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 2015 TO MARCH 2016

AUTHOR

P.J. Hobbs

(Pr.Sci.Nat.)

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PREPARED FOR
Management Authority
Cradle of Humankind World Heritage Site
Gauteng Provincial Government

PREPARED BY
Council for Scientific and Industrial Research
Natural Resources & the Environment
PO Box 395, Pretoria, 0001

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 8th such report since 2012. It covers the period April 2015 to March 2016 and, as such, represents a full-term monitoring report and deliverable in the MAs financial year 2015-2016, 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.

- 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 is likely to produce a runoff of ~33 Mm^3 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 (9330 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 in response to the late summer rains.

- 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 ~2000 mg SO_4/L. These circumstances are reflected in the continued rise of the SO_4 concentration in the Zwartkrans Spring water.

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.

PJHobbs.

PJ Hobbs (Pr.Sci.Nat.)
SENIOR RESEARCH HYDROGEOLOGIST

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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 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). This document represents the eighth such report, which covers the full-term period April 2015 to March 2016.

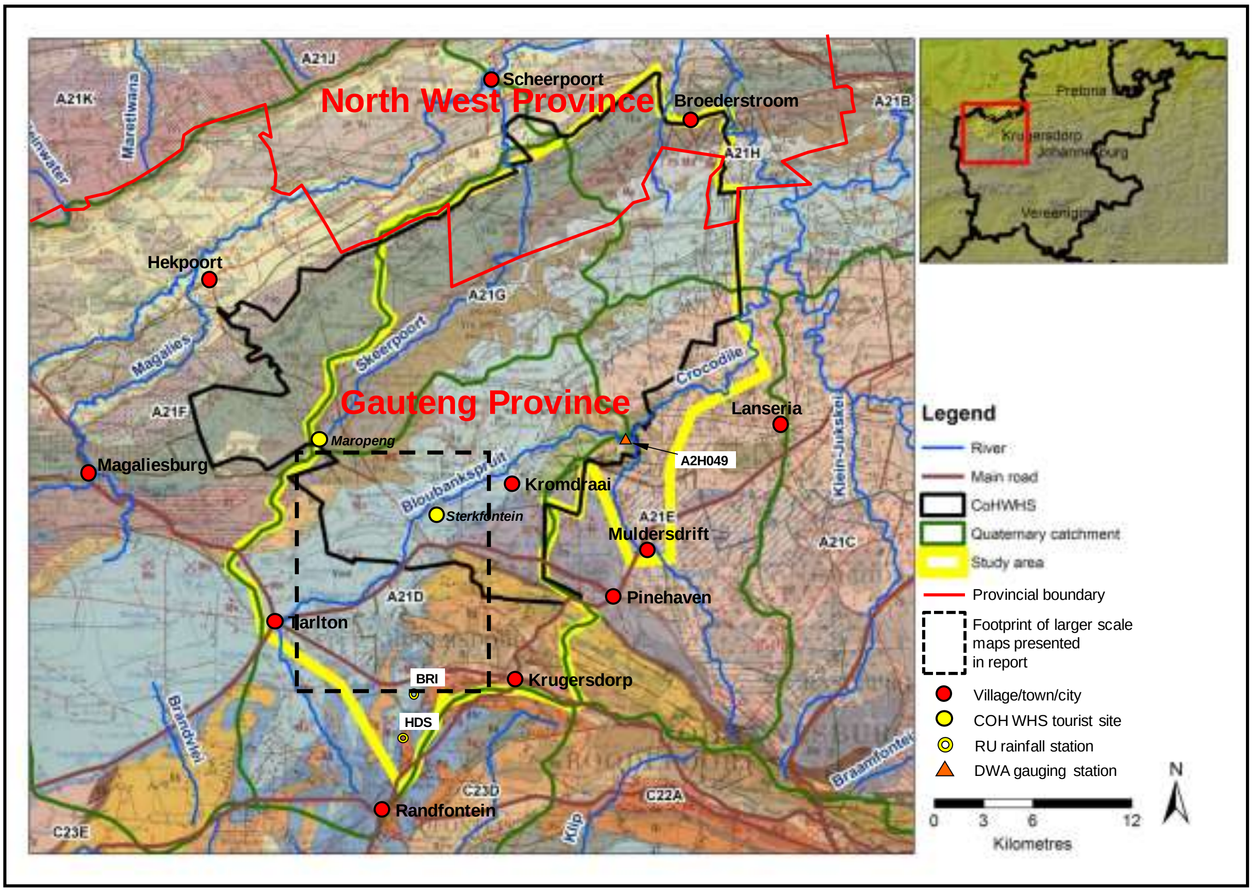


Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

2 TIMELINE OF KEY EVENTS

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 (Berger et al., 2015; Dirks et al., 2015) 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.

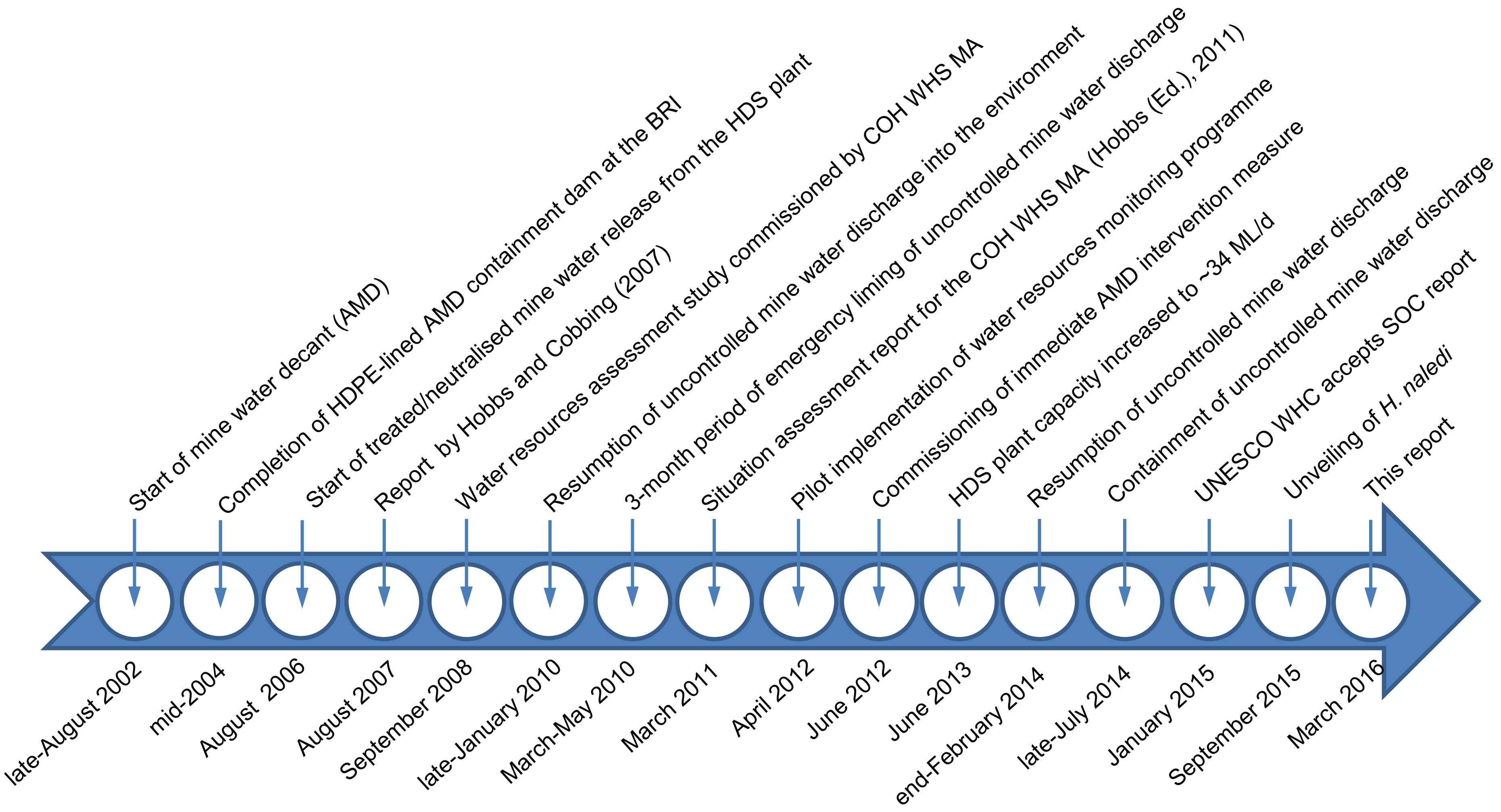


Figure 2 Updated timeline of events relevant to this report

3 RAINFALL

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

- the wetter than normal 2010–'11 and 2013–'14 summer rainfall seasons;
- the drier than normal 2014–'15 summer; and
- 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).

These circumstances are also reflected in **Figure 4**. It should be noted that the very wet late summer coincided with a severe El Niño Southern Oscilation (ENSO) event that caused 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 station located at Sterkfontein Caves. Data for the period June 2010 to March 2016 were provided by the DWS. The common monthly rainfall record (n = 70) for the HDS and Sterkfontein Caves stations indicates a good correlation ($R^2 = 0.89$, $p < 0.01$) (**Figure 5**).

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

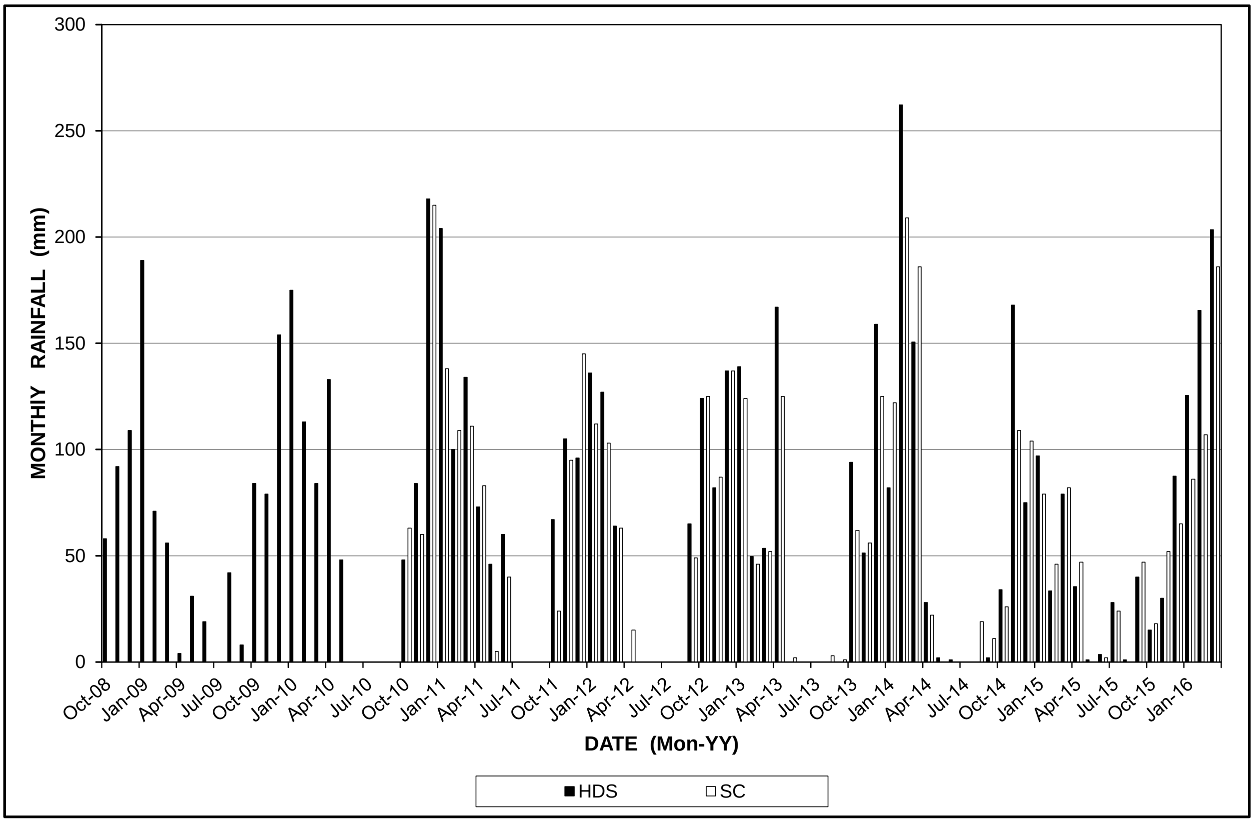


Figure 3 Monthly precipitation at the SG rainfall monitoring station HDS in the mine area and the available contemporary record for the Sterkfontein Caves station in the period October 2008 to March 2016

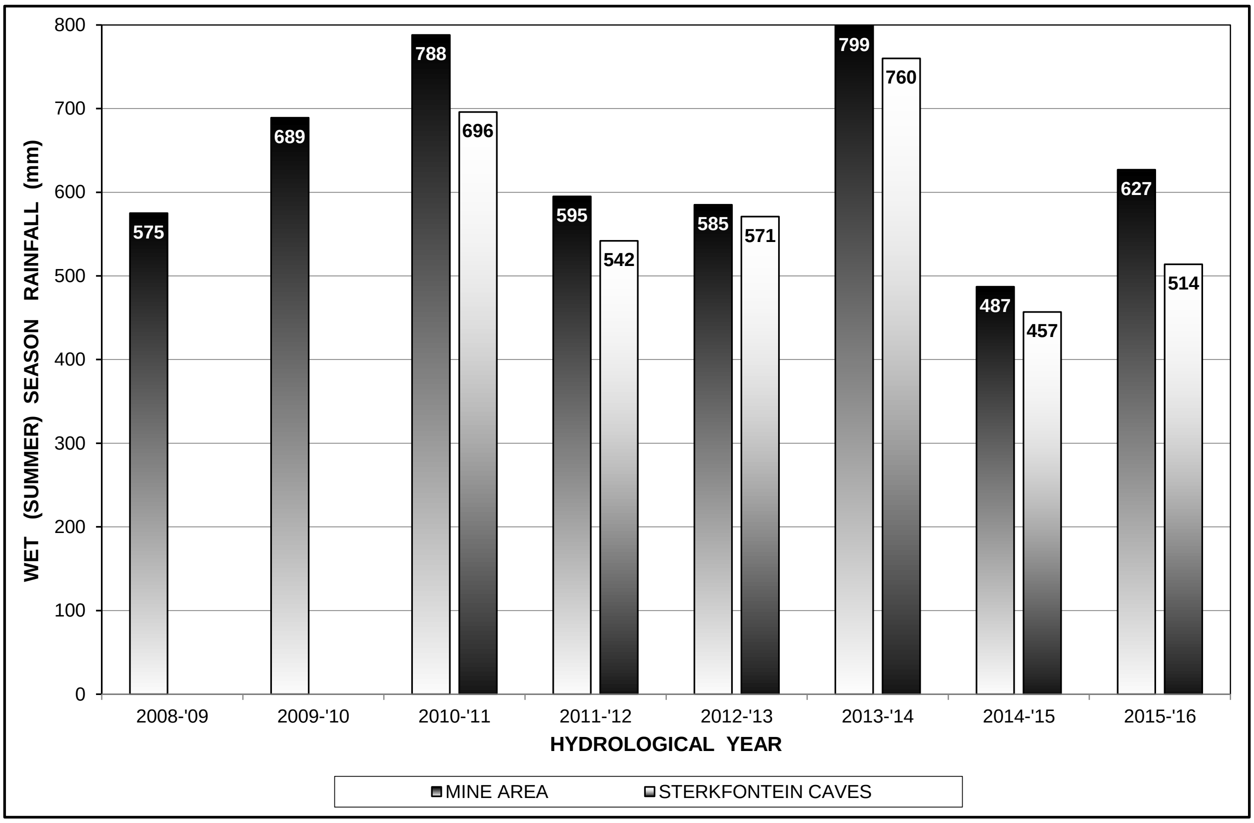


Figure 4 Total wet season (summer) rainfall in the mine area (HDS station) in the past eight hydrological years, also showing the comparison with that for the available contemporary Sterkfontein Caves record

