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 2016

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PREPARED FOR

Management Authority
Cradle of Humankind World Heritage Site
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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 9th such report since 2012. It covers the period April 2016 to September 2016 and, as such, represents a mid-term monitoring report and deliverable in the MAs financial year 2016–'17, the timeframe in which annual contracts are managed.

The Rising Star cave system, site of the *Homo naledi* fossil find, 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 series of water resources status reports. The outcome is summarised in the following observations.

- Despite the continuing existence of severe drought conditions nationally, the 2015–'16 wet (summer) season was characterised by high late-season precipitation, with ~58% of the total summer rainfall occurring in February and March 2016. This was followed by a wetter than usual dry (winter) season (rainfall of 195 mm was recorded in the period April to September 2016, with 23 and 49 mm being recorded in June and July respectively). However, the total of 822 mm for the 2015–'16 hydrological year equates to ~105% of the mean annual precipitation (~780 mm) in the past 8 years. As a consequence, these circumstances did not result in uncontrolled discharge of raw mine water into the environment.

- The 2015–'16 hydrological year produced a runoff for the Bloubank Spruit system of ~34 Mm^3 similar to the ~35 Mm^3 of the previous hydrological year. These values are well below the median and mean values of ~43 and ~45 Mm^3/a, respectively, recorded in the last six hydrological years starting in 2010–'11.

- The return to 'more normal' pre-2010 discharge water quality in the downstream receiving surface water 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, circum-neutral pH values, and sulfate concentrations of ~2 000 mg/L.

- Faecal coliform (*E. coli*) counts continue to reflect unacceptably high levels (9 330 MPN/100 mL) in the Bloubank Spruit system, highlighting the poor performance of the Percy Stewart Wastewater Treatment Works as the primary source of this contamination located further upstream on the Blougat Spruit tributary.

- The groundwater elevation in the south-western portion of the property (the Zwartkrans Compartment) where the allogenic recharge component is greatest, experienced a slight rise of ~0.5 m in response to the late summer rains. This has not had a negative impact on the tourist route through Sterkfontein Caves.

- Groundwater in the south-western portion of the property (the Zwartkrans Compartment) where the allogenic recharge component is greatest, continues to experience a compromised quality reflected primarily in sulfate levels of up to ~2 000 mg/L. These circumstances are reflected in the continued rise of the SO_4 concentration in the Zwartkrans Spring water. However, the pH value of ambient karst groundwater in this part of the study area still exceeds 6.4 and, as such, do not reflect acidic conditions in the karst aquifer. Under these circumstances, it is concluded that the threat to the fossil sites of concern, namely Bolt’s Farm and Sterkfontein, remains low even though the sites remain at high risk.

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.

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SYMBOLS, ACRONYMS & ABBREVIATIONS

~	approximately
>	greater than
<	less than
%	per cent (parts per hundred)
%ile	percentile
°C	degree(s) Celsius
Δh	change in head
a_h	hydrological year
AMD	acid mine drainage
amsl	above mean sea level
bc	below collar
bs	below surface
ca.	circa (about)
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 project delivered a situation assessment of the surface water and groundwater resource environments (Hobbs, 2011) that redefined the understanding of especially the geometry of the hydrogeologic environment and the very close interaction between surface and groundwater resources. 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; 2015b; 2016). This document represents the ninth such report, which covers the mid-term period April to September 2016.

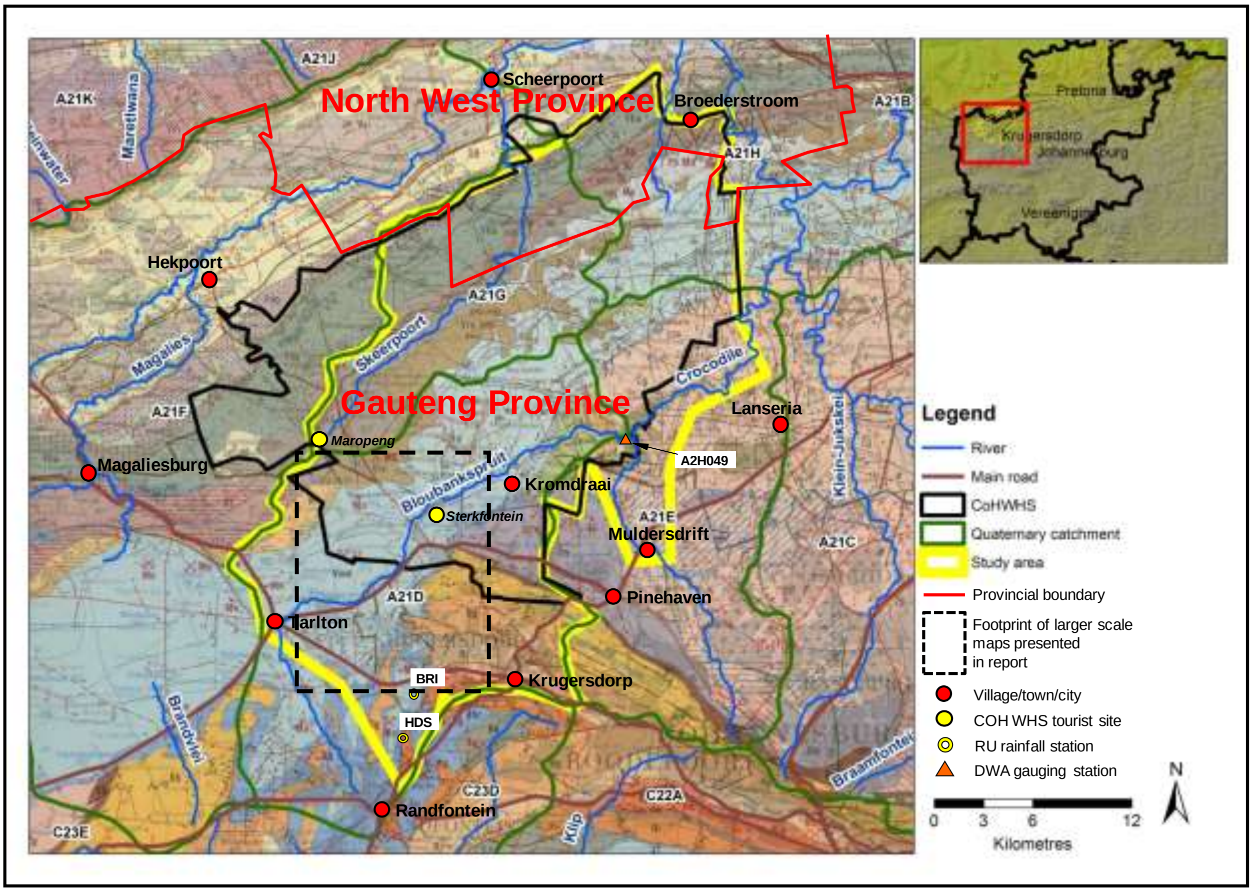


Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

2 TIMELINE OF KEY EVENTS

An updated timeline of key events to contextualise the material presented in this report is presented in **Figure 2**. The timeline starts with the inscription of the COH property as a World Heritage Site in 1999. The most recent landmark event on the timeline is the completion of a State of Conservation (SoC) report for submission to UNESCOs World Heritage Centre, for examination by the World Heritage Committee (WHC) at its 41st session in 2017. This is the second such report prepared for the WHC (see January 2015 inscription on the timeline).

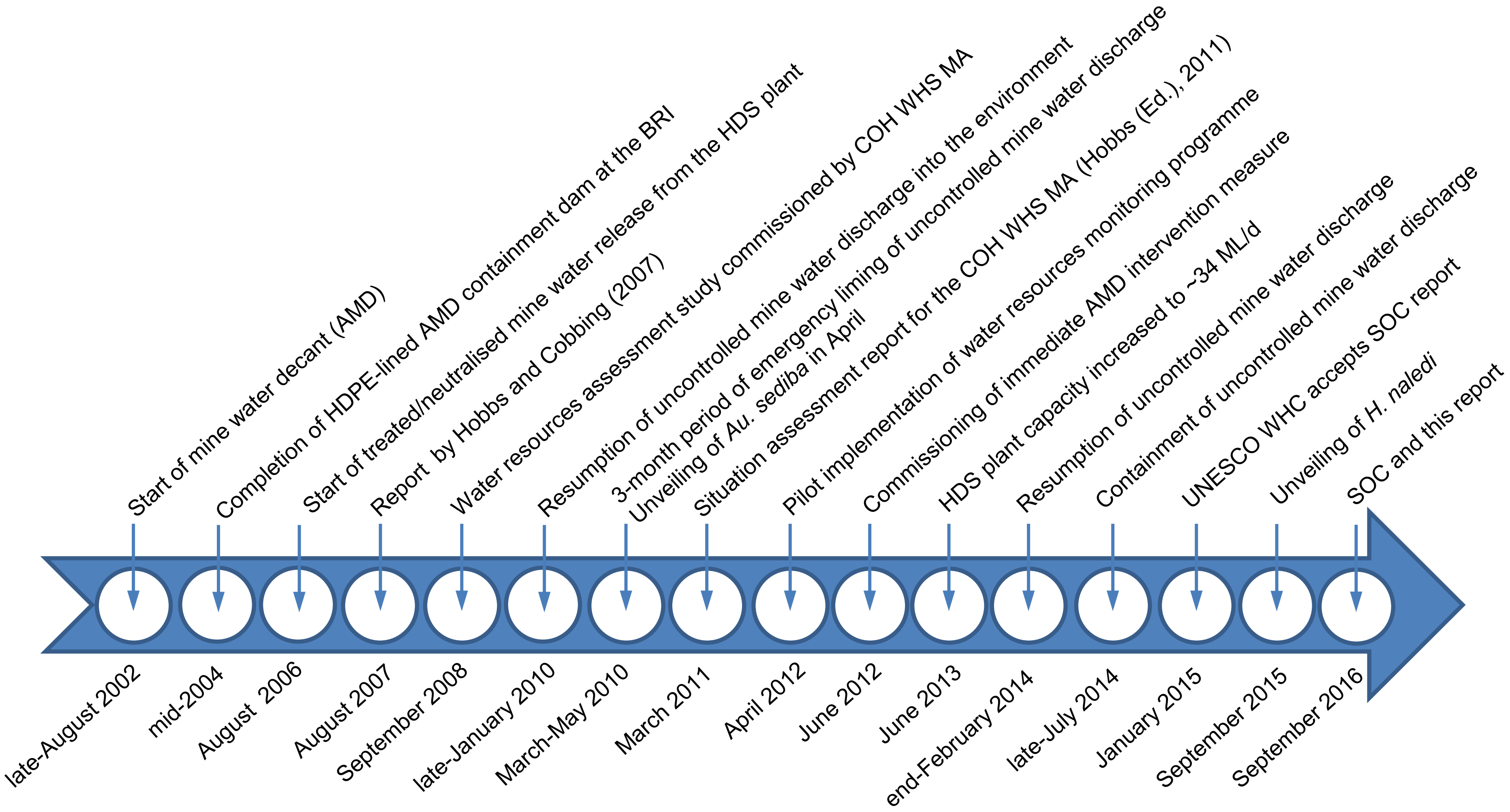


Figure 2 Updated timeline of events relevant to this report

3 RAINFALL

The monthly precipitation record for the period October 2008 to September 2016 at the Sibanye Gold (SG) rainfall station HDS (**Figure 3**) reveals the following:

- the 2015–'16 very wet late summer (in February and March 2016, 369 mm was recorded at the HDS station, representing ~59% of the total 2015–'16 wet season rainfall, and 293 mm at the Sterkfontein Caves, representing ~57% of the total wet season rainfall at this station);
- the wetter than normal 2015-'16 usually dry winter season (195 mm was recorded in the period April to September 2016, with 23 and 49 mm being recorded in June and July respectively); and despite these circumstances,
- the total of 822 mm for the 2015–'16 hydrological year (which equates to ~105% of the mean annual precipitation of ~780 mm in the past 8 years) by no means represents an abnormally wet year in the more recent past.

These circumstances are also reflected in **Figure 4**. It should be noted that the slightly wetter than normal hydrological year coincided with a severe El Niño Southern Oscilation (ENSO) event that continues to cause a severe drought over much of the country. Also shown in **Figure 3** and **Figure 4** are the contemporary rainfall data recorded by the DWS cumulative gauging instrument located at Sterkfontein Caves. The common monthly rainfall record (n = 76) for the HDS and Sterkfontein Caves stations indicates a good correlation ($R^2 = 0.87$, $p < 0.01$) (**Figure 5**).

Figure 5 *confirms earlier observations (Hobbs, 2012; 2013a; 2013b; 2014a; 2014b; 2015a; 2015b; 2016) that monthly rainfall to the north of the continental divide is generally ~10 to 15% less than that measured on the divide.*

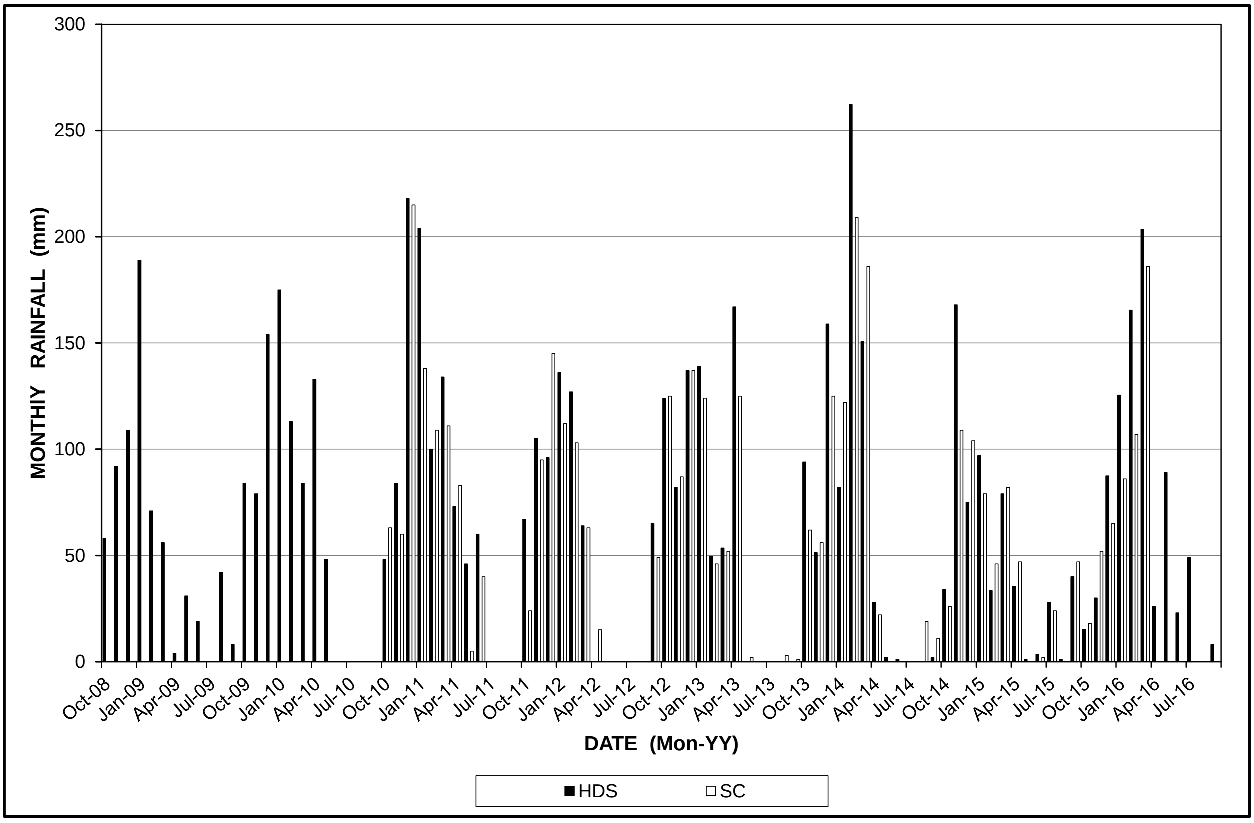


Figure 3 Monthly precipitation at the SG rainfall monitoring station HDS in the mine area and the available contemporary record for the Sterkfontein Caves station in the period October 2008 to September 2016

