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 2016 TO MARCH 2017

AUTHOR

P.J. Hobbs
(Pr.Sci.Nat.)

DATE

MARCH 2017

REPORT No.

CSIR/NRE/WR/ER/2017/0008/A

GWDMS No. & LIBRARY

265783 in PTA GENERAL

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 10th such report since 2012. It covers the period April 2016 to March 2017 and, as such, represents a full-term monitoring report and deliverable in the MAs financial year 2016–'17, the timeframe in which annual contracts are managed.

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 mine water (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 current outcome is summarised in the following observations.

- The 2016–'17 summer season experienced a comparatively high rainfall of ~864 mm, but this has yet to translate into an abnormal catchment discharge as at January 2017.

- The 2016–'17 hydrological year is likely to produce a smaller runoff than the ~34 Mm^3 of the previous hydrological year. The recent discharge pattern at gauging station A2H049 is therefore likely to continue, i.e. with Quaternary catchment A21D discharging at well below the median and mean of 42.7 and 44.5 Mm^3/a, respectively, recorded in the last seven hydrological years since 2009–'10.

- The return to 'more normal' pre-2010 discharge water quality in the downstream receiving hydrologic environment observed previously 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 ~1750 mg/L in mine water impacted surface water entering the karst environment of the Zwartkrans Compartment.

- Faecal coliform (*E. coli*) bacteria counts continue to reflect unacceptably high levels (>2500 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. By comparison, *E. coli* levels in the mine water impacted surface water amount to ~1300 MPN/100 mL.

- 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 high summer rainfall. This is also reflected in the lake water level in Sterkfontein Cave, which again has approached its maximum elevation of ~1439.5 m amsl.

- Groundwater in the south-western portion of the property (the Zwartkrans Compartment) also 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, albeit it at a gradually reducing rate, of the SO_4 concentration in the Zwartkrans Spring water, where a concentration of 462 mg SO_4/L was recorded in February 2017.

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

CONTENTS

Page

FIGURES

TABLES

ANNEXURES

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; 2016a; 2016b). This document represents the tenth such report, which covers the full-term period April 2016 to March 2017.