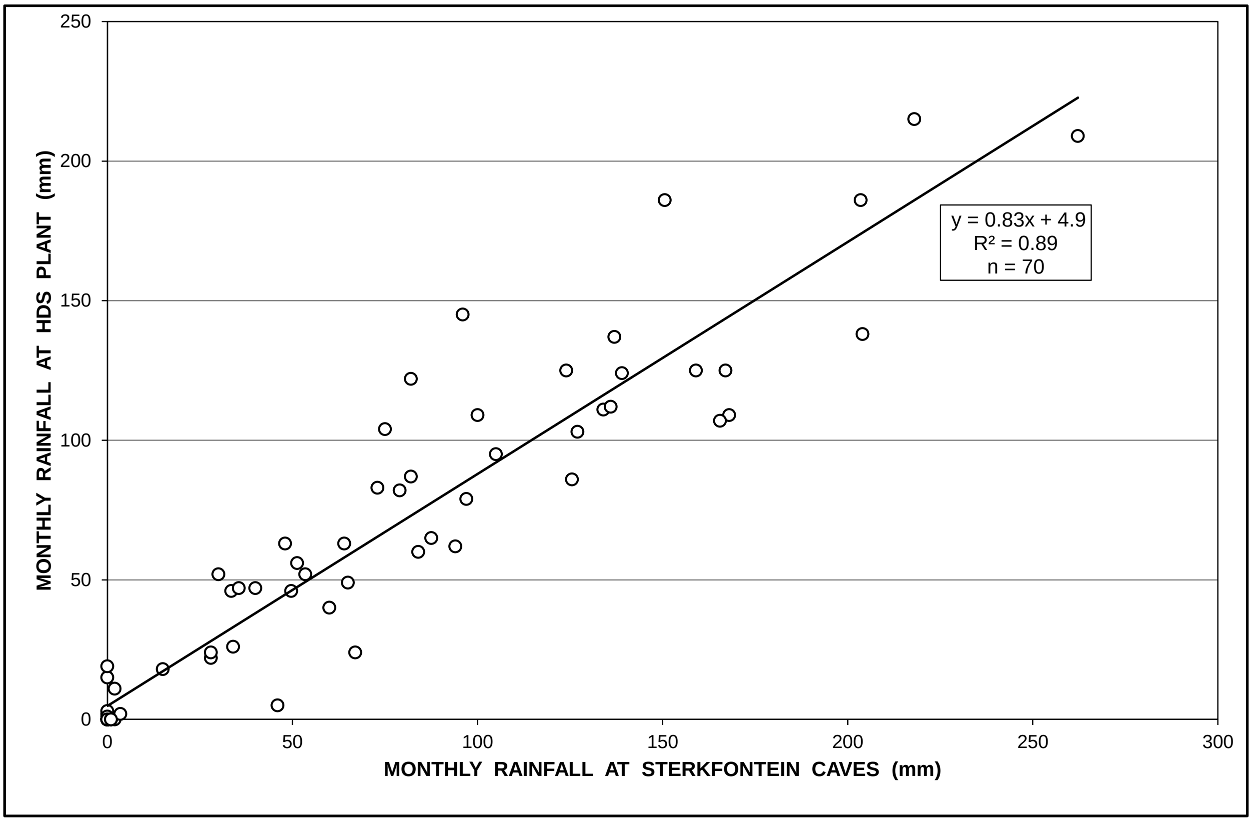


Figure 5 Correlation of monthly rainfall at Sterkfontein Caves with that at the HDS plant in the mine area

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**.

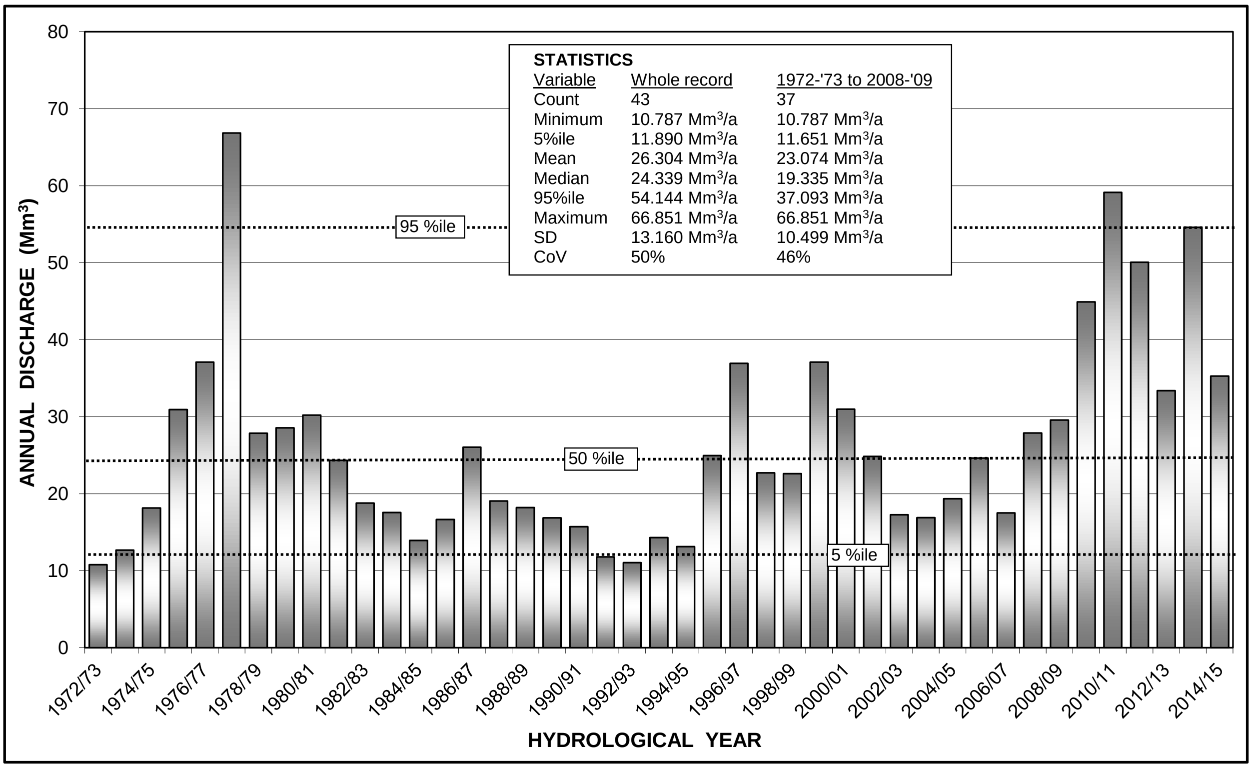
Table 1 Statistical analysis of Bloubank Spruit monthly discharge data gauged at station A2H049 in the period October 1972 to April 2016

Variable	**Month**											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	42	42	43	43	44	44	44	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	0.787	0.853	1.042	1.097	0.899	1.058	1.185	0.986	0.956	0.958	0.914	0.800
Mean	1.858	1.868	2.265	2.705	2.645	3.009	2.403	2.250	2.065	2.038	1.919	1.789
Median	1.616	1.742	2.040	2.428	2.087	2.512	1.986	1.844	1.746	1.640	1.603	1.502
95%ile	3.848	2.956	4.514	5.390	6.376	7.997	5.400	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	0.926	0.832	1.104	1.936	1.915	2.228	1.297	1.205	0.982	0.938	0.874	0.888
CoV (%)	49.8	44.5	48.8	71.6	72.4	74.0	54.0	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**). Although not shown because of an incomplete record, the first seven months of the current (2015–'16) hydrological year have produced 20.2 Mm^3. As this period encompasses the wet summer season, it is unlikely that the remaining five months (four of which are typically dry winter months) will produce more than ~13 Mm^3. This would produce a total of ~33 Mm^3, similar to that of the previous (2014–'15) hydrological year.

The instantaneous monthly flow pattern at station A2H049 for the complete record October 1972 to April 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 discharge of treated/neutralised mine water from the Western Basin, with a subordinate contribution from the Percy Stewart Wastewater Treatment Works.



STATISTICS

Variable	Whole record	1972-'73 to 2008-'09
Count	43	37
Minimum	10.787 Mm^3/a	10.787 Mm^3/a
5%ile	11.890 Mm^3/a	11.651 Mm^3/a
Mean	26.304 Mm^3/a	23.074 Mm^3/a
Median	24.339 Mm^3/a	19.335 Mm^3/a
95%ile	54.144 Mm^3/a	37.093 Mm^3/a
Maximum	66.851 Mm^3/a	66.851 Mm^3/a
SD	13.160 Mm^3/a	10.499 Mm^3/a
CoV	50%	46%

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

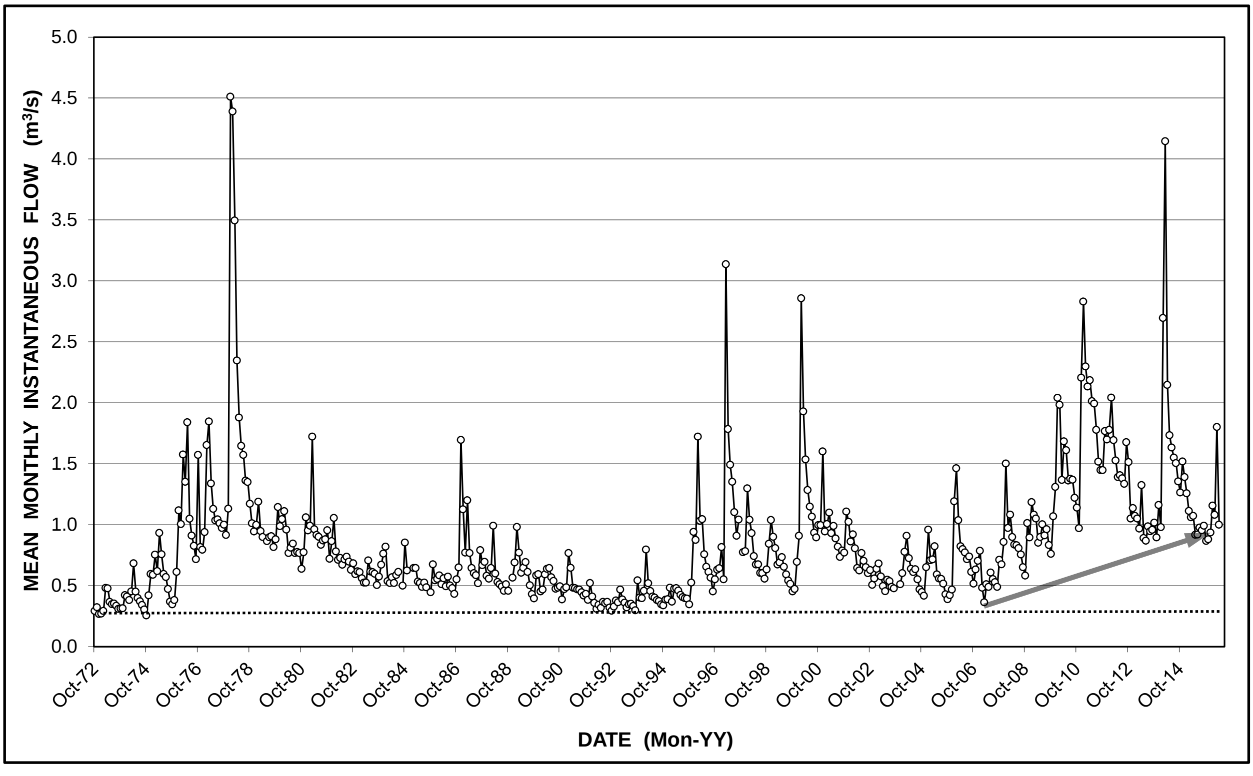


Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to April 2016

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.

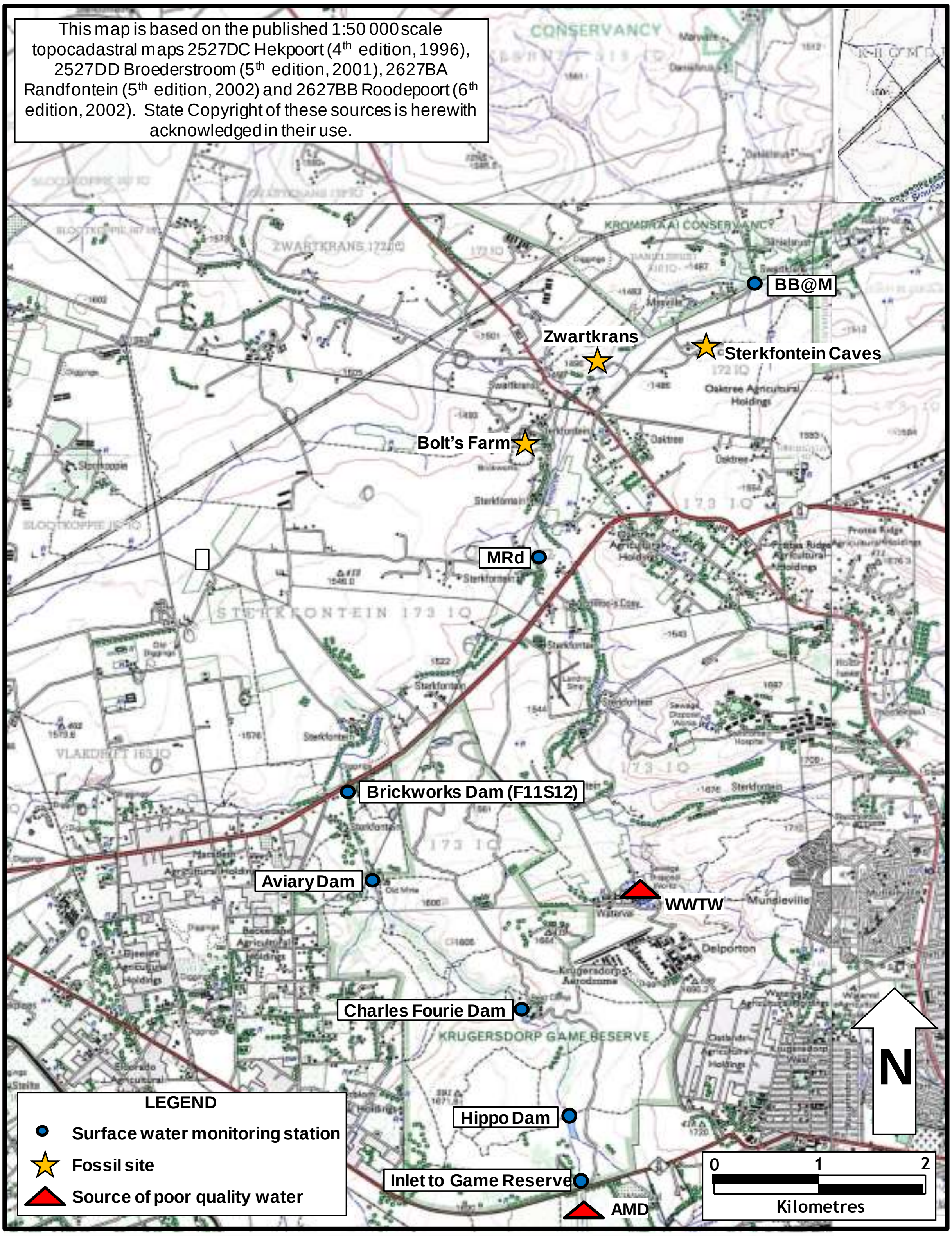


Figure 8 Locality map of surface water quantity and quality monitoring stations

The results reported in Hobbs (2015b), 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.