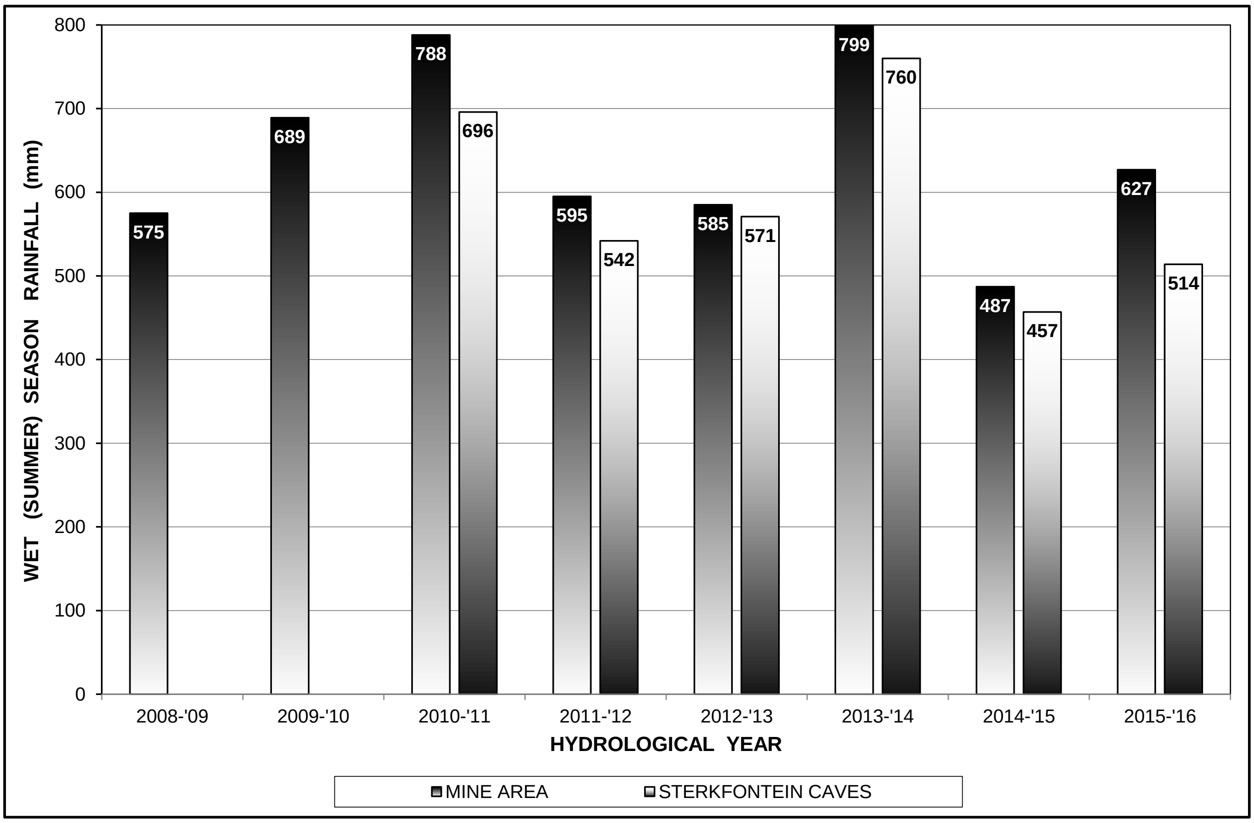


Figure 4 Total wet season (summer) rainfall in the mine area (HDS station) in the past eight hydrological years, also showing the comparison with that for the available contemporary Sterkfontein Caves record

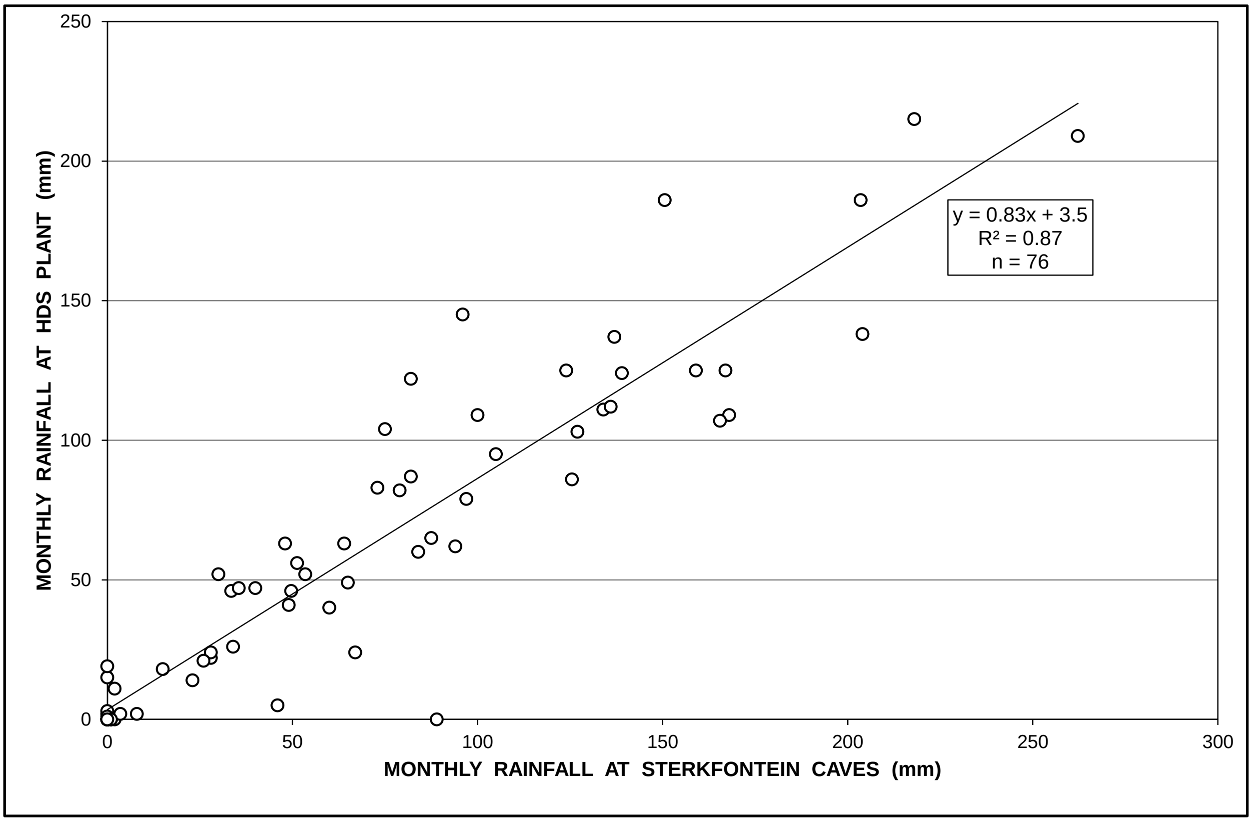


Figure 5 Correlation of monthly rainfall at Sterkfontein Caves with that at the HDS plant in the mine area

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 ~44-year discharge record for this catchment (Quaternary A21D) provides the monthly statistics reported in **Table 1**.

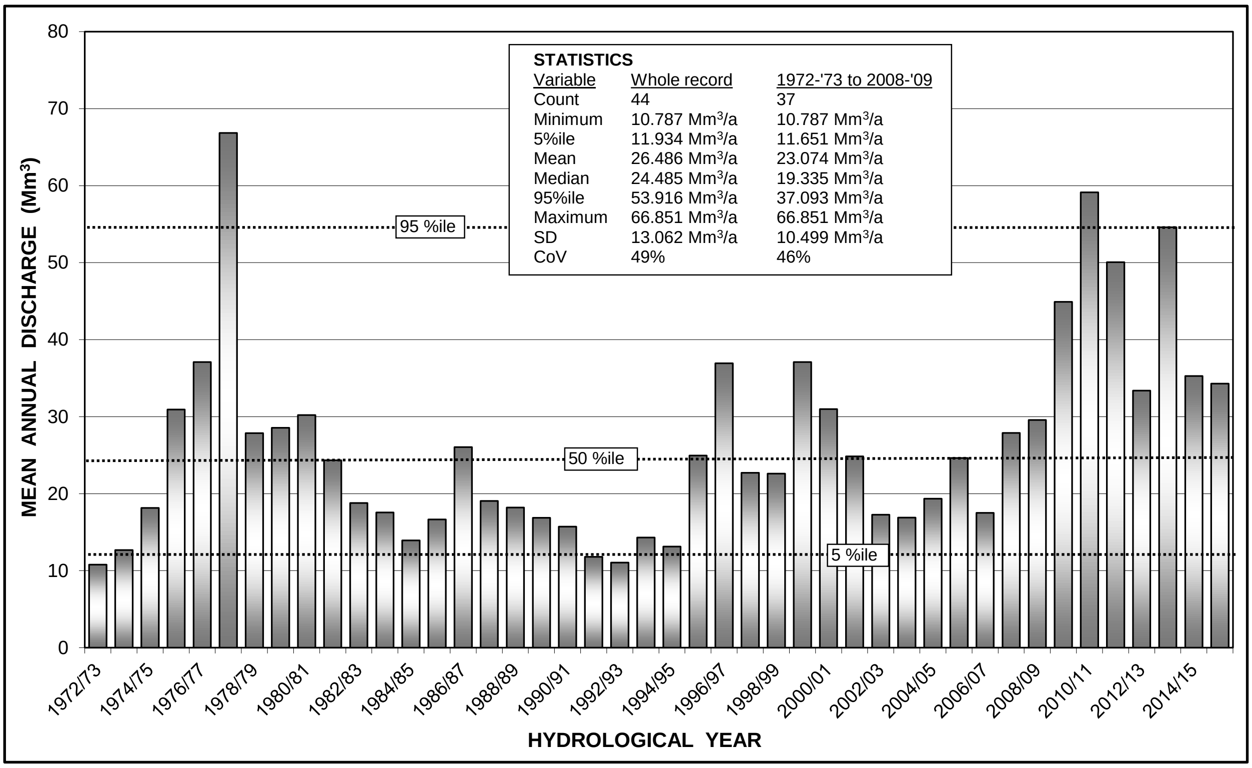
Table 1 Statistical analysis of Bloubank Spruit monthly discharge data gauged at station A2H049 in the period October 1972 to September 2016

Variable	**Month**											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	42	42	43	43	44	44	44	43	44	44	43	43
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	0.787	0.853	1.042	1.097	0.899	1.058	1.185	0.992	0.960	0.959	0.918	0.802
Mean	1.858	1.868	2.265	2.705	2.645	3.009	2.403	2.270	2.083	2.060	1.936	1.804
Median	1.616	1.742	2.040	2.428	2.087	2.512	1.986	1.888	1.772	1.668	1.609	1.561
95%ile	3.848	2.956	4.514	5.390	6.376	7.997	5.400	4.897	4.144	4.081	3.658	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	0.926	0.832	1.104	1.936	1.915	2.228	1.297	1.198	0.978	0.939	0.871	0.883
CoV (%)	49.8	44.5	48.8	71.6	72.4	74.0	54.0	52.8	46.9	45.6	45.0	49.0

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 2014–’15 and 2015–’16 hydrological years produced modest similar discharges of 35.3 and 34.3 Mm^3 respectively. The latter value is encouragingly close to the ~33 Mm^3 predicted for the 2015–’16 hydrological year (Hobbs, 2016). These values, however, remain above the median and mean whole record values of 24.5 and 26.5 Mm^3/a respectively (text box, **Figure 6**) but, more importantly, well below the median and mean values of 42.7 and 44.5 Mm^3/a, respectively, recorded in the last six hydrological years, i.e. since 2009–’10. It can be seen in **Figure 6** that this period experienced the greatest sustained discharge in the historical record.

The instantaneous monthly flow pattern at station A2H049 for the complete record October 1972 to September 2016 is shown in **Figure 7**. This reveals a comparatively constant pre-2007 lowest value of ~0.5 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 (>8 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. Since *circa* 2007, the lowest discharge value has gradually increased to a current value of ~1 m^3/s. The ~0.5 m^3/s (~43.2 ML/d) increase is attributed mainly to the increased sustained discharge of treated/neutralised mine water from the Western Basin (~25 ML/d), with a subordinate contribution of municipal wastewater effluent from the Percy Stewart Wastewater Treatment Works (~18 ML/d).



STATISTICS

Variable	Whole record	1972-'73 to 2008-'09
Count	44	37
Minimum	10.787 Mm³/a	10.787 Mm³/a
5%ile	11.934 Mm³/a	11.651 Mm³/a
Mean	26.486 Mm³/a	23.074 Mm³/a
Median	24.485 Mm³/a	19.335 Mm³/a
95%ile	53.916 Mm³/a	37.093 Mm³/a
Maximum	66.851 Mm³/a	66.851 Mm³/a
SD	13.062 Mm³/a	10.499 Mm³/a
CoV	49%	46%

Figure 6 Graph of Bloubank Spruit annual discharge gauged at station A2H049 in the period October 1972 to September 2016

