a
Median	24.339 Mm³/a	19.335 Mm³/a
95%ile	54.144 Mm³/a	37.093 Mm³/a
Maximum	66.851 Mm³/a	66.851 Mm³/a
SD	13.160 Mm³/a	10.499 Mm³/a
CoV	50%	46%

Figure 6 Graph of Bloubank Spruit annual discharge gauged at station A2H049 in the period October 1972 to September 2015

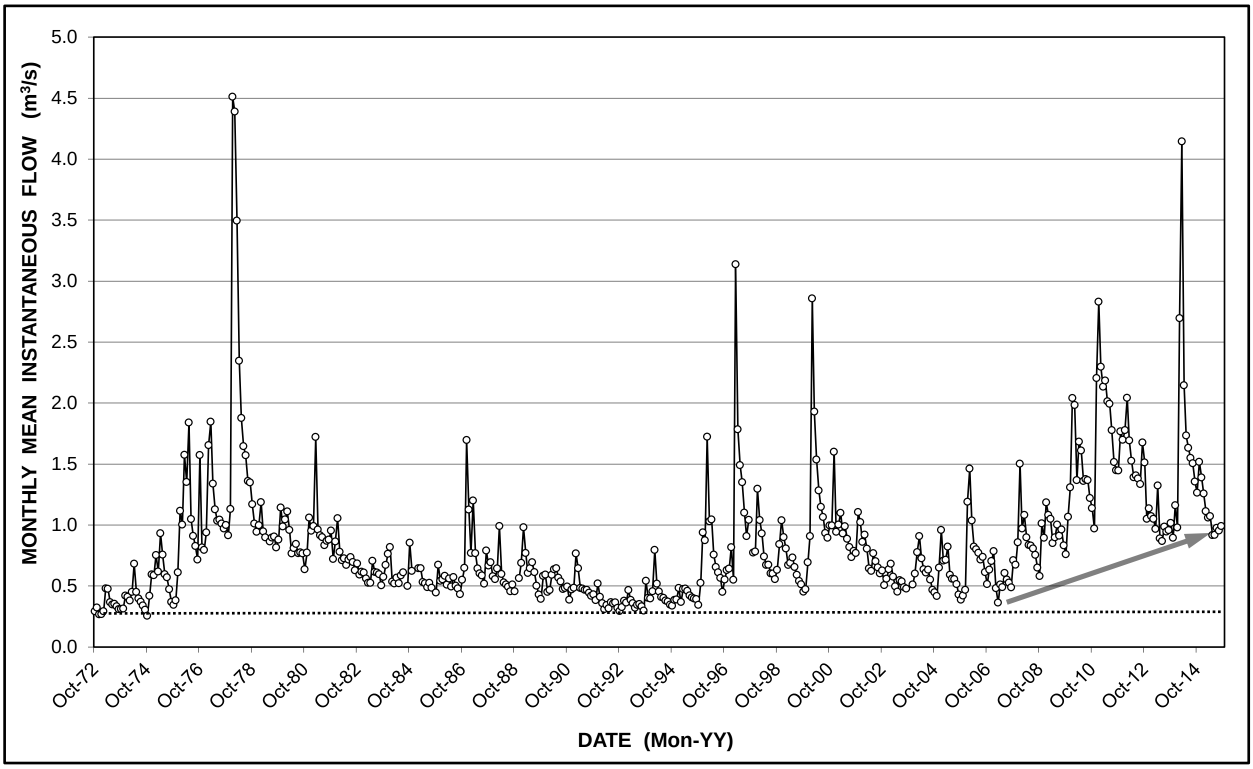
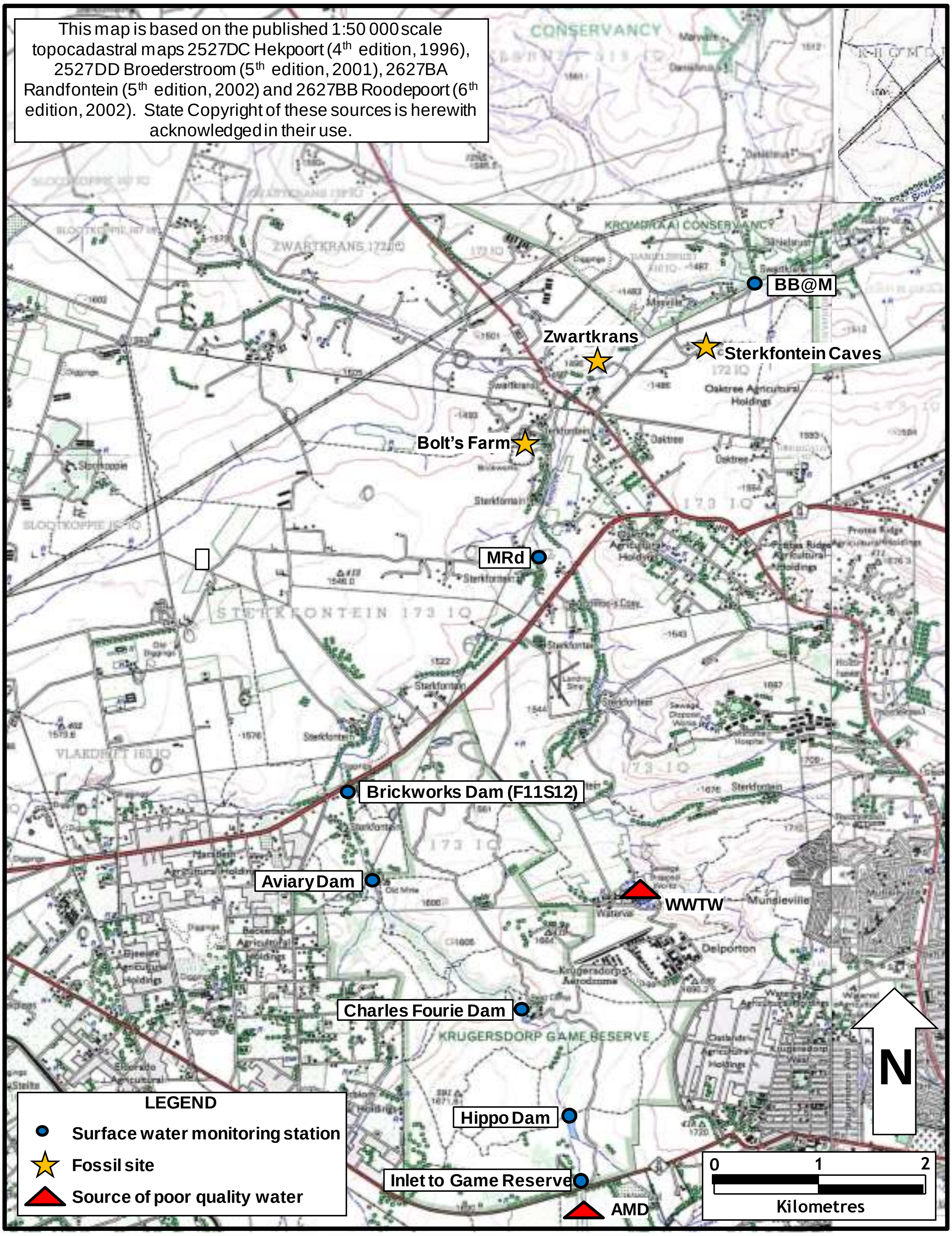


Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to September 2015

4.1.2 Surface Water Fluxes

In-stream synoptic discharge measurements (SDMs) made on 31 occasions (**Annexure A**) at stations F11S12 at the lower end of the Tweelopie Spruit, and MRd ~3.9 km further downstream on the Riet Spruit (**Figure 8**), quantify and elucidate the magnitude of surface water loss to the karst aquifer.



This map is based on the published 1:50 000 scale topocadastral maps 2527DC Hekpoort (4th edition, 1996), 2527DD Broederstroom (5th edition, 2001), 2627BA Randfontein (5th edition, 2002) and 2627BB Roodepoort (6th edition, 2002). State Copyright of these sources is herewith acknowledged in their use.

Figure 8 Locality map of surface water quantity and quality monitoring stations

The graphs of the SDM results (**Figure 9** and **Figure 10**) confirm previous measurements that indicate a minimum ingress converging at a value of ~14 ML/d, equivalent to ~42 L/s/km.

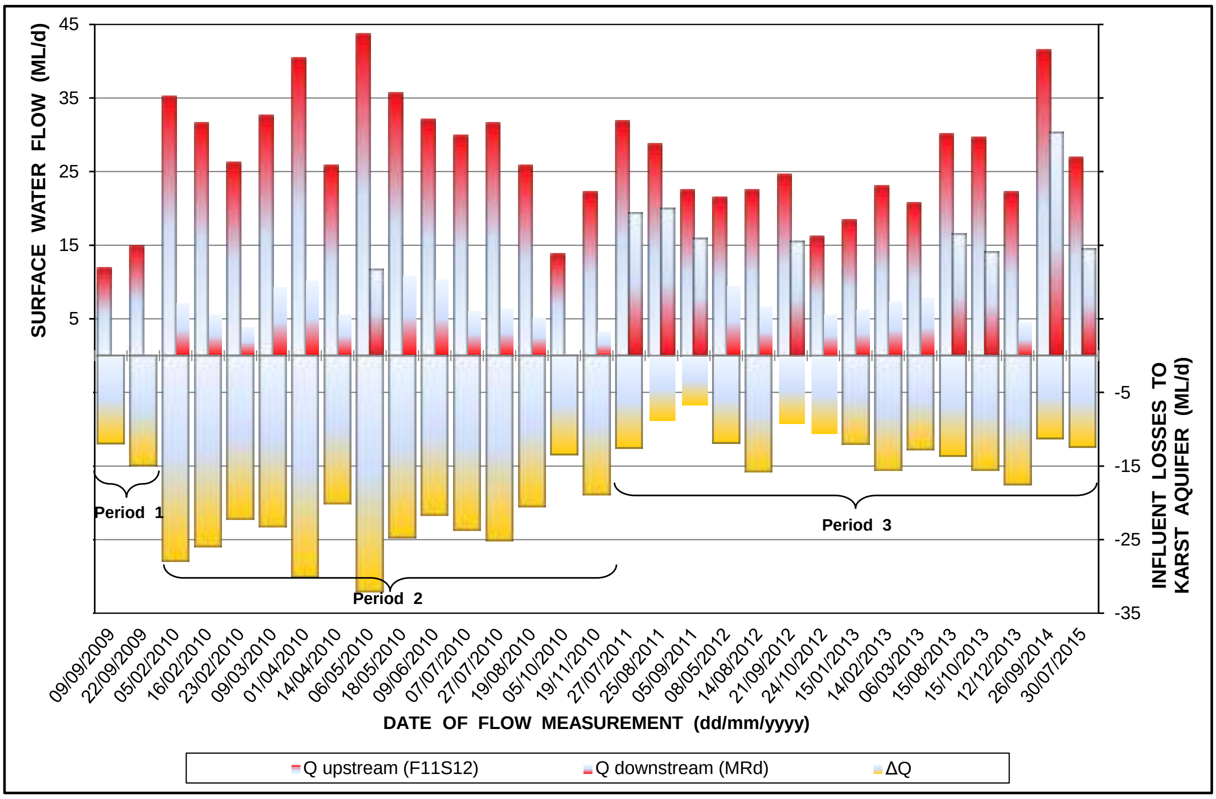


Figure 9 Graph of stream flow and influent losses to the karst aquifer in the lower Riet Spruit valley

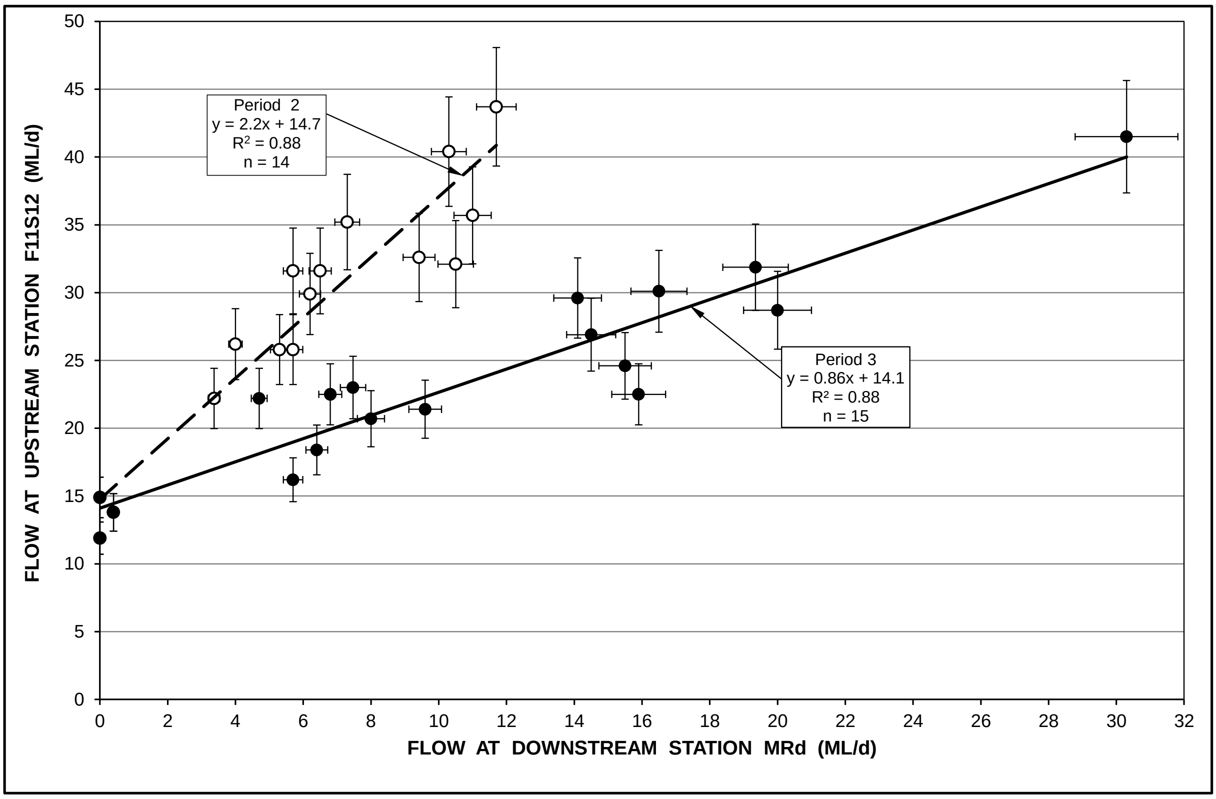


Figure 10 Correlation of stream flow at stations F11S12 and MRd in the Riet Spruit valley, with vertical error bars denoting ±10% at F11S12 and horizontal bars ±5% at MRd

It is evident that the different slopes of the Period 2 and Period 3 regression lines (**Figure 10**) indicates a significant ~94% reduction in allogenic recharge from ~70 L/s/km to ~36 L/s/km between these two distinct time periods. Whilst this is to the advantage of the receiving karst aquifer under circumstances where the quality (chemistry) of this water is strongly influenced by a mine water composition, an explanation of this phenomenon remains elusive.

After the mean loss of ~12 ML/d of mine water as allogenic recharge to the karst aquifer in Period 3, 13 ML/d (150 L/s) of mine water on average passed station MRd as surface flow. This is bracketed by minimum and maximum values of 4.7 ML/d (54 L/s) and 30.3 ML/d (351 L/s) respectively. Even the latter value is significantly less (by ~55%) than the mine water losses to the karst aquifer in the range 67.4–79.5 ML/d reported by Abiye et al. (2015) for a stream reach downstream of MRd. These circumstances prompted a discussion of the Abiye et al. (2015) data by Hobbs (2015b). More significant, however, is the progression associated with the surface flow at station MRd in each of the three periods of analysis. This is illustrated in **Figure 11**. The progression is significant for its indication of the increasing volume of treated/neutralised mine water contributing directly to surface flow downstream, and therefore its increasing importance as an additional allogenic water budget component in quaternary catchment A21D.

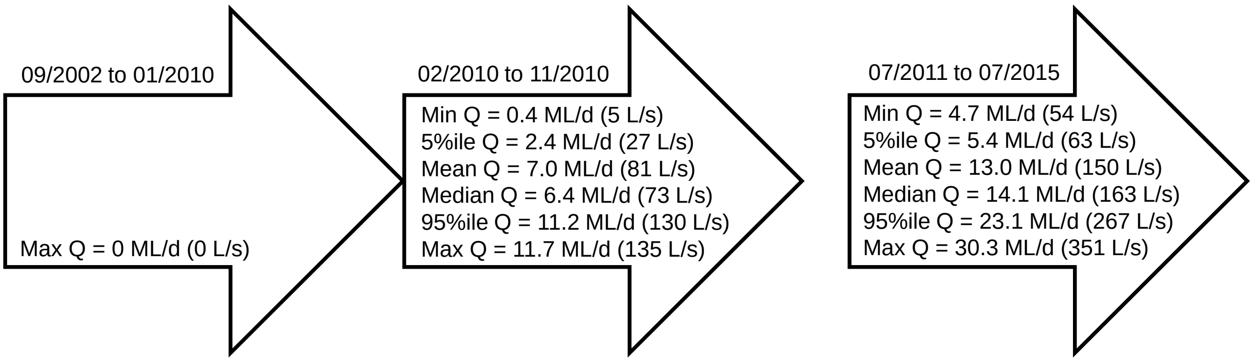


Figure 11 Episodic progression of surface flow measured at station MRd since the start of mine water decant

4.2 Chemical Hydrology

4.2.1 Tweelopie Spruit and Riet Spruit

The chemistry of surface water in the Tweelopie Spruit continues to be monitored by Sibanye Gold at five localities from where it leaves the mine property down to its confluence with the Riet Spruit at Glen Almond north of the Krugersdorp Game Reserve (KGR), a distance of ~6.6 km. These stations are identified in **Figure 8** as (a) the inlet to the KGR, (b) the Hippo Dam, (c) the Charles Fourie Dam, (d) the Aviary Dam and (e) the Brickworks Dam (station F11S12). The weekly monitoring of the variables pH, electrical conductivity (EC) and sulphate (SO_4) dates back to May 2004. The results of this monitoring, excluding the inlet to the KGR location[1], the Charles Fourie Dam[2] and the Aviary Dam[3], are presented in **Figure 12** (pH), **Figure 13** (EC), **Figure 14** (SO_4), **Figure 15** (Fe) and **Figure 16** (Mn).

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[1] These data are excluded for their close proximity to the Hippo Dam location, and consideration of the fact that the residence time of this water in the Hippo Dam renders the data for the latter location more representative of the surface water entering the Tweelopie Spruit.

[2] These data are excluded as their value to the assessment presented in this report is redundant.

[3] These data are excluded as they reflect excellent congruence with the Brickworks Dam (F11S12) data.

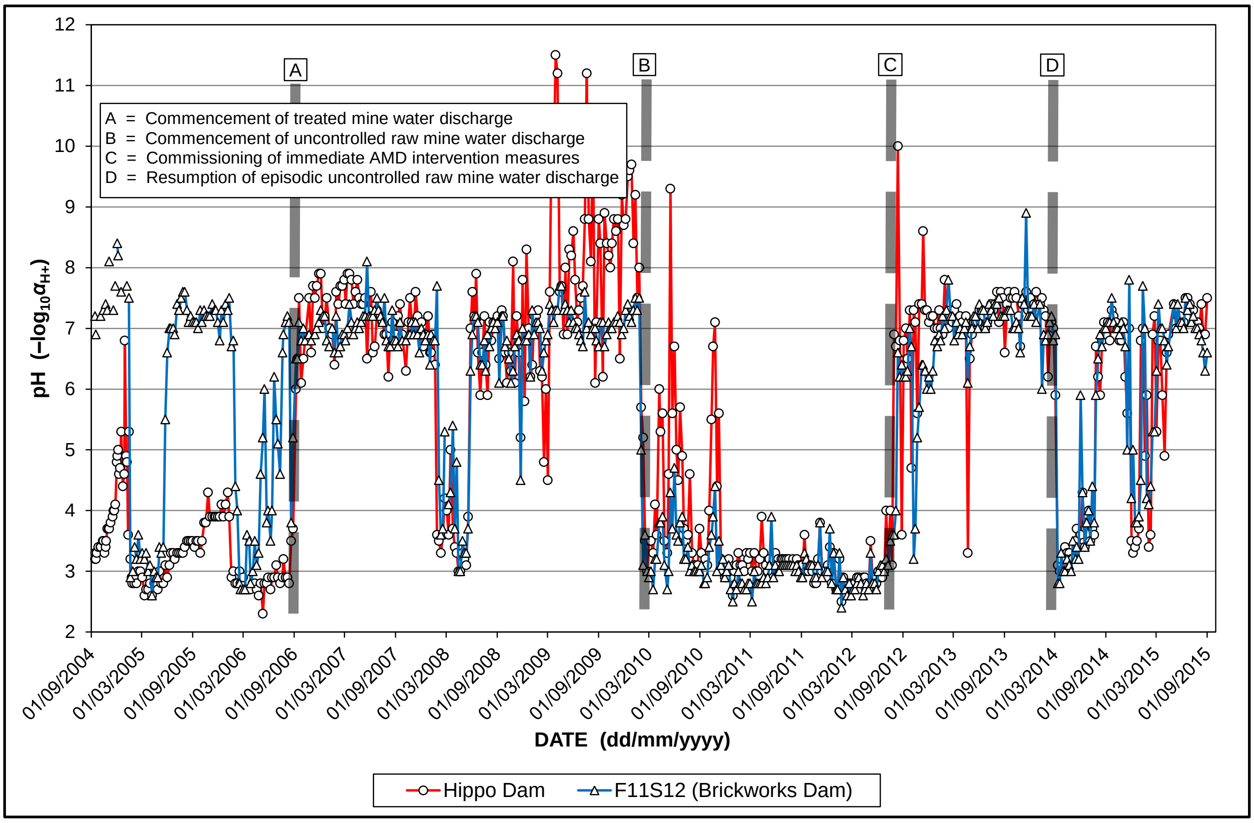


Figure 12 Pattern of Tweelopie Spruit pH values in the period September 2004 to September 2015