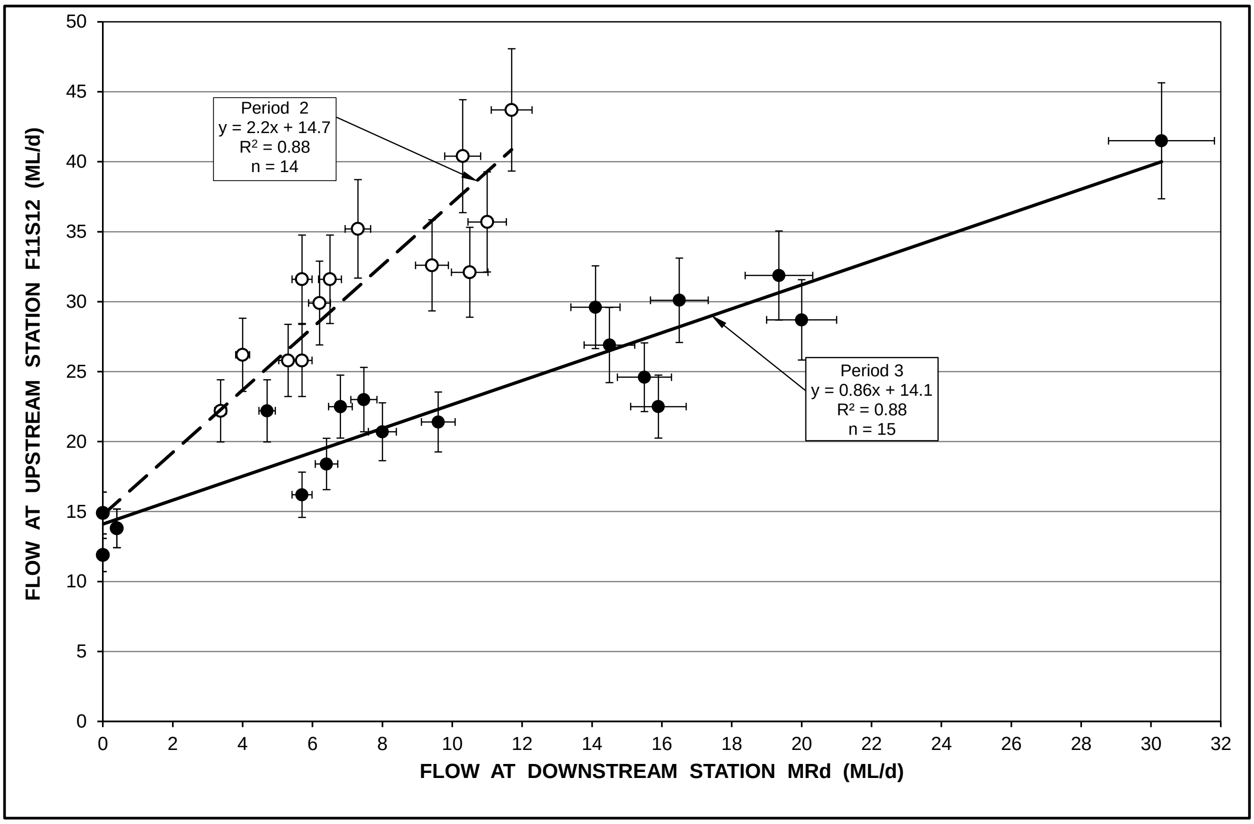


Figure 9 Correlation of stream flow at stations F11S12 and MRd in the Riet Spruit valley, with vertical error bars denoting ±10% at F11S12 and horizontal bars ±5% at MRd

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 (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.

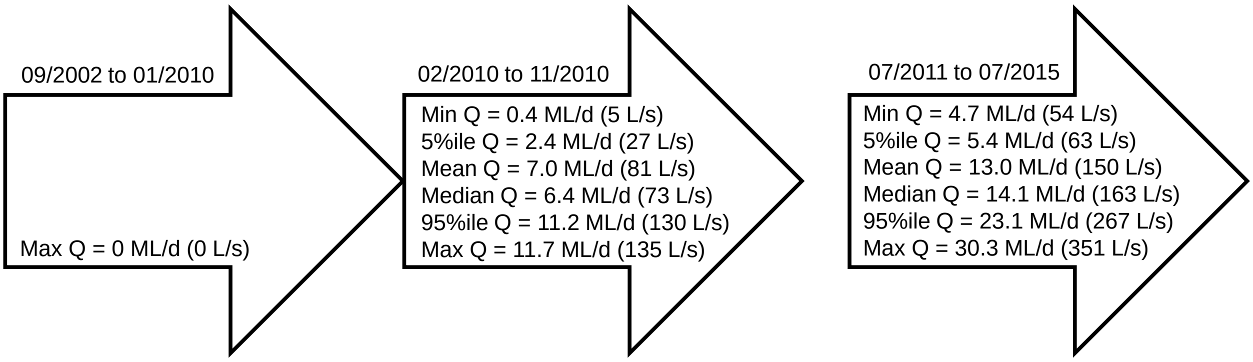


Figure 10 Episodic progression of surface flow measured at station MRd since the start of mine water decant

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 discussed in **Section 3**. The recovery of pH to circum-neutral values in late-April and May 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**. Only the information for period D– in **Table 2** has been updated. **Table 2** reveals the following salient differences between the data sets:

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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.

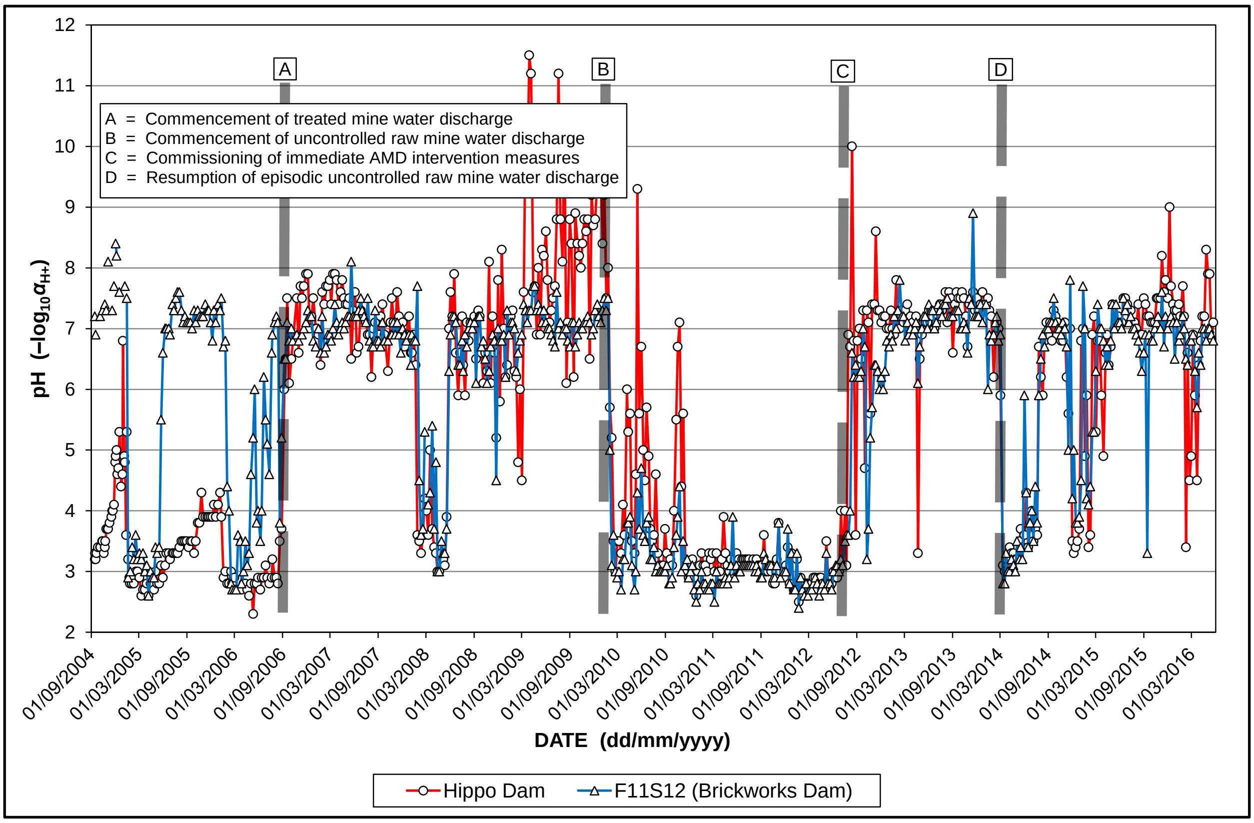


Figure 11 Pattern of Tweelopie Spruit pH values in the period September 2004 to May 2016

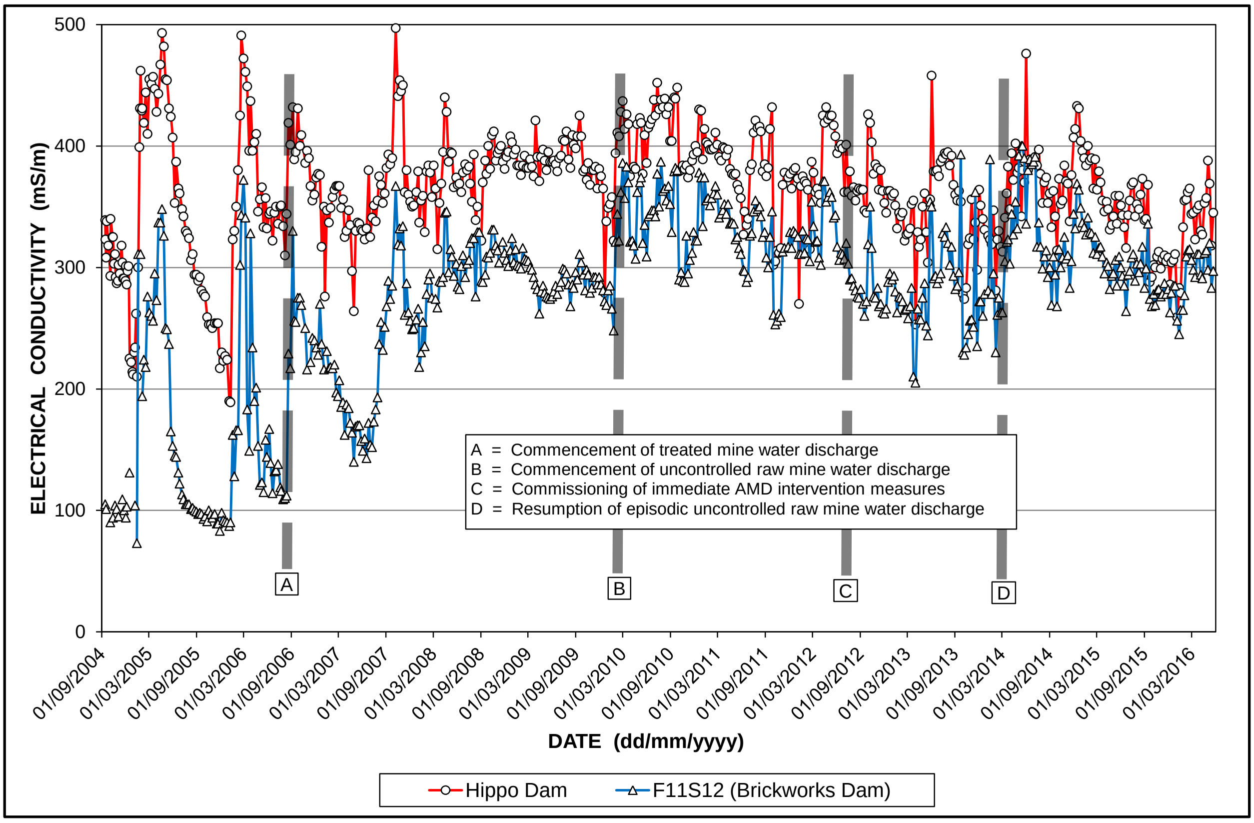


Figure 12 Pattern of Tweelopie Spruit EC values in the period September 2004 to May 2016

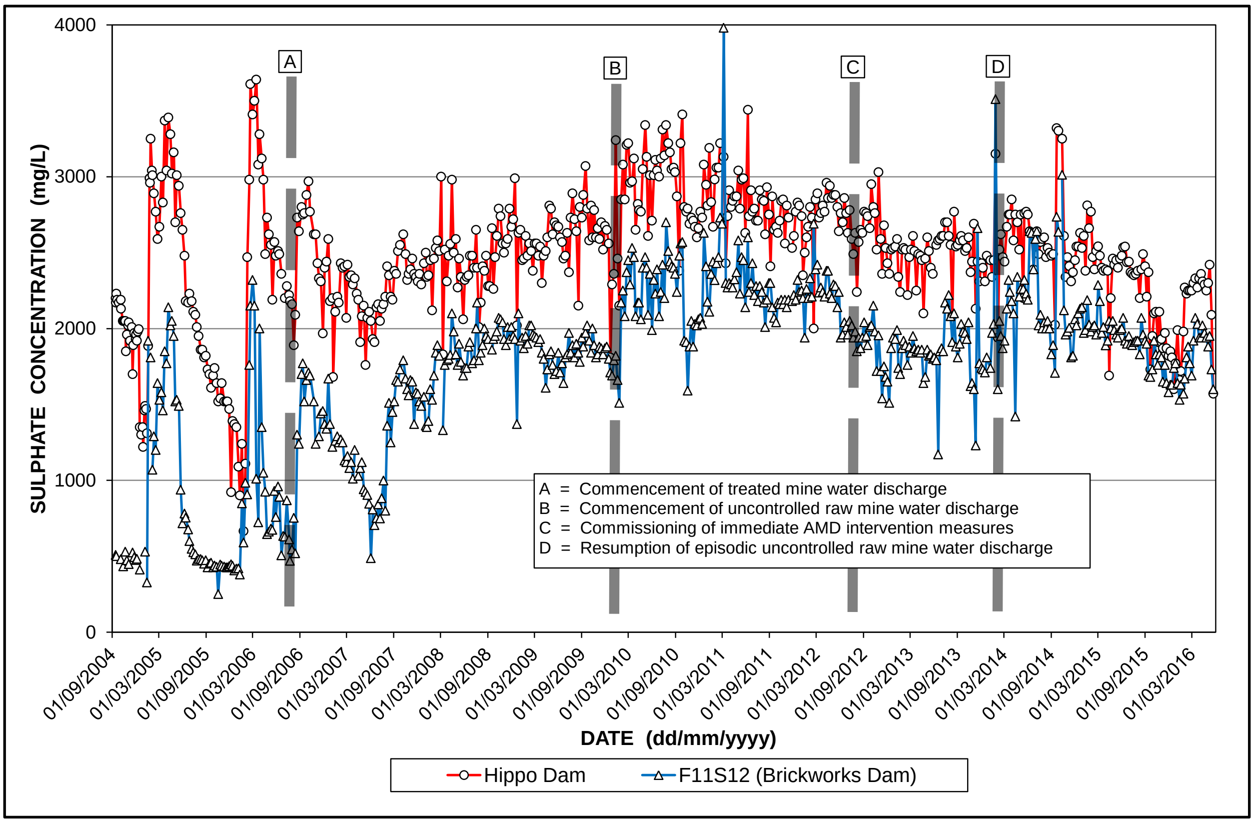


Figure 13 Pattern of Tweelopie Spruit SO_4 values in the period September 2004 to May 2016