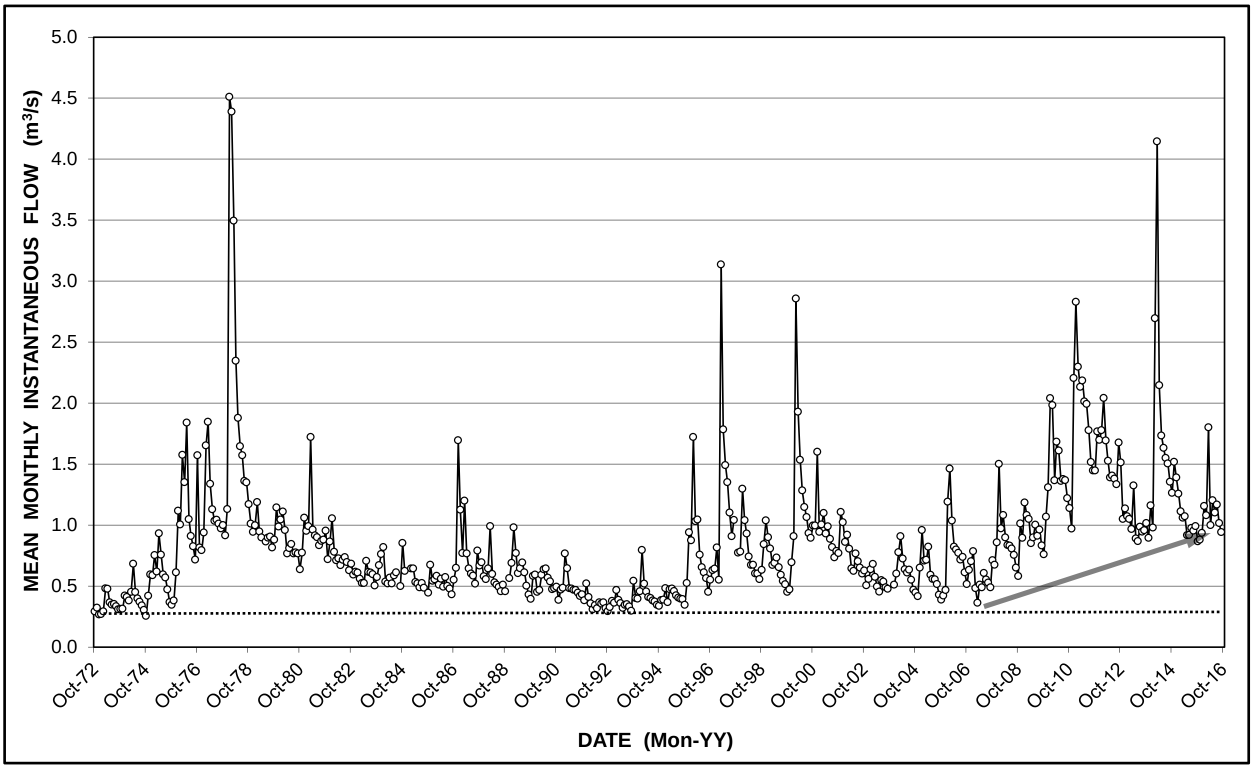
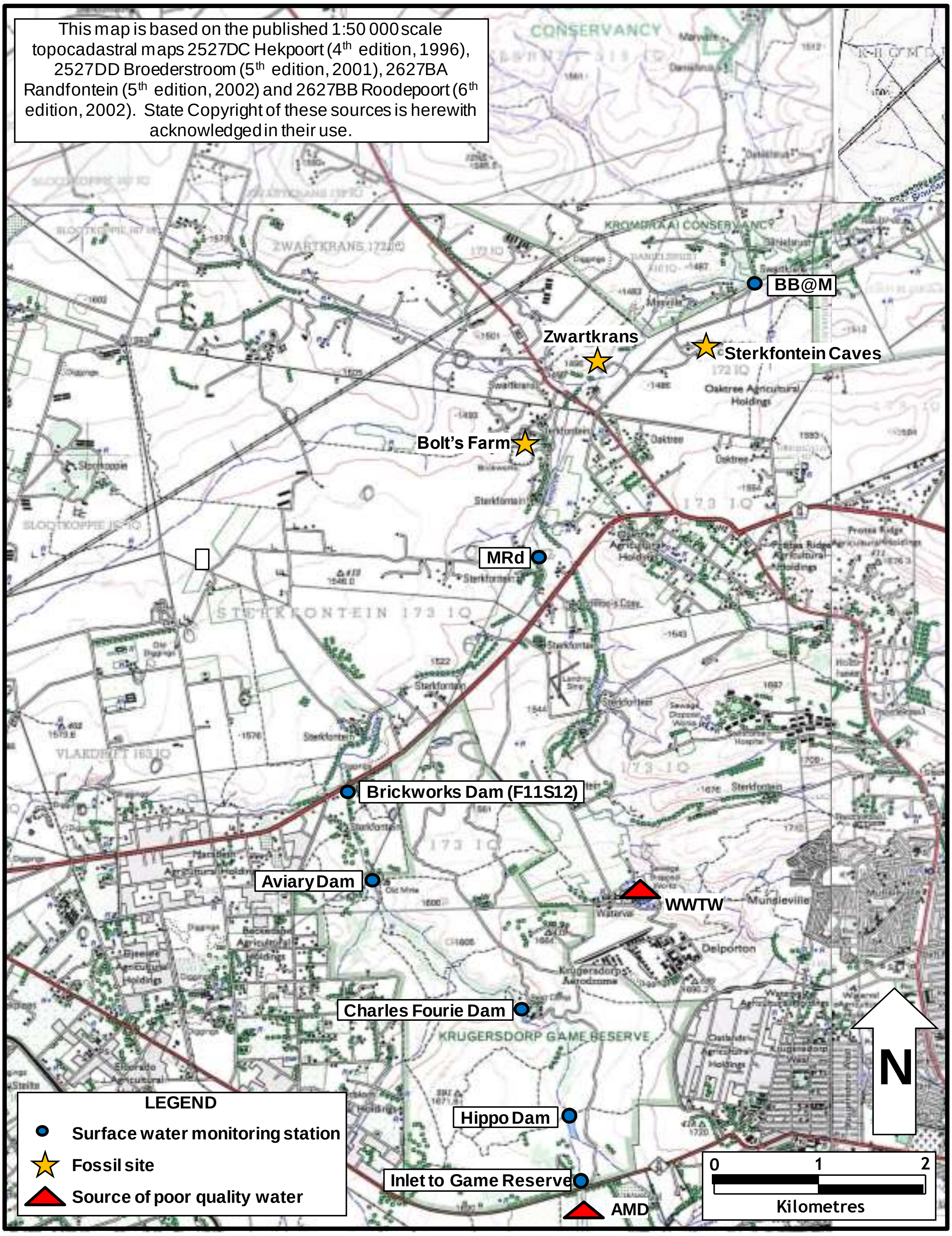


Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to September 2016

4.1.2 Surface Water Fluxes

In-stream flow measurements at stations F11S12 at the lower end of the Tweelopie Spruit and at 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. The last such measurements were made in July 2015.



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 results reported in Hobbs (2015b; 2016), however, are worth replicating for the insight they provide regarding the channel transmission losses between these two stations, and their role in the transmission flux between the surface and subsurface hydro-environments in this portion of the karst aquifer. **Figure 9** indicates that a minimum ingress converging at a value of ~14 ML/d, equivalent to ~42 L/s/km, characterises the stream reach in question. It is also evident from the different slopes of the Period 2 and Period 3 regression lines that a significant ~94% reduction in allogenic recharge from ~70 L/s/km to ~36 L/s/km distinguishes 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.

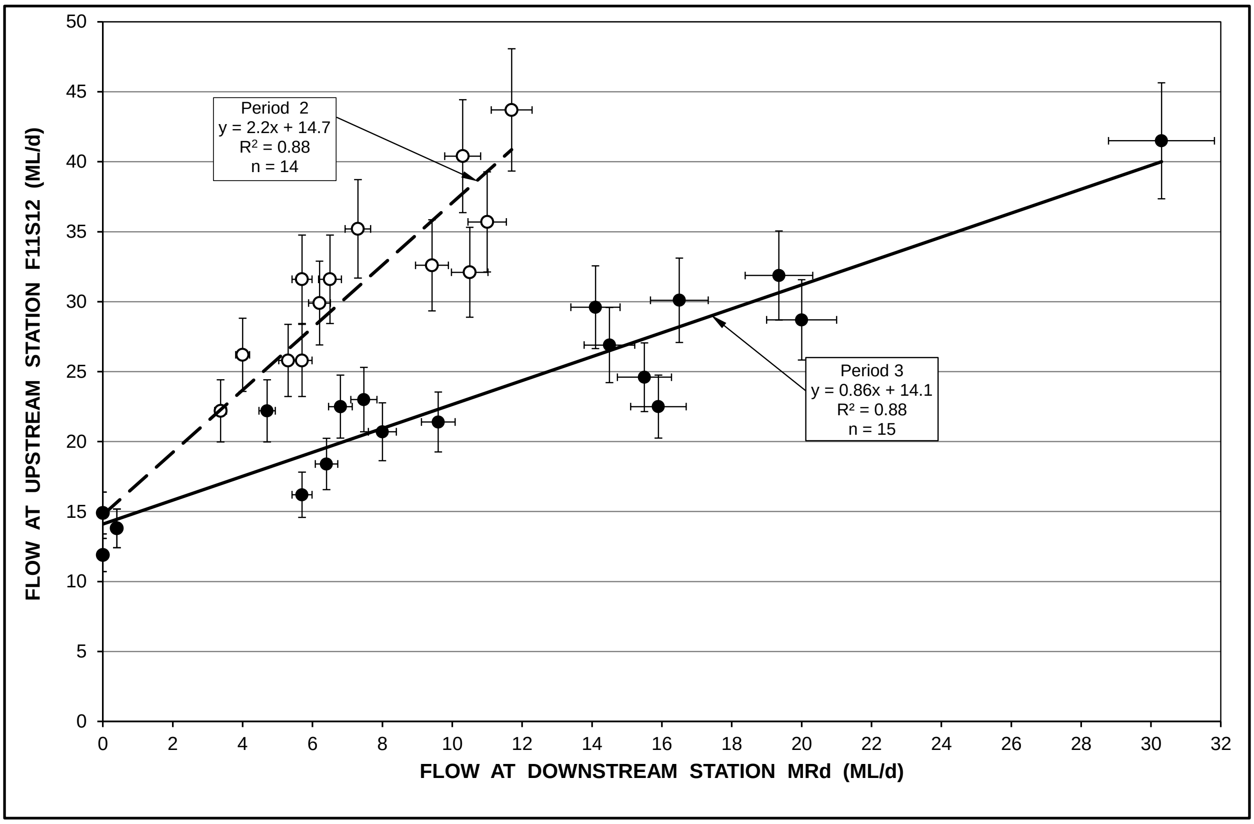


Figure 9 Correlation of streamflow at stations F11S12 and MRd in the Riet Spruit valley, with vertical error bars denoting ±10% at F11S12 and horizontal bars ±5% at MRd

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 to 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 (2015c). 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 10**.

The progression is significant for its indication of the increasing volume of treated/neutralised mine water contributing directly to downstream surface flow, and therefore its increasing importance as an additional allogenic water budget component in Quaternary catchment A21D that hosts the Bloubank Spruit system.

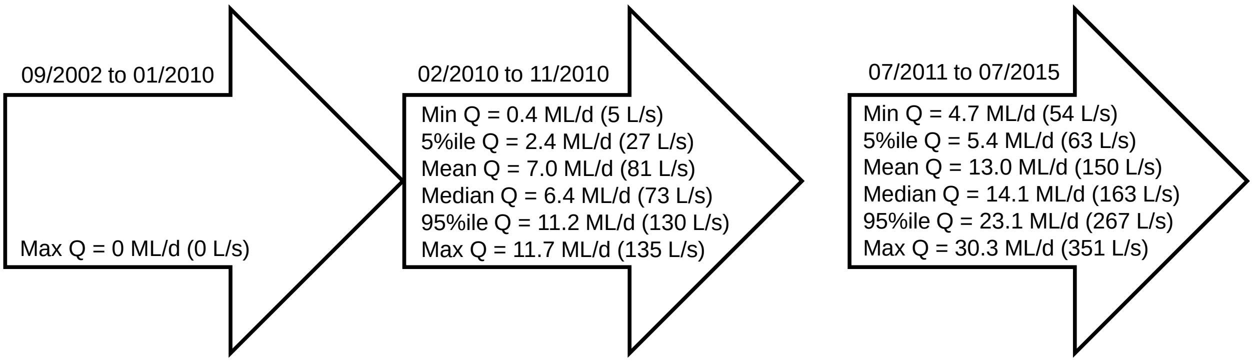


Figure 10 Episodic progression of surface flow measured at station MRd since the start of mine water decant

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 on a weekly basis 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 sulfate (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 11** (pH), **Figure 12** (EC), **Figure 13** (SO_4), **Figure 14** (Fe), **Figure 15** (Mn) and **Figure 16** (U).

The patterns revealed in **Figure 11** 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 excursion of pH toward acidic values (**Figure 11**) for a short period of two months in March and April 2016. This is associated with the very wet late summer of the 2015–'16 hydrological year as discussed in **Section 3**. The recovery of pH to circum-neutral values after April 2016 indicates the successful containment of the situation. Manganese (**Figure 15**) is the only other of the graphed variables that shows a distinct excursion in this period. 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 11** to **Figure 16**, and which returns the information presented in **Table 2**. It has only been necessary to update the information for period D–. The salient differences between the data sets previously described by Hobbs (2016) remain unaffected by the updated record, and are therefore not repeated here.

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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.

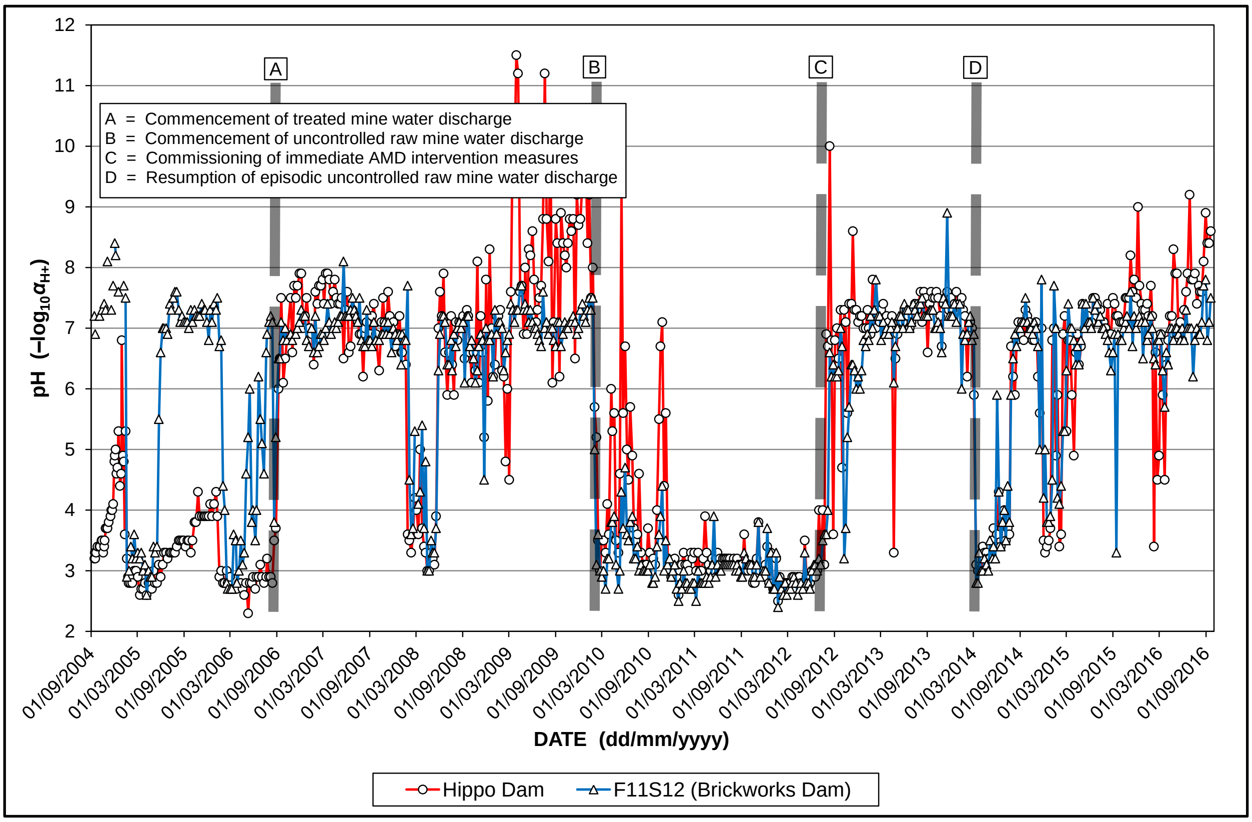


Figure 11 Pattern of Tweelopie Spruit pH values in the period September 2004 to September 2016