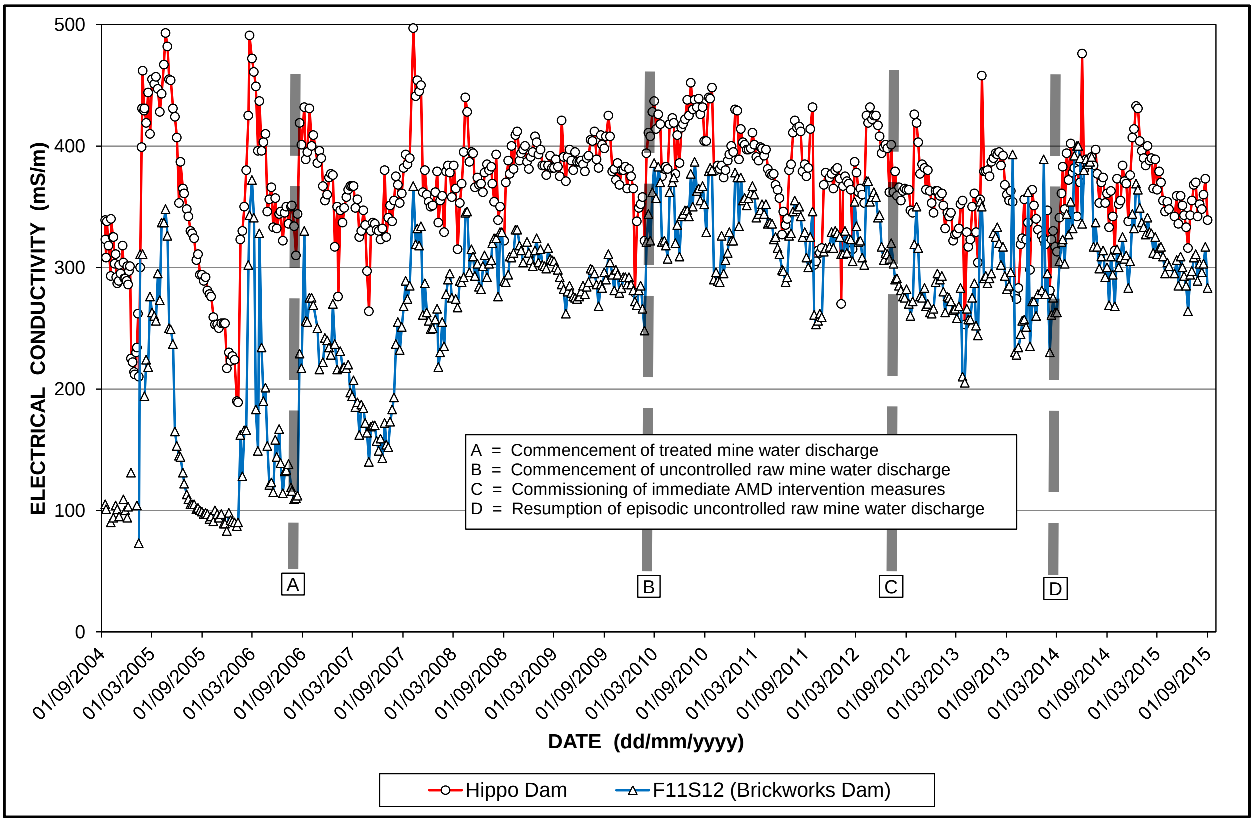


Figure 13 Pattern of Tweelopie Spruit EC values in the period September 2004 to September 2015

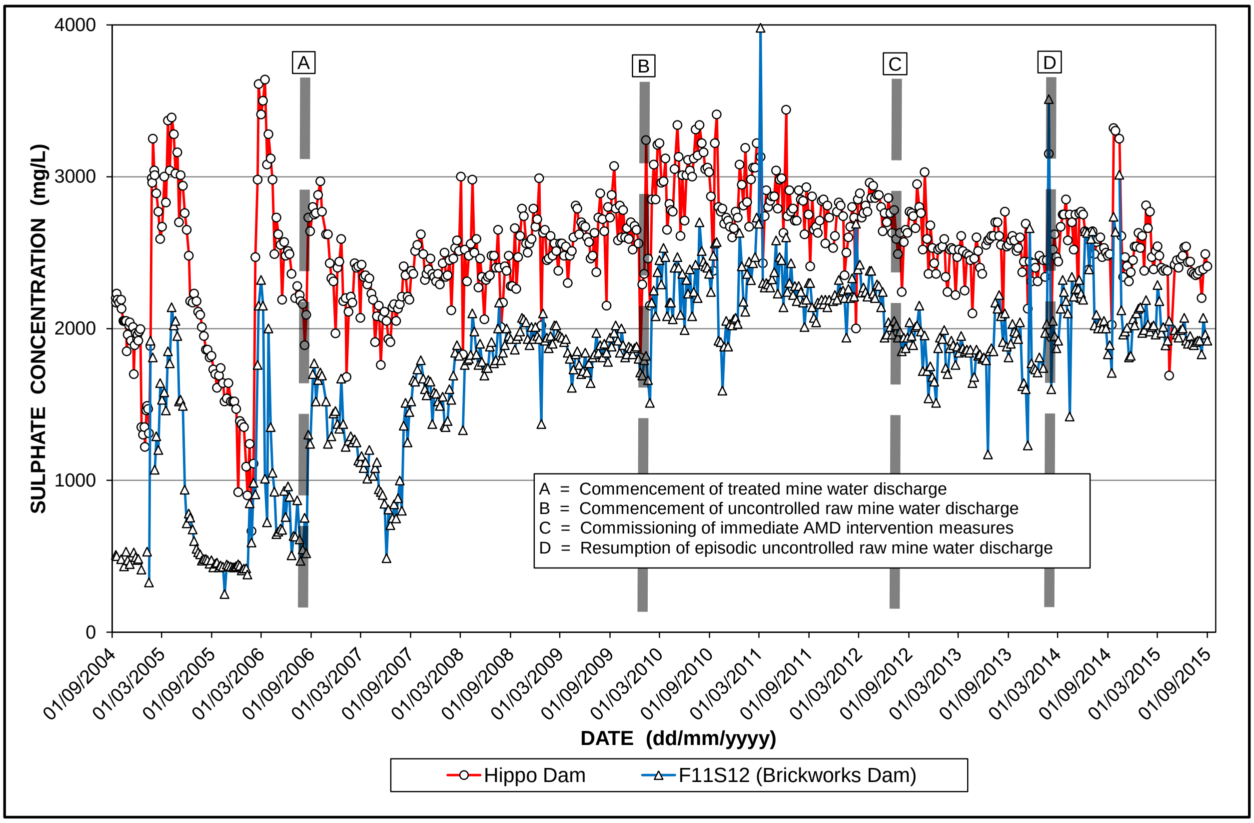


Figure 14 Pattern of Tweelopie Spruit SO_4 values in the period September 2004 to Sepember 2015

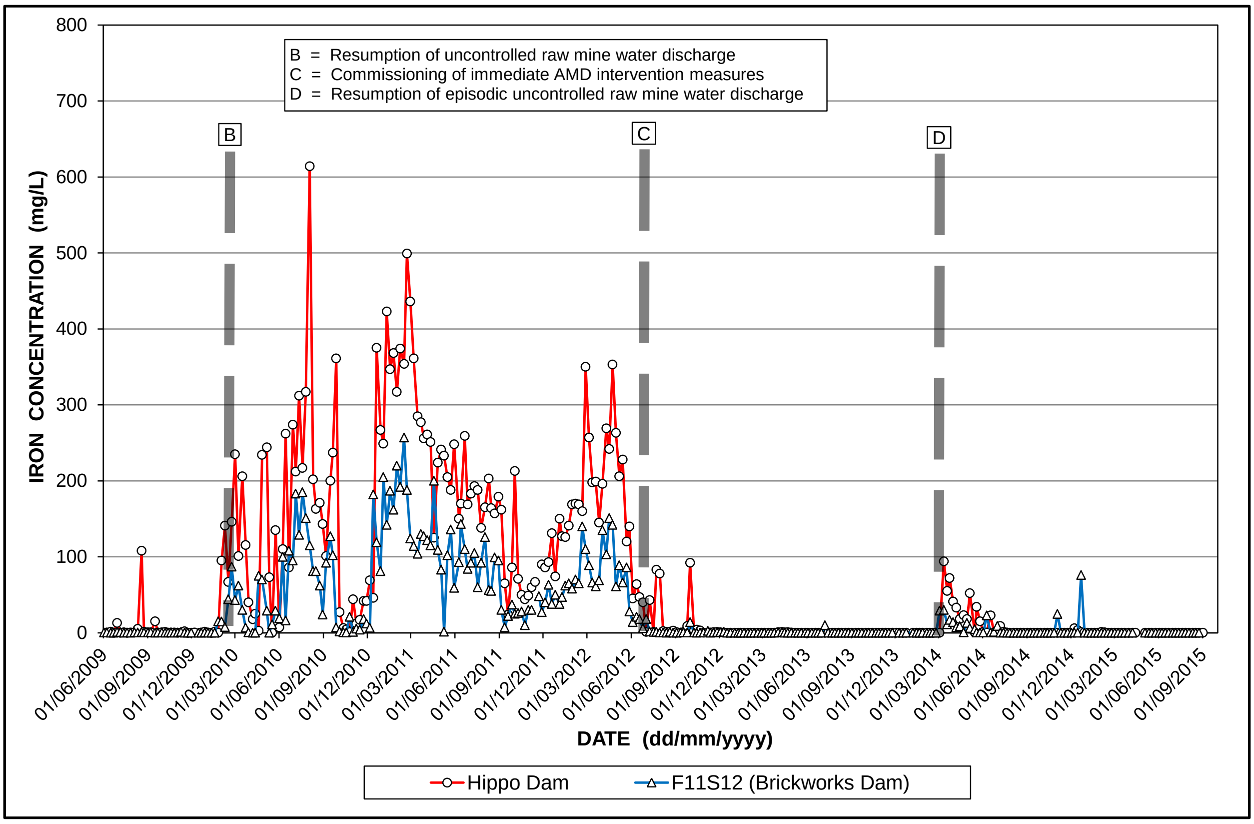


Figure 15 Pattern of Tweelopie Spruit Fe values in the period June 2009 to September 2015

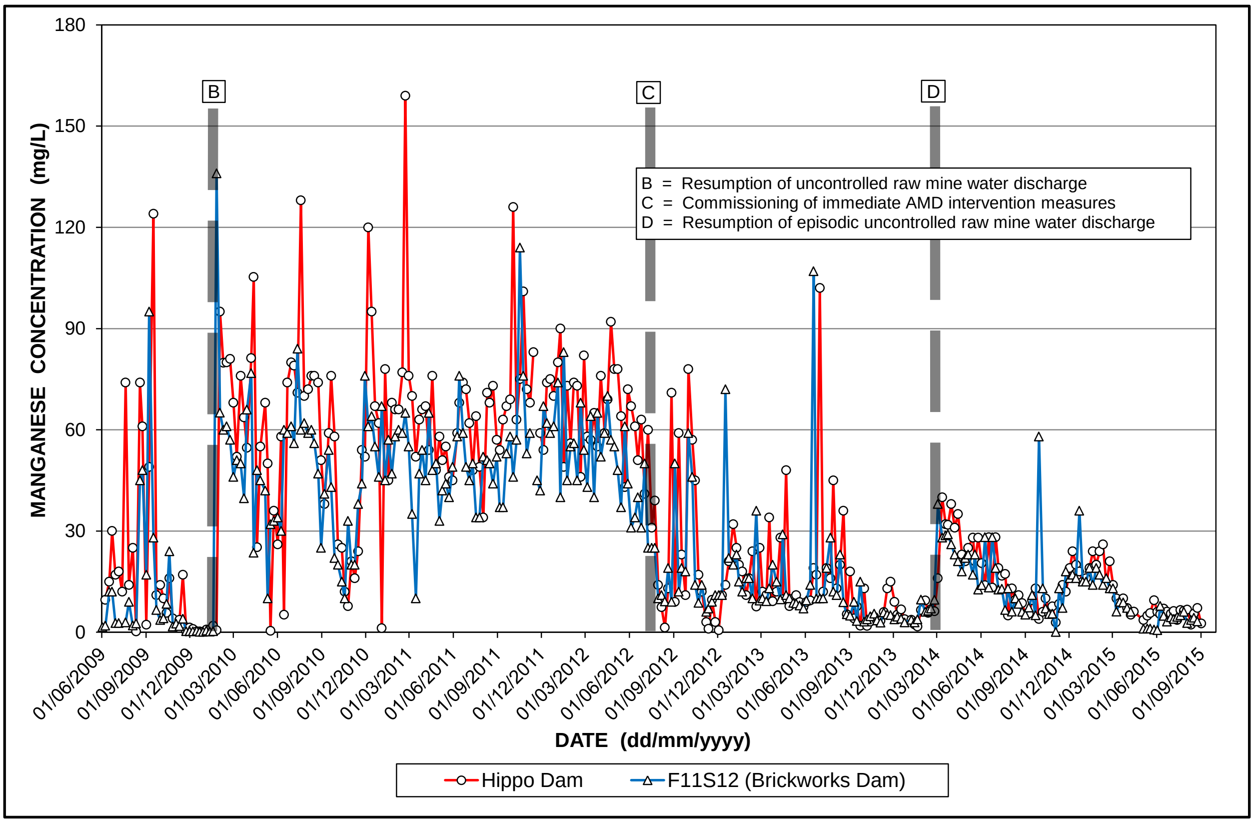


Figure 16 Pattern of Tweelopie Spruit Mn values in the period June 2009 to September 2015

The patterns revealed in **Figure 12** to **Figure 16** reflect the temporal variation and trend in the respective variable values in surface water through the KGR. The period(s) of most severe and sustained mine water impact have previously been discussed in Hobbs (2014b). Of relevance to the period spanned by this report is the somewhat equivocal pattern reflected in the most recent portion of the record, i.e. since November 2014. This is particularly evident in the pH values (**Figure 12**), which reveal regular excursions to pH values in the range 3–5 interspersed with near-neutral values. These circumstances are explained by the episodic occurrence of uncontrolled raw mine water discharge, and which qualify the observation that water quality conditions in the Tweelopie Spruit had recovered to pre-March 2014 conditions by the end of the previous reporting period (Hobbs, 2014b). This qualification finds support in the analysis of the data sets for each of the four periods of record A–B, B–C, C–D and D– defined by the divisions recognised in **Figure 12** to **Figure 16**, and which returns the information presented in **Table 2** and **Annexure C**.

Table 2 and **Annexure C** reveal the following salient differences between the data sets:

- the greater variability in pH values at both stations associated with period D– , which is attributed to the episodic occurrence of uncontrolled raw mine water discharge;
- the generally greater variability in analyte concentrations at the upstream Hippo Dam station compared to the F11S12 station, which is attributed to the closer proximity of this locality to the Sibanye “end-of-pipe”; and
- the typically lower analyte concentrations at the downstream F11S12 station compared to the Hippo Dam station, which is attributed to the modest addition of better quality karst groundwater via springs and seeps to the Tweelopie Spruit, as well as hydrochemical reactions in the water driven by factors such as aeration/oxygenation where cascading conditions occur.

Table 2 Summary statistics of period-related surface water chemistry variability in the Tweelopie Spruit

Variable	**Statistical Parameter**	**Hippo Dam**				**F11S12 (Brickworks Dam)**			
		A—B$^{(1)}$	**B—C$^{(2)}$**	**C—D$^{(3)}$**	**D—$^{(4)}$**	**A—B$^{(1)}$**	**B—C$^{(2)}$**	**C—D$^{(3)}$**	**D—$^{(4)}$**
pH $(-\log_{10}\alpha_{H+})$	n	176	129	83	79	173	128	83	79
	5%ile	3.6	2.8	5.9	3.2	3.9	2.7	5.3	3.0
	Mean	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	6.7	6.9	3.0	7.0	6.6
	95%ile	9.3	5.7	7.6	7.4	7.4	3.9	7.4	7.4
	SD	1.5	1.0	0.8	1.7	0.9	0.4	0.9	1.6
	CoV (%)	22.0	29.7	11.4	29.5	14.1	13.7	13.0	28.5
EC (mS/m)	n	175	129	83	79	172	128	83	79
	Mean	374	391	350	368	268	332	281	320
	Median	379	393	354	369	283	330	276	311
	95%ile	426	438	395	408	329	378	350	390
	SD	32	33	34.1	28	48	29	34	33
	CoV (%)	8.5	8.4	9.7	7.5	18.0	8.7	12.2	10.3
SO_4 (mg/L)	n	176	128	82	78	171	128	83	78
	Mean	2 448	2 846	2 520	2 525	1 636	2 264	1 879	2 086
	Median	2 460	2 815	2 525	2 490	1 760	2 240	1 870	2 015
	95%ile	2 82810	3 220	2 770	2 817	2 015	2 593	2 148	2 637
	SD	262	226	193	236	349	245	268	248
	CoV (%)	10.7	7.9	7.6	9.4	21.3	10.8	14.3	11.9
Fe (mg/L)	n	33	129	83	79	33	128	82	79
	Mean	4.7	168.4	2.490	6.4	0.3	72.9	0.466	3.5
	Median	0.4	163.0	0.030	0.03	0.2	64.0	0.075	0.02
	95%ile	13.8	365.2	3.090	42.1	0.8	186.3	1.000	23.1
	SD	18.8	116.2	13.146	17.0	0.3	57.7	1.896	10.6
	CoV (%)	399.1	69.0	527.9	265.3	94.4	79.1	407.2	300.8
Mn (mg/L)	n	34	129	83	79	33	128	83	79
	Mean	18.1	62.7	16.5	14.0	10.3	50.3	14.4	12.6
	Median	9.8	65.0	11.0	11.0	2.7	50.0	10.0	11.0
	95%ile	74.0	95.0	56.1	31.8	46.2	76.0	45.0	28.7
	SD	27.6	23.5	18.0	9.5	19.4	17.6	15.8	10.1
	CoV (%)	152.5	37.6	109.3	67.5	187.6	35.1	110.1	80.6

(1) 09/2006 – 01/2010 (2) 02/2010 – 07/2012 (3) 08/2012 – 02/2014 (4) 03/2014 – 09/2015

The EC, pH and SO_4 values measured (and derived in the case of SO_4) on the occasion of each SDM reported for stations F11S12 and MRd in **Annexure B**, are graphed in **Figure 17** (EC), **Figure 18** (pH) and **Figure 19** (SO_4). The EC and pH data reflect the elevated salinity values (>350 mS/m) and low pH values (<3) characteristic of a significant raw mine water impact on the surface water lost to the karst aquifer (**Section 4.1.2**) in the period mid-2010 to mid-2012. Similarly, **Figure 19** reflects the elevated contemporary SO_4 levels (>2 000 mg/L) in this water. The improvement in water quality since mid-2012 is equally evident. This is revealed by the standard deviation (SD) and coefficient of variation (CoV) values reported in **Table 2** for EC and SO_4 at station F11S12 for the period D–. These circumstances have prevailed to September 2015.

Figure 18 reveals the slightly lower pH values recorded at the downstream station F11S12 compared to at the Hippo Dam. This is attributed to hydrolysis reactions, in this instance the precipitation of iron out of the water to produce free hydrogen (H^+) ions, the increase in H^+-ion activity driving down the pH. Note in this regard that **Table 2** indicates the occurrence in the period D– of significant Fe concentrations (~42 mg/L at the 95%ile level) at the Hippo Dam location, compared to the ~23 mg/L at this level at station F11S12.