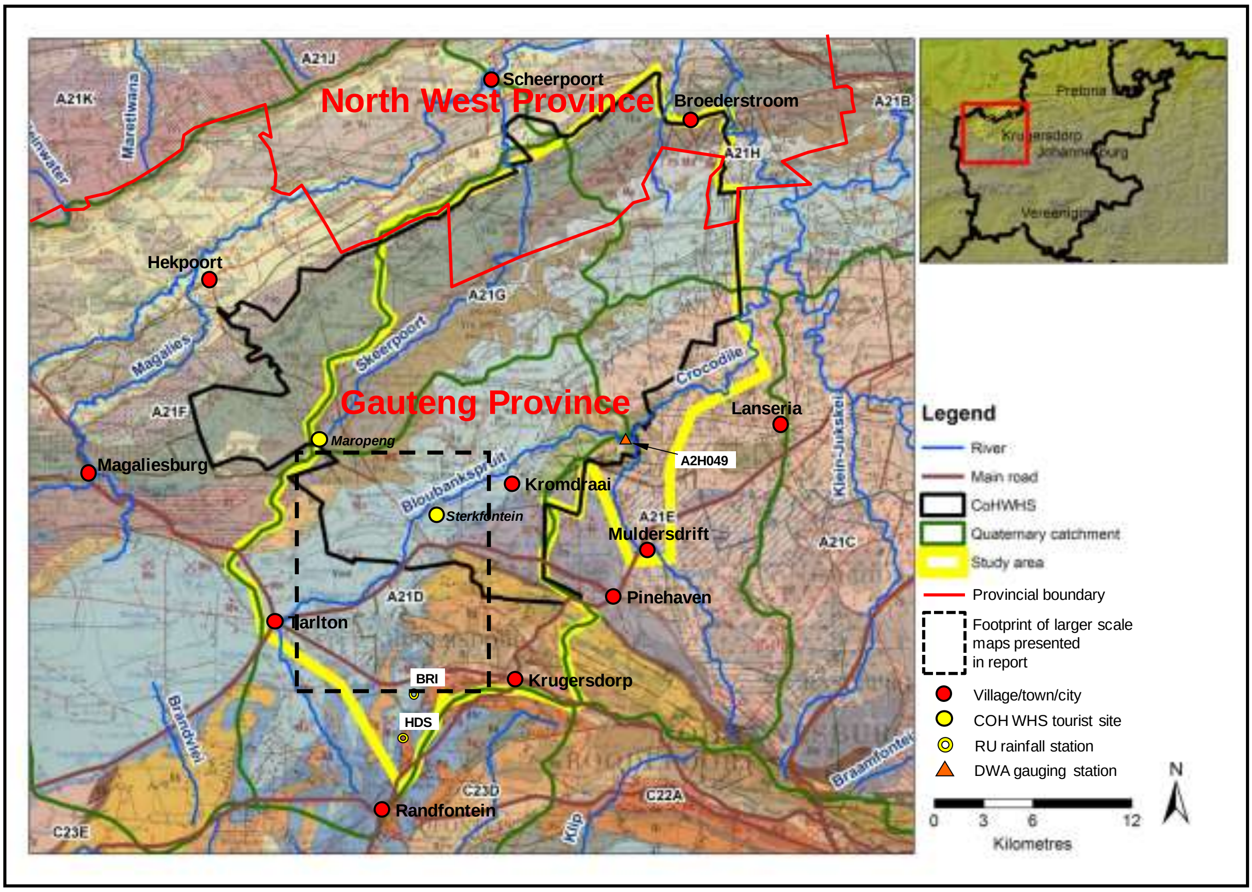


Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

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 completion of a State of Conservation (SoC) report (DEA, 2016) submitted to UNESCOs World Heritage Centre, for examination by the World Heritage Committee at its 41st session in 2017.

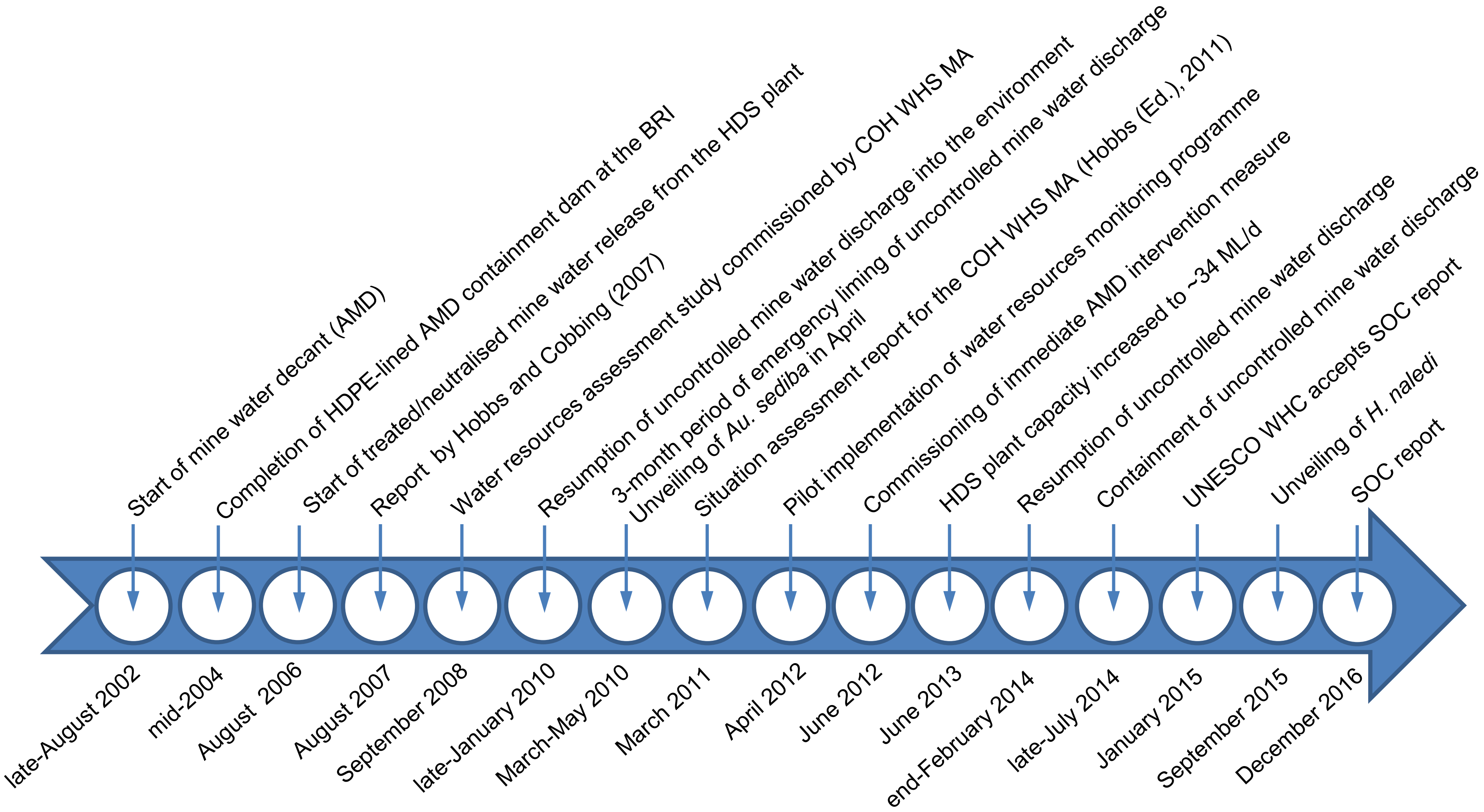


Figure 2 Updated timeline of events relevant to this report

3 RAINFALL

The monthly precipitation record for the period October 2008 to March 2017 at the Sibanye Gold (SG) rainfall station HDS and at the Sterkfontein Cave station SC (**Figure 3**) reveals the following:

- the very wet 2016–'17 mid-summer period — in November 2016 to February 2017, 748 mm was recorded at the HDS station, representing ~87% of the total 2016–'17 wet season rainfall of 864 mm;
- at Sterkfontein Cave, 564 mm was recorded in the period November 2016 to February 2017 — this is associated with the 3rd wettest summer (590 mm) in the past seven years after 2013−'14 (760 mm) and 2010−'11 (696 mm).