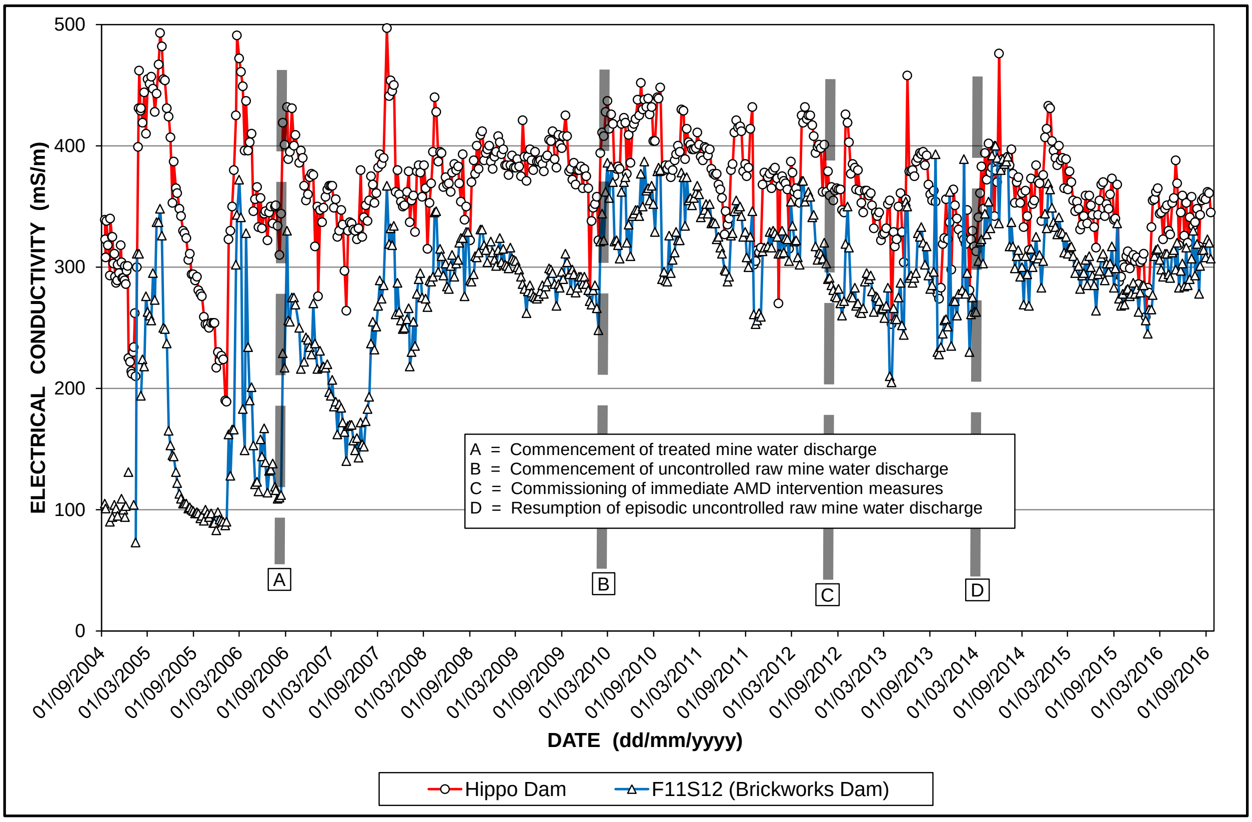


Figure 12 Pattern of Tweelopie Spruit electrical conductivity values in the period September 2004 to September 2016

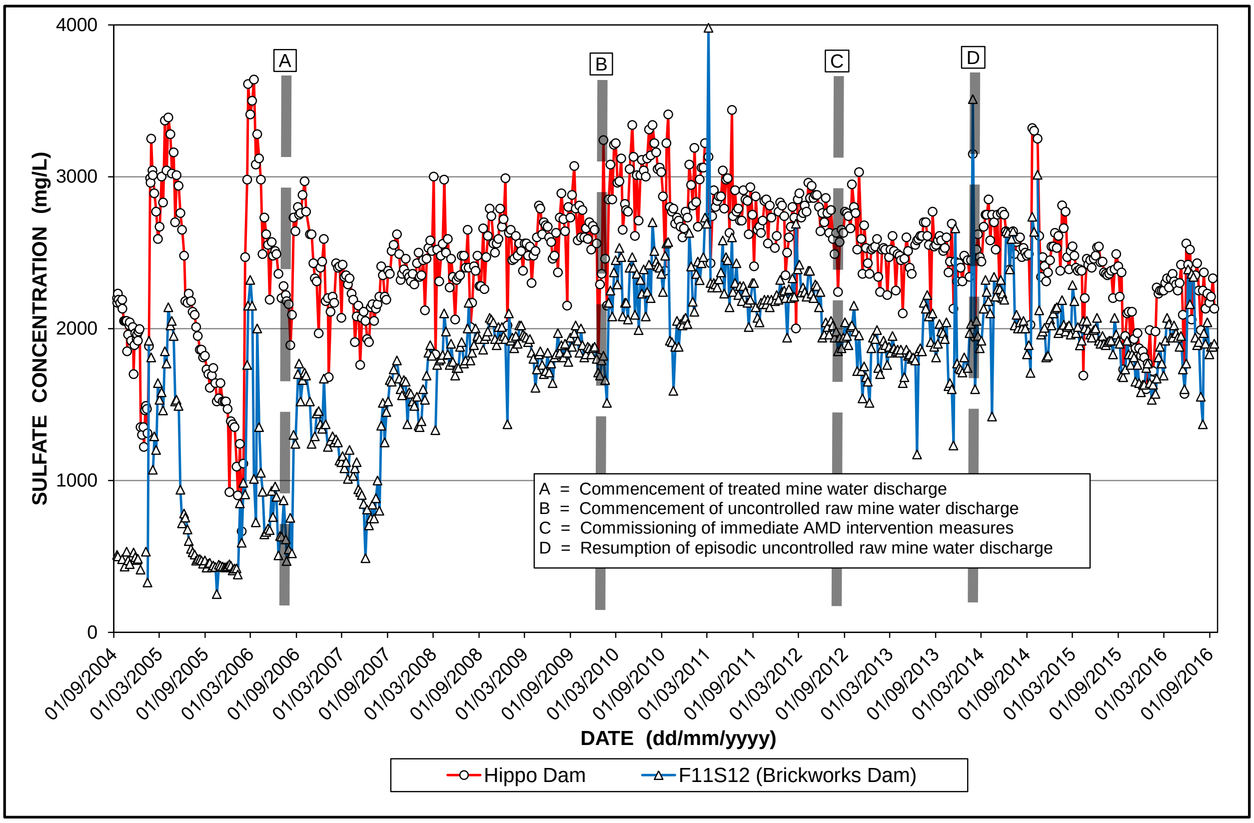


Figure 13 Pattern of Tweelopie Spruit sulfate values in the period September 2004 to September 2016

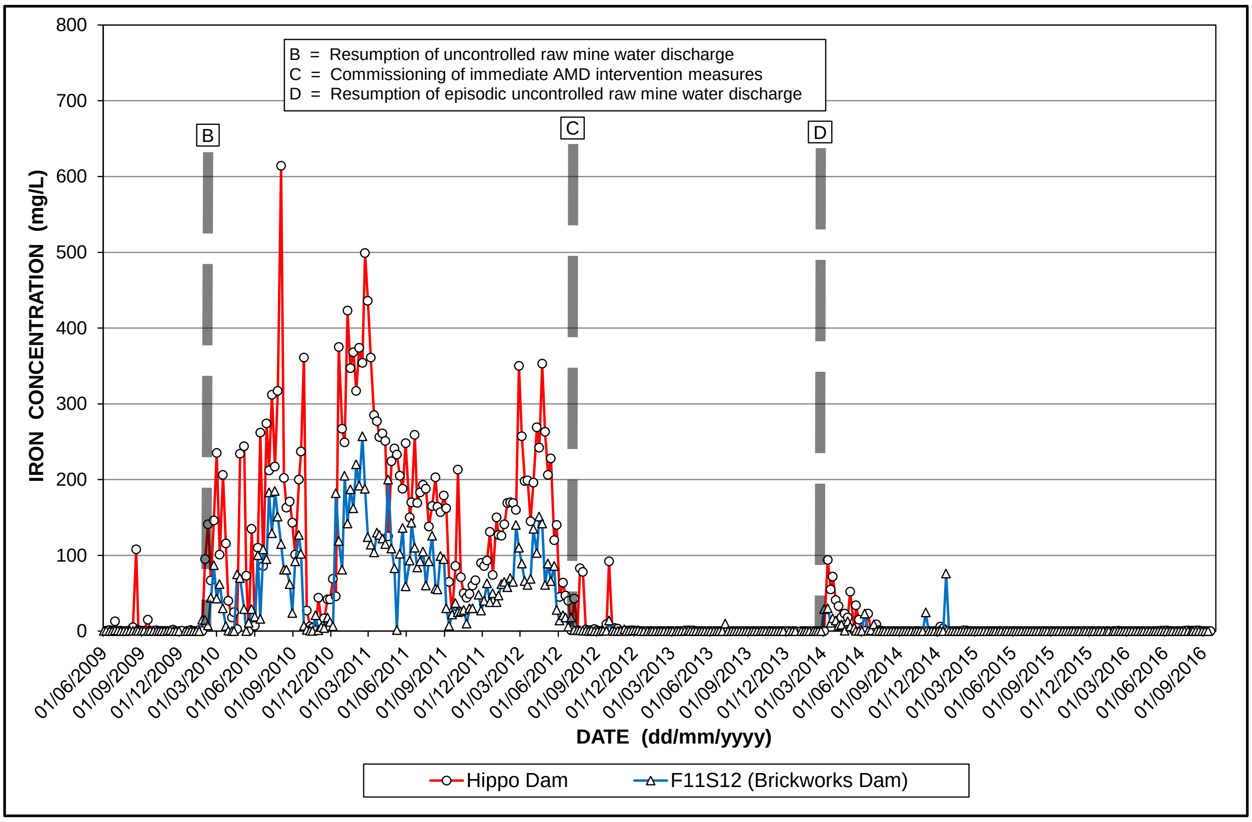


Figure 14 Pattern of Tweelopie Spruit iron values in the period June 2009 to September 2016

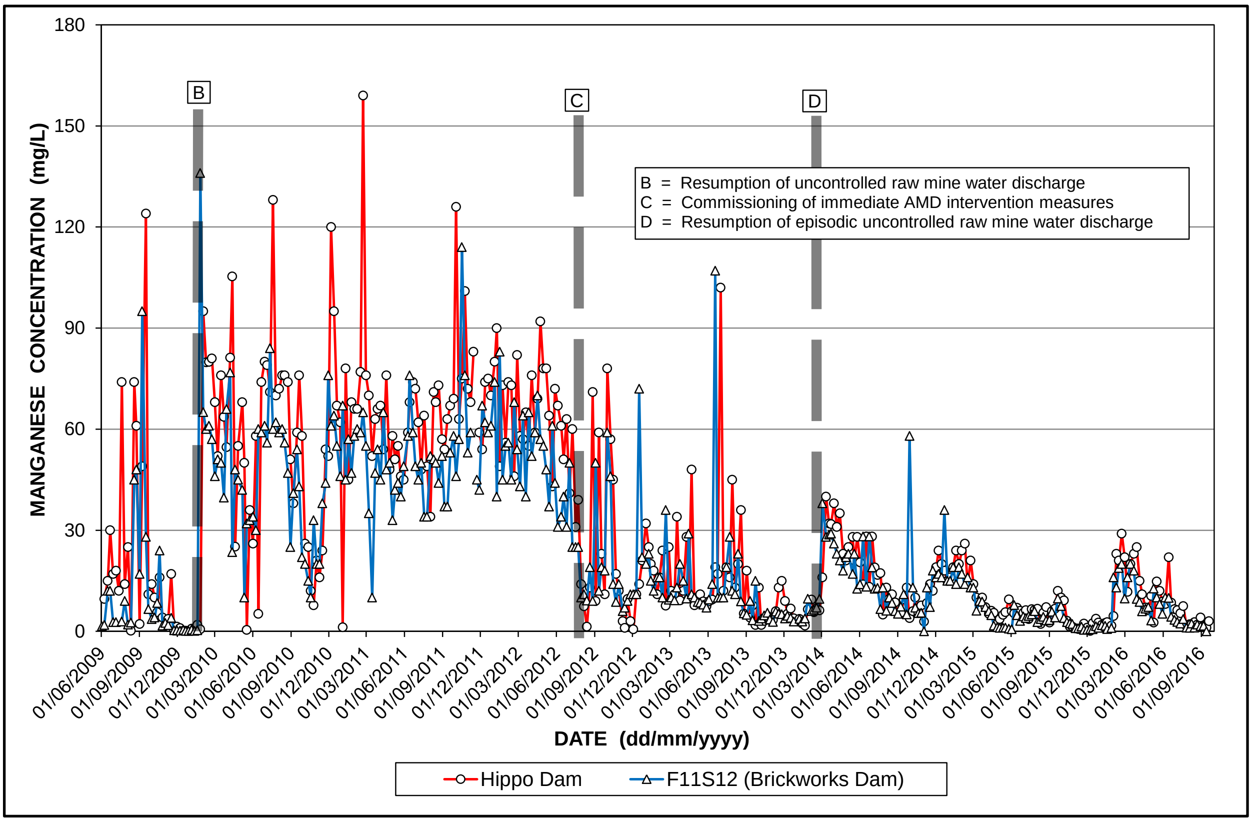


Figure 15 Pattern of Tweelopie Spruit manganese values in the period June 2009 to September 2016

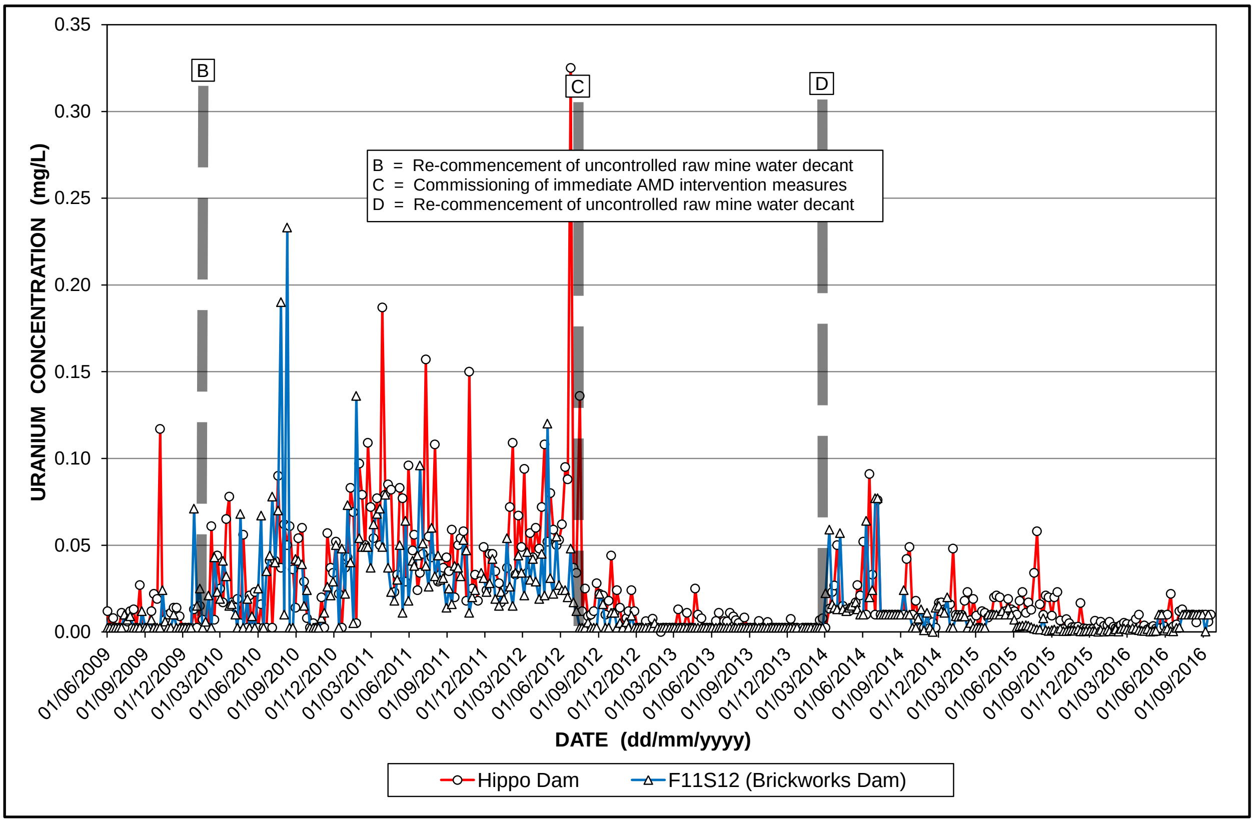


Figure 16 Pattern of Tweelopie Spruit uranium values in the period June 2009 to September 2016