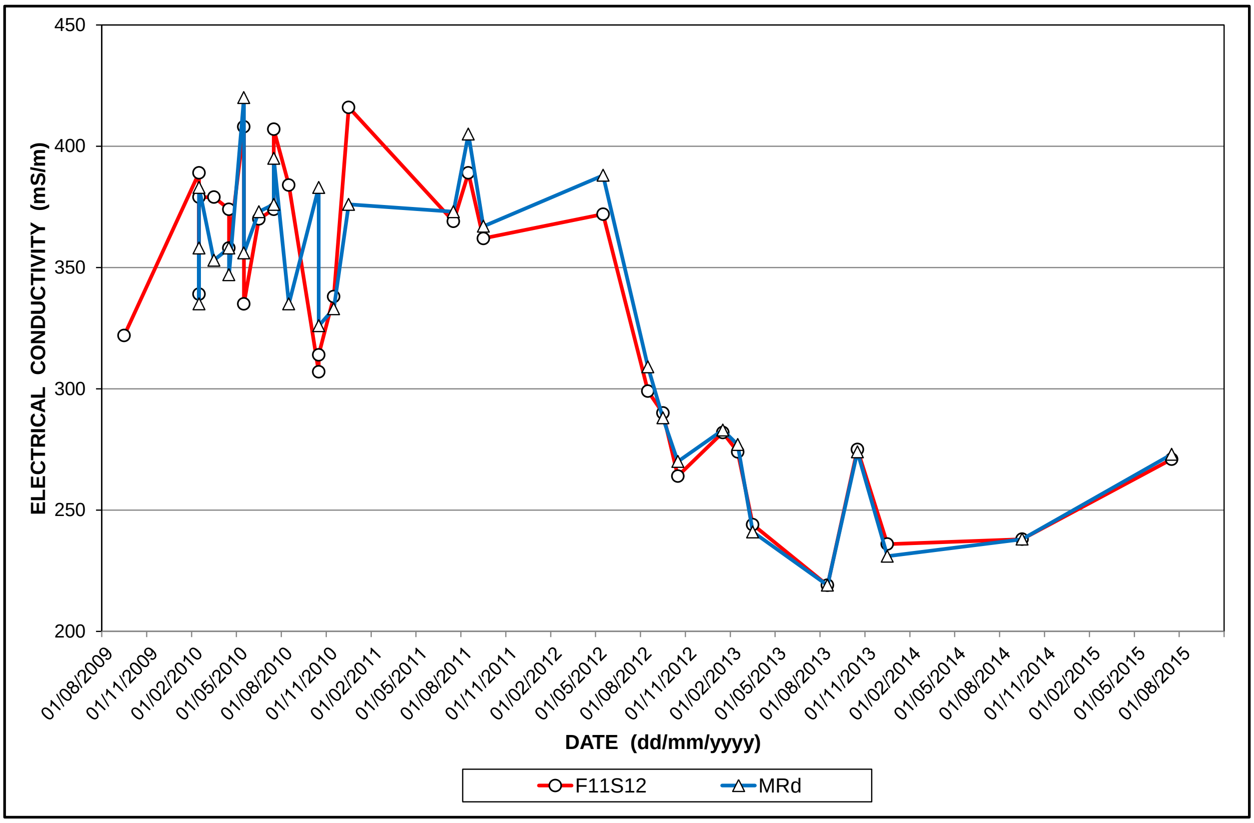


Figure 17 Pattern of EC values at stations F11S12 and MRd as reported in **Annexure B**

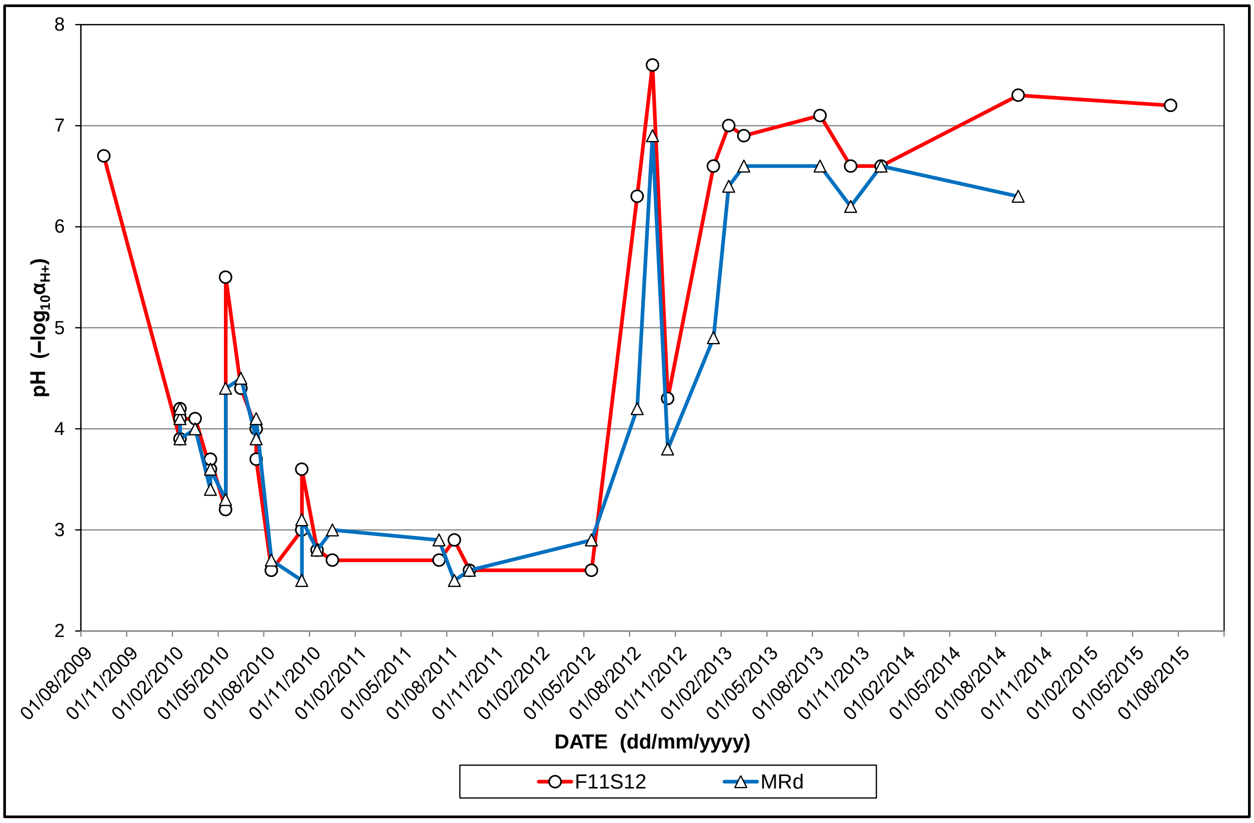


Figure 18 Pattern of pH values at stations F11S12 and MRd as reported in **Annexure B**

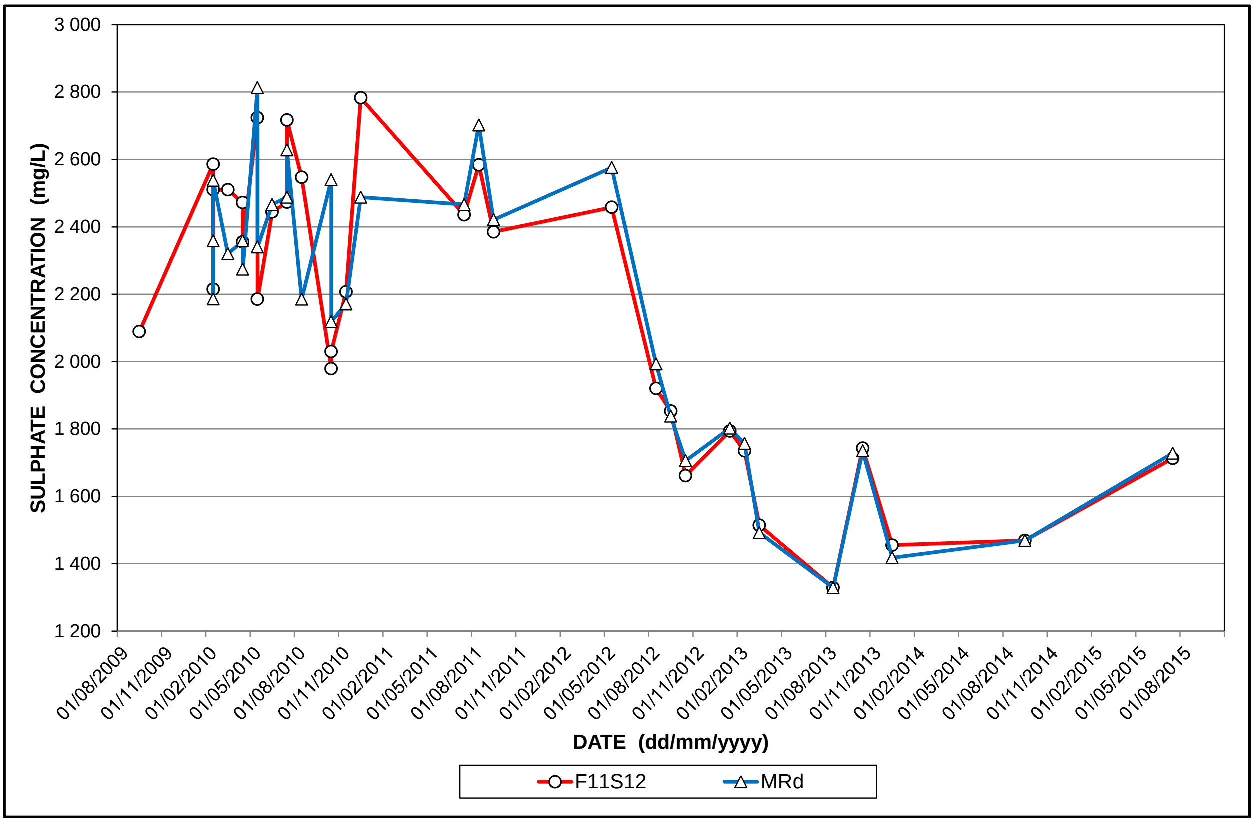


Figure 19 Pattern of derived SO_4 values at stations F11S12 and MRd as reported in **Annexure B**

4.2.2 Bloubank Spruit

An analysis of the surface water chemistry data for DWS flow gauging station A2H049 at the lower end of the Bloubank Spruit system, provides the synoptic overview presented in **Table 3**. None of the variables/analytes reported in **Table 3** exceed the respective SANS (2015a; 2015b) health-related limit where specified.

Table 3 Synoptic overview of Bloubank Spruit water chemistry at station A2H049 in the period May 1979 to July 2015

Variable	**Statistical Parameter**							**SANS (2015a)$^{(1)}$**
	n	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	
pH ($-\log_{10}\alpha_{H+}$)	1 029	7.4	—	8.2	8.5	0.3	4	5.0–9.7
EC (mS/m)	1 129	51.1	62.0	60.9	77.5	19.2	31	<170
TDS (mg/L)	862	353.7	447.3	449.0	529.6	65.5	15	<1 200
Ca (mg/L)	945	43.5	55.9	53.9	86.2	14.1	25	n.s.
Mg (mg/L)	943	25.2	33.1	32.6	42.6	5.8	17	n.s.
Na (mg/L)	916	10.0	22.6	22.3	35.5	7.7	34	<200
K (mg/L)	924	0.7	2.0	1.8	3.7	1.0	48	n.s.
Cl (mg/L)	950	20.1	32.2	32.3	41.1	6.1	19	<300
SO_4 (mg/L)	947	65.4	100.9	84.3	251.7	63.8	63	<500
HCO_3 (mg/L)	945	143.6	190.2	195.7	219.5	26.1	14	n.s.
NO_3+NO_2 (mg N/L)	991	3.011	4.583	4.403	6.468	1.709	37	<11
PO_4 (mg P/L)	1 020	0.005	0.093	0.056	0.316	0.105	112	n.s.
Si (mg/L)	1 023	5.05	5.96	5.95	6.83	0.81	14	n.s.
Fe (mg/L)	116	0.004	0.029	0.014	0.118	0.047	164	<2
Mn (mg/L)	116	0.001	0.113	0.002	0.145	0.643	569	<0.5
Al (mg/L)	111	0.003	0.044	0.011	0.091	0.202	455	<0.3

(1) Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person

The surface water quality monitoring carried out at the Nedbank Olwazini Estate complex (station NOE in **Figure 20**) provides, amongst others, a valuable ‘reference’ of nutrient and bacteriological water quality in the lower reaches of the Bloubank Spruit.

The NOE data is particularly relevant under circumstances where discharge quality data for the Percy Stewart Wastewater Treatment Works remains embargoed by the local municipality.

The NOE monitoring has further significance for its location in proximity to where the Bloubank Spruit leaves the karst environment to traverse older strata down to its confluence with the Crocodile River. The NOE data therefore represent almost exclusively that of water which drains the headwater allogenic and karst portions of the catchment. The pH values and nutrient (NO_3-N, PO_4-P and COD) and bacterial levels in Bloubank Spruit water at the NOE complex in the period January 2009 to September 2015 (>6 years) are given in **Table 4**. The temporal pattern of the pH and bacterial variables is illustrated in **Figure 21**.

Table 4 Analysis of Bloubank Spruit water nutrient and bacterial content at the NOE property in the period January 2009 to September 2015

Variable / Analyte	**Statistical Parameter**								**SANS (2015a)$^{(1)}$**	**TWQR$^{(2)}$** **TWQR$^{(3)}$**
	n	**1%ile**	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**		
pH $(-\log_{10}\alpha_{H+})$	77	—	7.5	—	8.0	8.5	0.3	4	5.0–9.7	—
NO_3 (mg N/L)	68	—	2.9	7.4	6.8	**14.5**	3.4	45	<11	—
O-PO_4 (mg P/L)	77	—	0.0	0.3	0.3	0.8	0.3	95	n.s.	—
COD (mg/L)	59	—	6.0	47.6	33.0	133.5	48.4	102	n.s.	—
N:P (ratio)$^{(4)}$	65	—	7.2	51.5	28.8	144.9	105.9	205	—	—
Faecal coliforms (cfu/100 mL)	77	**20**	**39**	**850**	**310**	**3 664**	1 669	196	≤10 in 1% of samples	≤200$^{(2)}$ ≤130$^{(3)}$

(1) Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person.
(2) Target Water Quality Range for livestock watering as per DWAF (1996a).
(3) Target Water Quality Range for recreational water use as per DWAF (1996b).
(4) Derived from NO_3-N and PO_4-P values.
Bold text denotes value exceeds standard limit as described in note (1).

The faecal coliform count as far downstream as the NOE property reflects elevated levels even at the 1%ile level (**Table 4**). The association of higher faecal coliform levels with rainfall is evident in **Figure 21**. This suggests that significant municipal wastewater impacts on surface water bacteriological quality are driven by rainfall. The mean and median faecal coliform values of 850 and 310 cfu/100 mL respectively (**Table 4**), are compared to February 2013 *E. coli* levels of 980 and 1 553 MPN/100 mL obtained at the stations BG@N14 and BB@M (**Figure 20**) located further upstream. The lower NOE values match the decreasing pattern associated with ‘distance from source’ reported by Hobbs (2011a). Nevertheless, the results indicate severe non-conformance of faecal coliforms (and therefore almost certainly also of *E. coli*) in regard to potable, animal and recreational use at the NOE site in the Bloubank Spruit catchment. This situation undoubtedly worsens progressively with distance upstream.

In a recent report (Steynberg and Van der Merwe-Botha, 2015), it was noted that high manganese values (>2 mg/L) had been consistently recorded in the raw water drawn from the Bloubank Spruit since at least April 2014. An inspection of **Figure 16** shows that Mn levels spiked ca. April 2014 at levels of ~30 mg/L, and again ca. January and February 2015 at levels of ~20 mg/L, in the Tweelopie Spruit at station F11S12. It is evident from **Figure 9** that the volume of surface water passing station

MRd was much greater than ‘normal’, as shown by the value of ~30 ML/d recorded on 26/09/2014. The increasing volume of mine water contributing directly to surface flow downstream of station MRd has already been observed and discussed (**Section 4.1.2** and **Figure 11**), and its increasing importance as an additional allogenic water budget component in quaternary catchment A21D noted. The observation by Steynberg and Van der Merwe-Botha (2015) regarding elevated Mn values in the Bloubank Spruit surface water at the NOE confirms these circumstances.

Of greater concern, however, is the persistency of elevated maganese concentrations as far downstream (~15 km from F11S12 and ~11 km from MRd) as the NOE. At the upstream station F11s12, the low pH values (<4) (**Figure 12**) associated with each of the manganese spikes readily explain the Mn in solution. At the NOE locality, where pH values have typically been >7 (**Figure 21**), the persistence of manganese in solution for greater distances downstream from the source than iron at near-neutral or greater pH values, is clearly demonstrated.

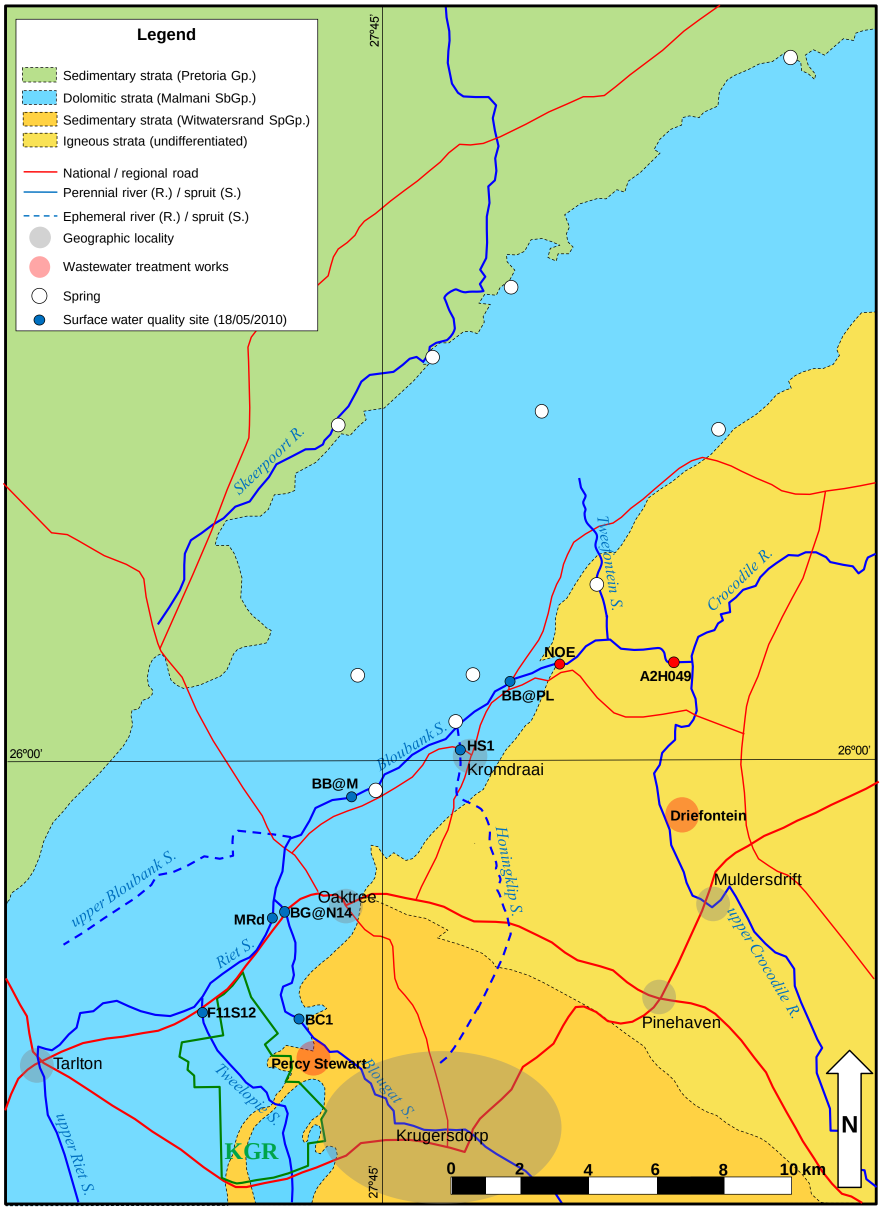


Figure 20 Surface water quality sampling sites in the study area

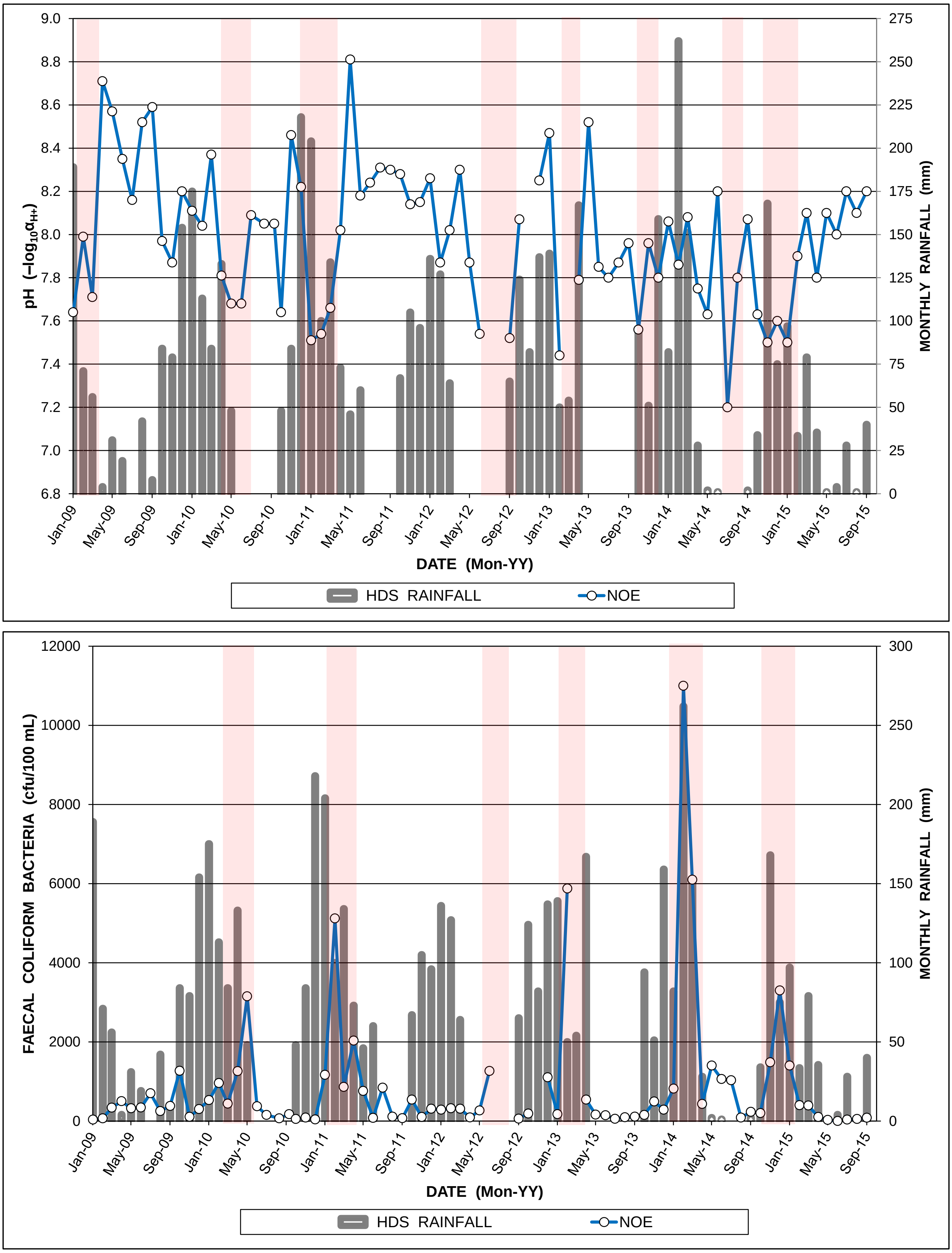


Figure 21 Correlation (vertical shaded columns) of pH (top) and faecal coliform bacteria (bottom) levels in the Bloubank Spruit at the NOE property with rainfall in the headwaters of the catchment

4.3 Salt Load

4.3.1 Riet Spruit

The combination of stream flow losses (**Annexure A**) and associated TDS and SO_4 concentrations (**Annexure B**) between stations F11S12 and MRd, allows for the derivation of the TDS and SO_4 loads lost to the karst aquifer. These are illustrated in **Figure 22** and **Figure 23** respectively.