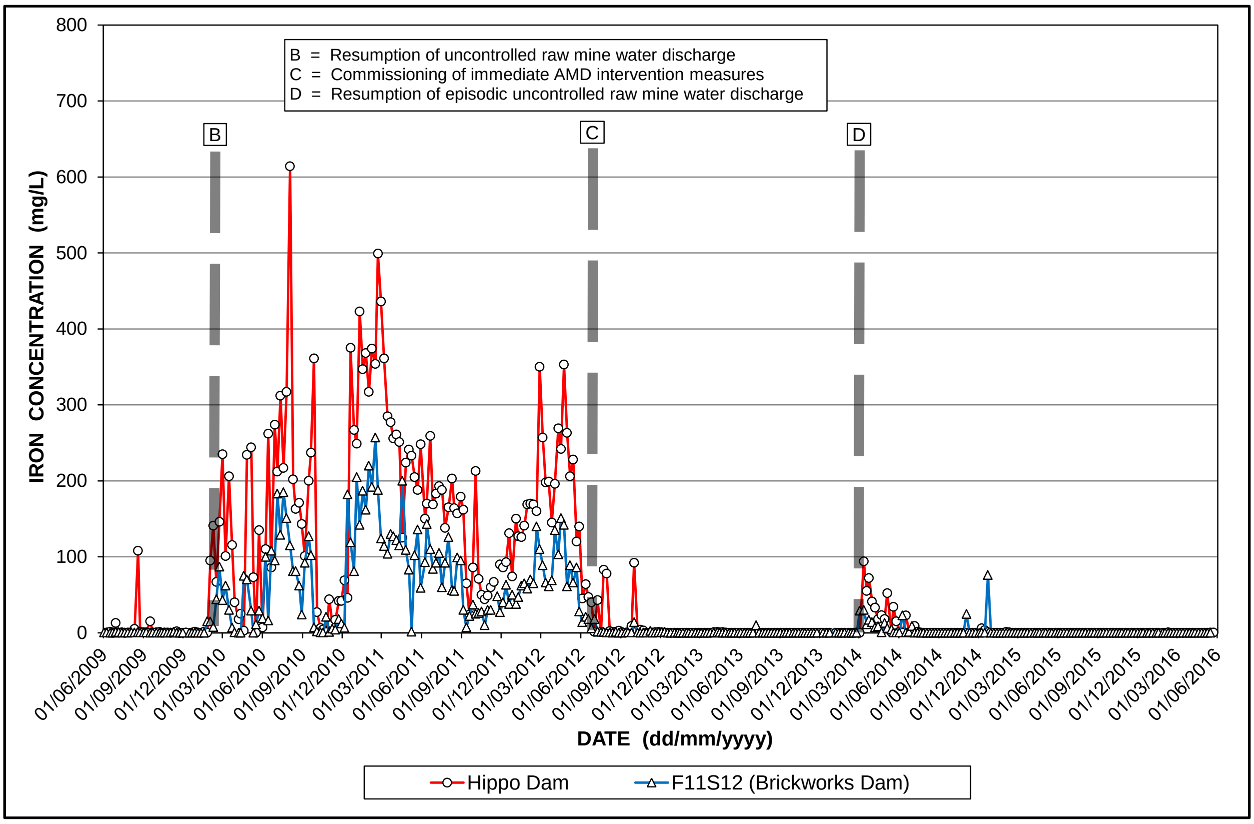


Figure 14 Pattern of Tweelopie Spruit Fe values in the period June 2009 to May 2016

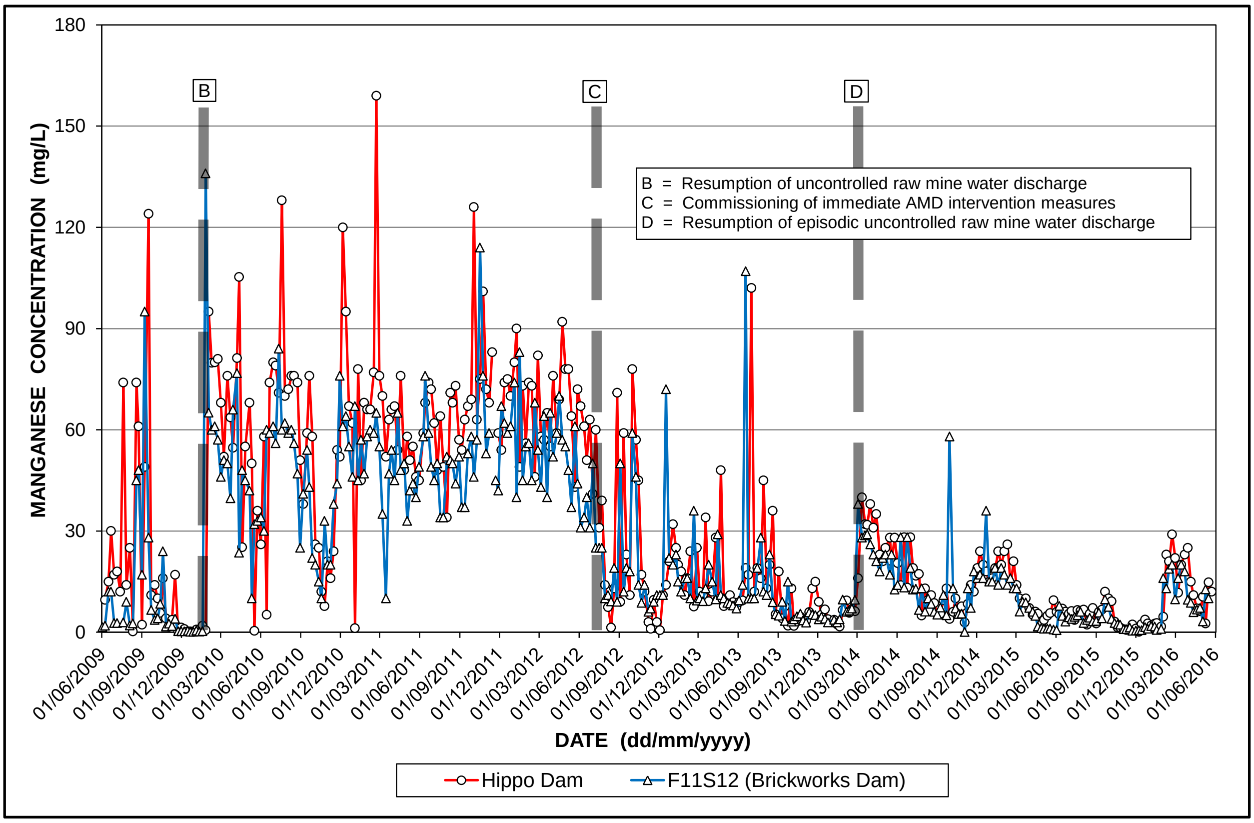


Figure 15 Pattern of Tweelopie Spruit Mn values in the period June 2009 to May 2016

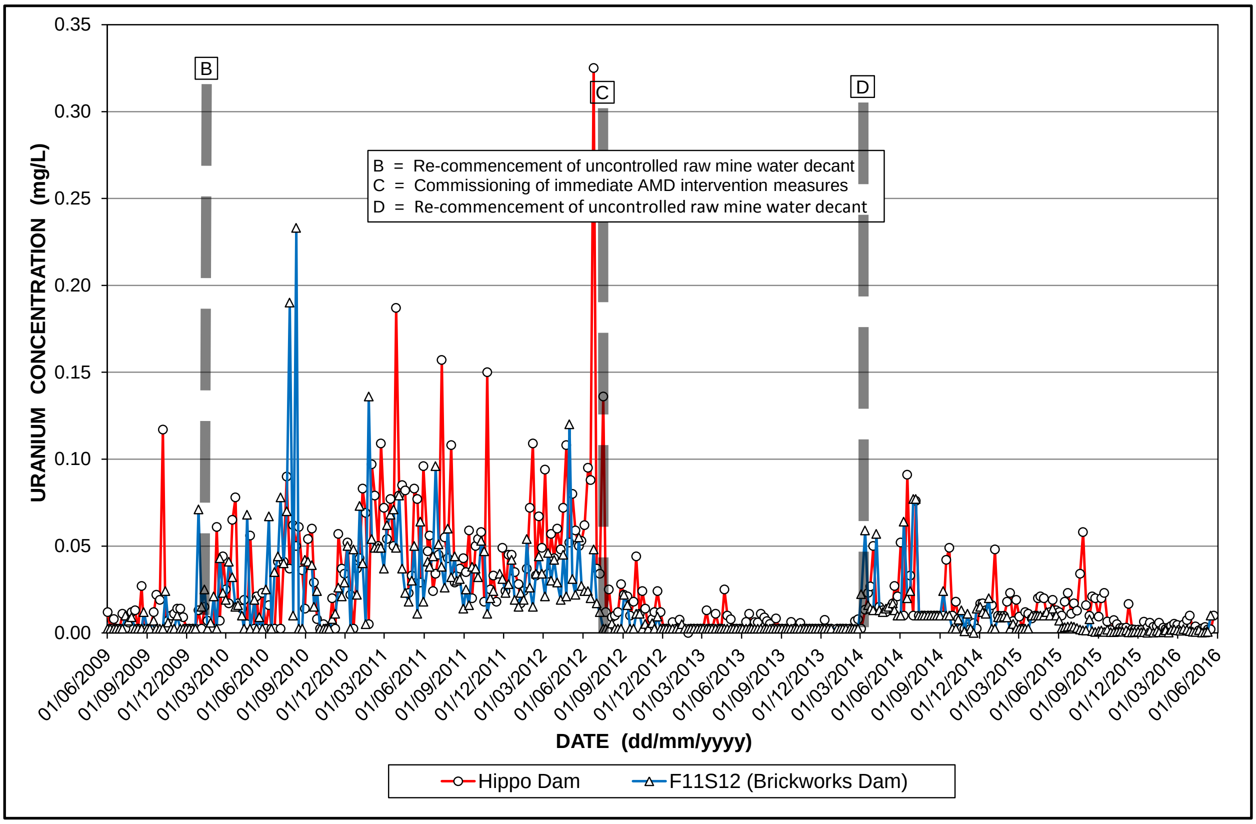


Figure 16 Pattern of Tweelopie Spruit U values in the period June 2009 to May 2016

It has only been necessary to update the information for period D– in **Table 2**, which reveals 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";
- 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; and
- the smaller differences between the pH and manganese values recorded for each period at each station, compared for example to the differences in sulfate and iron.

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 $(-\log_{10}\alpha_{\mathrm{H+}})$	n	176	129	83	117	173	128	83	117
	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	6.9	6.9	3.0	7.0	6.8
	95%ile	9.3	5.7	7.6	7.7	7.4	3.9	7.4	7.4
	SD	1.5	1.0	0.8	1.6	0.9	0.4	0.9	1.5
	CoV (%)	22.0	29.7	11.4	26.8	14.1	13.7	13.0	24.4
EC (mS/m)	n	175	129	83	117	172	128	83	117
	Mean	374	391	350	354	268	332	281	310
	Median	379	393	354	355	283	330	276	306
	95%ile	426	438	395	402	329	378	350	387
	SD	32	33	34.1	35	48	29	34	33
	CoV (%)	8.5	8.4	9.7	9.9	18.0	8.7	12.2	10.6
SO_4 (mg/L)	n	176	128	82	116	171	128	83	116
	Mean	2 448	2 846	2 520	2 374	1 636	2 264	1 879	1 987
	Median	2 460	2 815	2 525	2 400	1 760	2 240	1 870	1 965
	95%ile	2 82810	3 220	2 770	2 770	2 015	2 593	2 148	2 600
	SD	262	226	193	322	349	245	268	261
	CoV (%)	10.7	7.9	7.6	13.6	21.3	10.8	14.3	13.2
Fe (mg/L)	n	33	129	83	117	33	128	82	117
	Mean	4.7	168.4	2.490	4.3	0.3	72.9	0.466	2.4
	Median	0.4	163.0	0.030	0.02	0.2	64.0	0.075	0.02
	95%ile	13.8	365.2	3.090	33.2	0.8	186.3	1.000	14.6
	SD	18.8	116.2	13.146	14.2	0.3	57.7	1.896	8.8
	CoV (%)	399.1	69.0	527.9	328.4	94.4	79.1	407.2	370.9
Mn (mg/L)	n	34	129	83	117	33	128	83	117
	Mean	18.1	62.7	16.5	12.3	10.3	50.3	14.4	10.6
	Median	9.8	65.0	11.0	9.6	2.7	50.0	10.0	7.8
	95%ile	74.0	95.0	56.1	29.4	46.2	76.0	45.0	28.1
	SD	27.6	23.5	18.0	9.4	19.4	17.6	15.8	9.5
	CoV (%)	152.5	37.6	109.3	76.3	187.6	35.1	110.1	89.0

(1) 09/2006 – 01/2010 (2) 02/2010 – 07/2012 (3) 08/2012 – 02/2014 (4) 03/2014 – 05/2016

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 largely prevailed to May 2016, with the exception recently of comparatively brief excursions in the period February to April 2016.

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^+ activity driving down the pH. Note in this regard that **Table 2** indicates the occurrence in the period D– of significant Fe concentrations (~33 mg/L at the 95%ile level) at the Hippo Dam location, compared to the ~15 mg/L at this level at station F11S12.