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	134	173	128	83	134
	5%ile	3.6	2.8	5.9	3.3	3.9	2.7	5.3	3.2
	Mean	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	7.0	6.9	3.0	7.0	6.9
	95%ile	9.3	5.7	7.6	8.2	7.4	3.9	7.4	7.5
	SD	1.5	1.0	0.8	1.7	0.9	0.4	0.9	1.4
	CoV (%)	22.0	29.7	11.4	26.2	14.1	13.7	13.0	23.0
EC (mS/m)	n	175	129	83	134	172	128	83	134
	Mean	374	391	350	353	268	332	281	309
	Median	379	393	354	355	283	330	276	307
	95%ile	426	438	395	401	329	378	350	386
	SD	32	33	34.1	33	48	29	34	31
	CoV (%)	8.5	8.4	9.7	9.4	18.0	8.7	12.2	10.0
SO_4 (mg/L)	n	176	128	82	133	171	128	83	133
	Mean	2 448	2 846	2 520	2 362	1 636	2 264	1 879	1 981
	Median	2 460	2 815	2 525	2 390	1 760	2 240	1 870	1 960
	95%ile	2 828	3 220	2 770	2 764	2 015	2 593	2 148	2 470
	SD	262	226	193	308	349	245	268	261
	CoV (%)	10.7	7.9	7.6	13.0	21.3	10.8	14.3	13.2
Fe (mg/L)	n	33	129	83	134	33	128	82	133
	Mean	4.7	168.4	2.490	3.8	0.3	72.9	0.466	2.1
	Median	0.4	163.0	0.030	0.030	0.2	64.0	0.075	0.02
	95%ile	13.8	365.2	3.090	26.5	0.8	186.3	1.000	13.4
	SD	18.8	116.2	13.146	13.4	0.3	57.7	1.896	8.3
	CoV (%)	399	69	528	349	94	79	407	397
Mn (mg/L)	n	34	129	83	134	33	128	83	133
	Mean	18.1	62.7	16.5	11.4	10.3	50.3	14.4	9.8
	Median	9.8	65.0	11.0	8.5	2.7	50.0	10.0	7.2
	95%ile	74.0	95.0	56.1	28.5	46.2	76.0	45.0	28.1
	SD	27.6	23.5	18.0	9.2	19.4	17.6	15.8	9.2
	CoV (%)	153	38	109	81	188	35	110	94

(1) 09/2006 – 01/2010 (2) 02/2010 – 07/2012 (3) 08/2012 – 02/2014 (4) 03/2014 – 09/2016

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 (draining Quaternary catchment A21D), 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 for potable water, where specified, even at the 95%ile level and, in the case of pH, also at the 5%ile level.

A closer inspection of this record, that includes a breakdown into time periods in similar fashion to those reflected in **Figure 11** to **Figure 16**, is discussed in **Section 4.3**.

Table 3 Synoptic overview of Bloubank Spruit water chemistry at station A2H049 since May 1979

Variable	**Statistical Parameter**							**SANS (2015a)(1)**
	n	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	
pH ($-\log_{10}\alpha_{H+}$)	1 055	7.4	—	8.2	8.5	0.3	4	5.0–9.7
EC (mS/m)	1 144	51.5	63.2	61.1	94.8	20.3	32	<170
TDS (mg/L)	866	355.3	454.4	450.0	580.5	82.3	18	<1 200
Ca (mg/L)	959	43.7	57.5	54.0	96.9	16.9	29	n.s.
Mg (mg/L)	958	25.4	33.5	32.7	48.1	6.4	19	n.s.
Na (mg/L)	940	10.0	23.3	22.5	38.8	8.8	38	<200
K (mg/L)	937	0.8	2.1	1.9	4.0	1.0	50	n.s.
Cl (mg/L)	965	20.8	32.5	32.4	41.9	6.2	19	<300
SO_4 (mg/L)	972	65.5	107.6	84.7	330.9	75.6	70	<500
HCO_3 (mg/L)	971	143.4	189.5	194.7	219.4	26.2	14	n.s.
NO_3+NO_2 (mg N/L)	1017	3.026	4.640	4.447	6.855	1.735	37	<11
PO_4 (mg P/L)	1 046	0.005	0.093	0.055	0.315	0.110	118	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

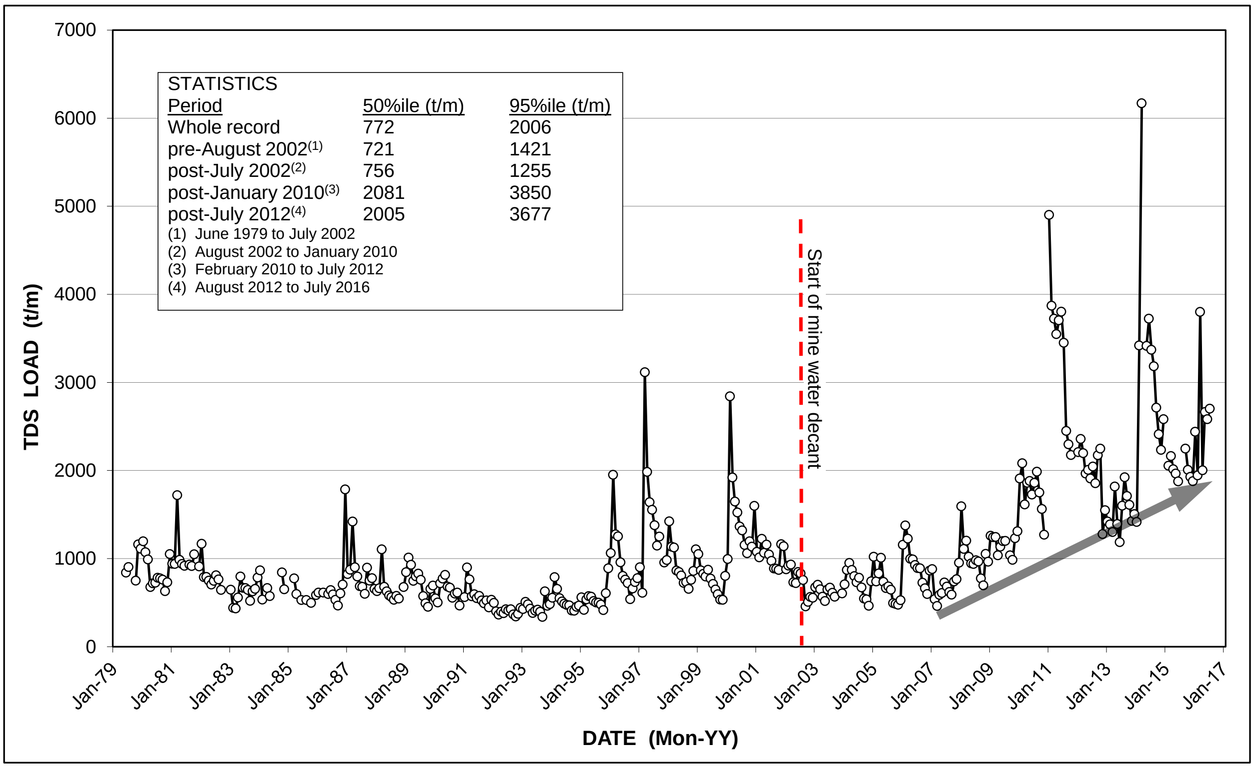
(1) Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person

4.3 Salt Load

The combination of flow and hydrochemical data allows for a re-assessment of the total dissolved solids (TDS) (**Figure 17**) and sulfate (**Figure 18**) load pattern and trend manifested at station A2H049. The long-term monthly trend in the TDS load delivered by the Bloubank Spruit (**Figure 17**) indicates an increasing salt load (as indicated by the visually inserted arrows) since early-2007. The text box in **Figure 17** lists the median and 95%ile values associated with different periods of record. The period February 2010 to July 2012 reveals the highest median and 95%ile values, which is readily attributable to the very high salt loads experienced in the 2010–'11 hydrological year. Similar conditions (albeit slightly more muted) prevailed in the subsequent period (August 2012 to July 2016) as indicated in **Figure 17** (text box).

The long-term monthly trend in the sulfate (SO_4) load delivered by the Bloubank Spruit (**Figure 18**) mimics the TDS load pattern (**Figure 17**) in the period since early-2007. This is unsurprising under circumstances where SO_4 comprises ~62% of the major ion concentration in mine water. Of interest is the observation that the most recent period (August 2012 to July 2016) exhibits a substantially higher median value of 880 t/m compared to the 526 t/m of the preceding period (February 2010 to July 2012). These circumstances indicate that the most recent period experienced consistently higher sulfate loads than previously. This is confirmed in **Figure 19** and **Figure 20**, which reflect more recent SO_4**:**TDS ratio values of ~45%.

The closer inspection in **Figure 21** of the SO_4 data recorded at station A2H049 indicates an approximate trebling of the SO_4 concentration (from ~100 mg/L to ~350 mg/L) between mid-2010 and mid-2014, followed by a period of comparatively consistent concentration levels. These circumstances are confirmed by the load and concentration statistics presented in the text boxes. The median SO_4 concentration of 319 mg/L for the most recent period explains the contemporary higher sulfate loads.

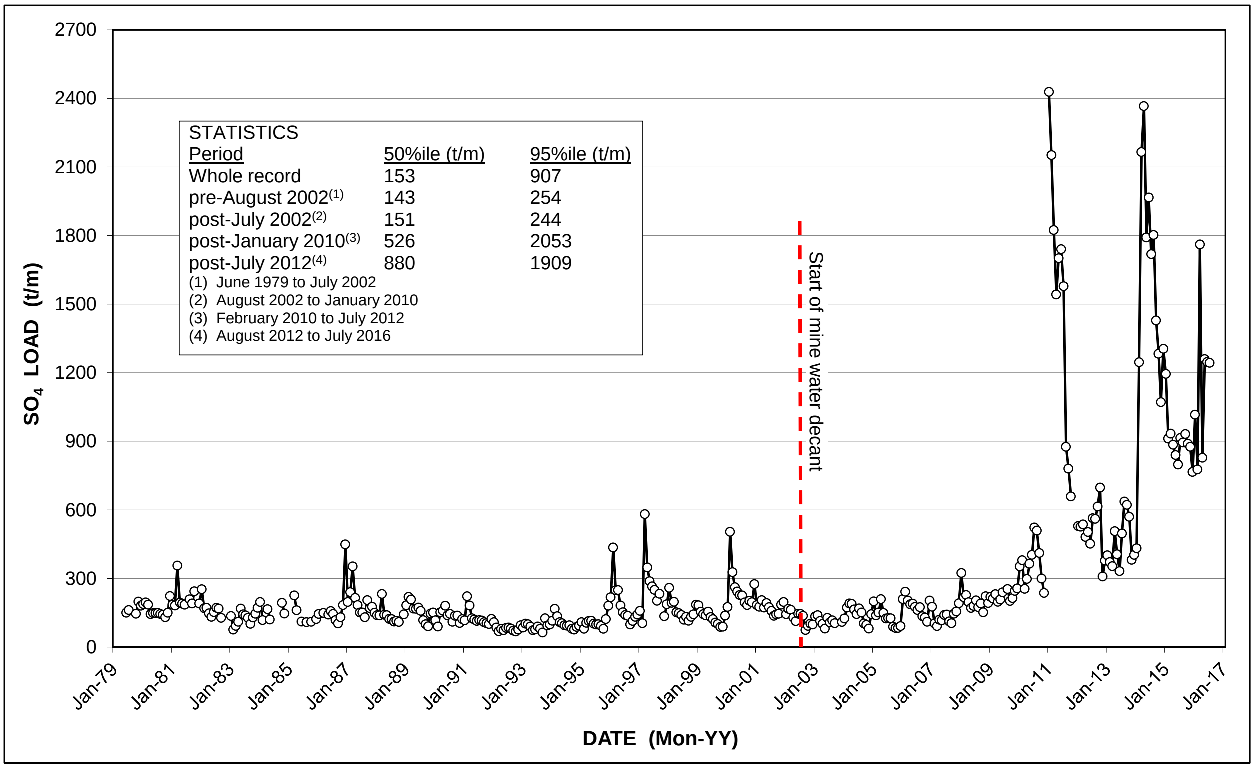


STATISTICS

Period	50%ile (t/m)	95%ile (t/m)
Whole record	772	2006
pre-August 2002(1)	721	1421
post-July 2002(2)	756	1255
post-January 2010(3)	2081	3850
post-July 2012(4)	2005	3677

(1) June 1979 to July 2002
(2) August 2002 to January 2010
(3) February 2010 to July 2012
(4) August 2012 to July 2016

Figure 17 Long-term (June 1979 to July 2016) monthly TDS load pattern and trend in the Bloubank Spruit at station A2H049



STATISTICS

Period	50%ile (t/m)	95%ile (t/m)
Whole record	153	907
pre-August 2002(1)	143	254
post-July 2002(2)	151	244
post-January 2010(3)	526	2053
post-July 2012(4)	880	1909

(1) June 1979 to July 2002
(2) August 2002 to January 2010
(3) February 2010 to July 2012
(4) August 2012 to July 2016

Figure 18 Long-term (June 1979 to July 2016) monthly SO_4 load pattern and trend in the Bloubank Spruit at station A2H049

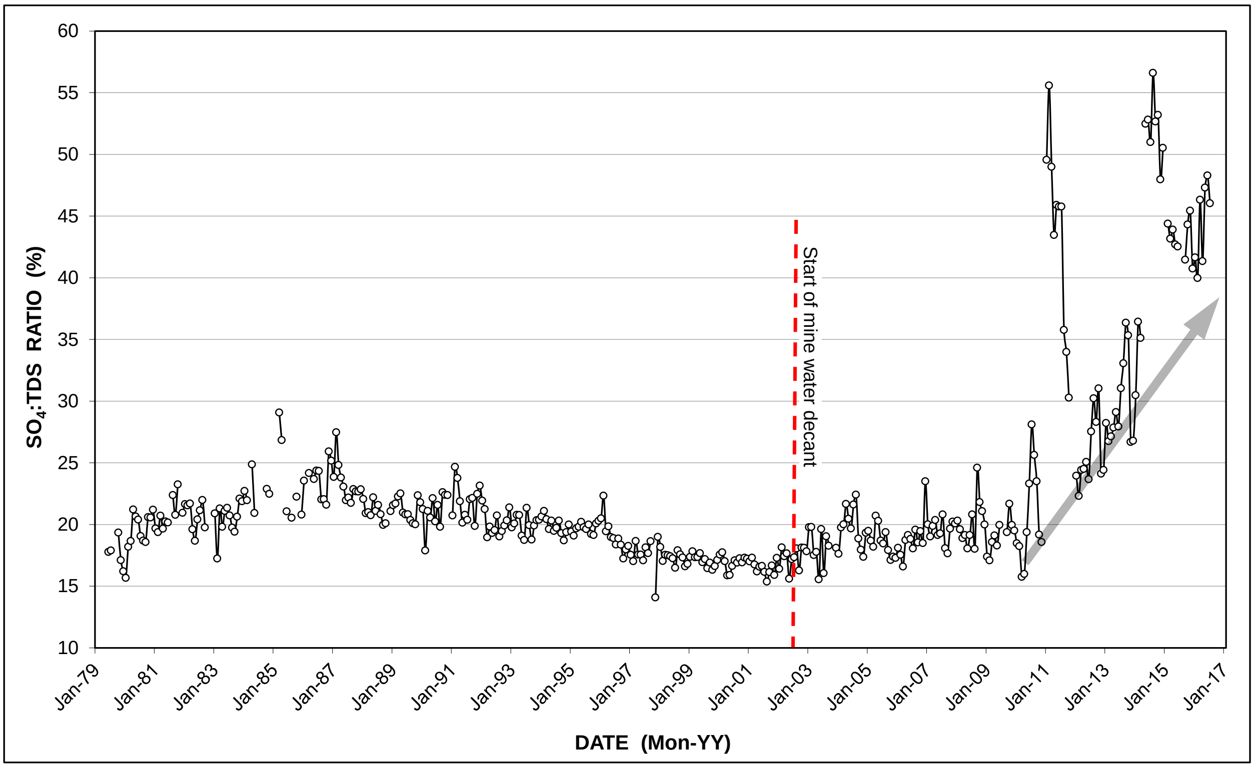


Figure 19 Long-term (June 1979 to July 2016) trend in the SO$_4$:TDS ratio at station A2H049