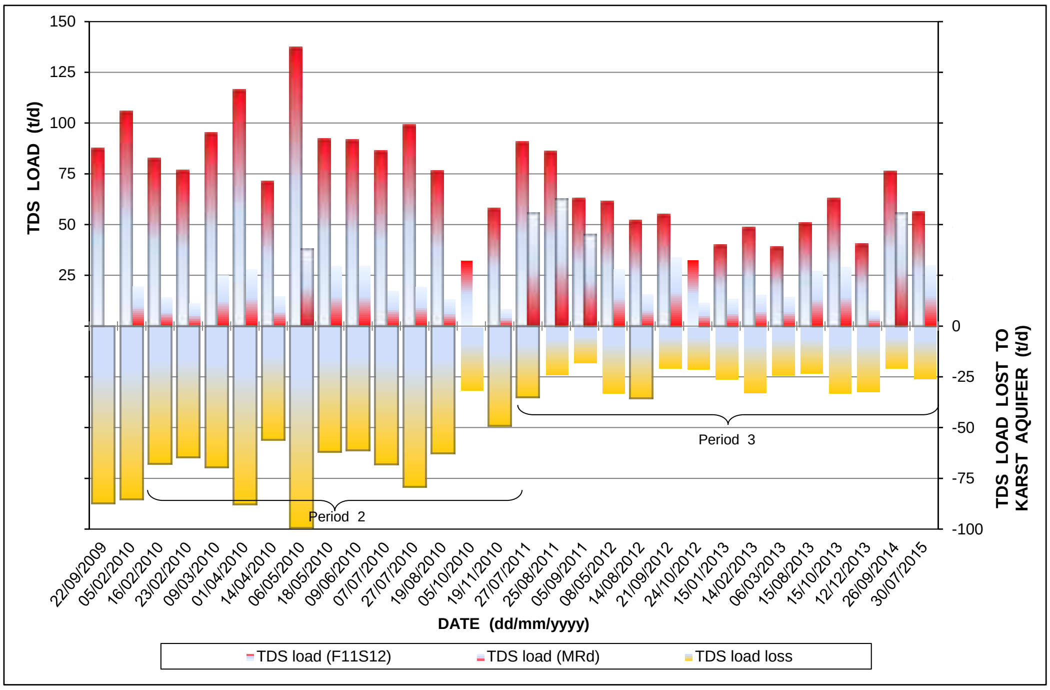


Figure 22 Graph of surface water TDS load lost to groundwater in the loosing reach of the Riet Spruit

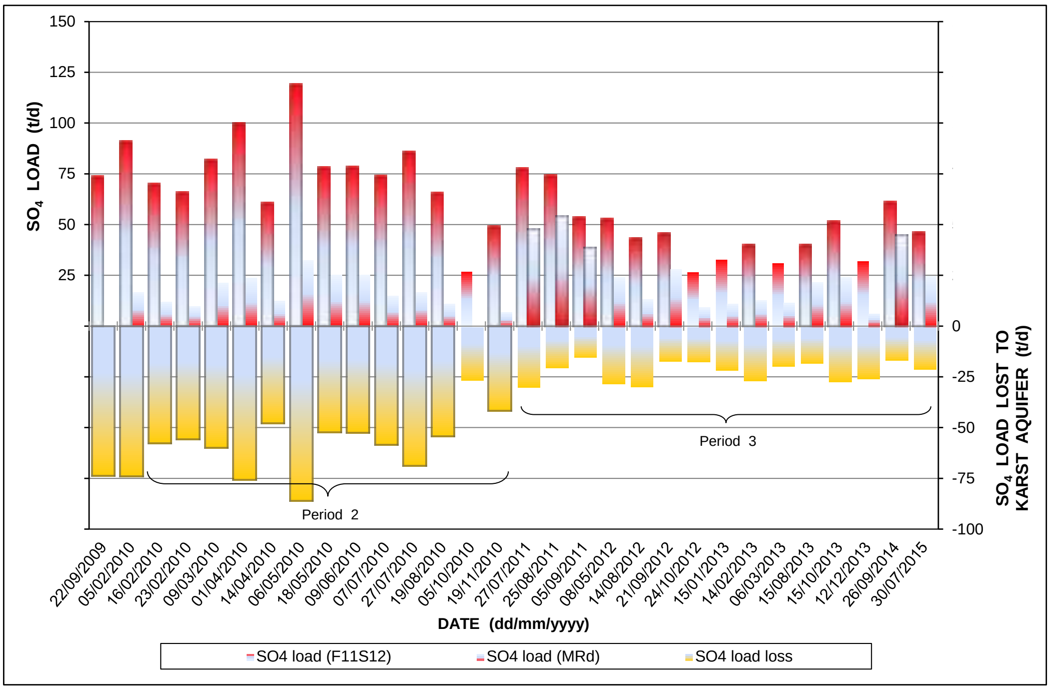


Figure 23 Graph of surface water SO_4 load lost to groundwater in the loosing reach of the Riet Spruit

The concern previously expressed for the quality of the water entering the karst aquifer is echoed in the respective median TDS and SO_4 loads associated with this allogenic recharge. These loads amount to ~68 t TDS/d and ~58 t SO_4/d in Period 2, and ~26 t TDS/d and ~21 t SO_4/d in Period 3. The latter losses represent ~53% of the median TDS and SO_4 loads passing station F11S12 in Period 3. There is no change from the similar data presented for both Periods 2 and 3 by Hobbs (2015a). The ~63% reduction in TDS and SO_4 load losses in Period 3 compared to Period 2 represents a positive outcome for the receiving karst aquifer.

4.3.2 Bloubank Spruit

The combination of flow and hydrochemical data similarly affords a re-assessment of the TDS (**Figure 24**) and SO_4 (**Figure 25**) load pattern and trend manifested at station A2H049. The ratio of SO_4 to TDS illustrated in **Figure 26** similarly reflects the rather dramatic difference between the pre- and post-2009 circumstances precipitated by the resumption of uncontrolled mine water discharge into the Bloubank Spruit system.

The long-term monthly trend in the TDS load delivered by the Bloubank Spruit (**Figure 24**) indicates an increasing TDS load (as indicated by the visually inserted arrows) since early-2007. The text box in **Figure 24** lists the median and 95%ile values associated with different periods of record. The post-September 2009 period reveals the greatest difference, which is readily attributable to the very high salt loads experienced in the 2010–’11 hydrological year. The long-term monthly trend in the SO_4 load delivered by the Bloubank Spruit (**Figure 25**) mimics the TDS load pattern (**Figure 24**) in the period since early-2007. This is unsurprising under circumstances where SO_4 comprises ~62% of the major ion concentration in mine water.

A further analysis of the potential impact of AMD on the chemistry of surface water at the downstream end of the Bloubank Spruit system is based on the SO_4**:**TDS ratio at station A2H049. This is illustrated in **Figure 26** for the long-term record, and in **Figure 27** for the period since the start of decant.

The closer inspection in **Figure 28** of the SO_4 data recorded at station A2H049 indicates an approximate trebling of the SO_4 concentration (from ~100 mg/L to ~300 mg/L) between mid-2010 and mid-2015. This is also reflected in the SO_4**:**TDS ratio, which increases from ~20% to ~50% in this timeframe (**Figure 27**).

An inspection of **Figure 24** reveals that the TDS load passing station A2H049 ca. January 2014 represents the highest in the historical record, surpassing the January 2011 value by >1 000 t/m. By comparison, **Figure 25** reveals that the SO_4 load passing this station at this time represents the second highest in the historical record, falling ~300 t/m short of the January 2011 value. Under circumstances where **Figure 7** shows that the ca. January 2014 discharge at A2H049 exceeds that in January 2011 by ~40%, it is evident that the more recent mine water chemical influence is substantially mitigated at A2H049 compared to that experienced in 2010–’11. This is also reflected in **Figure 28**, which shows that the ca. January 2014 SO_4 concentrations at A2H049 are ~50% of those recorded in January 2011.

The obvious and immediate cause-and-effect revealed in the response of surface water chemistry to mine water impacts reflected in **Figure 24** to **Figure 28**, remains obtuse and delayed in regard to the response of groundwater chemistry to similar impacts (**Section 5.2**).

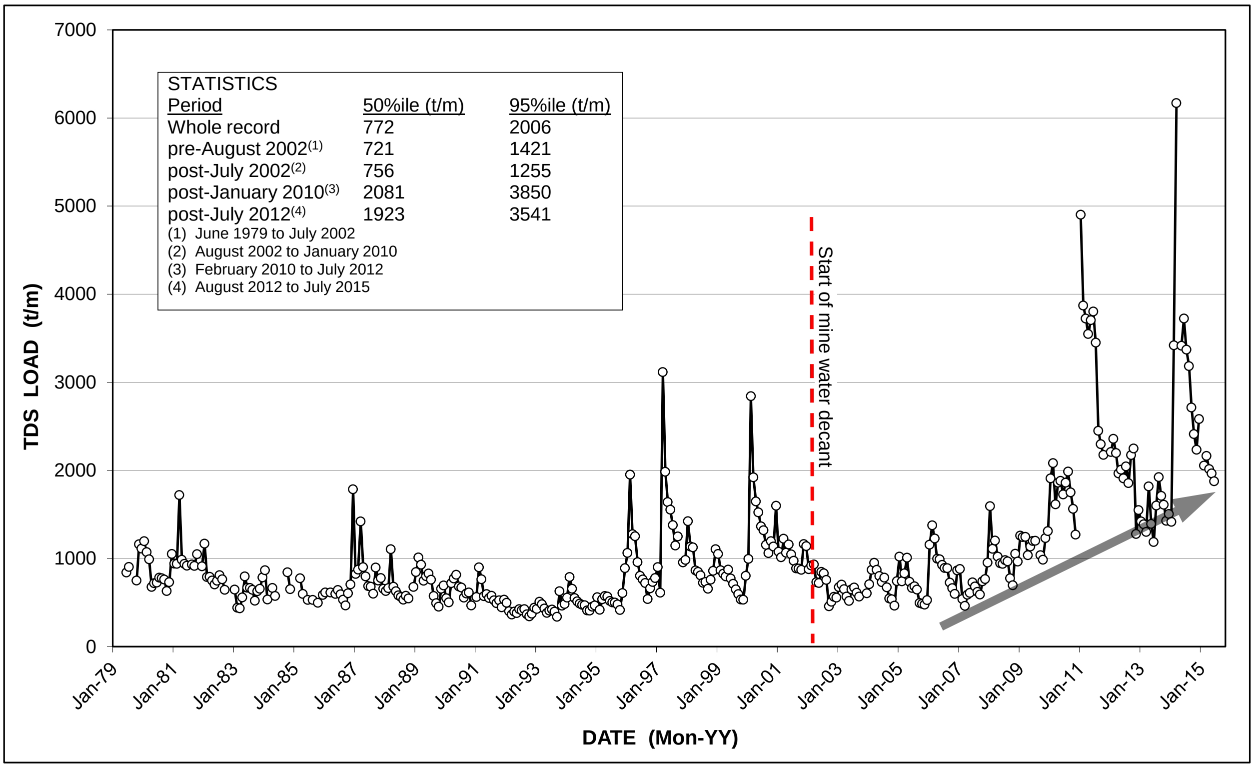


Figure 24 Long-term (June 1979 to July 2015) monthly TDS load pattern and trend in the Bloubank Spruit at station A2H049

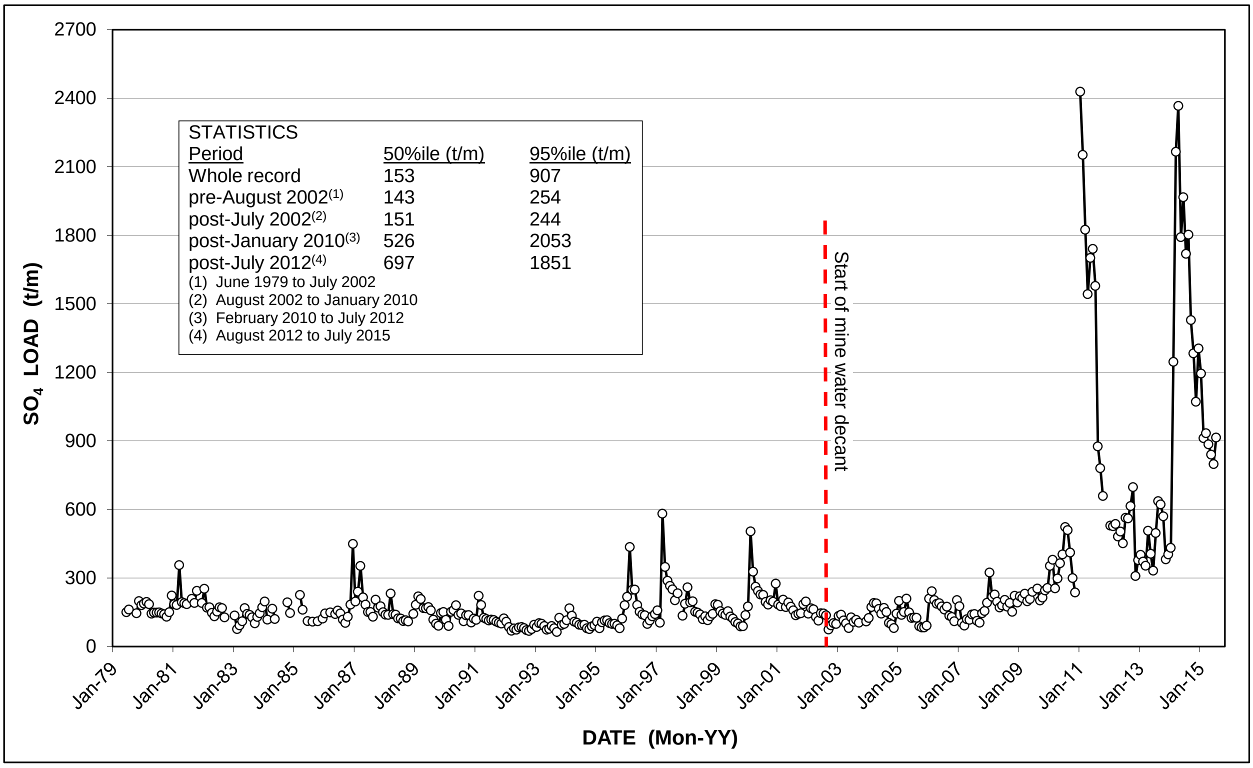


Figure 25 Long-term (June 1979 to July 2015) monthly SO_4 load pattern and trend in the Bloubank Spruit at station A2H049

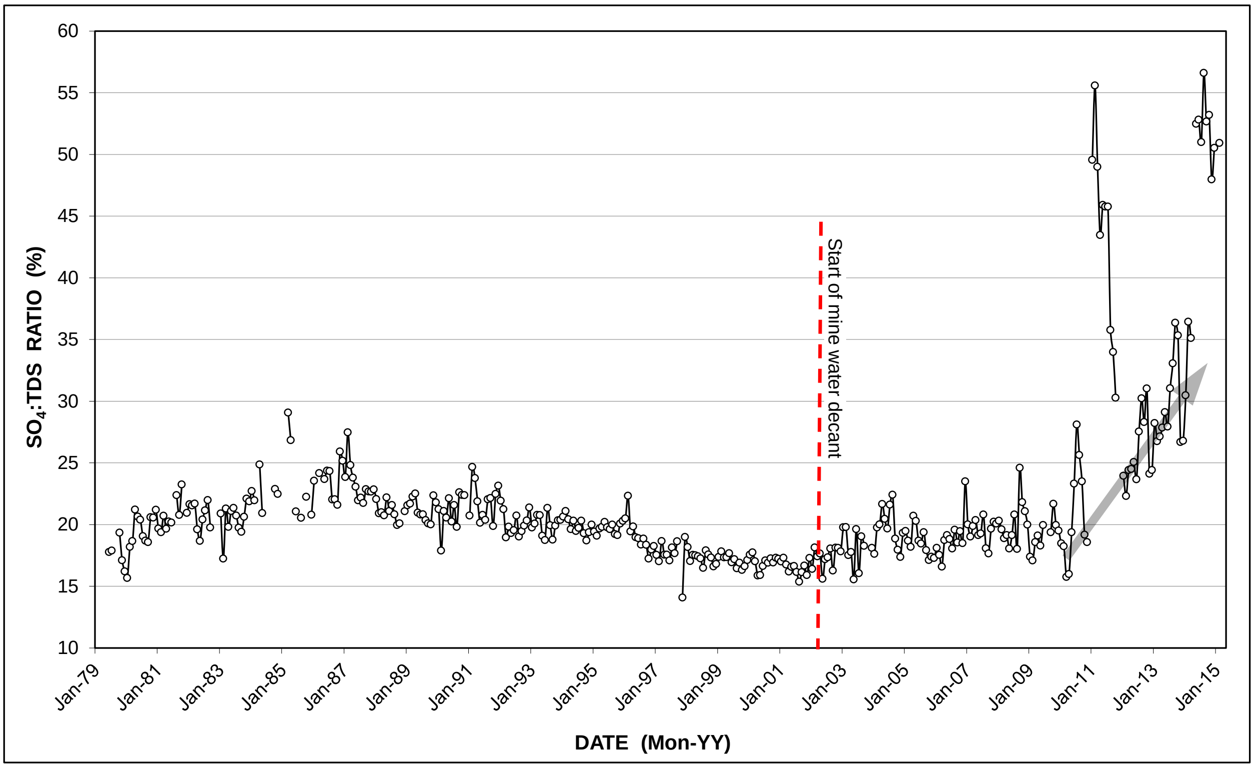


Figure 26 Long-term (June 1979 to July 2015) trend in the SO_4:TDS ratio at station A2H049

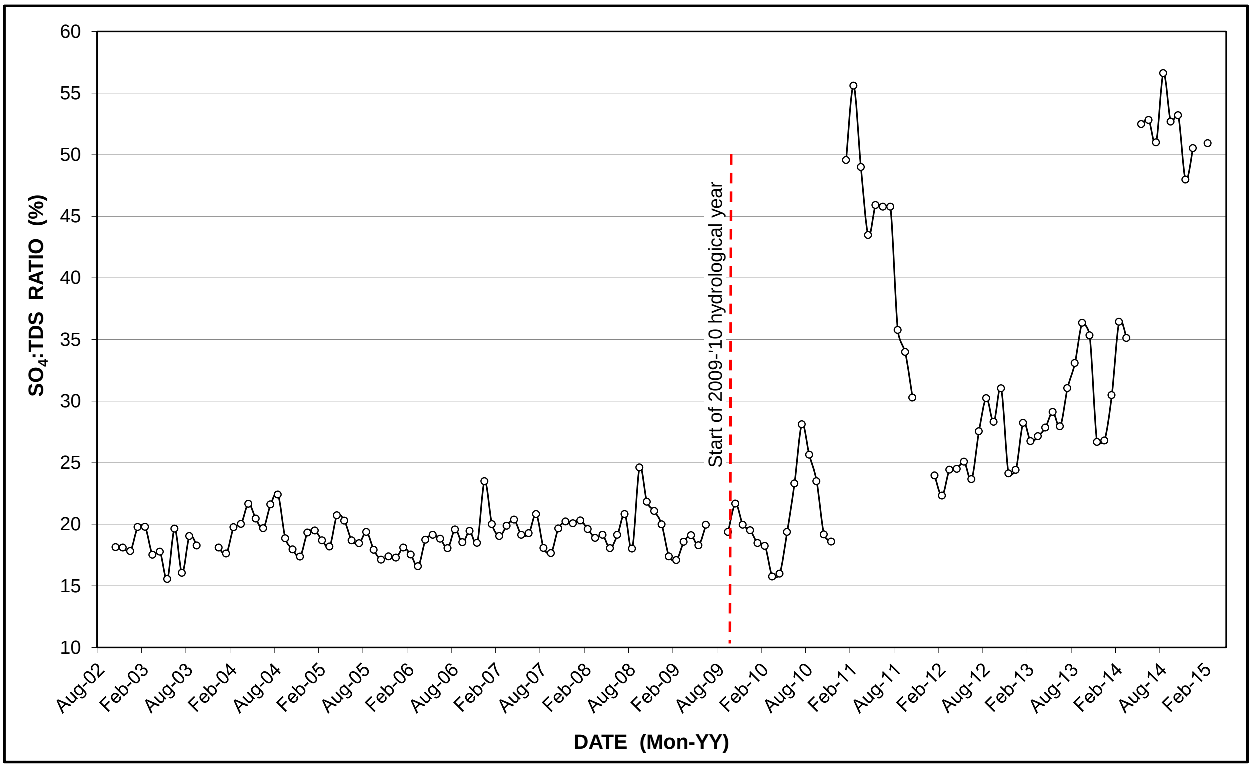


Figure 27 Pattern and trend of the SO_4:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin

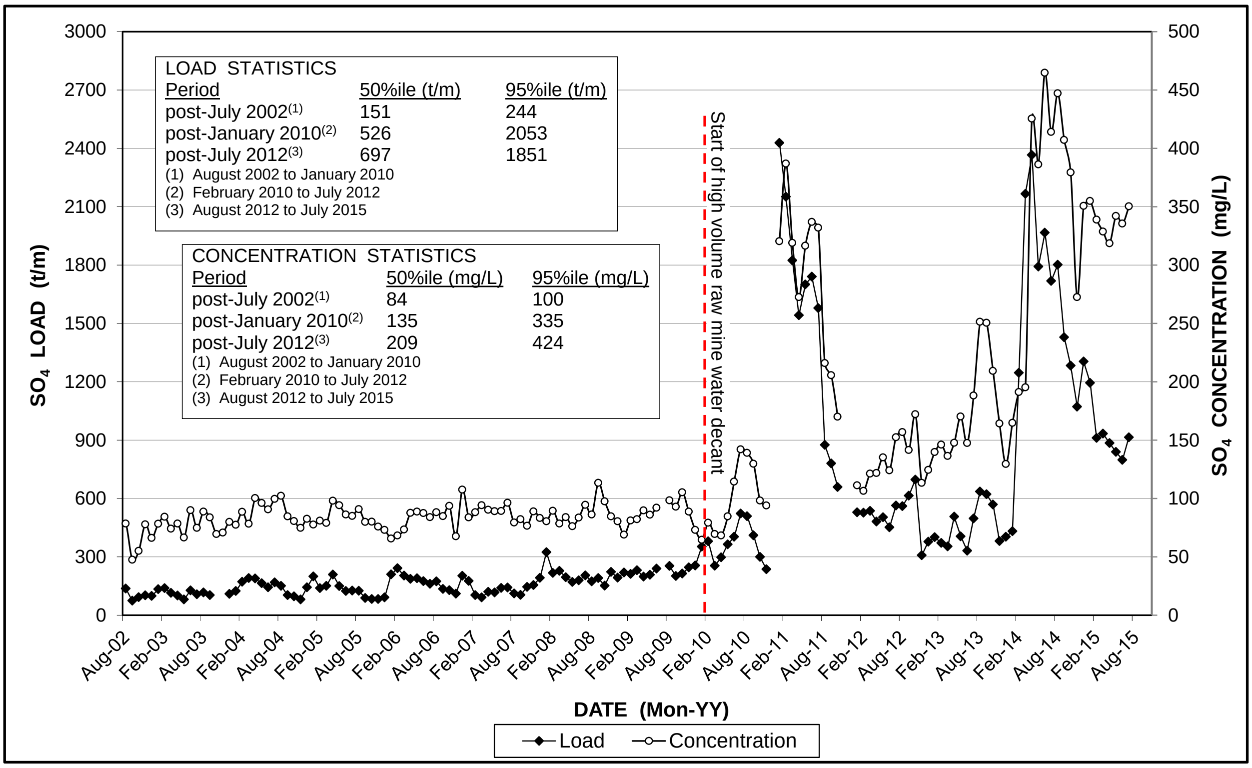


Figure 28 Monthly SO_4 concentration and load pattern and trend in the Bloubank Spruit at station A2H049 since mid-2002

The SO_4 concentration in the surface water more recently passing station A2H049 (**Figure 28**) shows a decline toward the gradually rising trend that started in the 2009–'10 hydrological year. It is since mid-2010 that the recent large and uncontrolled AMD discharges resulted in a significant change in the chemical composition of surface water leaving the Bloubank Spruit system. This confirms that a significantly greater mine water component, and in particular raw mine water, characterised the surface water chemistry in the middle and lower reaches of the Bloubank Spruit system than before mid-2010. The subregional and regional influence of these circumstances on the recent TDS loads delivered by individual drainages in the Hartbeespoort Dam catchment to this impoundment, are explored on the basis of comparison with the long-term record in **Section 6**.