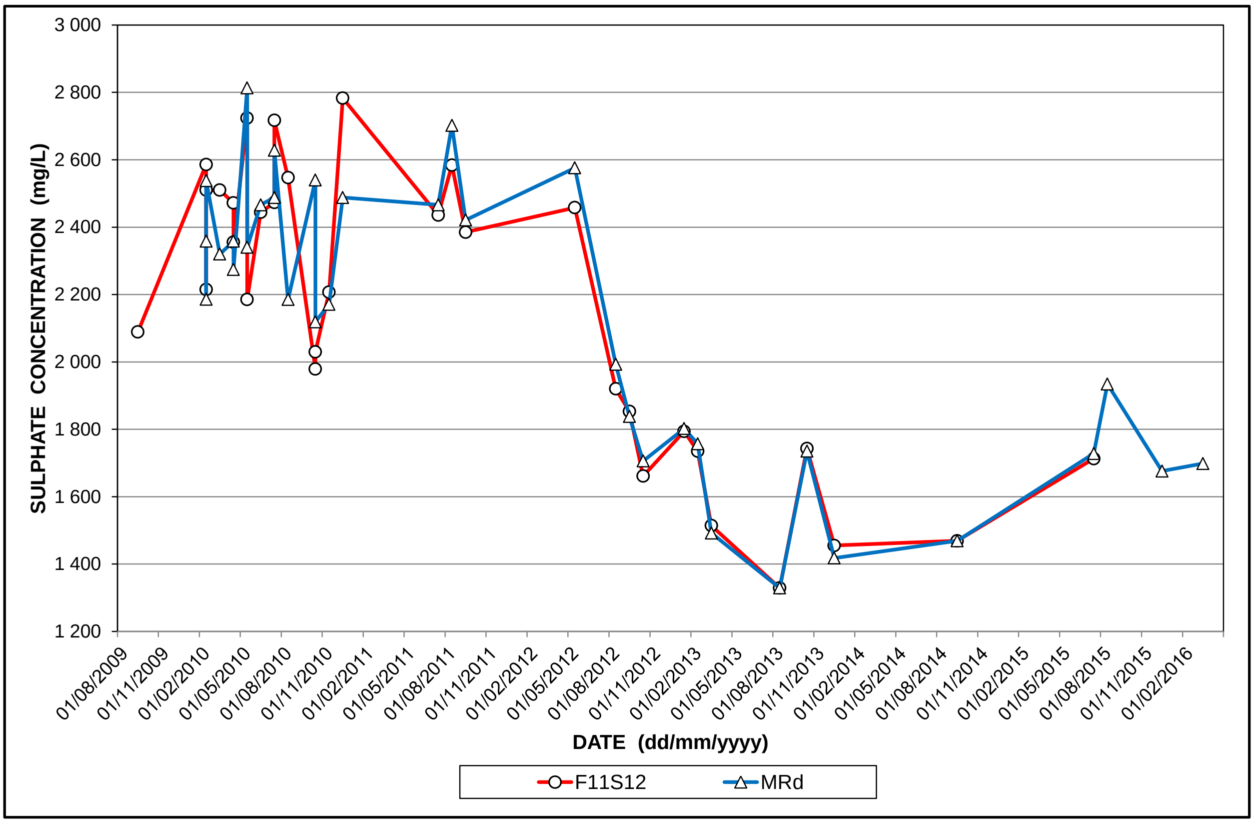


Figure 17 Pattern of EC values at stations F11S12 and MRd as reported in Annexure B

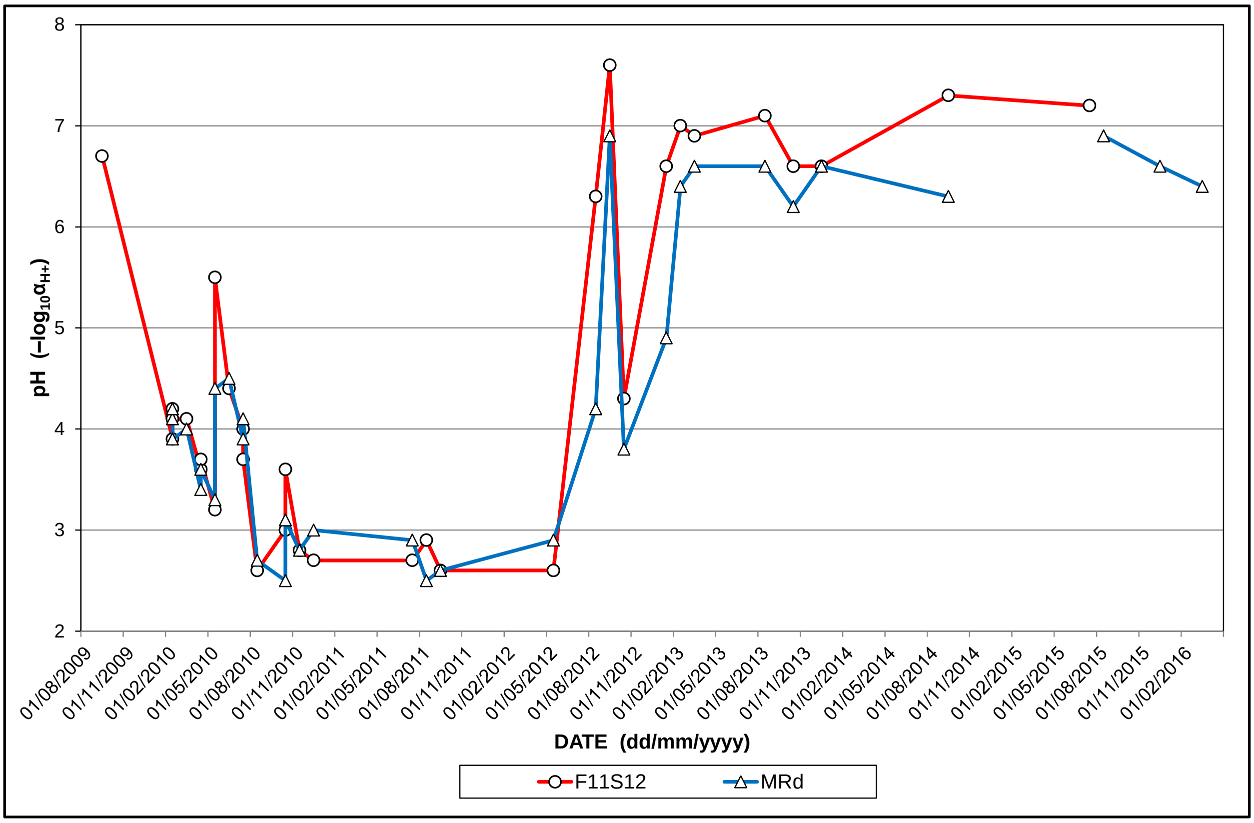


Figure 18 Pattern of pH values at stations F11S12 and MRd as reported in Annexure B

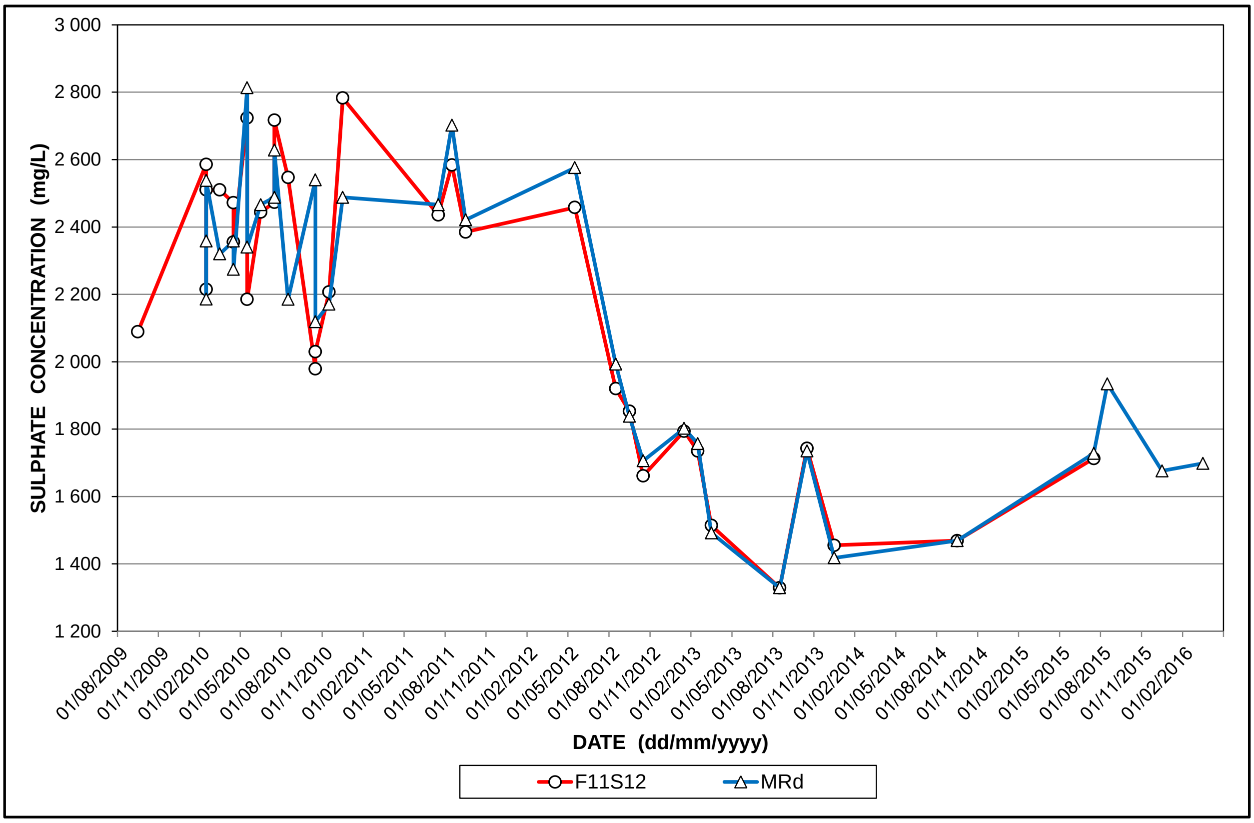


Figure 19 Pattern of derived SO_4 values at stations F11S12 and MRd as reported in Annexure B

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 for potable water where specified.

Table 3 Synoptic overview of Bloubank Spruit water chemistry at station A2H049 since May 1979 (from Hobbs, 2015b)

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

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 20** and **Figure 21** respectively.

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 22**) and SO_4 (**Figure 23**) load pattern and trend manifested at station A2H049. The ratio of SO_4 to TDS illustrated in **Figure 24** 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.

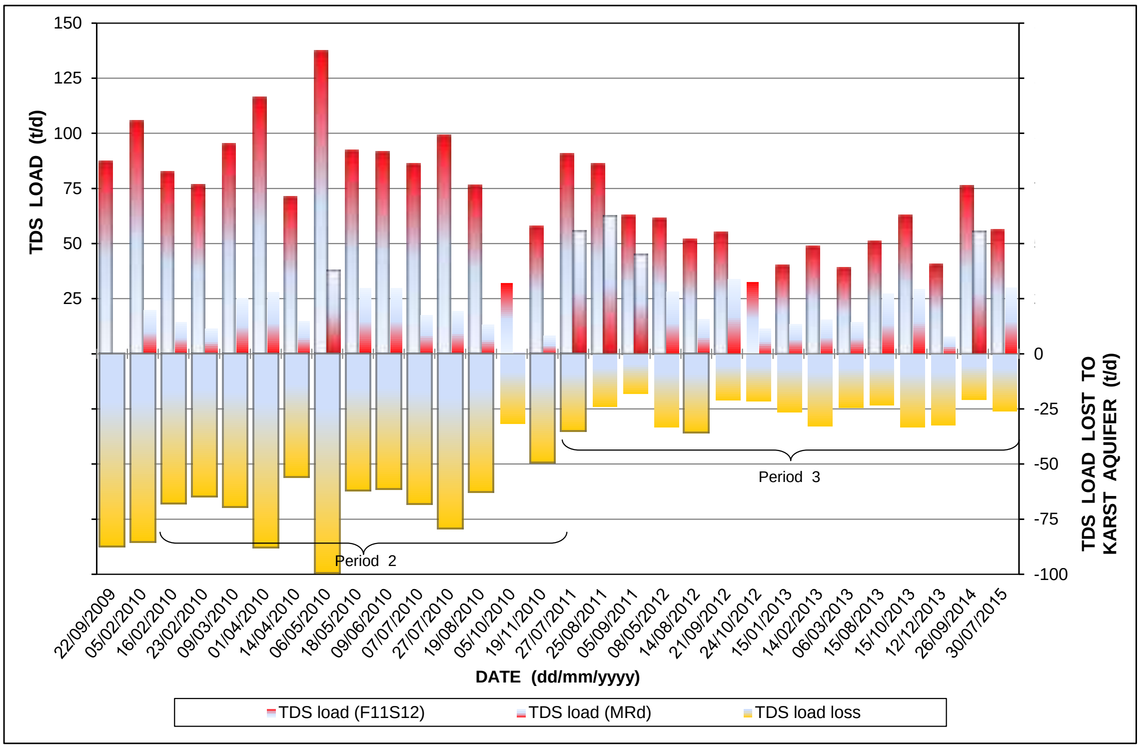


Figure 20 Graph of surface water TDS load lost to groundwater in the loosing reach of the Riet Spruit (from Hobbs, 2015b)

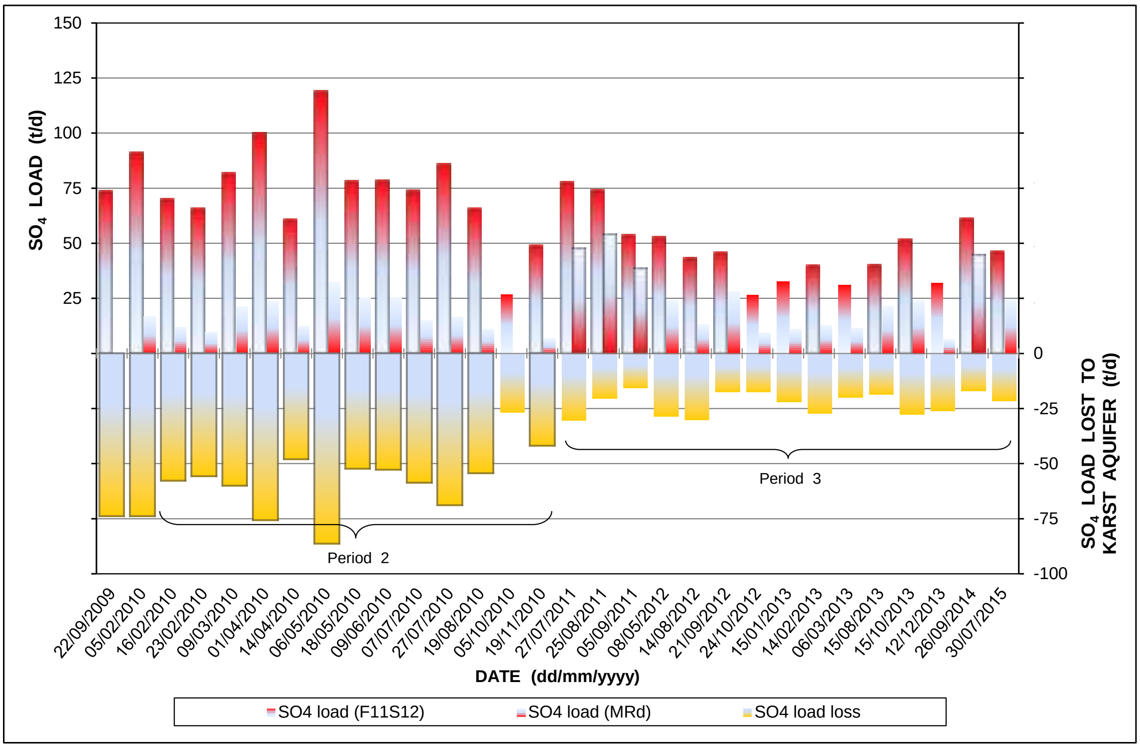


Figure 21 Graph of surface water SO_4 load lost to groundwater in the loosing reach of the Riet Spruit (from Hobbs, 2015b)

The long-term monthly trend in the TDS load delivered by the Bloubank Spruit (**Figure 22**) indicates an increasing TDS load (as indicated by the visually inserted arrows) since early-2007. The text box in **Figure 22** 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 23**) mimics the TDS load pattern (**Figure 22**) in the period since early-2007. This is unsurprising under circumstances where SO_4 comprises ~62% of the major ion concentration in mine water.