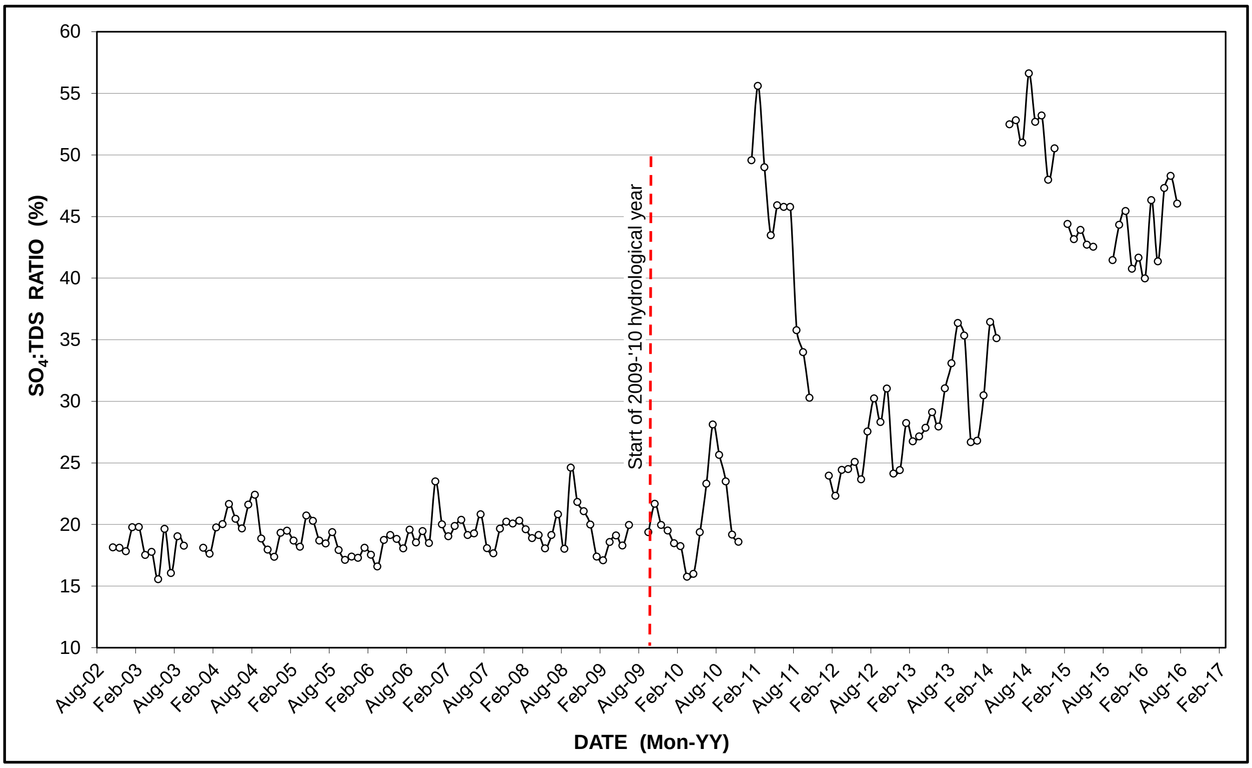
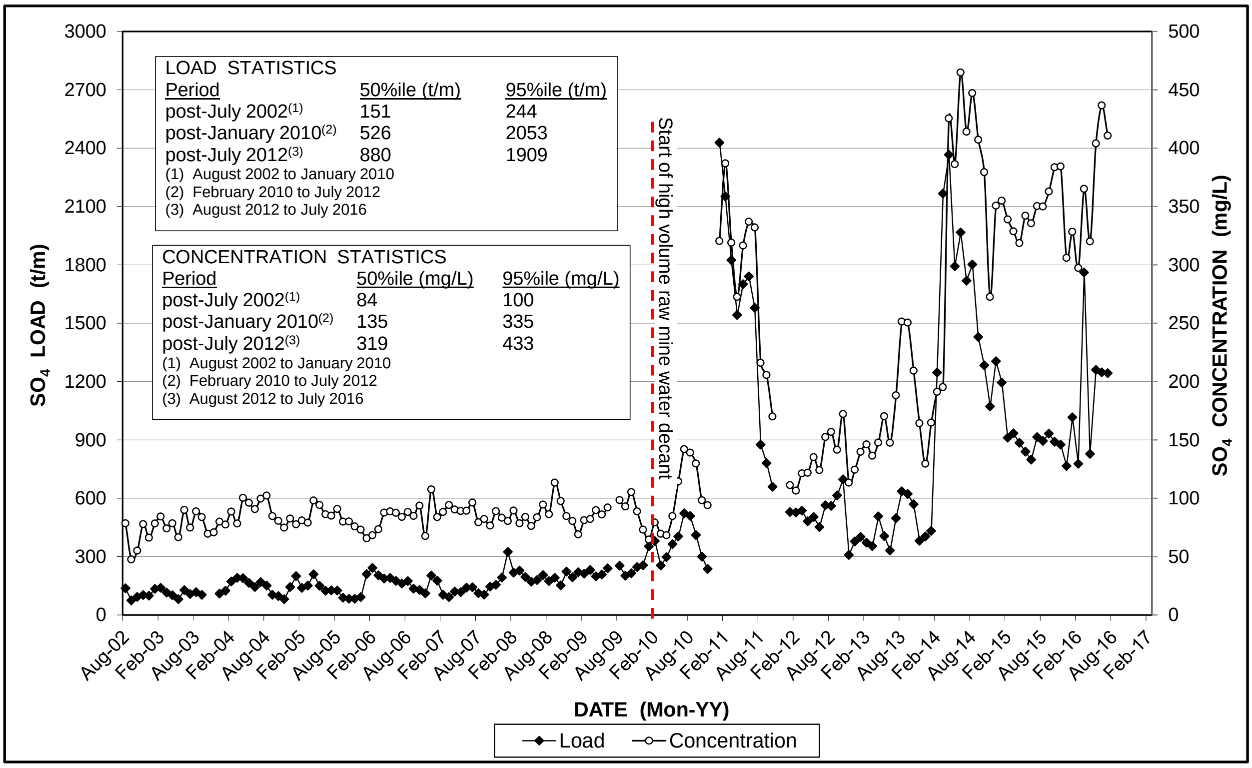


Figure 20 Pattern and trend of the SO$_4$:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin



LOAD STATISTICS

Period	50%ile (t/m)	95%ile (t/m)
post-July 2002[(1)]	151	244
post-January 2010[(2)]	526	2053
post-July 2012[(3)]	880	1909

(1) August 2002 to January 2010
(2) February 2010 to July 2012
(3) August 2012 to July 2016

CONCENTRATION STATISTICS

Period	50%ile (mg/L)	95%ile (mg/L)
post-July 2002[(1)]	84	100
post-January 2010[(2)]	135	335
post-July 2012[(3)]	319	433

(1) August 2002 to January 2010
(2) February 2010 to July 2012
(3) August 2012 to July 2016

Figure 21 Monthly SO_4 concentration and load pattern and trend in the Bloubank Spruit at station A2H049 since mid-2002

4.4 Municipal Wastewater Impact

The paucity of municipal wastewater quality data for the Mogale City Percy Stewart Wastewater Treatment Works (WWTW) has previously been reported (e.g. Hobbs, 2014b; 2015a; 2015b; 2016). This facility discharges treated municipal wastewater effluent into the Blougat Spruit, an upper tributary of the Bloubank Spruit (**Figure 22**). The facility has, however, consistently scored poorly in the Green Drop ratings by which the DWA (2012) evaluates the performance of such facilities.

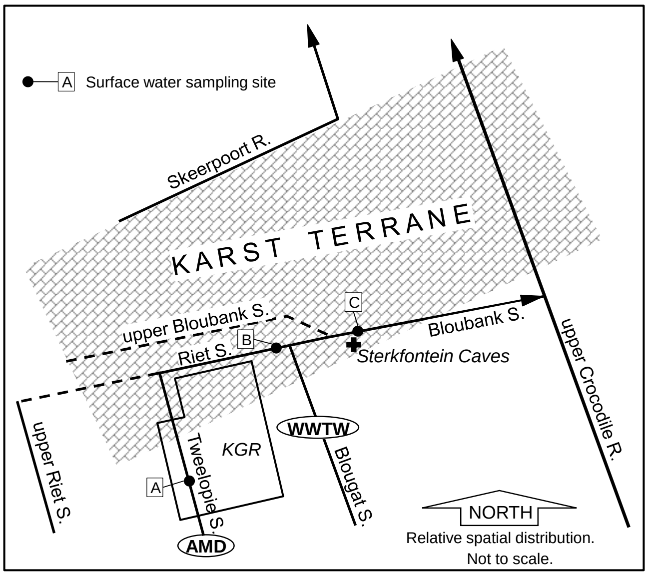


Figure 22 Schematic diagram showing the position of the surface water sampling sites reported in Annexure A, and their relative location in the wider sub-regional drainage network.

An indication of the impact of this facility on the downstream receiving water environment *circa* July 2016 is reflected in the bacteriological results (*E. coli* and total coliform counts) reported in Annexure A. The results are for sites A, B and C in **Figure 22**, and reveal the substantial increase in bacteriological contamination levels between site B which receives mainly mine water effluent via the Tweelopie Spruit (site A), and site C which receives the additional contribution of municipal wastewater via the Blougat Spruit. These circumstances are illustrated in **Figure 23**, together with the trend in variables that characterise mine water chemistry, namely sulfate and the metals Al, Fe and Mn. Especially concerning is the *E. coli* count of 9 330 per 100 mL at site C a short distance (~1.5 km) downstream of Sterkfontein Caves. This far exceeds the limit of nil counts per 100 mL (i.e. not detected) set by the SANS (2015a; 2015b) guideline for drinking water.

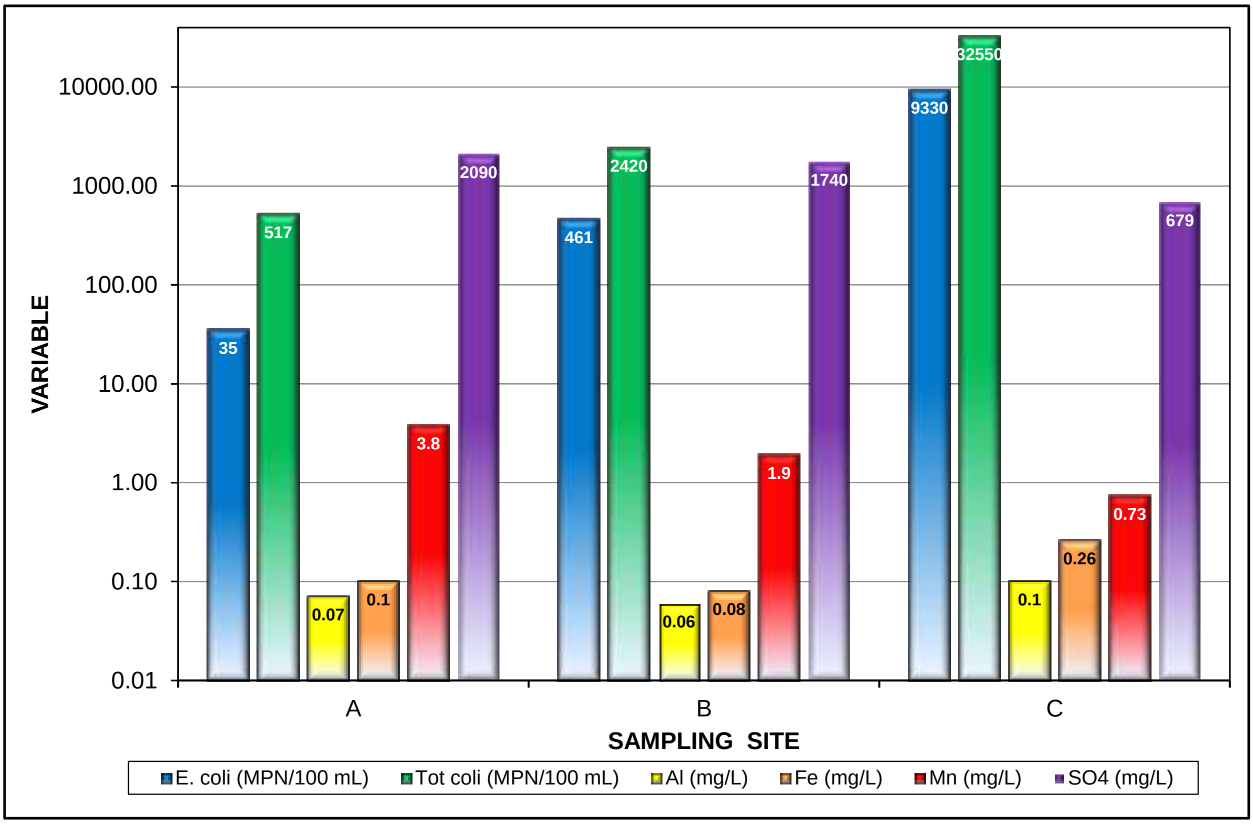


Figure 23 Comparison of the level of bacteriological contamination of surface water *circa* July 2016 in the Bloubank Spruit (site C) with upstream sites A (Tweelopie Spruit) and B (Riet Spruit), also showing the levels of characteristic mine water variable concentrations at each of the sites.

Other patterns and trends that are evident in **Figure 23** are the following:

- the general decrease in Mn levels from the upstream site A to site C, which likely represents a combination of dilution of the mine water with municipal wastewater effluent (especially in a drier period of the hydrological year), and the precipitation of Mn as Mn-oxyhydroxides with passage downstream;
- the substantial decrease in sulfate concentration from site B to site C, again probably as a result of dilution of the mine water with municipal wastewater effluent (which typically contains <50 mg SO_4/L); and
- the low Al and Fe concentrations at all three sites commensurate with the ready precipitation of these metals as a result of oxygenation and hydrolysis in an aerated stream system.

5 GROUNDWATER HYDROLOGY

5.1 Physical Hydrogeology

5.1.1 Groundwater Levels

An inspection of the more recent potentiometric response in DWS monitoring boreholes located downstream of the mine area is presented in **Figure 25.** The boreholes are grouped into a southern, a central and a northern segment to distinguish between their relative location, viz. upper, middle and lower reach, respectively, in the receiving hydrogeologic environment. This distinction is particularly evident in the absolute groundwater level elevations, which describe a decrease from south to north both within and between the respective segments.

The similarity in the hydrographs for stations GP00313 and SF1 (**Figure 25**, northern segment) indicate their common illustration of the groundwater level behaviour in Sterkfontein Caves. The similarity is explored in **Figure 24**, which reveals a good correlation (R^2) of 0.92 amongst 15 values. The regression equation

$$y = 0.75x + 356$$

allows for the calculation of an approximate cave water level elevation from groundwater rest level measurements (translated into absolute elevation values) made in borehole GP00313.