5 GROUNDWATER HYDROLOGY

5.1 Physical Hydrogeology

5.1.1 Groundwater Levels

The behaviour of groundwater levels associated with the karst aquifer is reflected in the long-term water level records for DWS monitoring boreholes in the study area. An assessment of these data returns the statistics presented in **Table 5** and graphical representations shown in **Figure 29**. A comparison with the previous data set reported in Hobbs (2015a) reveals differences (where present) of <0.05 m. An analysis of the %ile change in head (Δh) data yields a 25%ile value of 3.7 m, a mean value of 5.04 m, and a 75%ile value of 6.52 m. Most of these hydrographs are compared in **Figure 30**, which indicates two distinct groupings, namely Group A (**Figure 31**) occupying an elevation of >1 530 m amsl, and Group B (**Figure 32**) occupying an elevation <1 490 m amsl. The >40 m elevation difference reflects their spatial distribution between two different compartments/subcompartments.

Table 5 Salient statistics for long-term DWS groundwater level monitoring data

Station	**Groundwater Rest Level (m bc)**							**Record**
	n	**5%ile**	**Mean**	**Median**	**95%ile**	**Max Δh(2)**	**%ile Δh(3)**	**Period(1)**
A2N0580	278	–59.95	–54.50	–54.28	–51.00	11.13	8.95	05/1985–07/2015
A2N0582	210	–42.91	–40.11	–40.15	–35.77	8.53	7.14	05/1985–12/2010
A2N0583	237	–45.54	–44.94	–44.86	–44.40	1.84	1.14	05/1985–05/2015
A2N0584	276	–28.09	–25.39	–26.10	–21.16	8.19	6.93	05/1985–05/2015
A2N0586	292	–28.67	–26.19	–27.14	–21.33	8.54	7.34	05/1985–07/2015
A2N0589	169	–29.90	–28.89	–28.97	–27.92	3.85	1.98	05/1985–06/2010
A2N0590	192	–36.46	–34.57	–35.08	–31.51	6.11	4.95	05/1985–07/2015
A2N0592	282	–78.53	–76.88	–77.33	–73.63	6.33	4.90	06/1985–07/2015
A2N0594	183	–74.41	–72.79	–72.80	–70.86	4.91	3.55	01/1985–09/2008
A2N0598	89	–63.32	–58.76	–58.84	–53.53	12.17	9.79	07/1985–05/2010
A2N0600	211	–25.38	–23.89	–24.38	–21.23	5.07	4.15	04/1989–07/2015
A2N0602	237	–55.95	–54.25	–54.80	–51.05	6.44	4.90	06/1987–07/2015
A2N0605	203	–63.65	–62.48	–62.75	–60.18	4.16	3.48	04/1989–12/2014
A2N0606	74	–69.50	–67.06	–67.02	–64.86	5.11	4.65	08/1989–07/2014
A2N0607	173	–70.67	–66.93	–66.84	–64.15	8.09	6.52	10/1993–07/2015

(1) From month of first measurement to month of most recent available measurement as at September 2015 update from DWS; shaded rows denote stations no longer in service

(2) Difference between minimum and maximum values (not shown in this table)

(3) Difference between the 5%ile and 95%ile values

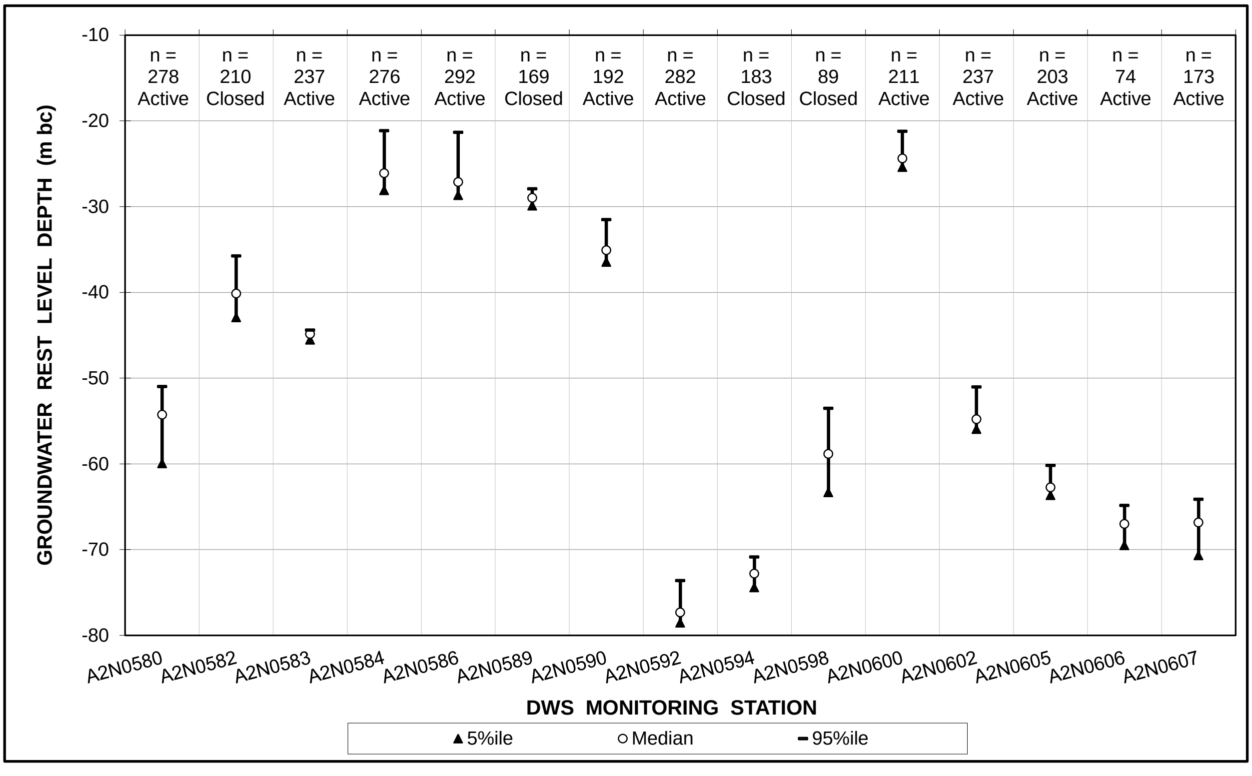


Figure 29 Graphic comparison of the statistical hydrographic response observed in the DWS long-term groundwater level monitoring stations in the period 1985 to 2015 (data from **Table 5**)

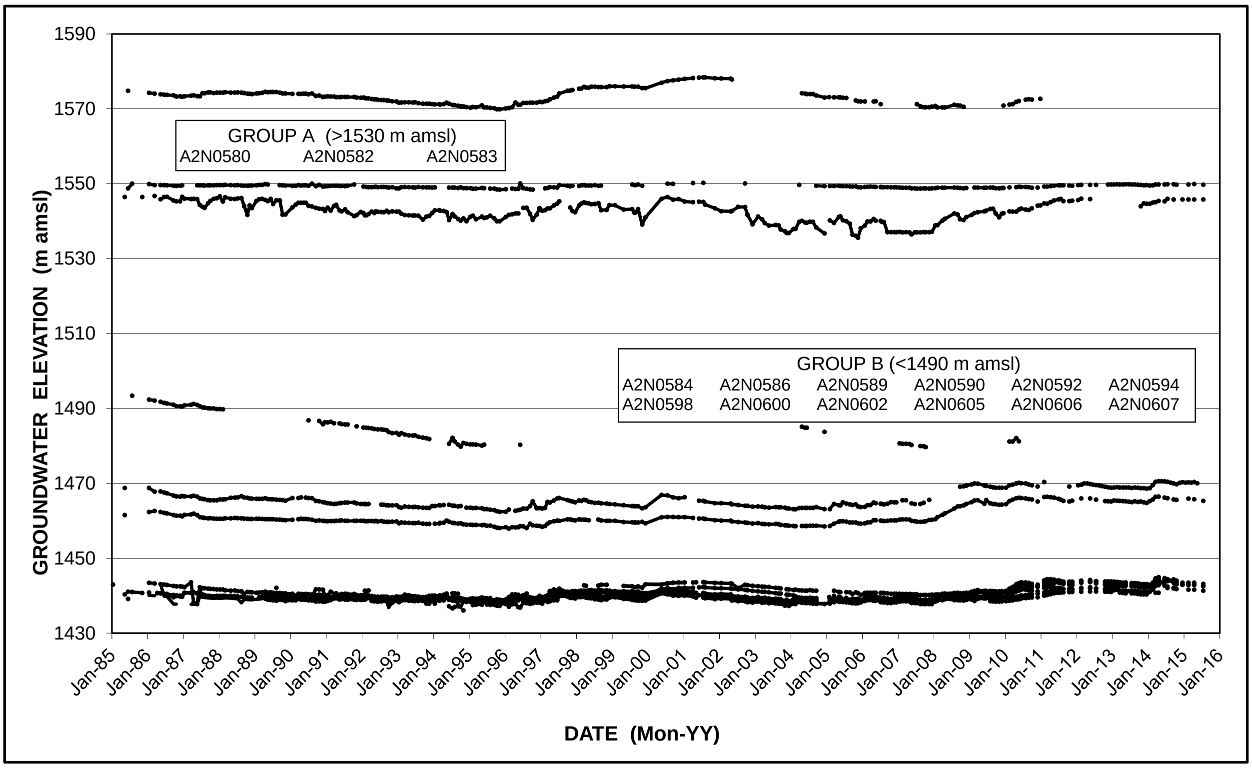


Figure 30 Long-term groundwater level response pattern in DWS monitoring boreholes

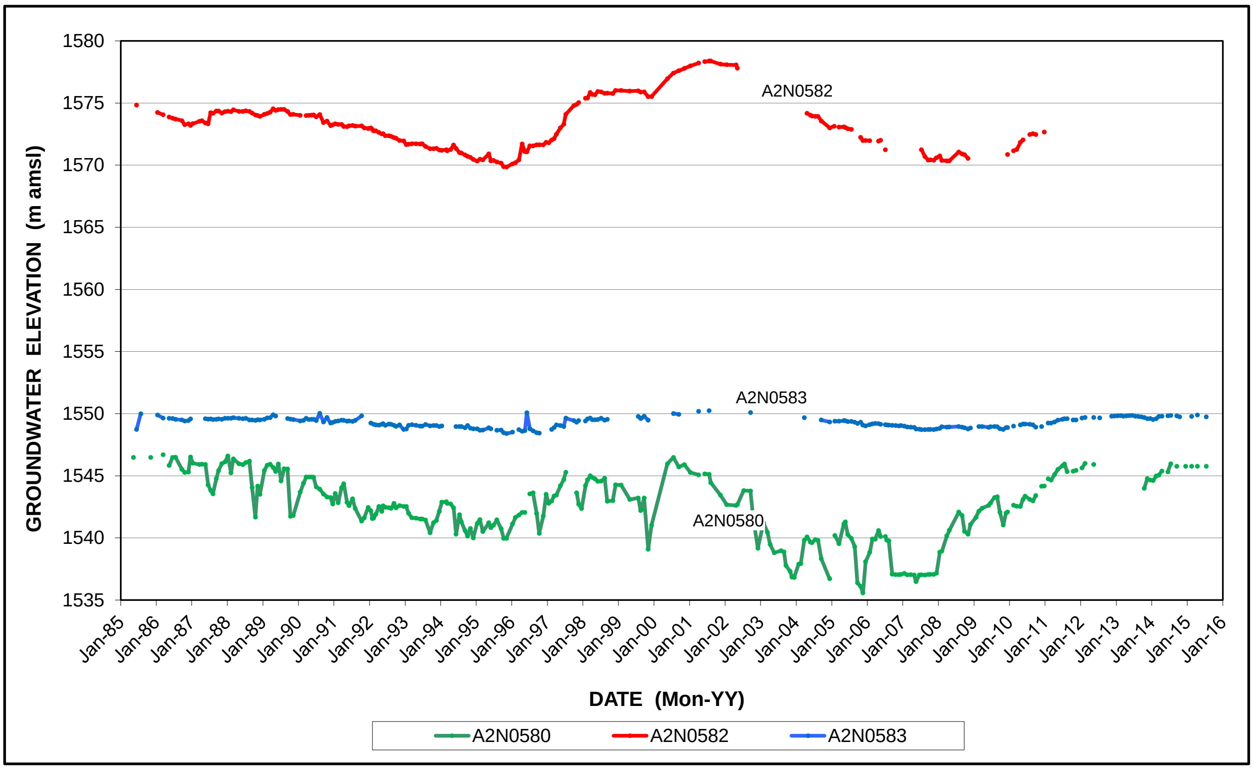


Figure 31 Long-term groundwater level response pattern in Group A boreholes from **Figure 30**

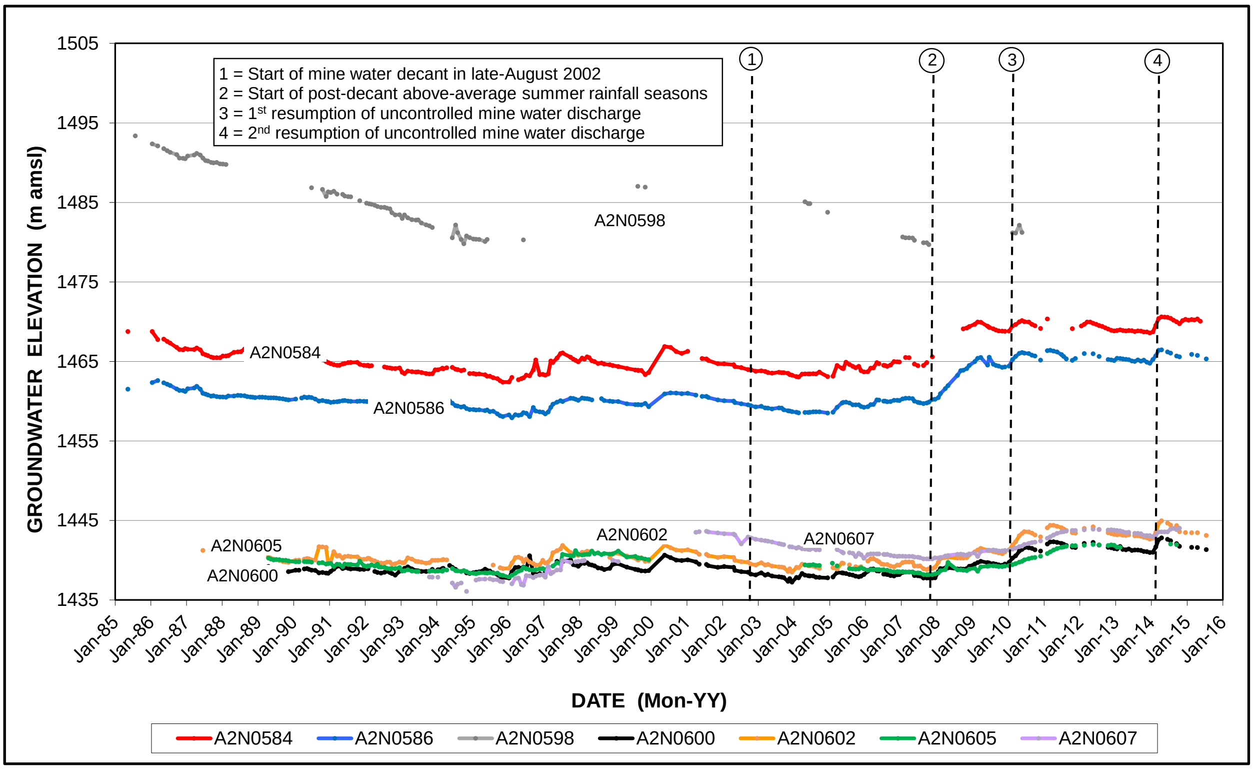
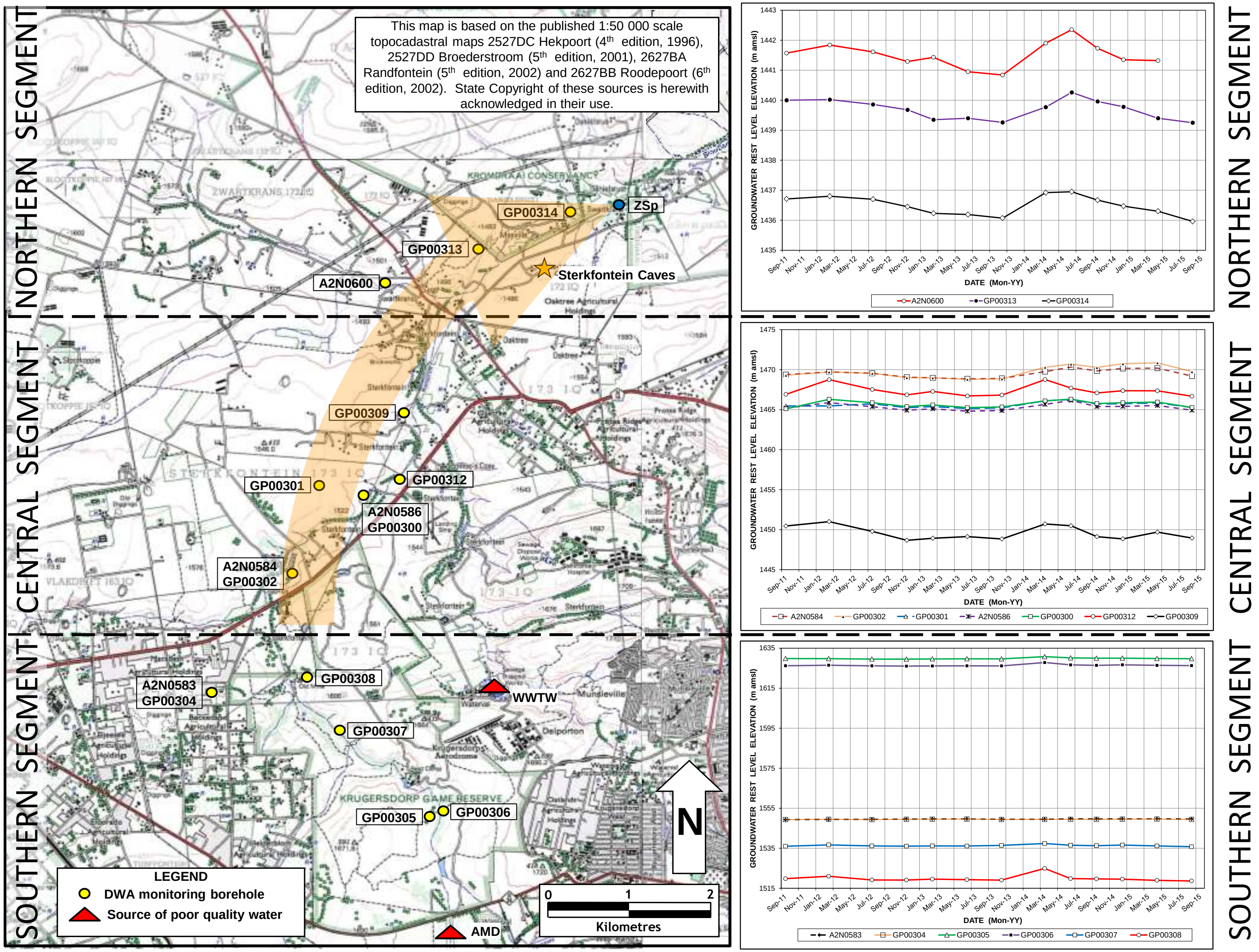


Figure 32 Long-term groundwater level response pattern in Group B boreholes from **Figure 30**

The unprecedented rise in the groundwater level observed in stations A2N0584 and A2N0586 since late-2007 (**Figure 32**) reflects the impact of exceptional recharge associated with raw and/or treated mine water being lost from the Riet Spruit downstream of the Tweelopie Spruit confluence (**Section 4.1.2**). Both these stations are located in proximity to the Riet Spruit (**Figure 33**). These circumstances were precipitated by the wet summers experienced in the region starting with the 2007–'08 hydrological year, and resulting in treated mine water discharges in excess of 25 ML/d to the Tweelopie Spruit. The additional contribution of raw mine water to this discharge in the much wetter 2010–'11 and 2013–'14 rainy seasons (**Figure 4**) has, on occasion, increased the allogenic flow in this drainage to >60 ML/d. It is therefore not surprising that the long-term hydrographs presented in **Figure 32**, in particular those of stations A2N0584, A2N0586 and A2N0600, indicate that groundwater elevations in the last five years are the highest in the ~30-year record of measurements. The exception in this regard (station A2N0598) is readily explained by the position of this borehole ~2.9 km west of the Tweelopie Spruit / Riet Spruit confluence. This position places it upstream of the hydraulic influence exerted by allogenic recharge along the losing reach of the Riet Spruit. The modification of the natural hydrologic and hydrogeologic balances brought about by the elevated and sustained mine water discharges (both treated/neutralised and/or raw mine water) will certainly alter the long-term natural groundwater level recession pattern and trend especially in the lower reaches of the Zwartkrans Compartment. It is postulated that this impact on the physical manifestation of groundwater change will result in higher baseflows in the Bloubank Spruit system in the future. The magnitude of this increase is still anticipated to be in the order of 15–20% (2.9–3.9 Mm^3/a) as reported previously (Hobbs, 2014b).