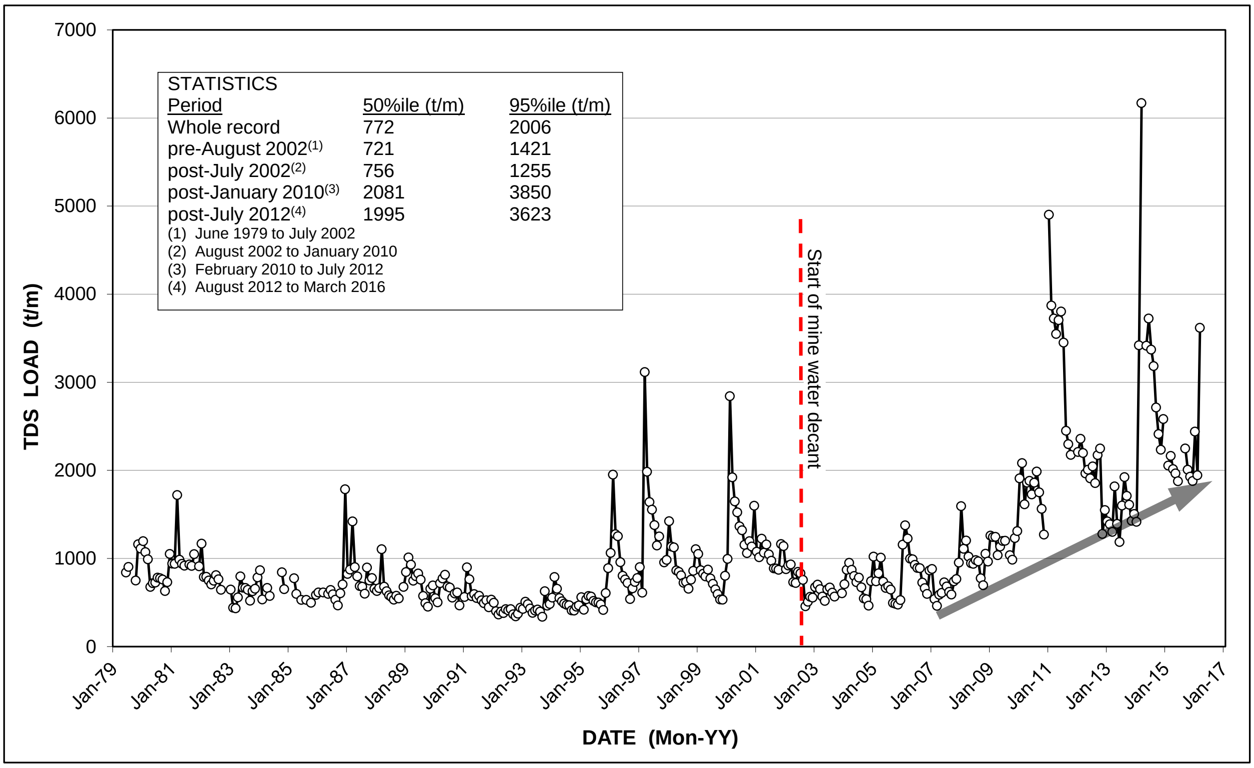
A further analysis of the potential impact of AMD on the chemistry of surface water at the downstream end of the Bloubank Spruit system is based on the SO_4**:**TDS ratio at station A2H049. This is illustrated in **Figure 24** for the long-term record, and in **Figure 25** for the period since the start of decant.

The closer inspection in **Figure 26** 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 25**).

An inspection of **Figure 22** 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 23** 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 26**, which shows that the ca. January 2014 SO_4 concentrations at A2H049 are ~50% of those recorded in January 2011. The immediate cause-and-effect that is revealed in the response of surface water chemistry to mine water impacts reflected in **Figure 22** to **Figure 26** is obvious.

The SO_4 concentration in the surface water more recently passing station A2H049 (**Figure 26**) 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 to this impoundment by individual drainages in the Hartbeespoort Dam catchment, are described by Hobbs (2015b) on the basis of comparison with the long-term record. It is worth repeating the main findings of this assessment, namely that:

- the Bloubank Spruit catchment delivered ~26 kt/a TDS to the dam in the period 2009–'10 to 2014–'15, compared to the 176 kt/a of the Jukskei and Hennops tributaries, i.e. respective contributions of ~12% and 78% out of a total of 224 kt/a;
- springs discharging into the Bloubank Spruit deliver an aggregate and relatively constant groundwater-derived TDS load of ~7.8 kt/a, and those feeding the Skeerpoort River an aggregate and relatively constant TDS load of ~3.0 kt/a.

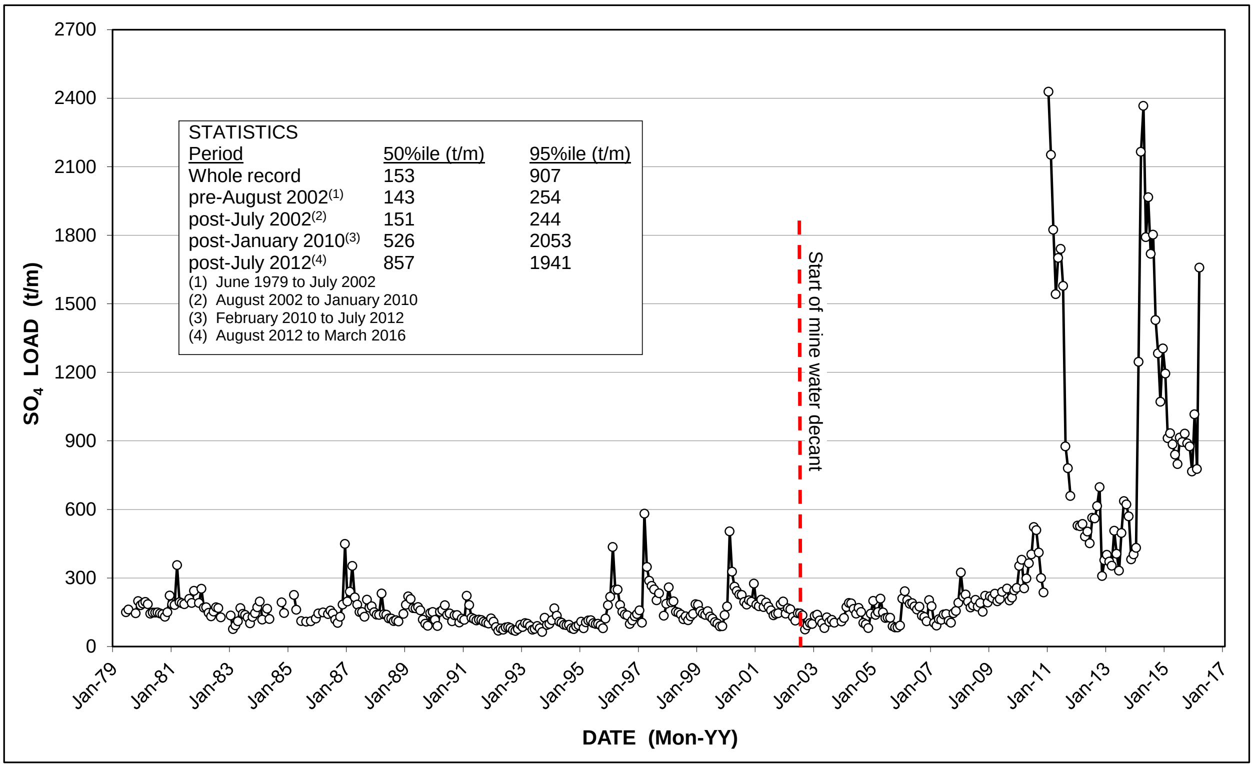


STATISTICS

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⁾	1995	3623

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

Figure 22 Long-term (June 1979 to March 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⁾	857	1941

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

Figure 23 Long-term (June 1979 to March 2016) monthly SO$_4$ load pattern and trend in the Bloubank Spruit at station A2H049

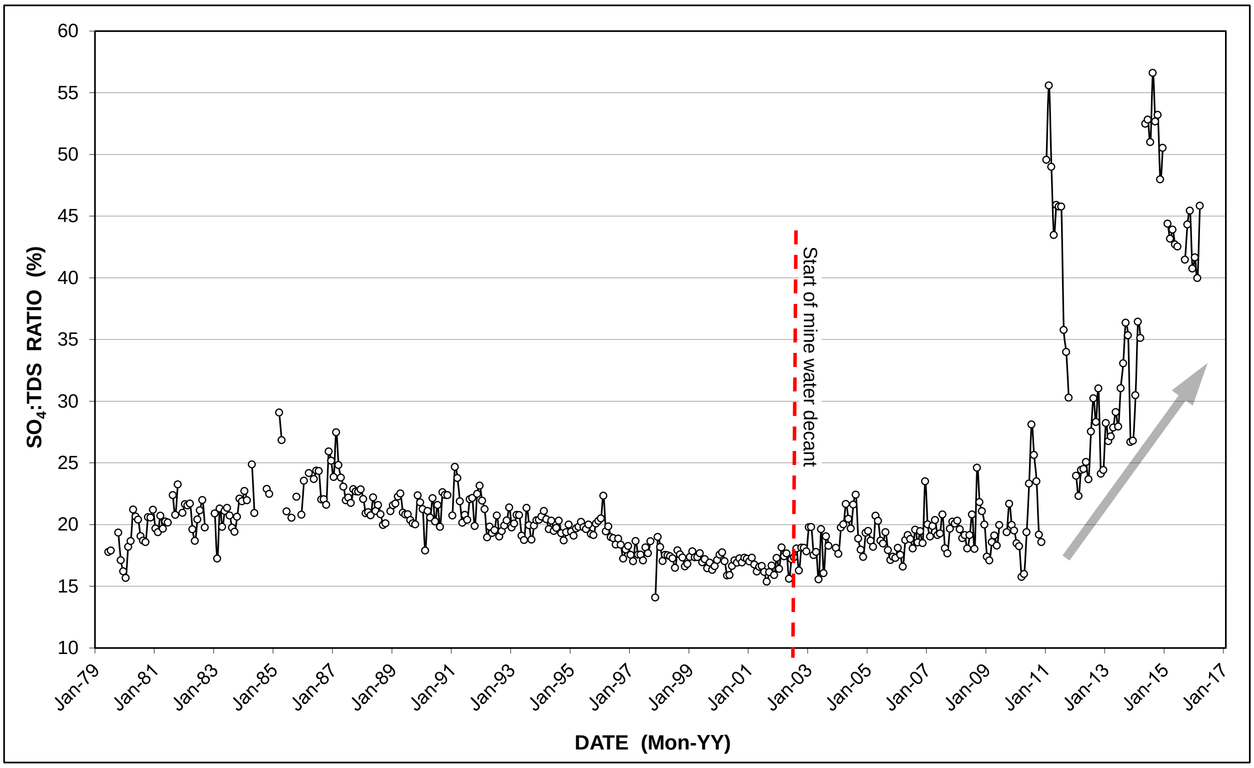


Figure 24 Long-term (June 1979 to March 2016) trend in the SO$_4$:TDS ratio at station A2H049

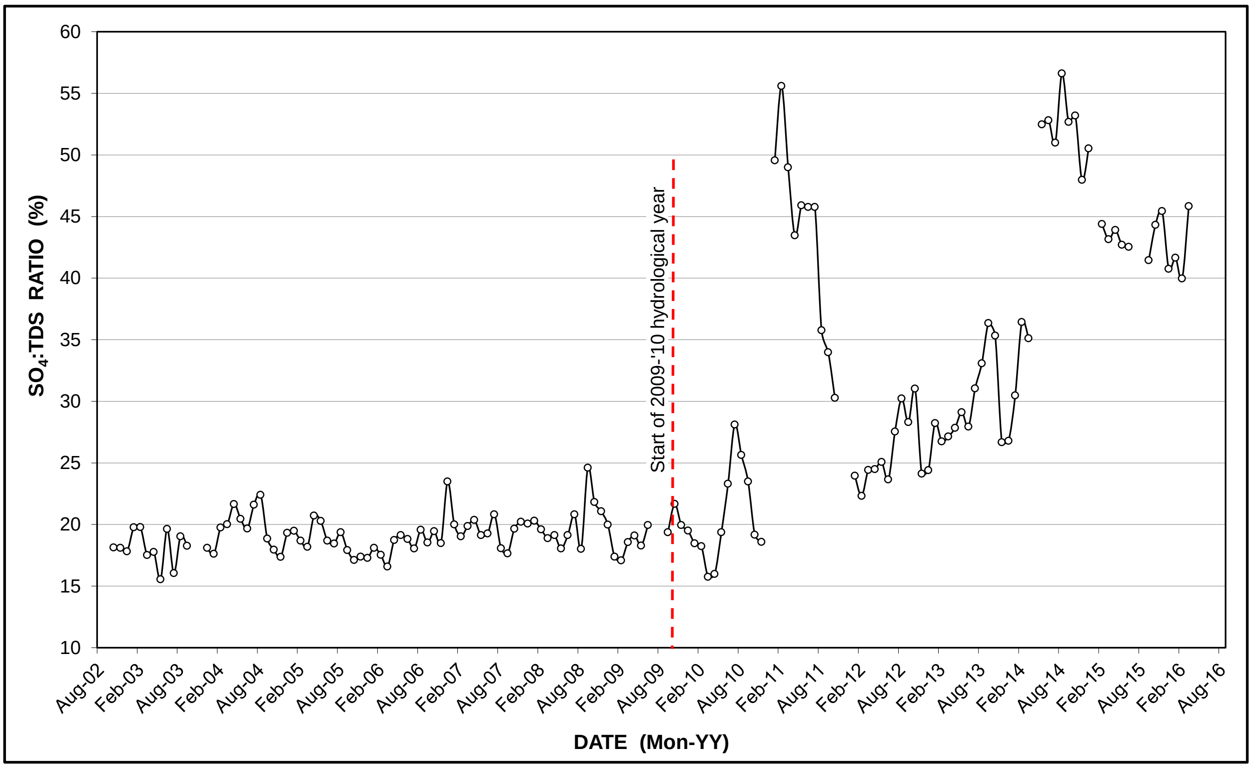
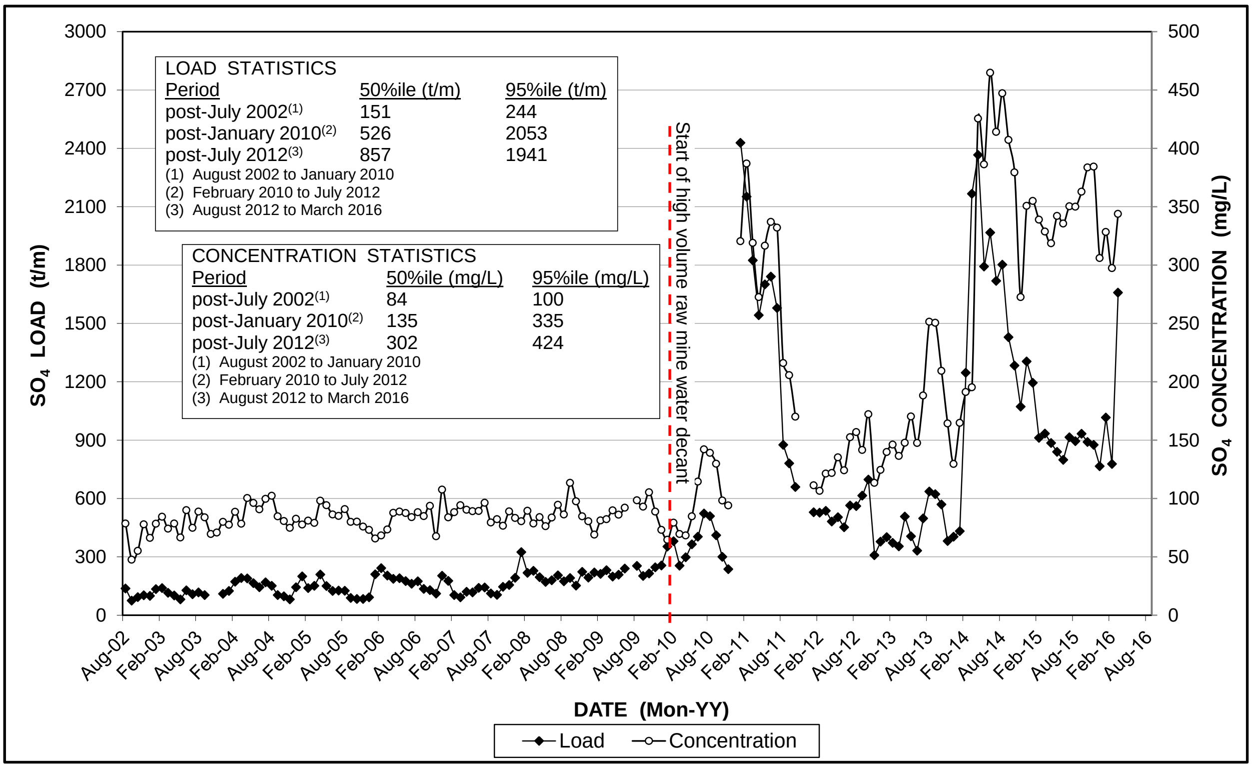


Figure 25 Pattern and trend of the SO$_4$:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin



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)]	857	1941

(1) August 2002 to January 2010
(2) February 2010 to July 2012
(3) August 2012 to March 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)]	302	424

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

Figure 26 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 dearth of municipal wastewater quality data in regard to the Mogale City Percy Stewart Wastewater Treatment Works (WWTW) has previously been reported (e.g. Hobbs, 2014b; 2015a; 2015b). This facility discharges treated municipal wastewater effluent into the Blougat Spruit, a tributary of the Bloubank Spruit (**Figure 27**). This facility has, however, scored poorly in the Green Drop ratings by which the DWS (2012) evaluates the performance of such facilities.