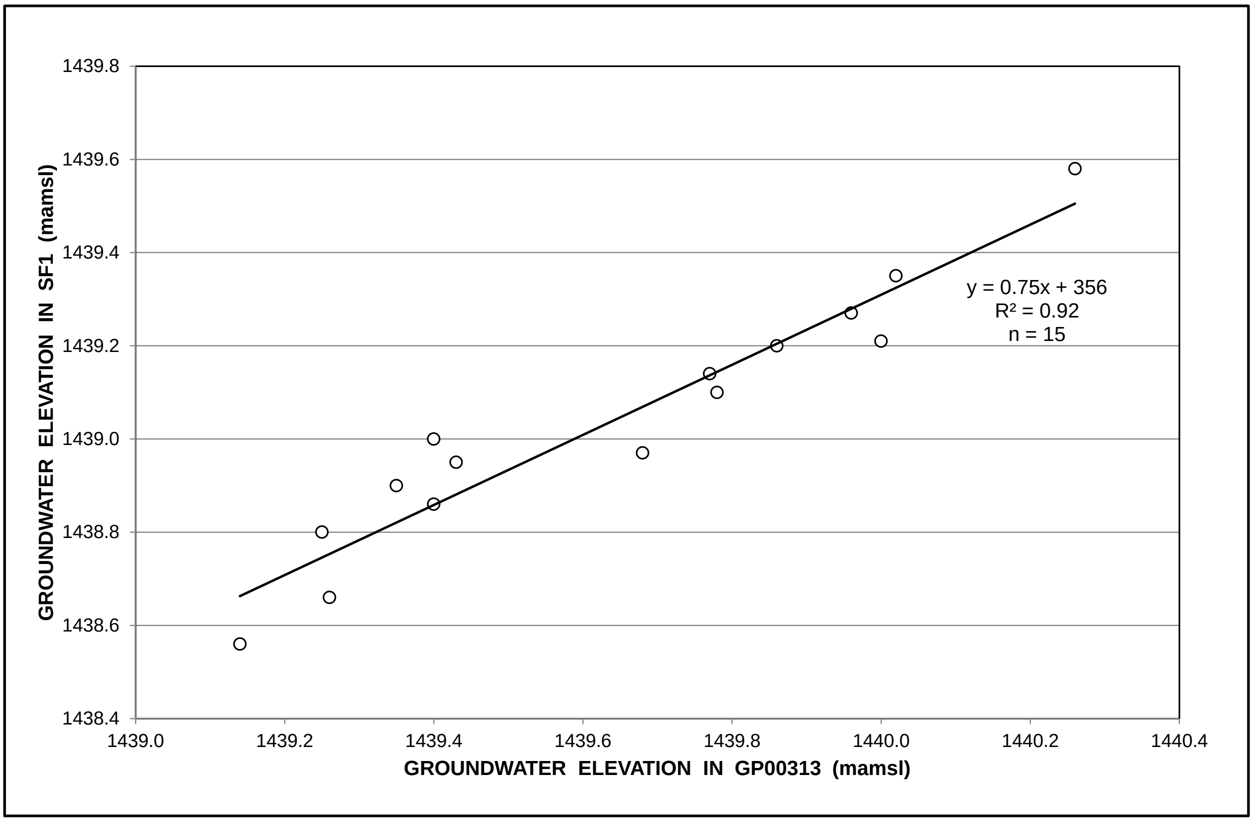
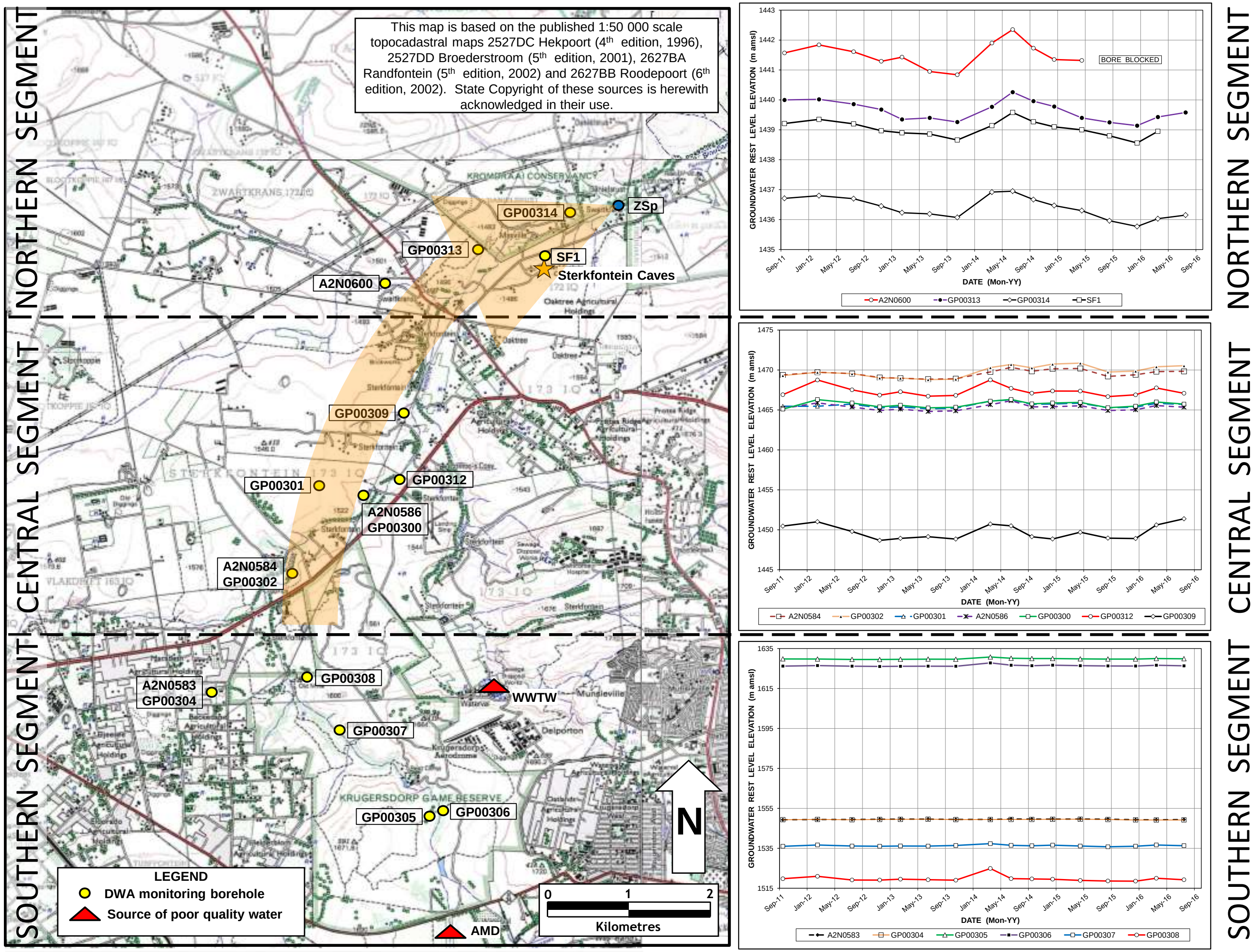


Figure 24 Correlation of groundwater rest level elevations in stations GP00313 and SF1



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 25 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 of ~3 m in the cave water level observed 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.

Figure 26 reveals that the recent steady decline in water level since late-2014 was interrupted in March 2016. This response is also evident in the central and northern segments (**Figure 25**), and is readily attributed to the very wet late summer of the 2015–'16 hydrological year (**Section 3**), and its broader impacts in the form of natural (autogenic) and mine water (allogenic) recharge (**Section 4.1.2**).

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, namely the Tweelopie/Riet Spruit system and the Blougat Spruit system, and associated groundwater recharge from allogenic mine water and municipal wastewater, respectively, 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).

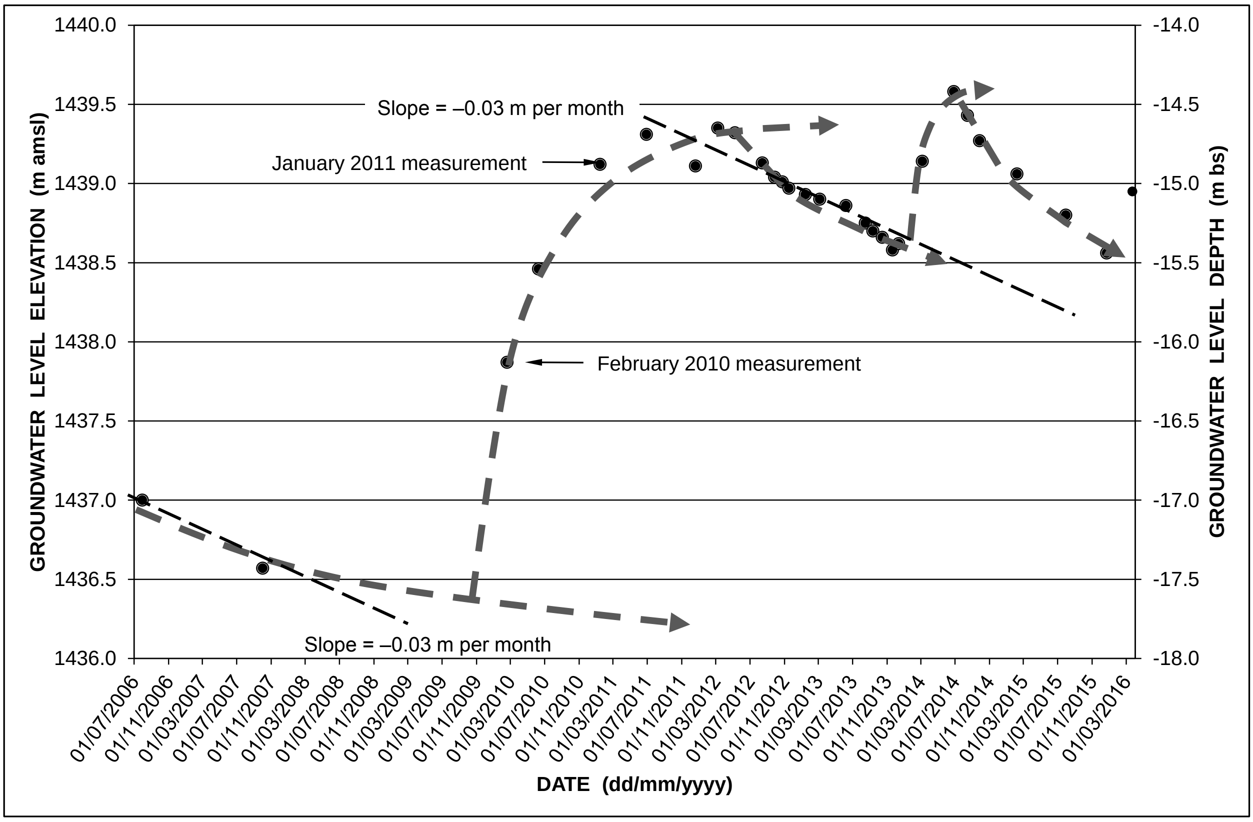


Figure 26 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the cave lake water level in Sterkfontein Caves

5.2 Chemical Hydrogeology

5.2.1 Monitoring Framework

The 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 GP003##) 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 27** and **Figure 28**. 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 results of this monitoring that forms the basis for evaluating the impact of mine water on the receiving karst environment (**Section 5.2.2**).

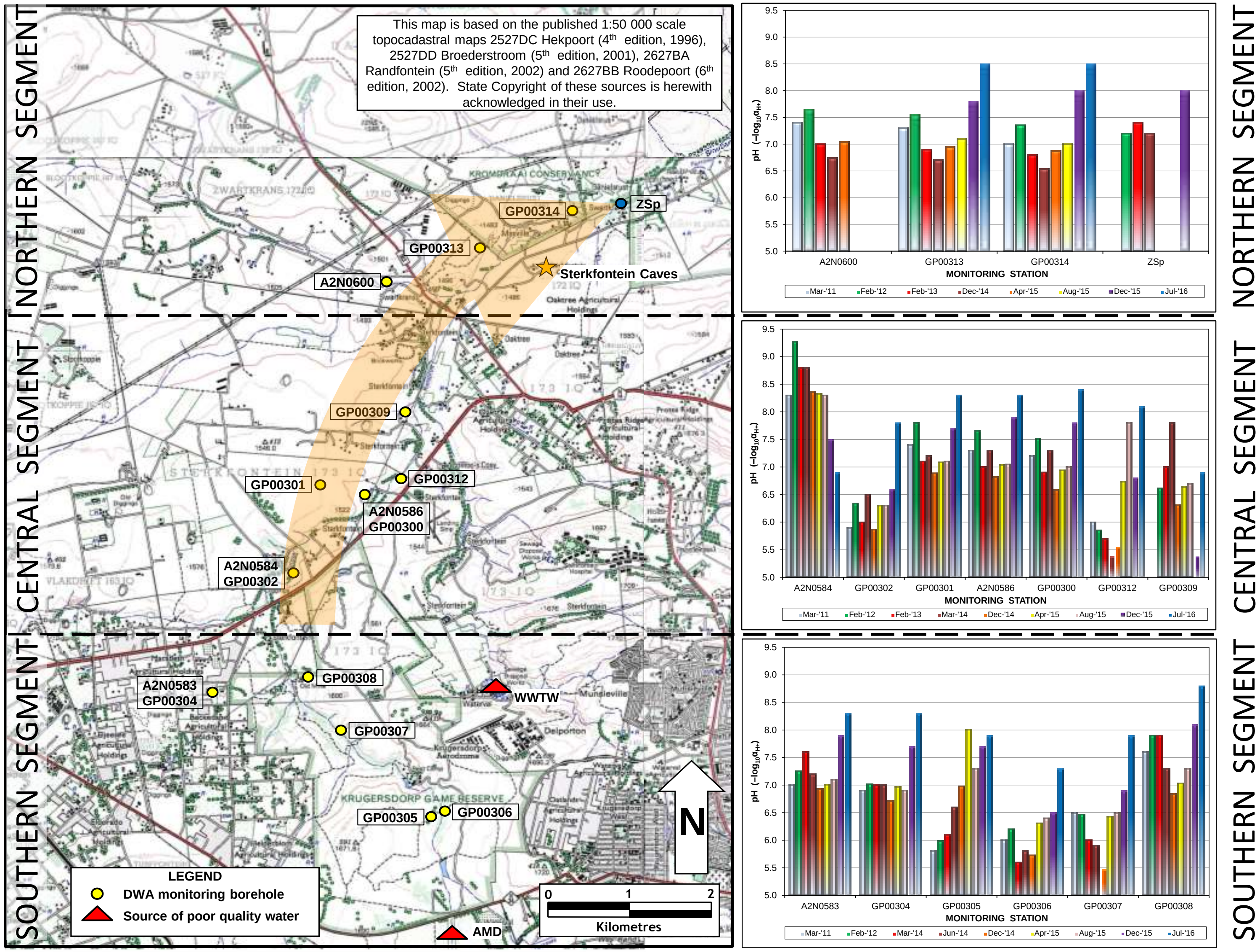
5.2.2 Mine Water Impact

There has been little change in this aspect in the reporting period compared to the previous period (Hobbs, 2016). 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 27** and **Figure 28** with the aid of bar graphs for the chemical variables pH and EC respectively. In order to maintain legibility, the bar graphs represent 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 27** 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. It is evident that the pH value on the four most recent sampling occasions (since April 2015) is above 6.4 at all monitoring stations.

The bar graphs in **Figure 28** 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 27**), 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 that is also described in **Figure 29**.

Figure 29 provides an indication of the extent of the mine water impact, as well as the SO_4 trend in terms of up, stable or down on the basis of the last four values. It is apparent that the trend at the “upstream” stations (A2N0584, A2N0586, GP00312 and GP00309) is stable to increasing, at the “midstream” stations (A2N0600 and GP00313) is generally stable, and at the “downstream” stations (GP00314 and ZSp) is generally increasing.