An inspection of the more recent potentiometric response in DWS monitoring boreholes located downstream of the mine area is presented in **Figure 33.** The boreholes are grouped into a southern, a central and a northern segment to distinguish between their location in the downstream receiving hydrogeologic environment. This distinction is particularly evident in the absolute groundwater level elevations that describe a decrease from south to north both within and between the respective segments.



This map is based on the published 1:50 000 scale topocadastral maps 2527DC Hekpoort (4th edition, 1996), 2527DD Broederstroom (5th edition, 2001), 2627BA Randfontein (5th edition, 2002) and 2627BB Roodepoort (6th edition, 2002). State Copyright of these sources is herewith acknowledged in their use.

Figure 33 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); arrow denotes principal direction of impacted groundwater flow

5.1.2 Sterkfontein Caves Water Level

The international significance of Sterkfontein Caves as the flagship fossil site in the COH WHS focuses attention on any perceived impact on this site. The substantial rise in the cave water level through 2010 to early-2012 caused Maropeng āAfrika (the authority responsible for managing the tourist component of the site) to reroute the tourist path through the caves to successively higher elevations. These circumstances focussed attention on the hydrostatic behaviour of the cave water level.

In sympathy with the observed rise in water levels in the Zwartkrans Compartment in the more recent past (**Section 5.1.1**), a similar response is observed in the Sterkfontein Caves. The associated trend is shown in **Figure 34**, and suggests that the cave lake (referred to as the Main Lake by Martini et al., 2003) water level might have started rising in mid-2009. After a ~3 m rise peaking at an elevation of ~1 439.4 m amsl in mid-2012, a decline by ~0.8 m to an elevation of ~1 438.6 m amsl by late-2013 was interrupted by a rise of ~1 m to an elevation of ~1 439.6 m amsl by mid-2014. The most recent rise is associated with the very wet 2013–'14 summer (**Section 3**) and its broader impacts in the form of natural (autogenic) and mine water (allogenic) recharge. Most recently, the cave lake water level has resumed a decline at a rate of 0.03 m per month to an elevation of ~1 438.7 m amsl in July 2015.

The elevation of 1 439.6 m amsl (**Figure 34**) is similar to that determined for the Bloubank Spruit channel to the north of the caves. This suggests that the cave water level reaches equilibrium at this elevation (equal to a depth of ~14.5 m bs in borehole SF1), when the karst water table intersects the stream channel of the Bloubank Spruit. Significantly, the recent maximum rise of ~3 m which led to this condition, 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).

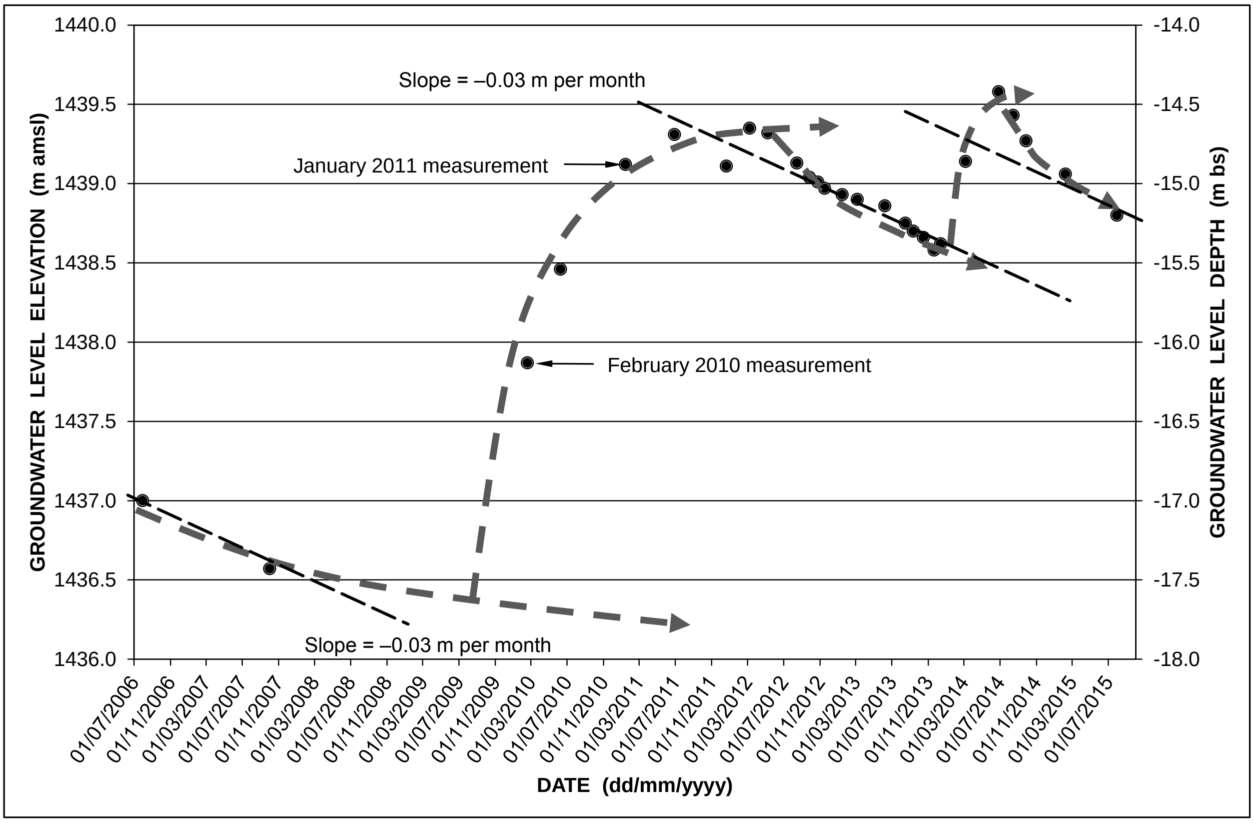


Figure 34 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the cave lake water level in Sterkfontein Caves

It is postulated that the cave lake will maintain a high water level into the future because of sustained above-normal discharge in the upper tributaries of the Bloubank Spruit, and associated allogenic groundwater recharge in the Zwartkrans Compartment. This is premised on the greater sustained discharge of treated/neutralised mine water associated with the immediate and short-term AMD control and management interventions in the Western Basin (DWA, 2011).

5.2 Chemical Hydrogeology

5.2.1 Monitoring Framework

The DWS groundwater monitoring programme in the south-western portion of the property was substantially expanded with the establishment of an additional 13 monitoring boreholes in late-2010. These stations (identified by the alpha-numeric code GP00###) supplement the four stations (identified by the alpha-numeric code A2N0###) that are the legacy of the mid-1980s DWAF study (Bredenkamp et al., 1986) in the region. The distribution of the monitoring network is shown in **Figure 35** and **Figure 36**. Whereas the older stations support a quasi-continuous monitoring record dating back to 2003, the record of the newer stations commences in March 2011. It is the fruits of this monitoring that forms the basis for evaluating the impact of mine water on the receiving karst environment (**Section 5.2.2**).

5.2.2 Mine Water Impact

5.2.2.1 Local Karst Environment

There has been little change in this aspect of monitoring in the reporting period compared to the previous period (Hobbs, 2015a). As a consequence, much of the discussion that follows is drawn from the previous monitoring report.

The local karst environment is defined by the ~9 800 ha Zwartkrans Compartment, which occupies only ~19% of the COH footprint (~52 000 ha), and ~36% of the ~26 860 ha karst footprint of the property. This part of the property bears the brunt of any mine water impact from allogenic discharge via the Tweelopie Spruit, and allogenic recharge along the losing reach of the receiving Riet Spruit. The groundwater chemistry data generated by the monitoring programme in the Zwartkrans Compartment provides an indication of the extent and magnitude of the mine water impact on the karst aquifer in this portion of the COH. This is illustrated in **Figure 35** and **Figure 36** with the aid of bar graphs for the chemical variables pH and EC respectively. In order to maintain legibility, the bar graphs reflect a truncated data set that reflects a lesser frequency of monitoring than actually exists, whilst still showing the pattern and trend of the complete data set.

The bar graphs in **Figure 35** reflect the general progressive decrease in pH from south to north within the central and northern segments. This pattern is reflected both in the individual stations and in a spatial context, although the latter is heavily influenced by proximity to the influent (losing) reach of the Riet Spruit in the central segment.

The bar graphs in **Figure 36** similarly reflect the general progressive increase in salinity from south to north within the central segment. In the northern segment, however, the spatial trend along the flow path is a declining one, even though all of the stations individually reflect an increase in salinity. The significant influence exerted by proximity to the Riet Spruit in the central segment is again evident. As in the case of pH (**Figure 35**), this influence is least at the southern margin (stations A2N0584 and GP00302), and increases down-gradient to station GP00309. This pattern reflects the north to north-easterly flow path followed by the allogenic recharge of mine water in the karst aquifer.

The historical pattern and trend of groundwater EC and SO_4 levels in proximity to the losing reach of the Riet Spruit is reflected in the longer term monitoring data associated with the paired stations A2N0584 / GP00302 and A2N0586 / GP00300, and station A2N0600. These are presented in **Figure 38**, and reveal the pattern and trend of EC and SO_4 levels that define the footprint of the mine water impact in the karst aquifer. The postulated commencement of the rise in concentrations ca. September 2008 is based on the SO_4 response at station A2N0584 located the furthest upstream along the Riet Spruit. It might be expected that a response at the downstream stations (especially A2N0600) would manifest later because of travel times in the subsurface. The variable of concern is SO_4, which exceeds the SANS (2015a; 2015b) standard health-related limit of 500 mg/L (**Table 3**) in all five instances.

It would also appear from **Figure 38** that recent SO_4 levels along the Riet Spruit exhibit a levelling off after the “spike” observed in 2014, whereas the SO_4 level at the downstream station A2N0600 has only recently peaked. These circumstances are attributed to the most recent discharge of raw and treated mine water from the mine area. The SO_4 response at A2N0600 reflects the more distal location of this station in the pseudoplume.

The distribution of SO_4 concentrations associated with the stations represented in the central and northern segments of **Figure 35** and **Figure 36**, is shown in **Figure 37**. This provides an indication of the extent of this impact, as well as the SO_4 trend in terms of up, stable or down compared to the previous (September 2014) values. It is apparent that the trend at the “upstream” stations (A2N0584, A2N0586, GP00312 and GP00309) is generally down, at the “midstream” stations (A2N0600 and GP00313) is generally stable, and at the “downstream” stations (GP00314 and ZSp) is generally up. These circumstances are interpreted as reflecting the passage of a “slug” of AMD-impacted groundwater through the aquifer. An inspection of **Figure 38** suggests that the introduction of this “slug” occurred in early-2014.

5.2.2.2 Broader Karst Environment

The broader karst environment is defined by the ~26 860 ha footprint of karst strata that underlies the COH property. The quality of groundwater in this environment is adequately described by the hydrochemistry of groundwater discharged by the major karst springs in the COH. These are identified in **Annexure C** together with the most recent water chemistry results associated with each feature. The results are compared to historical values in **Figure 39**. Except for the Zwartkrans Spring, the comparisons reveal the similarity of the recent springwater chemistries with the historical compositions reported by Hobbs (2011a).

The Zwartkrans Spring water chemistry shows comparatively little difference between the May 2014 and February 2015 sampling events. Nevertheless, the ~13% increase in SO_4 concentration (from 6.33 to 7.16 meq/L) is in keeping with the rising trend observed at monitoring station GP00314 (**Figure 37**).

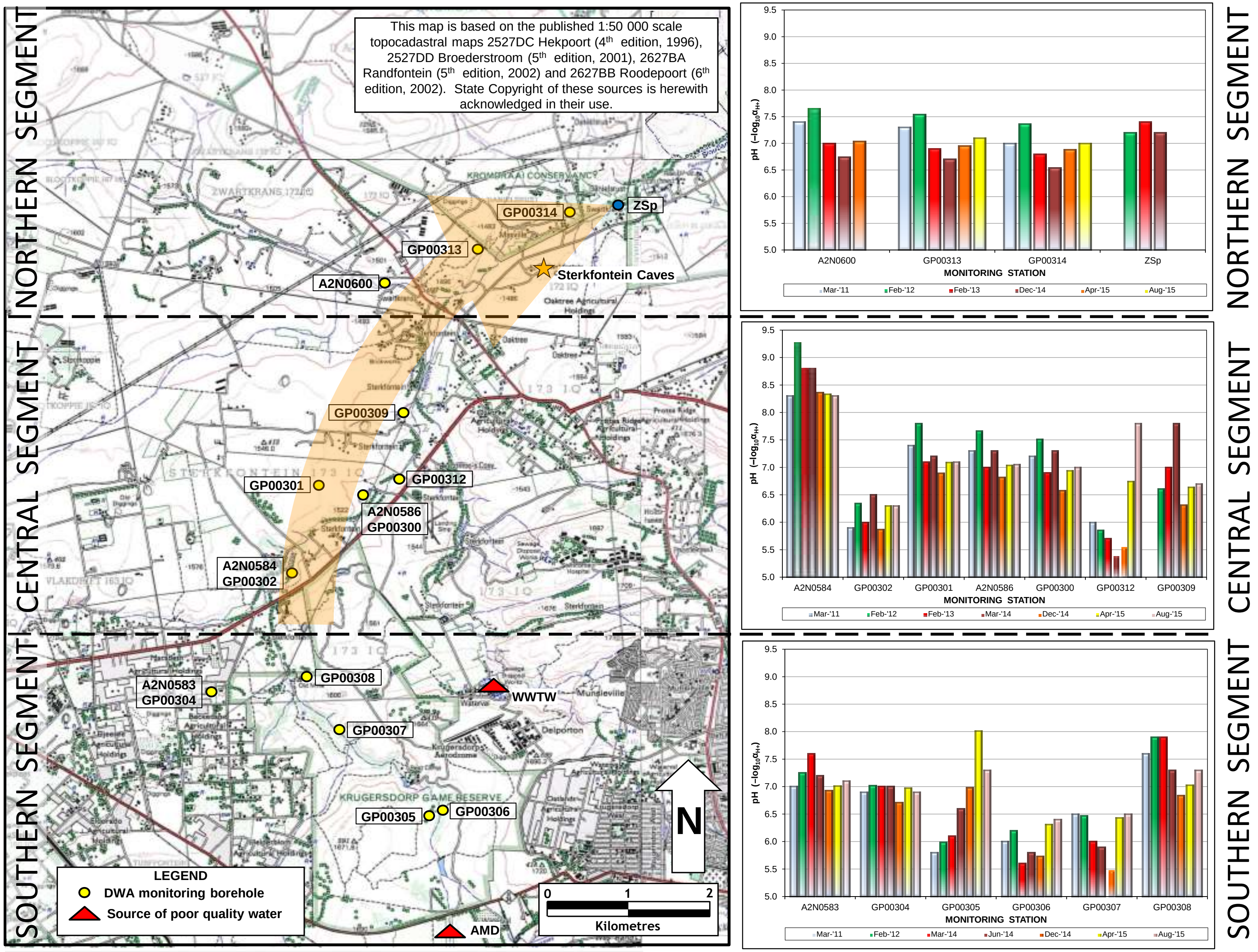
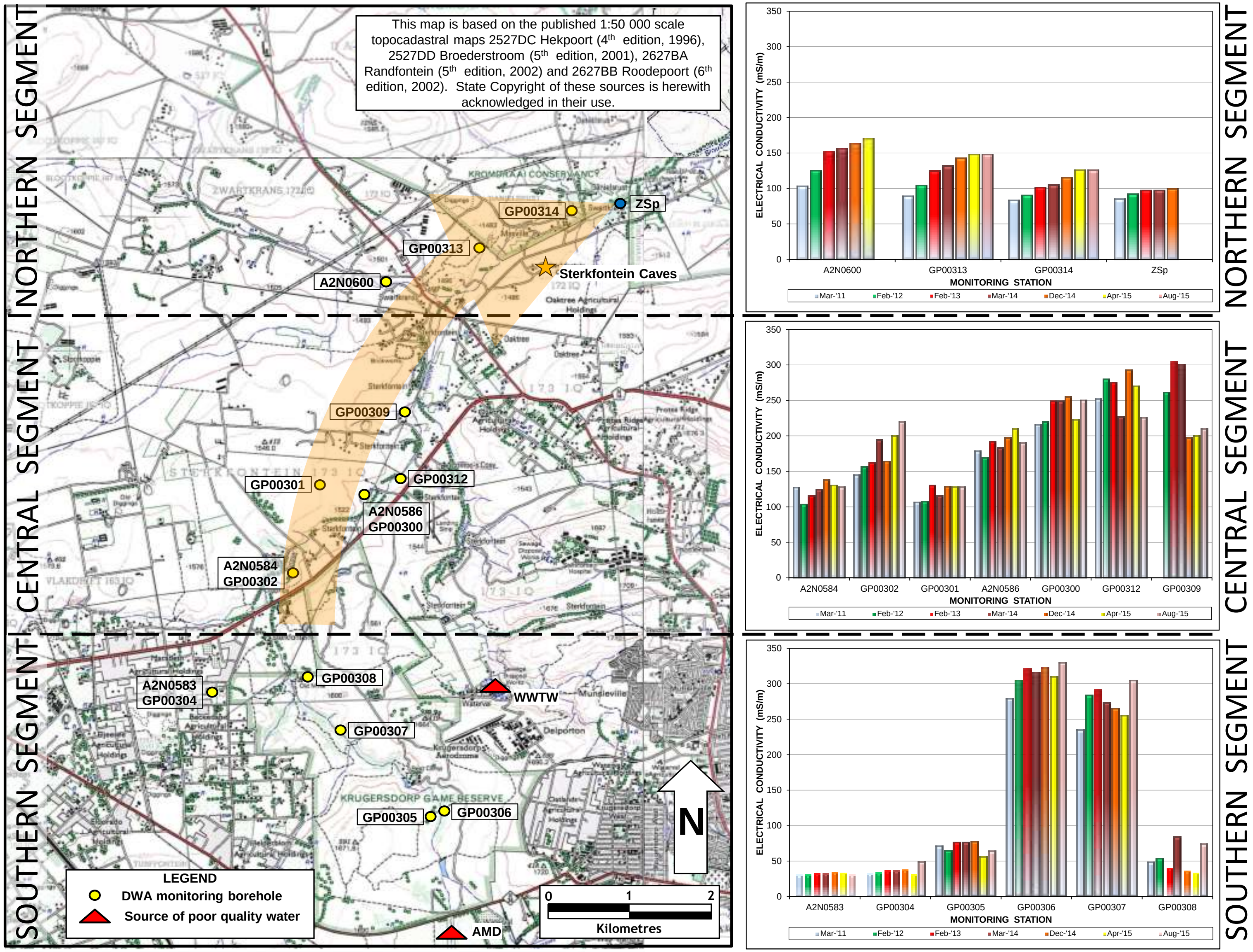


Figure 35 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow



This map is based on the published 1:50 000 scale topocadastral maps 2527DC Hekpoort (4th edition, 1996), 2527DD Broederstroom (5th edition, 2001), 2627BA Randfontein (5th edition, 2002) and 2627BB Roodepoort (6th edition, 2002). State Copyright of these sources is herewith acknowledged in their use.

Figure 36 Distribution of DWS monitoring boreholes with EC pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow

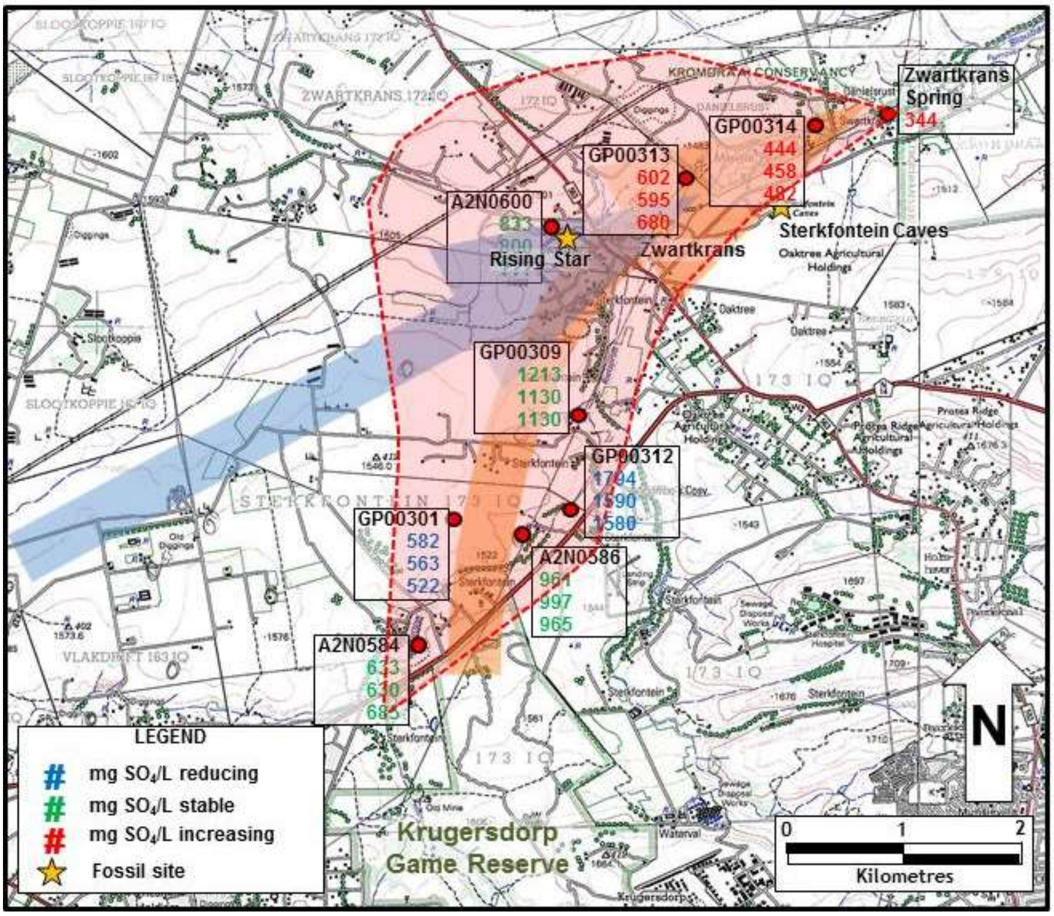


Figure 37 Distribution of SO_4 concentrations in groundwater of the Zwartkrans Compartment in December 2014, April 2015 and August 2015, also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow), the postulated footprint (shaded area) of a mine water impact in the karst aquifer, and SO_4 trend INCREASING (red text), STABLE (green text) or REDUCING (blue text)

5.3 Land Stability

The occurrence of karst phenomena such as ground subsidence, doline formation and sinkhole development has not attracted discussion in previous monitoring reports. The recent occurrence of a sinkhole/swallet along the R563 Oaktree-Hekpoort regional road, however, necessitates that also this aspect of the karst environment be discussed. It was understood from 3rd party information that the feature occurred in the north-western corner of the R563 and Royal Thatch/Sterkfontein Poultry gravel road junction in late-September. In any event, the situation requires at least an attempt at identifying a cause/trigger in the context of a subregional mine water impact.