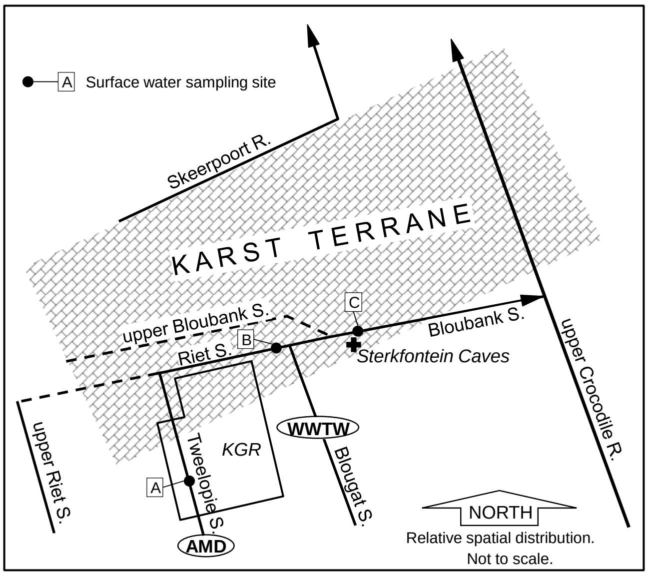


Figure 27 Schematic diagram showing the position of the surface water sampling sites reported in Annexure C, and their relative location in the wider sub-regional drainage network.

An indication of the impact of this facility on the downstream receiving water environment is reflected in the bacteriological results (*E. coli* and total coliform counts) reported in Annexure C. The results are for sites A, B and C in **Figure 27**, and reveal the substantial increase in bacteriological levels between site B which receives mainly mine water effluent via the Tweelopie Spruit, and site C which receives the additional contribution of municipal wastewater via the Blougat Spruit. These circumstances are illustrated in **Figure 28**, together sulfate (SO_4) with the metals Al, Fe and Mn that characterise mine water chemistry. Especially concerning is the *E. coli* count of 9330 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.

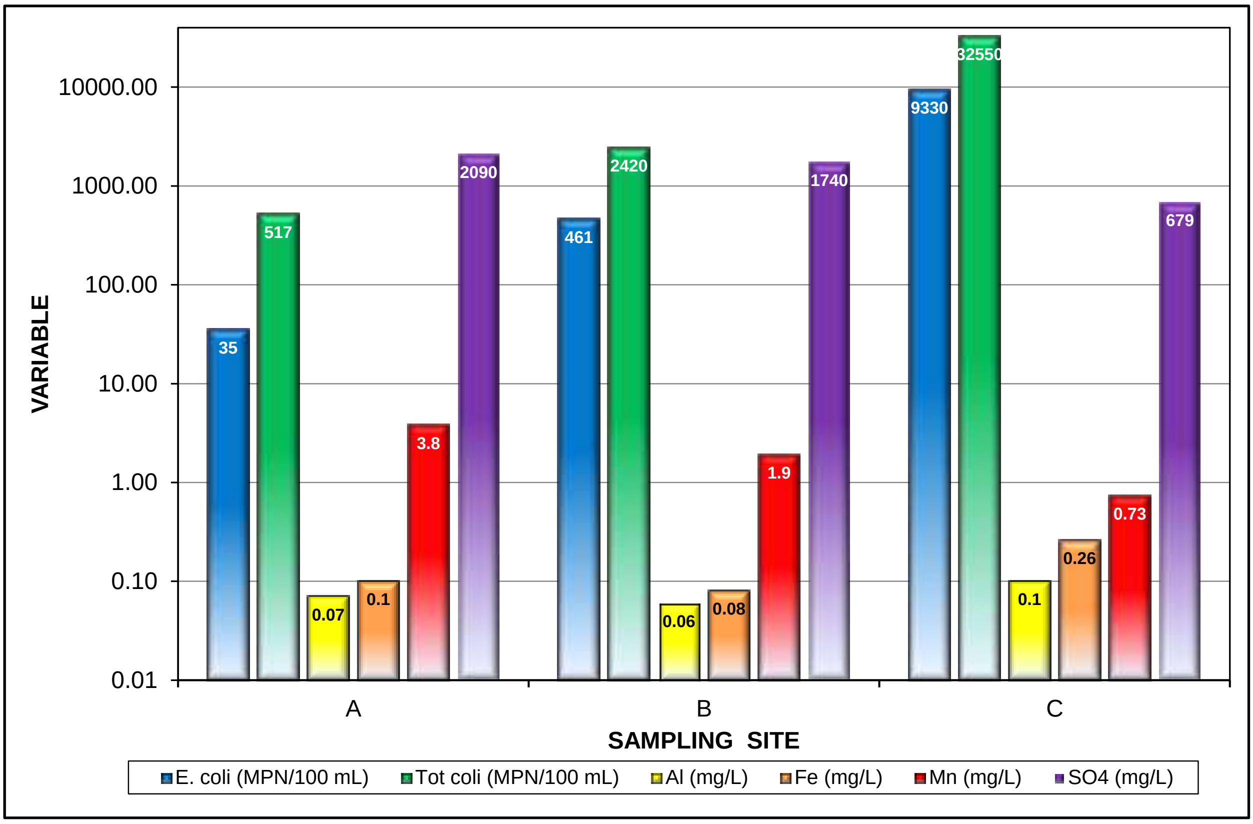


Figure 28 Comparison of the level of bacteriological contamination of surface water in the Bloubank Spruit (site C) with upstream sites A (Tweelopie Spruit) and B (Riet Spruit), also showing the levels of characteristic mine water variable concentrations at each of the sites.

Other patterns and trends that are illustrated in **Figure 28** 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, and the precipitation of Mn as Mn-oxyhydroxides with passage downstream;
- the substantial decrease in sulfate concentration from site B to site C, probably as a result of dilution of the mine water with municipal wastewater effluent; and
- the typically low Al and Fe concentrations at all three sites.

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 29.** The boreholes are grouped into a southern, a central and a northern segment to distinguish between their relative 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.

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 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 30 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 29**), and is readily attributed to the very wet late summer of the current (2015–'16) hydrological year (**Section 3**) and its broader impacts in the form of natural (autogenic) and mine water (allogenic) recharge.

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 allogenic groundwater recharge of 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).

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 31** and **Figure 32**. 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**).

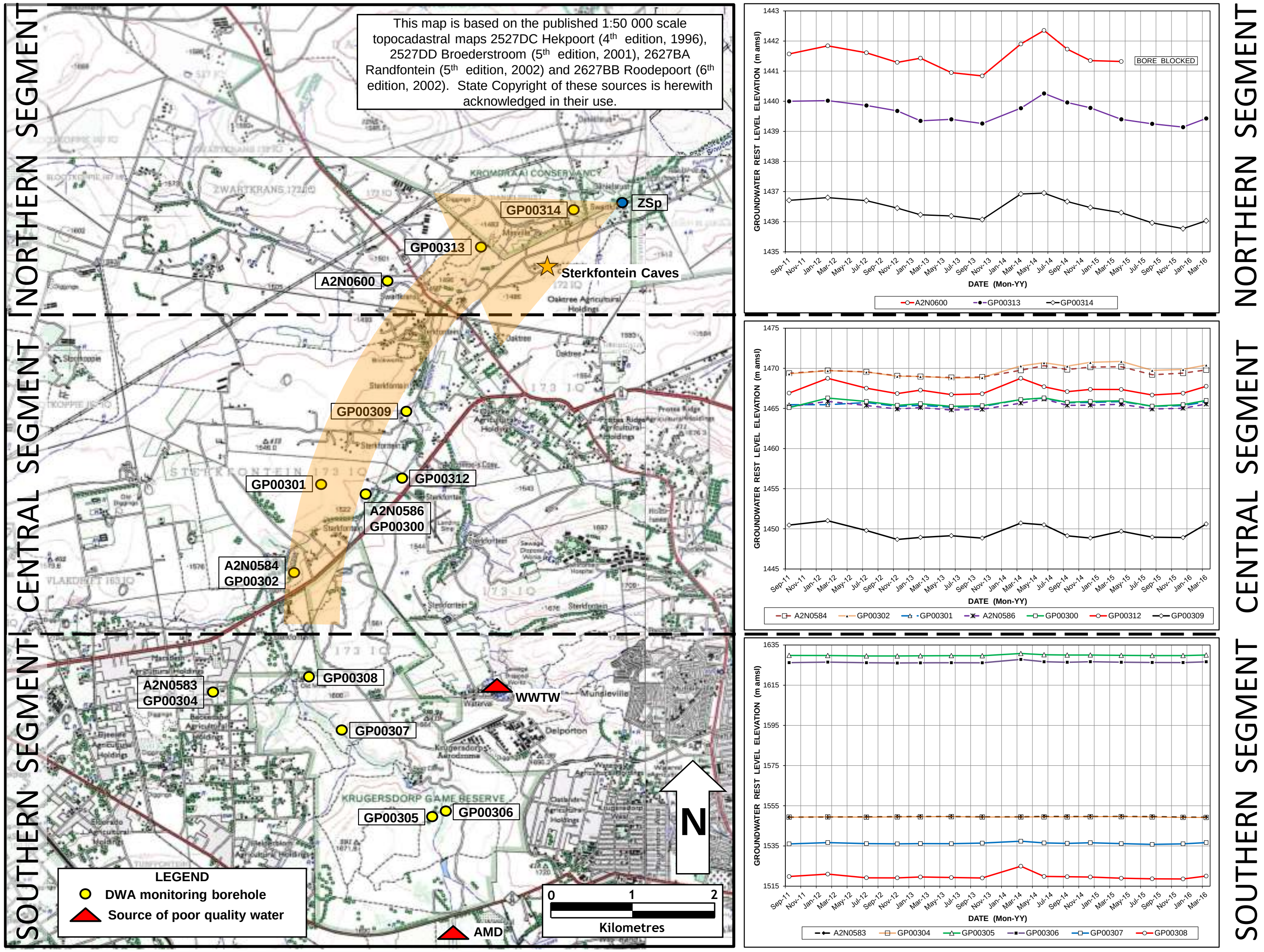


Figure 29 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); arrow denotes principal direction of impacted groundwater flow

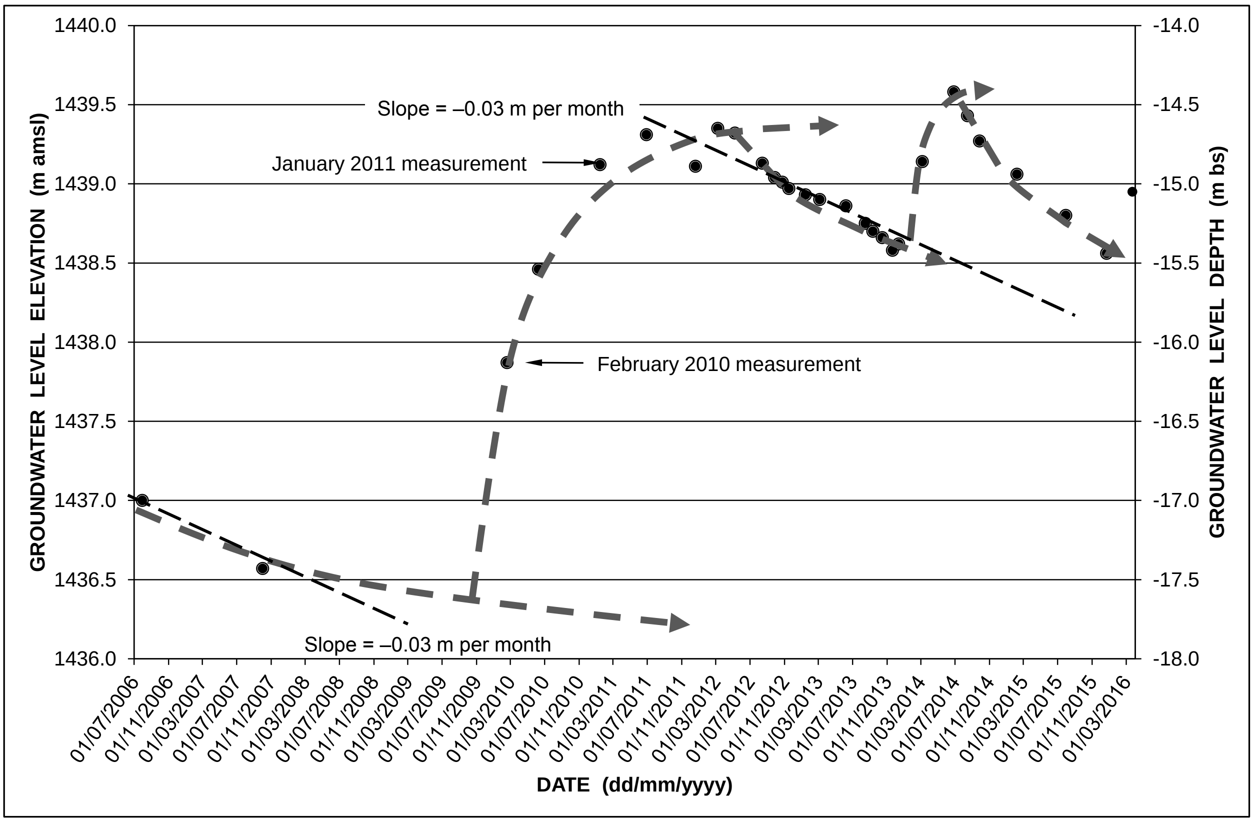


Figure 30 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the cave lake water level in Sterkfontein Caves

5.2.2 Mine Water Impact

There has been little change in this aspect in the reporting period compared to the previous period (Hobbs, 2015b). 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 31** and **Figure 32** 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 31** 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 32** 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 31**), 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 33**. The latter 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 toward the Zwartkrans Spring.