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

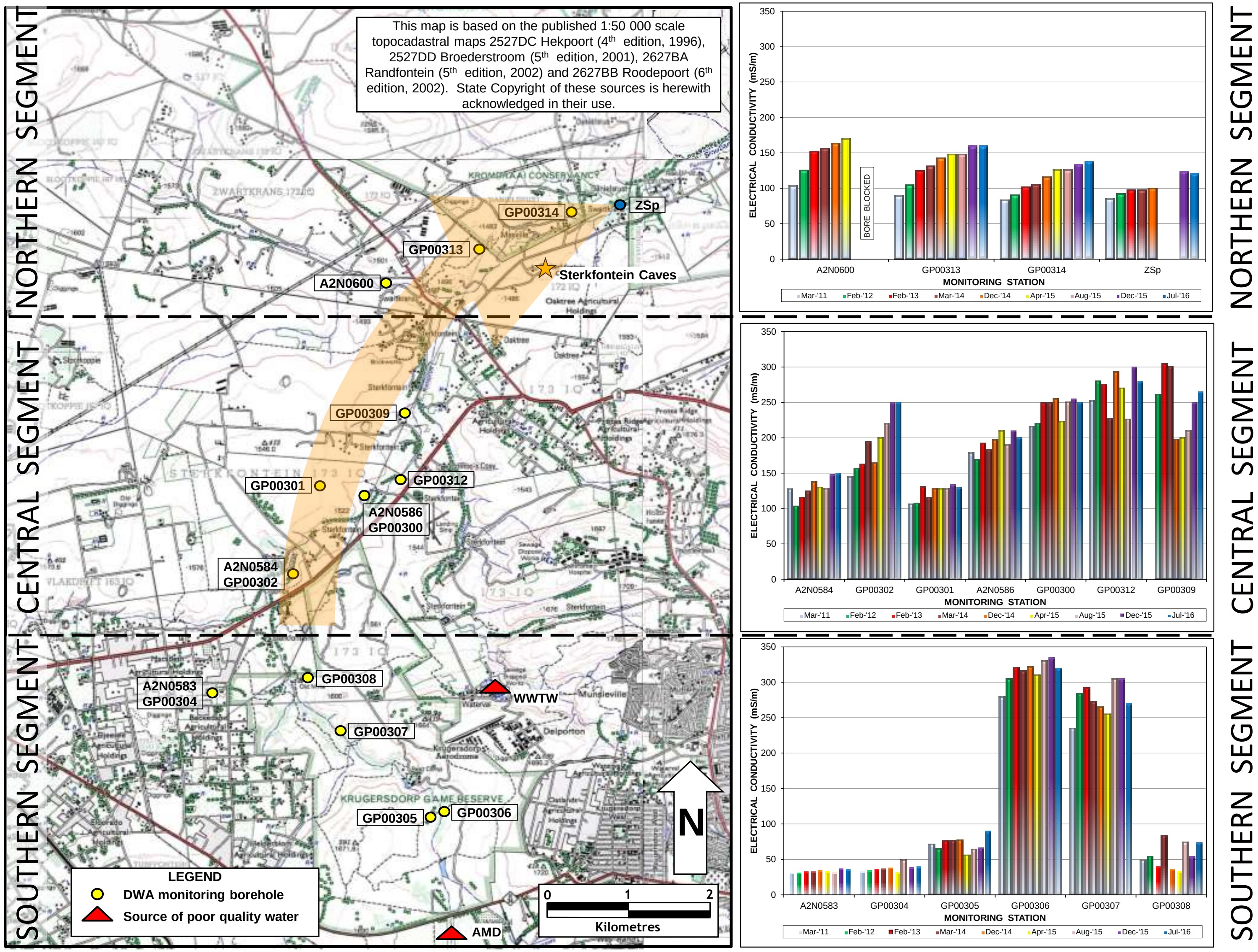


Figure 28 Distribution of DWS monitoring boreholes with EC pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow

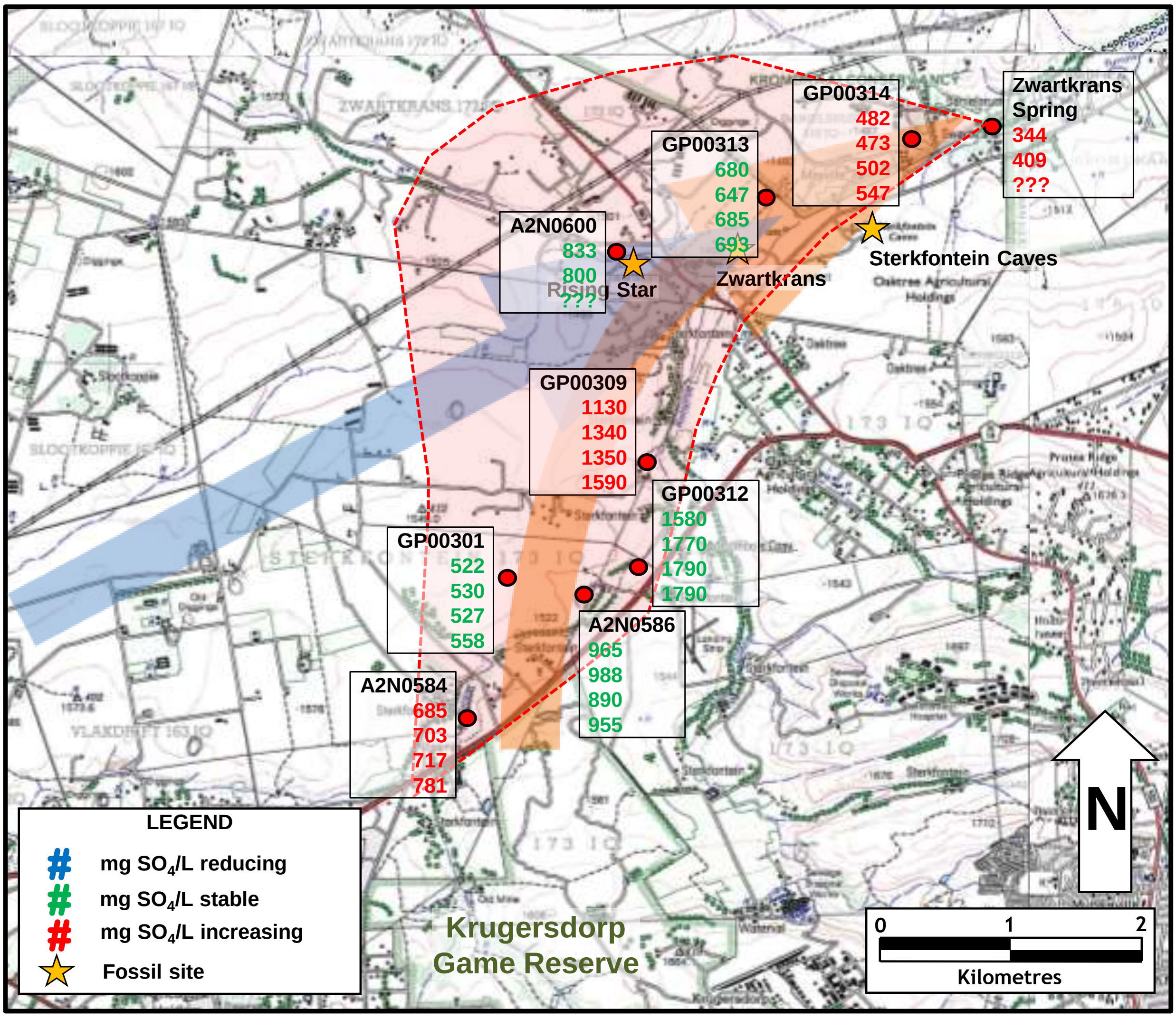


Figure 29 Distribution of SO_4 concentrations in groundwater of the Zwartkrans Compartment in August 2015, December 2015, March 2016 and July 2016, also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow), the postulated footprint (shaded area) of a mine water impact in the karst aquifer, and SO_4 trend INCREASING (red text), STABLE (green text) or REDUCING (blue text)

6 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 stabilisation or slight increase in SO_4 levels in the "upstream" reaches, and an increase in the "downstream" reaches in the July 2016 monitoring results compared to the March 2016 results. These circumstances continue to be interpreted as describing 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 2015–'16 wet (summer) season was characterised by high late-season precipitation, with ~58% of the total summer rainfall occurring in February and March 2016. These circumstances did not, however, translate into an uncontrolled discharge of raw mine water into the environment.

- The 2015–’16 hydrological year produced a runoff of ~34 Mm^3 from Quaternary catchment A21D, the Bloubank Spruit system. This is similar to the ~35 Mm^3 of the previous hydrological year. It remains to be seen what the coming 2016–’17 wet season will produce, following as it will a continuing drought caused by a severe El Niño Southern Oscilation (ENSO) event.

- 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 sulfate values of ~2000 mg/L.

- Faecal coliform counts continue to reflect unacceptably high levels (9 330 MPN *E. coli* per100 mL) in the Bloubank Spruit system, highlighting the poor performance of the Percy Stewart Wastewater Treatment Works as the primary source of this contamination.

- The groundwater elevation in the south-western portion of the property (the Zwartkrans Compartment) where the allogenic recharge component is greatest, experienced a slight rise of ~0.5 m in response to the late summer rains. This has not had a negative impact on the tourist route through Sterkfontein Caves.

- Groundwater in the south-western portion of the property (the Zwartkrans Compartment) where the allogenic recharge component is greatest, continues to experience a compromised quality reflected primarily in sulfate levels of up to ~2 000 mg/L. These circumstances are reflected in the continued rise of the SO_4 concentration in the Zwartkrans Spring water. However, the pH value of ambient karst groundwater in this part of the study area still exceeds 6.4 and, as such, do not reflect acidic conditions in the karst aquifer. Under these circumstances, it is concluded that the threat to the fossil sites of concern, namely Bolt’s Farm and Sterkfontein, remains low even though the sites remain at high risk.

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.

7 ACKNOWLEDGEMENTS

The compilation of this report would not have been possible without the contribution of DWS field personnel Messrs Theo Moolman and Nico de Meillon in the collection of field data. The services of the DWS staff Ms Shouneez Chaka (GeoRequests), Ms Marica Erasmus (Resource Quality Services) and Mr Elias Nhlapo (PDA-Requests) in the provision of water resources monitoring data is also recognised and appreciated. The TCTAs Mr Themba Ngomane is thanked for the provision of Western Basin monitoring data collected by Sibanye Gold. Ms Karen du Plessis of Sibanye Gold is thanked for the provision of rainfall data. Finally, the goodwill and cooperation of numerous landowners (too many to list individually) in granting permission to access their properties for the purpose of collecting water resource data, is gratefully acknowledged.

8 REFERENCES

Bredenkamp, D.B., Van der Westhuizen, C., Wiegmans, F.E. and Kuhn, C.M. 1986. *Ground-water supply potential of dolomite compartments west of Krugersdorp.* Report GH3440. Vols. 1 & 2. Department of Water Affairs & Forestry. Pretoria. 81 pp.

DWA 2011. *Mine water management in the Witwatersrand gold fields with special emphasis on acid mine drainage.* Report to the Inter-Ministerial Committee on Acid Mine Drainage. 128 pp.

DWA 2012. *Green drop progress report: Chapter 7 Gauteng.* Waste Water Service Regulation. Department of Water and Sanitation. Pretoria. Available at
http://www.dwaf.gov.za/dir_ws/GDS/Docs/DocsDefault.aspx

Hobbs, P.J. (Ed.) 2011. *Situation assessment of the surface water and groundwater resource environments in the Cradle of Humankind World Heritage Site.* Report prepared for the Management Authority. Department of Economic Development. Gauteng Province. South Africa. 424 pp.

Hobbs, P.J. 2012. *Pilot implementation of a surface water and groundwater resources monitoring programme for the Cradle of Humankind World Heritage Site: Status report for the period April to September 2012.* Report no. CSIR/NRE/WR/ER/2012/0088/B. Council for Scientific & Industrial Research. Pretoria. 39 pp.

Hobbs, P.J. 2013a. *Pilot implementation of a surface water and groundwater resources monitoring programme for the Cradle of Humankind World Heritage Site: Situation assessment and status report for the period April 2012 to March 2013.* Report no. CSIR/NRE/WR/ER/2013/0023/B. Council for Scientific & Industrial Research. Pretoria. 48 pp.

Hobbs, P.J. 2013b. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2013.* Report no. CSIR/NRE/WR/ER/2013/0083/A. Council for Scientific & Industrial Research. Pretoria. 47 pp.

Hobbs, P.J. 2014a. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2013 to March 2014.* Report no. CSIR/NRE/WR/IR/2014/0049/A. Council for Scientific & Industrial Research. Pretoria. 42 pp.

Hobbs, P.J. 2014b. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2014.* Report no. CSIR/NRE/WR/ER/2014/0063/A. Council for Scientific & Industrial Research. Pretoria. 55 pp.

Hobbs, P.J. 2015a. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2014 to March 2015.* Report no. CSIR/NRE/WR/ER/2015/0026/A. Council for Scientific & Industrial Research. Pretoria. 53 pp.

Hobbs, P.J. 2015b. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2015.* Report no. CSIR/NRE/WR/ER/2015/0067/A. Council for Scientific & Industrial Research. Pretoria. 57 pp.

Hobbs, P.J. 2015c. *Discussion of surface water water and groundwater interaction in the upper Crocodile River basin, Johannesburg, South Africa: Environmental isotope approach by Abiye et al.* South African Journal of Geology. Vol. 118. No. 4. pp 511–515.

Hobbs, P.J. 2016. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2015 to March 2016.* Report no. CSIR/NRE/WR/ER/2016/0058/A. Council for Scientific & Industrial Research. Pretoria. 42 pp.

SANS 2015a. *South African National Standard (SANS) 241-1. Drinking water. Part 1: Microbiological, physical, aesthetic and chemical determinands*. Edition 2. Standards South Africa. Pretoria. 14 pp.

SANS 2015b. *South African National Standard (SANS) 241-2. Drinking water. Part 2: Application of SANS 241-1*. Edition 2. Standards South Africa. Pretoria. 14 pp.

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ANNEXURE A

RECENT CHEMISTRY OF SURFACE WATER IN THE UPPER AND MIDDLE REACHES OF THE BLOUBANK SPRUIT CATCHMENT

Variable/analyte	**Unit**	**Sampling Station**		
		Tweelopie Spruit (Site A in Fig. 22)	**Riet Spruit (Site B in Fig. 22)**	**Bloubank Spruit (Site C in Fig. 22)**
Date	dd/mm/yyyy	14/07/2016	14/07/2016	14/07/2016
Temperature*	°C	14.9	13.1	19.3
Electrical conductivity*	mS/m	24.5	256	137.7
Electrical conductivity	mS/m	335	295	160
pH*	$-\log_{10}\alpha_{H+}$	6.8	6.7	7.1
pH	$-\log_{10}\alpha_{H+}$	7.6	4.8	8.0
Calcium	mg Ca/L	647	533	170
Magnesium	mg Mg/L	109	94	58
Sodium	mg Na/L	152	118	81
Potassium	mg K/L	16	12	7.4
Chloride	mg Cl/L	59	52	57
Sulfate	mg SO_4/L	2090	1740	679
Total alkalinity	mg $CaCO_3$/L	30	3.1	88
Nitrate + nitrite	mg N/L	1.2	6.7	8.8
Silica	mg Si/L	2.1	1.9	4.8
Aluminium (total)	mg Al/L	0.07	0.06	0.10
Iron (total)	mg Fe/L	0.10	0.08	0.26
Manganese (total)	mg Mn/L	3.8	1.9	0.73
E. coli	MPN/100 mL	35	461	9330
Total coliforms	MPN/100 mL	517	>2419	32 550

* Field values

MPN most probable number