Hobbs (2011b) assigned a hydro-vulnerability rating of VERY HIGH to the Bolt's Farm complex of caves and cave systems. The Rising Star cave system is located on the north-western margin of this complex, and must also therefore be assigned a hydro-vulnerability rating of VERY HIGH. The immediate concern is for a possible mine water impact, which would have been the first time that a subsidence feature was attributed to this cause in the COH. The pH of ~7 and EC of 166 mS/m of the ambient groundwater suggests, however, that a mine water influence is not sufficiently dominant to be the cause. The depth to the water table is in the order of 20–25 m below surface.

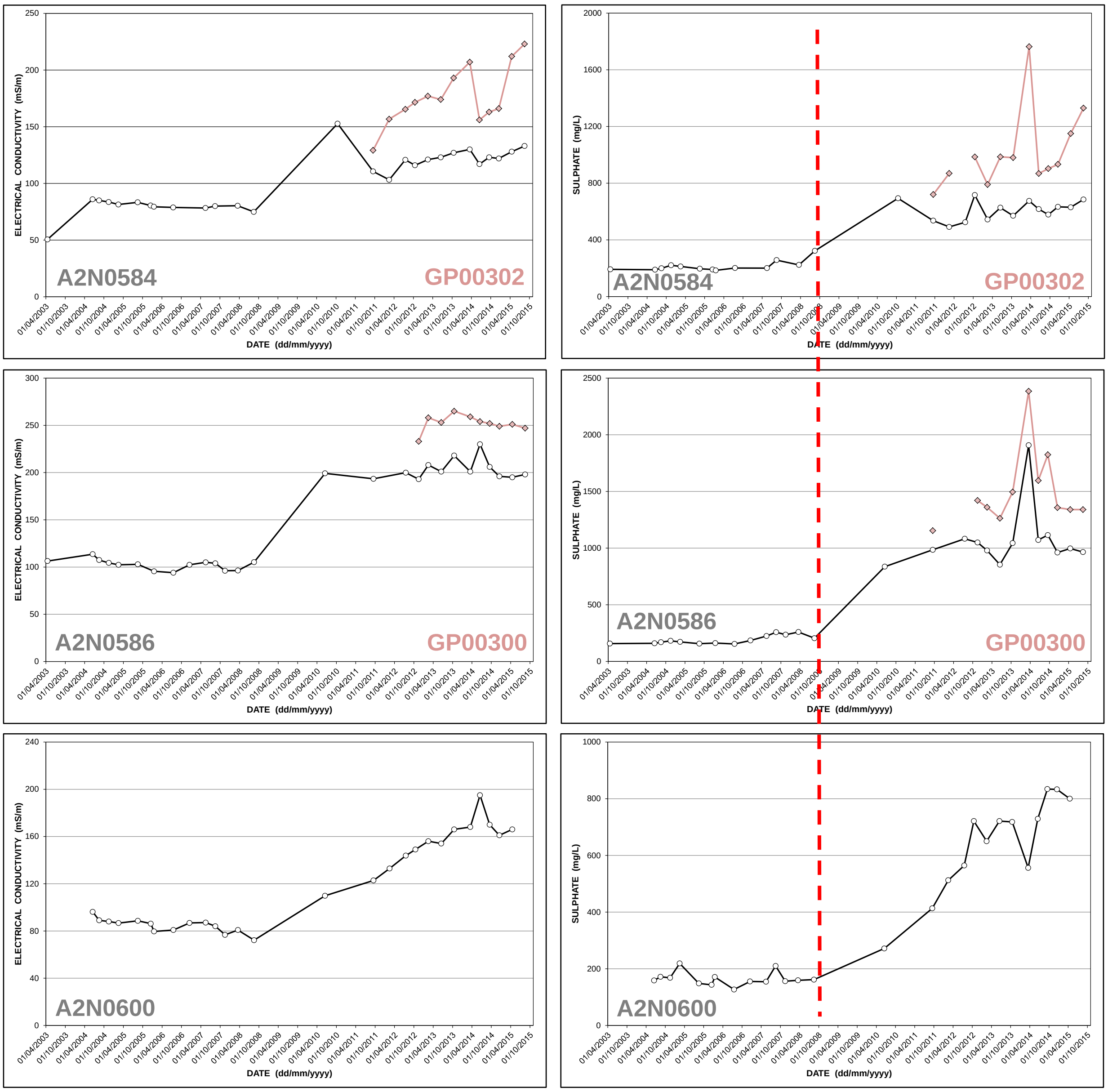


Figure 38 Long-term pattern and trend of EC (left) and SO_4 (right) in karst groundwater from paired DWS monitoring stations A2N0584 / GP00302 and A2N0586 / GP00300, and station A2N0600; note common time scales and postulated commencement of rise in concentrations (vertical pecked line)

It is observed in **Section 3** that the region experienced 18 mm of precipitation in late-July, and a further 38 mm in early-September. Especially the last event would have generated runoff from the R563 pavement, some of which would have been shed toward and converged on the area of the recent subsidence. It would need to be established whether there is a culvert beneath the gravel road that would convey runoff to the south of the road. If not, then R563 pavement runoff north of the gravel road would collect upgradient of the junction.

Of equal concern is the haste and unilateral manner in which infilling of the "sinkhole" commenced without notifying an authority such as the Council for Geoscience or, for that matter, the Management Authority. It is appreciated that the circumstances necessitate remedial action as soon as possible, but this must be informed by expert assessment of the situation. Emergency contact numbers for the various agency representatives will reduce response times to a minimum. A related concern is the nature of the material used for infilling. In other instances (e.g. along the Danielsrust Game Farm road on Boland Farm), it was observed that the material comprised rubble containing waste such as plastic bottles. These circumstances raise numerous concerns, amongst others for the suitability of the material for infilling purposes (i.e. to prevent bridging that would only cause a repeat occurrence), and the impact on groundwater quality in an area where many landowners still rely on their boreholes for a water supply.

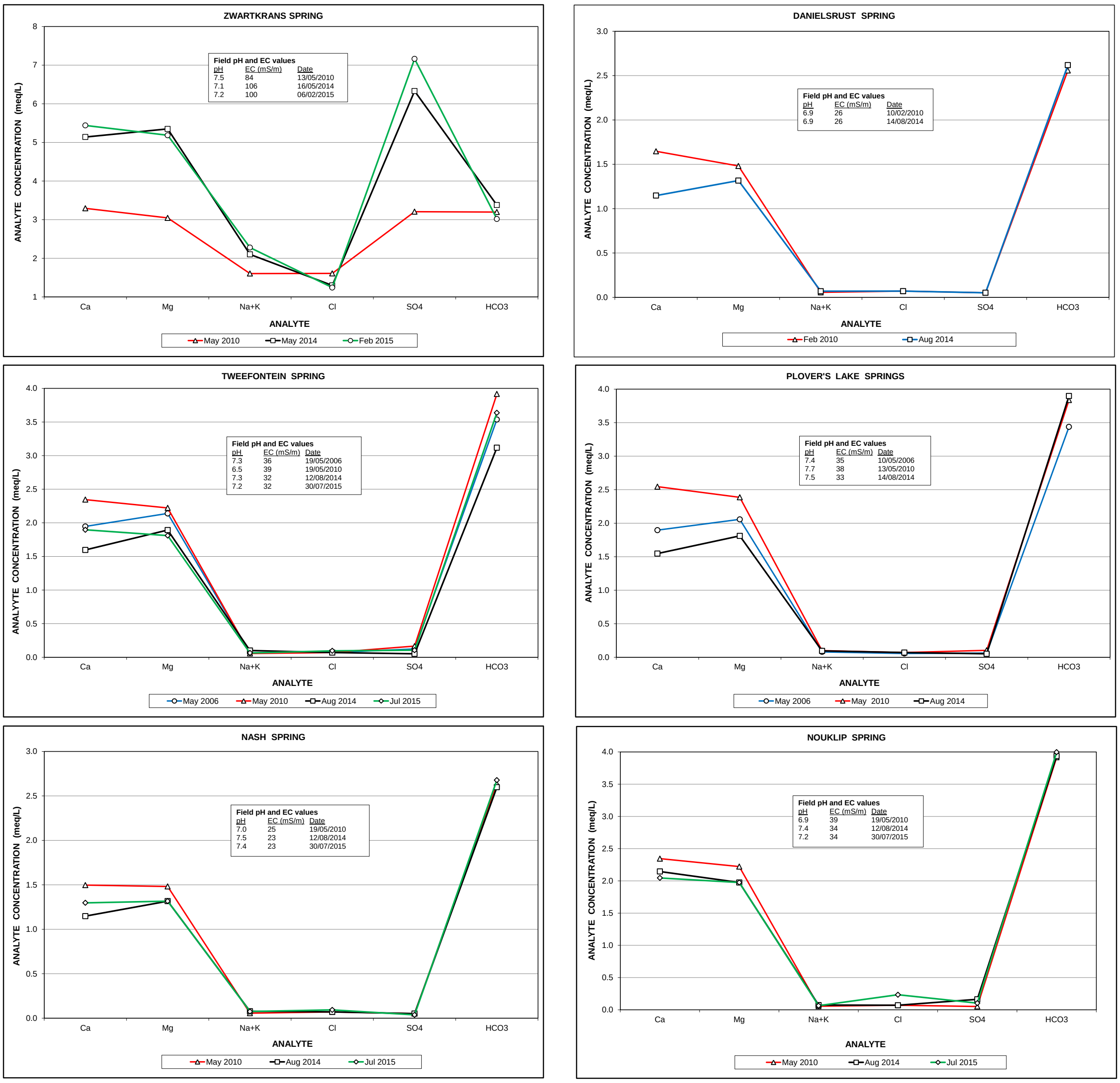


Figure 39 Graphical comparison of recent and historical springwater chemistry in the COH

6 HOLISTIC MINE WATER IMPACT APPRAISAL

6.1 Introduction

An appraisal by Hobbs and Mills (2015) was accomplished by evaluating the discharge and chemical data associated with the DWS gauging stations shown in **Figure 40**. The shortest of these records that defines the period of mutual record for both discharge and chemistry data for all the stations, dates back to the 1979–'80 hydrological year.

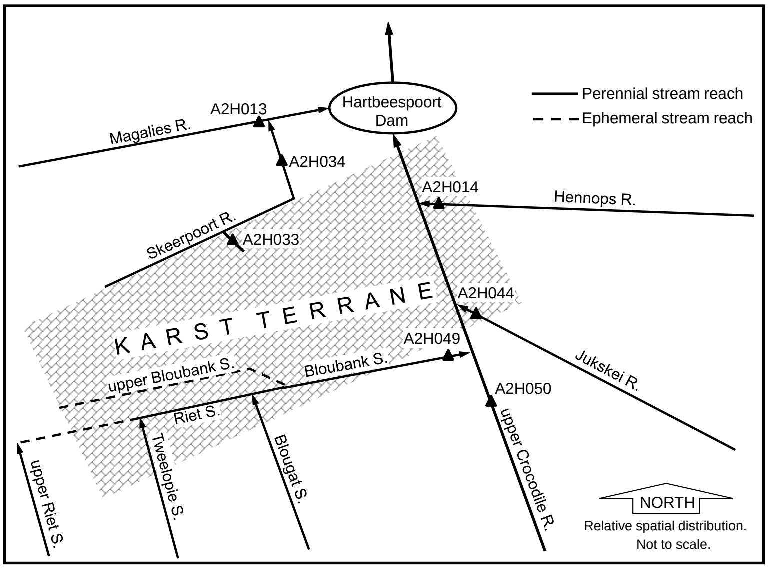


Figure 40 Schematic diagram of surface drainage and gauging network superimposed on karst footprint

Whereas Hobbs and Mills (2015) considered only two periods, viz. 1979–'80 to 2008–'09 (long-term) and 2009–'10 to 2013–'14 (recent) in their analysis, the analysis presented here has been updated and extended to include three periods. These are defined as (a) the long-term record ending with the 2008–'09 hydrological year, (b) the long-term record ending with the 2014–'15 hydrological year, and (c) the recent record spanning the 2009–'10 to 2014–'15 hydrological years. The last six hydrological years witnessed a consistently higher SO_4:TDS ratio and SO_4 concentration, respectively, than the pre-2009–'10 values (see **Figure 26** and **Figure 28**), reflecting a greater impact from mine water discharges rising more recently in the Western Basin. The inclusion of the 1979–'80 to 2014–'15 long-term record explores the impact of the recent period on the respective historical data sets.

6.2 Discharge Dynamics

6.2.1 Surface Water

The appraisal first considers the subregional surface water discharge associated with stations A2H034 (Skeerpoort River), A2H049 (Bloubank Spruit) and A2H050 (upper Crocodile River) in the three periods of record. The results illustrated in **Figure 41** reveal the considerably greater median aggregate discharge of ~96 Mm^3/a delivered in the recent period, compared to the ~40–50 Mm^3/a of the long-term records. Despite the difference in discharge, the Bloubank Spruit contribution is similar (~51%) in both periods. An analysis of the regional surface water discharge in the two periods of record is illustrated in **Figure 42**. The results again reveal the considerably greater median aggregate discharge of ~554 Mm^3/a delivered in the recent period, compared to the ~218–260 Mm^3/a of the long-term record. As in the subregional context described above, the contribution (9%) of the Bloubank Spruit remains similar in all periods of record. This observation also applies to all of the regional drainages in the analysis.

The analysis of the surface discharge characteristics indicates that the excessive mine water discharges in the last six years, i.e. since the advent of periodic uncontrolled raw mine water releases to the environment in early-2010, manifest no discernible difference in the relative discharge contribution of the Bloubank Spruit in either a subregional or regional context.

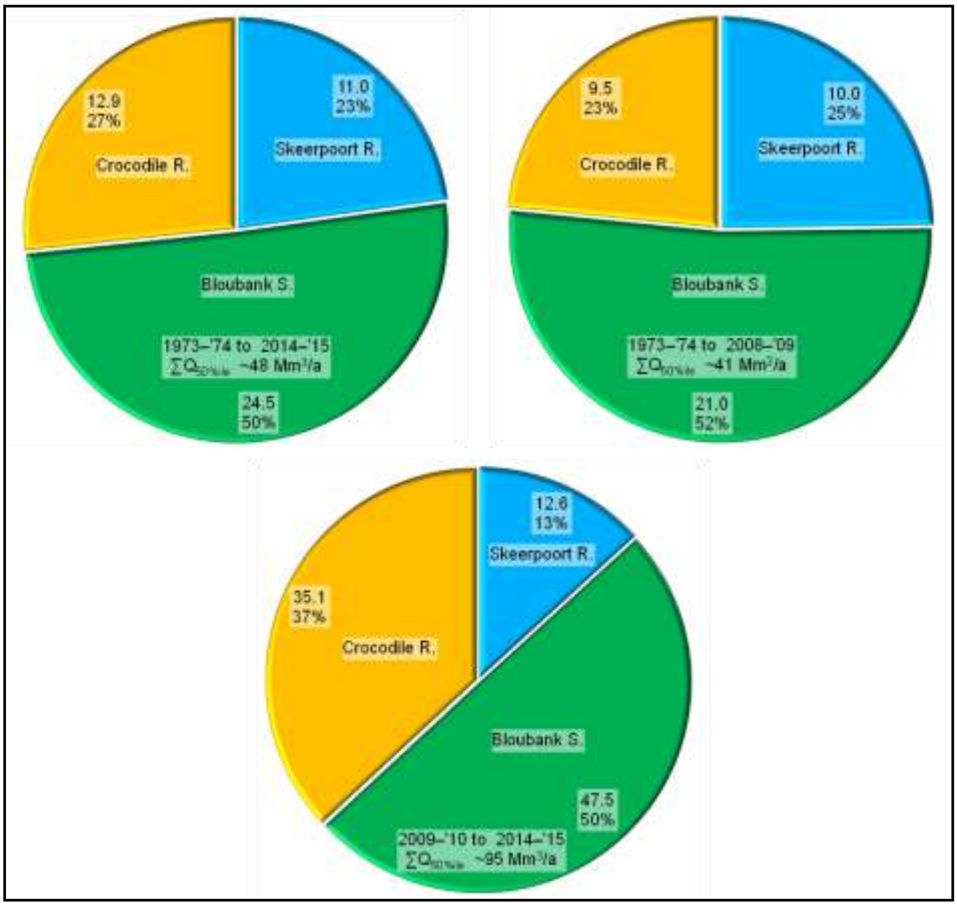


Figure 41 Comparison of long-term and recent subregional discharge

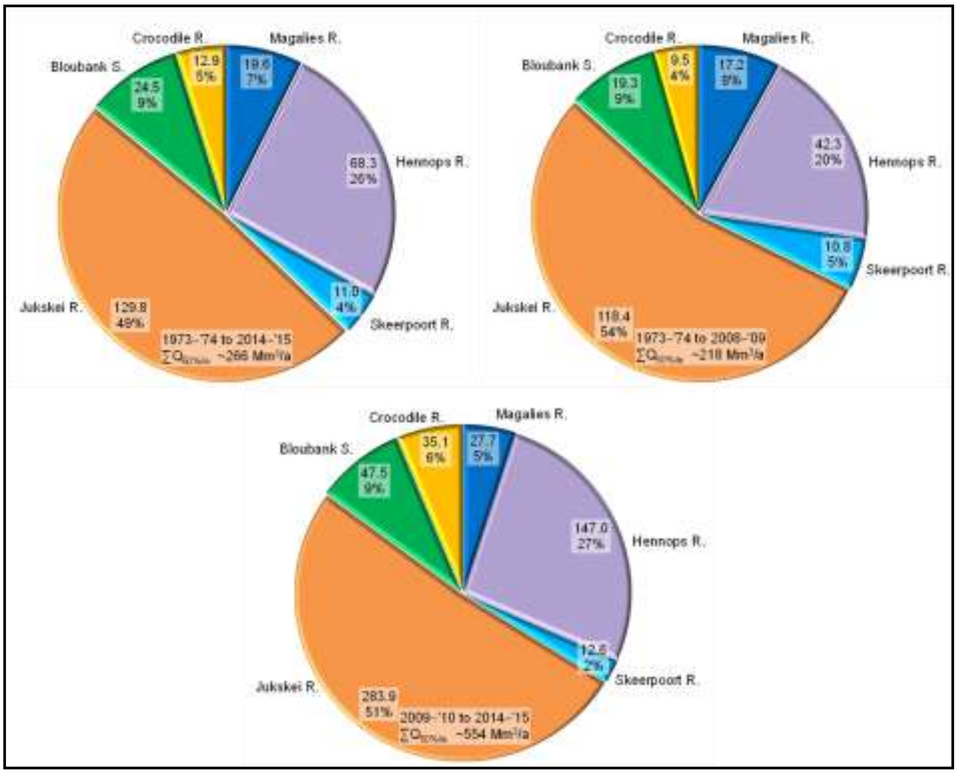


Figure 42 Comparison of long-term and recent regional discharge

6.2.2 Groundwater

The aggregate discharge of major springs contributing to flow in the Bloubank Spruit and Skeerpoort River amounts on average to ~506 L/s (~16 Mm^3/a) and ~361 L/s (~11.4 Mm^3/a) respectively. Together these discharges represent ~14% of the ~190 Mm^3 full supply capacity of Hartbeespoort Dam. A characteristic of springs draining the late Archaean and early Proterozoic carbonate strata of the South African interior is their relatively constant flows. Martini (2006) refers to “very regular discharges at resurgences”. This is in contrast to the ‘flashy’ nature of springs that drain the telogenetic and much younger European karst formations (Florea and Vacher, 2006). This characteristic is attributed to the crucial hydrologic functions and roles played by the epikarst and vadose zone also in the regional karst system in the COH. In this regard, Klimchouk (2004) recognises the retardation of throughflow and mixing of recharge in its often lengthy and tortuous pathway to the aquifer as one of the principal factors.

A possible springwater contribution to the upper Crocodile River discharge was not considered. Although the quartzitic strata of the Witwatersrand Supergroup that form the continental divide are known to support numerous springs, their individual discharges are typically small compared to those draining the Malmani Subgroup dolomitic strata. Further, their discharge is also more variable than that of the much higher-yielding karst springs. This is attributed to a combination of more rapid response to recharge from rainfall and a lower storativity that characterises the mainly fractured host aquifer.