The Zwartkrans Spring water chemistry continues to show an increase in the sulfate concentration, the December 2015 value of 8.52 meq/L (409 mg/L) representing an increase of 19% over the 7.16 meq/L (344 mg/L) of February 2015. This is in keeping with the rising trend observed in regard electrical conductivity (**Figure 32**).

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 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 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 is likely to produce a runoff of ~33 Mm^3 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 (9330 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 in response to the late summer rains.

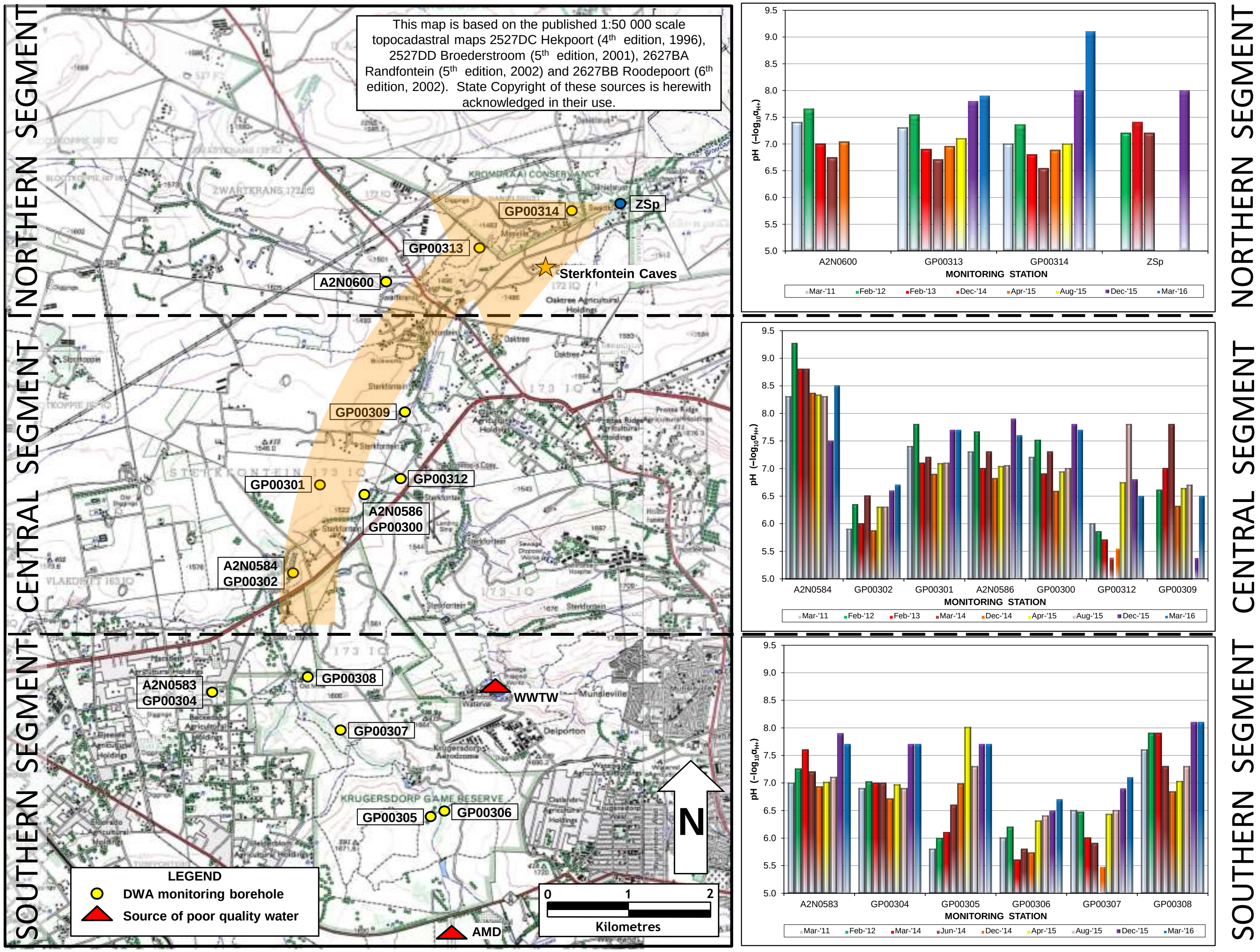

This map is based on the published 1:50 000 scale topocadastral maps 2527DC Hekpoort (4th edition, 1996), 2527DD Broederstroom (5th edition, 2001), 2627BA Randfontein (5th edition, 2002) and 2627BB Roodepoort (6th edition, 2002). State Copyright of these sources is herewith acknowledged in their use.

Figure 31 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow

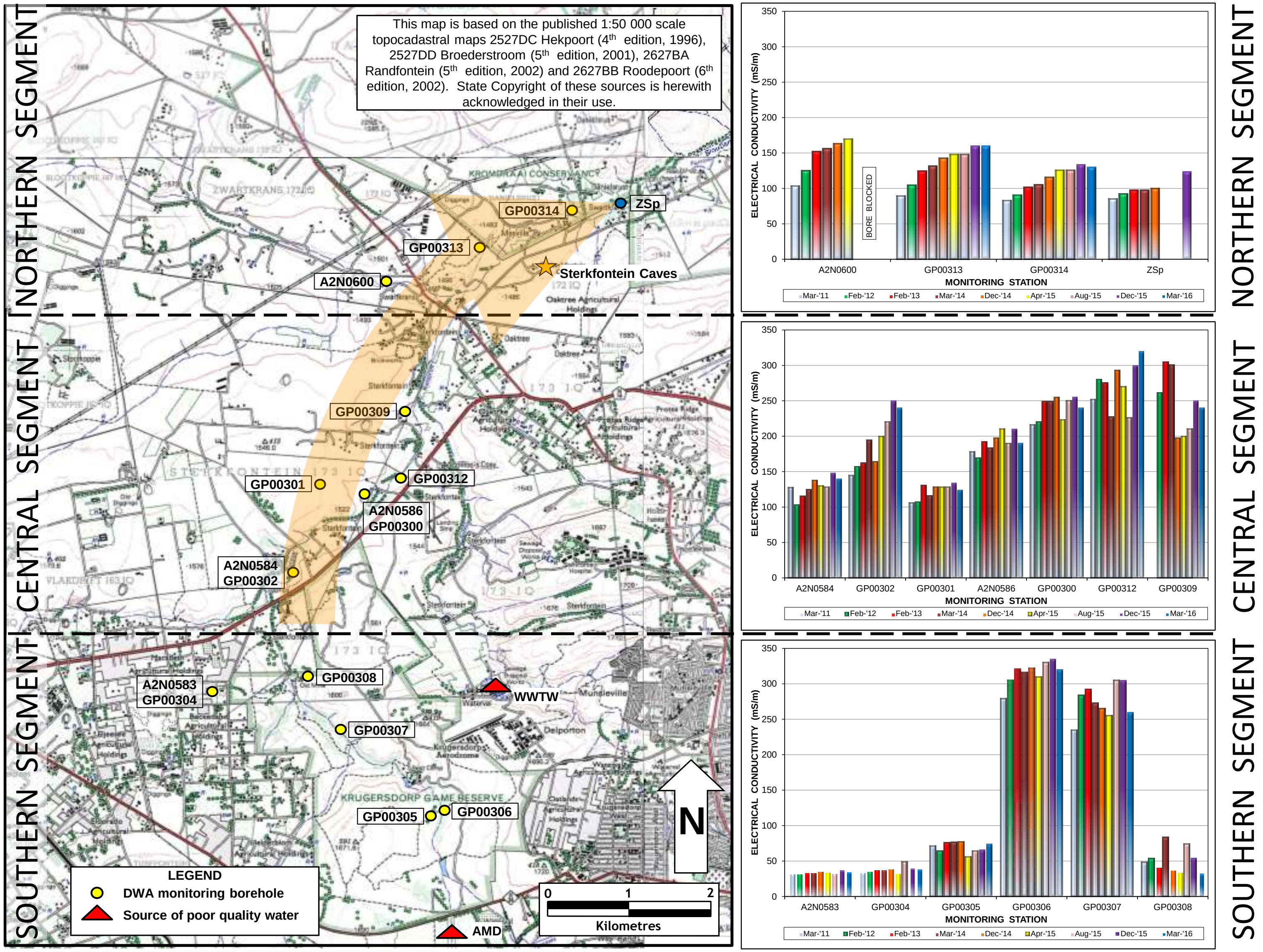


Figure 32 Distribution of DWS monitoring boreholes with EC pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow

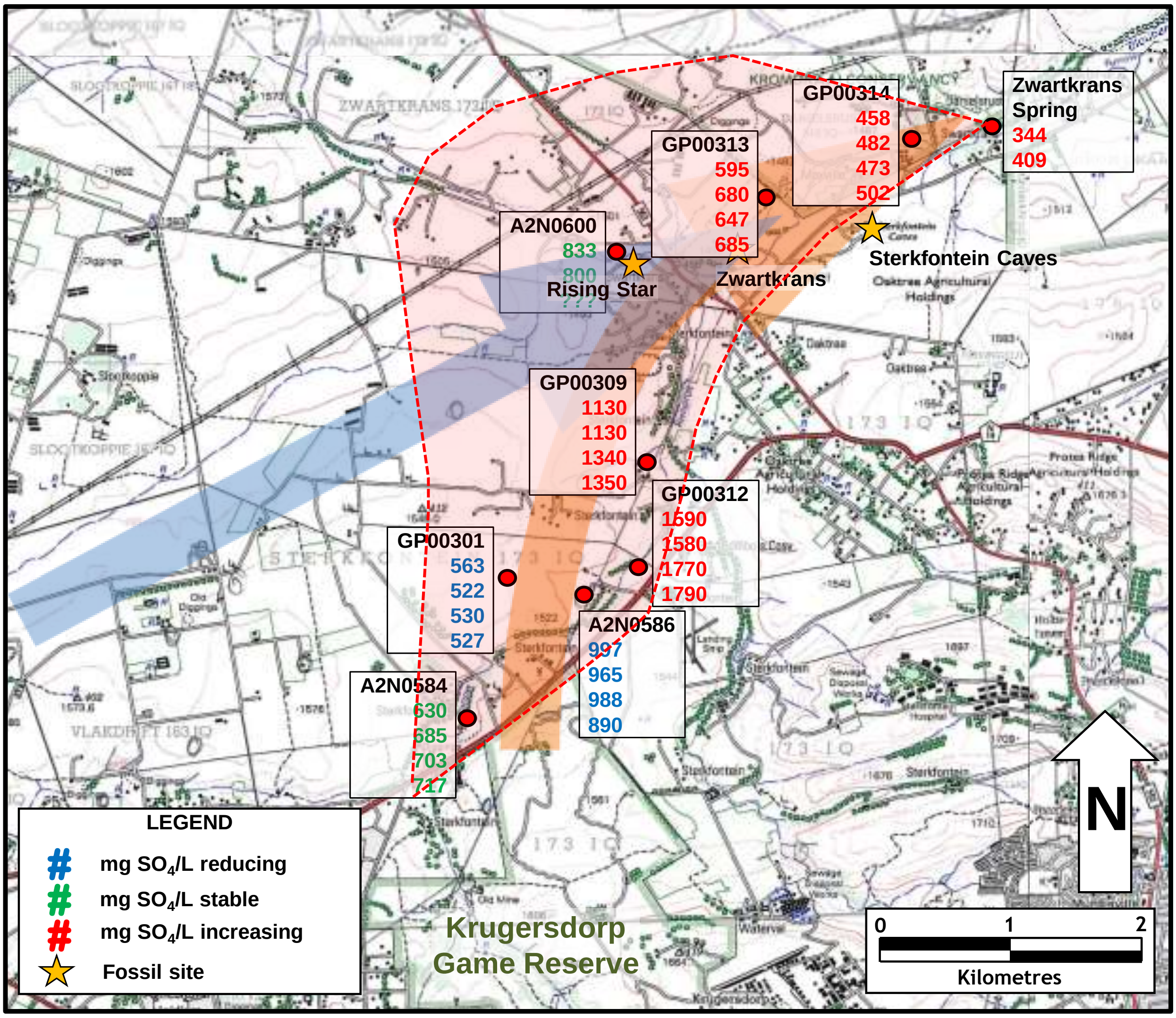


Figure 33 Distribution of SO_4 concentrations in groundwater of the Zwartkrans Compartment in April 2015, August 2015, December 2015 and March 2016, also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow), the postulated footprint (shaded area) of a mine water impact in the karst aquifer, and SO_4 trend INCREASING (red text), STABLE (green text) or REDUCING (blue text)

- 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 ~2000 mg SO_4/L. These circumstances are reflected in the continued rise of the SO_4 concentration in the Zwartkrans Spring water.

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.

ACKNOWLEDGEMENTS

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7 REFERENCES

Berger, L.R., Hawks, J., De Ruiter, D.J., Churchill, S.E., Schmid, P., Delezene, L.K., Kivell, T.L., Garvin, H.M., Williams, S.A., DeSilva, J.M., Skinner, M.M., Musiba, C.M., Cameron, N., Holliday, T.W., Harcourt-Smith, W., Ackermann, R.R., Bastir, M., Bogin, B., Bolter, D., Brophy, J., Cofran, Z.D., Congdon, K.A., Deane, A.S., Dembo, M., Drapeau, M., Elliott, M.C., Feuerriegel, E.M., Garcia-Martinez, D., Green, D.J., Gurtov, A., Irish, J.D., Kruger, A., Laird, M.F., Marchi, D., Meyer, M.R., Nalla, S., Negash, E.W., Orr, C.M., Radovcic, D., Schroeder, L., Scott, J.E., Throckmorton, Z, Tocheri, M.W., VanSickle, C., Walker, C.S., Wei, P., Zipfel, B. 2015. *Homo naledi, a new species of the genus Homo from the Dinaledi Chamber, South Africa.* eLife. 4:e09560. 35 pp.

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.

Dirks, P.H.G.M., Berger, L.R., Roberts, E.M., Kramers, J.D., Hawks, J., Randolph-Quinney, P.S., Elliott, M., Musiba, C.M., Churchill, S.E., de Ruiter, D.J., Schmid, P., Backwell, L.R., Belyanin, G.A., Boshoff, P., Hunter, K.L., Feuerriegel, E.M., Gurtov, A., du G Harrison, J., Hunter, R., Kruger, A., Morris, H., Makhubela, T.V., Peixotto, B., Tucker, S. 2015. *Geological and taphonomic evidence for deliberate body disposal by the primitive hominin species Homo naledi from the Dinaledi Chamber, South Africa.* eLife 4:e09651. 37 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.

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.

PJ Hobbs.

PJ Hobbs (Pr.Sci.Nat.)
SENIOR RESEARCH HYDROGEOLOGIST

ANNEXURE A

QUANTIFICATION OF STREAM FLOW LOSS RATE IN THE RIET SPRUIT BETWEEN STATIONS F11S12 AND MRd (from Hobbs, 2015b)

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 (from Hobbs 2015b)

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 CHEMISTRY OF SURFACE WATER IN THE BLOUBANK SPRUIT CATCHMENT

Variable/analyte	**Unit**	**Sampling Station**		
		Tweelopie Spruit (Site A in Fig. 27)	**Riet Spruit (Site B in Fig. 27)**	**Bloubank Spruit (Site C in Fig. 27)**
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