6.3 Total Dissolved Solids Load

6.3.1 Surface Water

An analysis of the subregional TDS loads reveals a recent median value of ~40 kilotons per annum (kt/a) that is ~2.5 times greater than the long-term values of ~14–17 kt/a (**Figure 43**). Further, that the relative load contributed by the Bloubank Spruit in each period of record is similar, increasing from the long-term 61% to the more recent 66% despite the 2.6-fold increase in actual load from ~10 to ~26 kt/a. The percent increases represented by the recent TDS loads compared to the long-term loads for each of the subregional drainages is ~172% for the Bloubank Spruit, ~203% for the Crocodile River and ~18% for the Skeerpoort River. In relative terms, therefore, the Crocodile River delivered a greater TDS load to Hartbeespoort Dam in the last six years than did the Bloubank Spruit. It is postulated that the mine water impact on the Bloubank Spruit system was significantly mitigated by the better quality spring discharges rising in this catchment. The TDS loads delivered by the Skeerpoort River show the least variability, ranging from ~2.8 kt/a in the long-term to 3.3 kt/a in the last six years. This is discussed further in **Section 6.3.2**.

The mitigation evident in the Bloubank Spruit system TDS load in a subregional context is more evident in a regional context. This is reflected in the 12% TDS load contribution of this drainage in the last six years compared to the long-term contributions of 10% (**Figure 44**). The combined TDS loads delivered by the Jukskei and Hennops rivers remains similar at ~80% in all three periods of analysis, as does the scale of individual contributions of the other drainages (**Figure 44**). Whereas the Bloubank Spruit and Crocodile River show 2% increased contributions, the Skeerpoort River reflects a 2% decreased contribution.

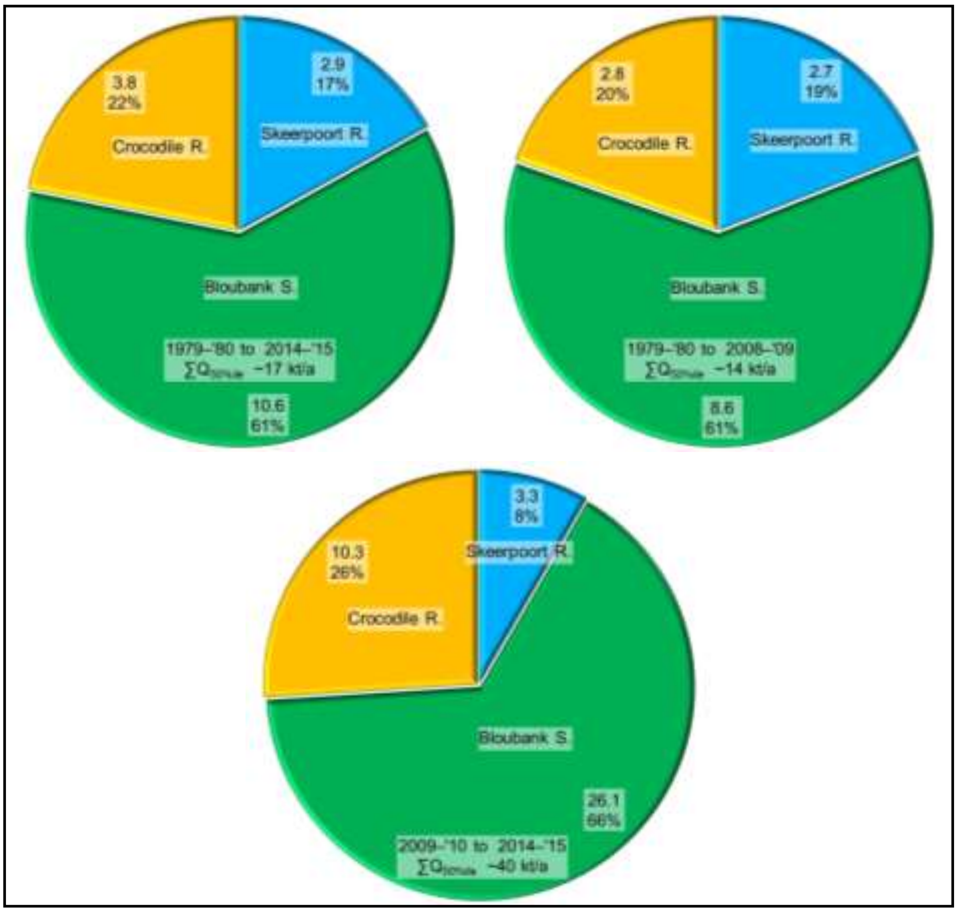


Figure 43 Comparison of long-term and recent subregional TDS load

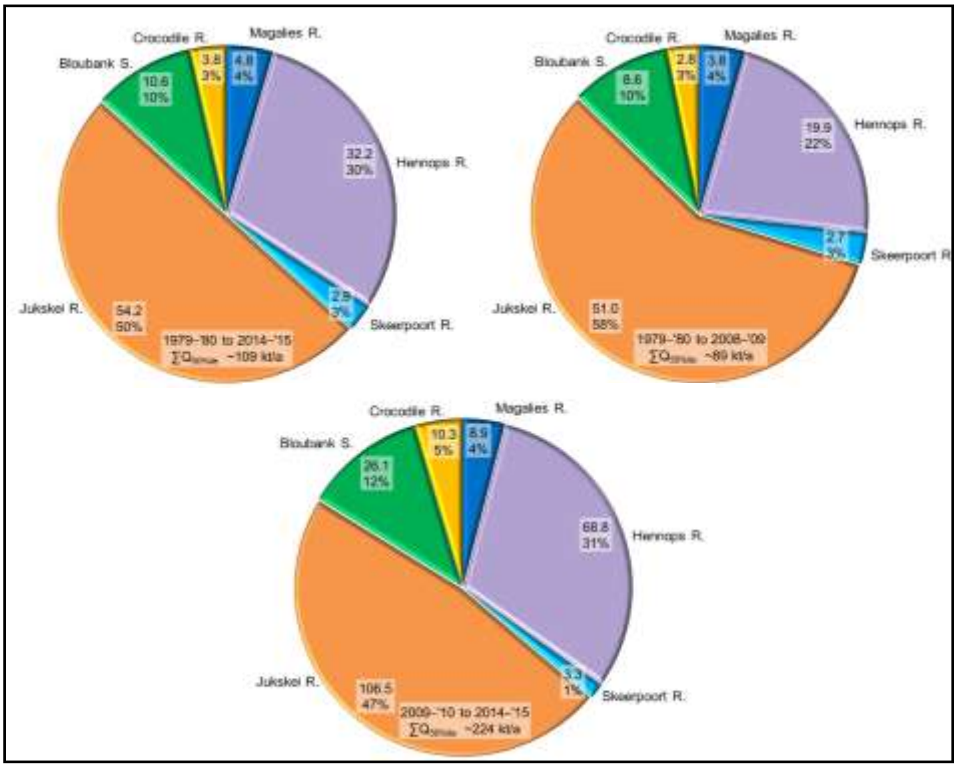


Figure 44 Comparison of long-term and recent regional TDS load

6.3.2 Groundwater

The TDS load contributed by groundwater to the Bloubank Spruit and Skeerpoort River via spring discharges is not subject to significant temporal variations in either median flow or TDS. Although the latter varies from spring to spring, that delivered by each spring is fairly uniform.

The springs discharging into the Bloubank Spruit deliver an aggregate and relatively constant groundwater-derived TDS load of ~7.8 kt/a to this system. This is in reasonable agreement with the 8.6 kt/a delivered in the 1979–'80 to 2008–'09 period (**Figure 43**), i.e. excluding the last six years of greater surface water TDS load. This is attributed to the mitigating influence of the better quality spring discharges rising in this catchment. This influence is moderately negated by the ~235% greater load in the recent period of record attributed to a mine water impact.

Similarly, the springs discharging into the Skeerpoort River deliver an aggregate and relatively constant groundwater-derived TDS load of ~3.0 kt/a to this system. This is in excellent agreement with both the long-term surface water subregional values of 2.9 and 2.7 kt/a, and the recent value of 3.3 kt/a (**Figure 43**). This is to be expected from a primarily groundwater-driven surface drainage.

6.4 Summary

An analysis of the discharge and water chemistry records associated with the main drainages in the Hartbeespoort Dam catchment for two historical periods of record (1979–'80 to 2008–'09 and 1979–'80 to 2014–'15) and a recent (2009–'10 to 2014–'15) period of record provides an informative measure of the temporal mine water impact in both a subregional and a regional context. The derivation of a TDS load for each record period and spatial scale reveals a recent mine water impact in a subregional context that is much less evident in a regional context. This is attributed to the contribution of good to excellent quality dolomitic groundwater via high-yielding karst springs that rise on the COH property. Biased in favour of the Bloubank Spruit that receives mine water, this contribution naturally acts to reduce the mine water impact. Its moderating influence at a regional scale is masked by the similar or greater loads contributed by larger drainages than the Bloubank Spruit.

7 OBSERVATIONS AND CONCLUSION

The karst environment of a portion of the Zwartkrans Compartment in the south-western quadrant of the property, which previously reflected a significant deterioration in groundwater quality, shows a slight reduction in SO_4 levels in the "upstream" reaches and an increase in the "downstream" reaches in the December 2014 monitoring results compared to the September 2014 results. These circumstances are interpreted to reflect the passage of an AMD-impacted groundwater "slug" through the aquifer introduced during a short period of uncontrolled mine water discharge in early-2014. Further observations are listed as follows:

- The 2014–'15 wet (summer) season is the driest since 2008–'09, experiencing ~15% less than the next lowest (2011–'12) season. These circumstances have translated into a below average recharge of the mine void, resulting in a reduced mine water discharge (decant) on surface that has assisted in reversing the negative impacts driven by the very wet 2013–'14 summer season. This situation was maintained through the 2014–'15 dry (winter) season.

- The 2014–’15 hydrological year produced a similar runoff (~35 Mm^3) as the 2012–’13 hydrological year (~33 Mm^3), which is roughly 42% greater than the long-term (whole record) median discharge of ~24 Mm^3/a. It remains to be seen what the coming 2015–’16 wet season, which it is forecast will experience the effects of a severe El Niño Southern Oscilation (ENSO) event, will produce.

- The return to ‘more normal’ pre-2010 discharge water quality in the downstream receiving hydrologic environment observed in the previous reporting period has continued into the current reporting period. This is reflected in electrical conductivity values of ~300 mS/m, near-neutral pH values, and sulphate values of ~2000 mg/L.

- Faecal coliform counts continue to reflect unacceptably high levels (median of 310 cfu/100 mL) in the lower reaches of the Bloubank Spruit system, highlighting the poor performance of the Percy Stewart Wastewater Treatment Works as the primary source located further upstream.

- The groundwater elevation continues to show the greatest decline in the south-western portion of the property (the Zwartkrans Compartment) where the allogenic recharge component is greatest. This is exemplified by the Main Lake water level in Sterkfontein Caves, which has dropped by ~0.8 m since the maximum in the ~30-year period of monitoring was reached in July 2014.

- A comparison of the TDS loads delivered by major drainages to Hartbeespoort Dam in the last six hydrological years, with those delivered in the periods 1979–’80 to 2008–’09 (which defines the period of negligible mine water impact) and 1979–’80 to 2014–’15 (which defines the whole record including the period of greatest mine water impact and exceptionally high runoff), reveals moderate impacts from mine water at a subregional scale, and slight impacts at a regional scale. This is attributed to the contribution of good to excellent quality dolomitic groundwater from high-yielding karst springs that rise on the COH property. Their bias in favour of the mine water receiving Bloubank Spruit naturally acts to reduce a mine water impact in a subregional context, whereas their moderating influence at a regional scale is muted by the much greater loads contributed by the larger Jukskei and Hennops rivers.

It is concluded that the water resources monitoring results documented in this report confirm the conceptual hydrophysical and hydrochemical model developed for the COH WHS in the situation assessment report. As with previous water resources status reports, it has not revealed any major inconsistencies, nor has it exposed significant flaws that might question the water resources situation assessment and monitoring programme as originally formulated.

The global focus on the Rising Star site resulting from the *Homo naledi* fossil find (Berger et al., 2015; Dirks et al., 2015), elevates any environmental impact in the vicinity beyond measure. Irresponsible actions, no matter how well-intentioned, sabotage efforts to demonstrate responsible curatorship of the environment. It is recommended that a portion of the additional funding promised by Government to uplift the tourist potential of the region, should be channelled toward stormwater management over the karst areas of the COH. This can be directed quite specifically at high-risk areas such as road junctions, and comprise engineered spreading basins to mediate concentrated infiltration.

8 ACKNOWLEDGEMENTS

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ANNEXURE A

QUANTIFICATION OF STREAM FLOW LOSS RATE IN THE RIET SPRUIT BETWEEN STATIONS F11S12 AND MRd

Date	Flow @ F11S12 (ML/d)	Flow @ MRd (ML/d)	Flow Loss (ML/d)	Flow Loss Rate[(1)] (L/s/km)	
09/09/2009	11.9 ± 1.2	0	11.9	35	
22/09/2009	14.9 ± 1.5	0	14.9	44	
05/02/2010	35.2 ± 3.5	7.3 ± 0.4	27.9	83	Period 2
16/02/2010	31.6 ± 3.2	5.7 ± 0.3	25.9	77	
23/02/2010	26.2 ± 2.6	4.0 ± 0.2	22.2	66	
09/03/2010	32.6 ± 3.3	9.4 ± 0.5	23.2	69	
01/04/2010	40.4 ± 4.0	10.3 ± 0.5	30.1	89	
14/04/2010	25.8 ± 2.6	5.7 ± 0.3	20.1	60	
06/05/2010	43.7 ± 4.4	11.7 ± 0.6	32.0	95	
18/05/2010	35.7 ± 3.6	11.0 ± 0.6	24.7	73	
09/06/2010	32.1 ± 3.2	10.5 ± 0.5	21.6	64	
07/07/2010	29.9 ± 3.0	6.2 ± 0.3	23.7	70	
27/07/2010	31.6 ± 3.2	6.5 ± 0.3	25.1	74	
19/08/2010	25.8 ± 2.6	5.3 ± 0.3	20.5	61	
05/10/2010	13.8 ± 1.4	0.4	13.4	40	
19/11/2010	22.2 ± 2.2	3.4 ± 0.2	18.8	56	
27/07/2011	31.9 ± 3.2	19.4 ± 1.0	12.5	Period 3	37
25/08/2011	28.7 ± 2.9	20.0 ± 1.0	8.7		26
05/09/2011	22.5 ± 2.3	15.9 ± 0.8	6.6		20
08/05/2012	21.4 ± 2.1	9.6 ± 0.5	11.9		35
14/08/2012	22.5 ± 2.3	6.8 ± 0.3	15.7		47
21/09/2012	24.6 ± 2.5	15.5 ± 0.8	9.1		27
24/10/2012	16.2 ± 1.6	5.7 ± 0.3	10.5		31
15/01/2013	18.4 ± 1.8	6.4 ± 0.3	12.0		36
14/02/2013	23.0 ± 2.3	7.5 ± 0.4	15.5		46
06/03/2013	20.7 ± 2.1	8.0 ± 04	12.7		38
15/08/2013	30.1 ± 3.0	16.5 ± 0.8	13.6		40
15/10/2013	29.6 ± 3.0	14.1 ± 0.7	15.5		46
12/12/2013	22.2 ± 2.2	4.7 ± 0.2	17.5		52
26/09/2014	41.5 ± 4.2	30.3 ± 1.5	11.2		33
30/07/2015	26.9 ± 2.7	14.5 ± 0.7	12.4		37
Count	31	31	31	14	15
Minimum	11.9	0.0	6.6	39.8	19.6
Mean	26.9	9.4	17.5	69.8	36.7
Median	26.2	7.5	15.5	69.6	36.8
Maximum	43.7	30.3	32.0	95.0	51.9

(1) Based on a distance of ~3.9 km between localities
Error margin of ±10% at F11S12 and ±5% at MRd

ANNEXURE B

RECORD OF ELECTRICAL CONDUCTIVITY AND pH MEASUREMENTS MADE AT STATIONS F11S12 AND MRd ON THE OCCASION OF FLOW GAUGING MEASUREMENTS (SDMs), ALSO SHOWING DERIVED SO_4 AND TDS CONCENTRATIONS

Date	**Station F11S12**				**Station MRd**			
	EC (mS/m)	**$SO_4^{(1)}$ (mg/L)**	**$TDS^{(2)}$ (mg/L)**	**pH $(-\log_{10}\alpha_{H^+})$**	**EC (mS/m)**	**$SO_4^{(1)}$ (mg/L)**	**$TDS^{(2)}$ (mg/L)**	**pH $(-\log_{10}\alpha_{H^+})$**
22/09/2009	322	2 089	2 479	6.7				
05/02/2010	389	2 586	2 997	3.9	358	2 358	2 759	4.1
16/02/2010	339	2 215	2 610	4.2	335	2 186	2 581	4.2
23/02/2010	379	2 510	2 918	4.1	383	2 538	2 948	3.9
09/03/2010	379	2 510	2 918	4.1	353	2 320	2 720	4.0
01/04/2010	374	2 472	2 878	3.6	358	2 358	2 759	3.4
14/04/2010	358	2 355	2 757	3.7	347	2 274	2 672	3.6
06/05/2010	408	2 724	3 142	3.2	420	2 813	3 234	3.3
18/05/2010	335	2 185	2 580	5.5	356	2 340	2 741	4.4
09/06/2010	370	2 444	2 849	4.4	373	2 466	2 872	4.5
07/07/2010	374	2 473	2 880	4.0	376	2 488	2 895	3.9
27/07/2010	407	2 717	3 134	3.7	395	2 628	3 042	4.1
19/08/2010	384	2 547	2 957	2.6	335	2 185	2 580	2.7
05/10/2010	307	1 979	2 364	3.0	383	2 540	2 949	2.5
19/10/2010	314	2 030	2 418	3.6	326	2 119	2 510	3.1
19/11/2010	338	2 207	2 603	2.8	333	2 171	2 564	2.8
18/12/2010	416	2 783	3 203	2.7	376	2 488	2 895	3.0
27/07/2011	369	2 436	2 841	2.7	373	2 466	2 872	2.9
25/08/2011	389	2 584	2 995	2.9	405	2 702	3 119	2.5
05/09/2011	362	2 385	2 787	2.6	367	2 421	2 826	2.6
08/05/2012	372	2 458	2 864	2.6	388	2 576	2 988	2.9
14/08/2012	299	1 920	2 302	6.3	309	1 993	2 379	4.2
21/09/2012	290	1 853	2 233	7.6	288	1 838	2 218	6.9
24/10/2012	264	1 661	2 033	4.3	270	1 706	2 079	3.8
15/01/2013	282	1 794	2 171	6.6	283	1 802	2 179	4.9
14/02/2013	274	1 735	2 110	7.0	277	1 757	2 133	6.4
06/03/2013	244	1 514	1 879	6.9	241	1 492	1 856	6.6
15/08/2013	219	1 329	1 686	7.1	219	1 329	1 686	6.6
15/10/2013	275	1 743	2 118	6.6	274	1 735	2 110	6.2
12/12/2013	236	1 455	1 817	6.6	231	1 418	1 779	6.6
26/09/2014	238	1 469	1 833	7.3	238	1 469	1 833	6.0
30/07/2015	271	1 713	2 087	7.2	273	1 728	2 102	—
Count	31	31	31	31	31	31	31	30
Minimum	219	1 337	1 686	2.6	219	1 337	1 686	2.5
Mean	317	2 158	2 547	4.6	318	2 155	2 544	4.2
Median	302	2 219	2 610	4.1	309	2 277	2 672	4.0
Maximum	416	2 785	3 203	7.6	420	2 814	3 234	6.9

(1) $SO_4 = 7.38*EC - 287$ to derive a theoretical representative SO_4 value
(2) EC * 7.7 to derive a theoretical representative TDS value

ANNEXURE C

RECENT WATER CHEMISTRY ASSOCIATED WITH THE MAJOR KARST SPRINGS IN THE CRADLE OF HUMANKIND

Variable/analyte	**Unit**	**Spring**						
		Zwartkrans	**Danielsrust**	**Plover's Lake**	**Kromdraai**	**Tweefontein**	**Nouklip**	**Nash**
Date	dd/mm/yyyy	06/02/2015	14/08/2014	14/08/2014	20/08/2014	30/07/2015	30/07/2015	30/07/2015
Temperature*	°C	19.1	19.6	20.1	19.4	20.2	21.4	21.4
Electrical conductivity*	mS/m	99.8	22.6	32.6	54.1	31.7	34.3	22.9
pH*	$–\log_{10}\alpha_{H+}$	7.2	7.4	7.5	7.1	7.2	7.2	7.4
Eh*	mV	–25.0	–60.0	–61.0	–42.1	–42.8	–40.8	–55.6
ORP*	mV	–13.5	–17.1	–20.3	–10.6	–3.0	–2.1	–4.9
Calcium	mg Ca/L	109	23	31	68	38	41	26
Magnesium	mg Mg/L	63	16	22	32	22	24	16
Sodium	mg Na/L	51	1.3	1.9	23	1.3	1.3	1.5
Potassium	mg K/L	2.3	<1	<1	1.9	0.3	0.3	0.4
Chloride	mg Cl/L	44	<5	<5	29	3.4	8.3	3.3
Sulphate	mg SO_4/L	344	<5	<5	127	5.1	5.0	1.8
Total alkalinity	mg $CaCO_3$/L	151	131	195	159	182	200	134
Fluoride	mg F/L	<0.2	<0.2	<0.2	<0.2	—	—	
Nitrate + nitrite	mg N/L	9.2	0.29	0.3	3.9	0.6	0.3	0.2
Ortho-phosphate	mg PO_4/L)	—	<0.2	<0.2	<0.2	—	—	
Silica	mg Si/L	5.8	5.2	5.8	5.7	4.6	4.6	4.8
Iron (total)	mg Fe/L	<0.02	<0.02	<0.02	0.049	<0.01 (diss.)	<0.01 (diss.)	<0.01 (diss.)
Manganese (total)	mg Mn/L	<0.005	<0.005	<0.005	0.16	<0.01 (diss.)	<0.01 (diss.)	<0.01 (diss.)

* Field values