If the remaining 6 "dry" months of the 2016–'17 hydrological year remain dry, then the wet season rainfall will represent ~108% of the mean annual precipitation of ~800 mm in the past 9 years.

These circumstances are also reflected in **Figure 4**. Also shown in **Figure 3** and **Figure 4** are the contemporaneous rainfall data recorded by the DWS cumulative gauging instrument located at Sterkfontein Cave. The common monthly rainfall record (n = 81) for the HDS and Sterkfontein Cave stations indicates a good correlation ($R^2 = 0.88$, $p < 0.01$) (**Figure 5**), once again confirming the 10 to 15% lower annual rainfall north of the subcontinental divide compared to that on the watershed.

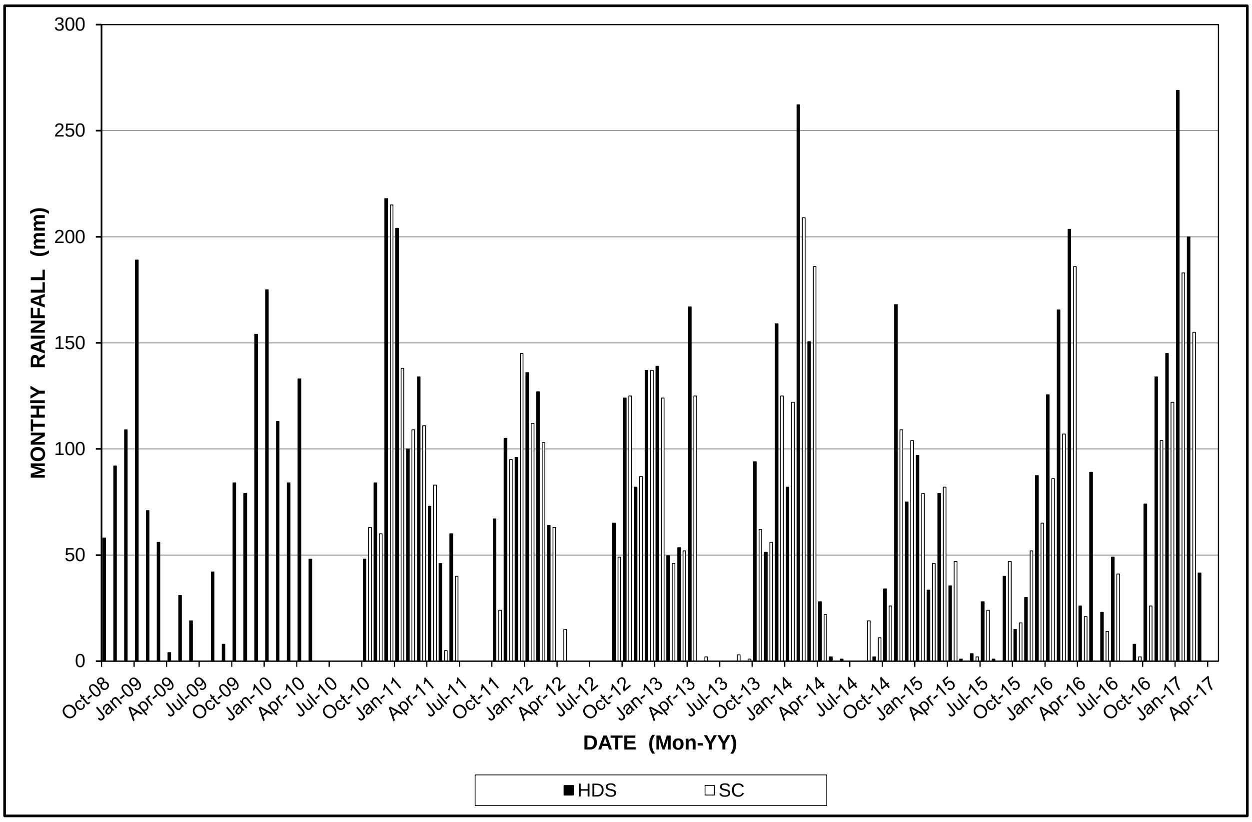


Figure 3 Monthly precipitation at the SG rainfall monitoring station HDS in the mine area from October 2008 to March 2017, and the available contemporaneous record for the Sterkfontein Cave station from June 2010 to February 2017

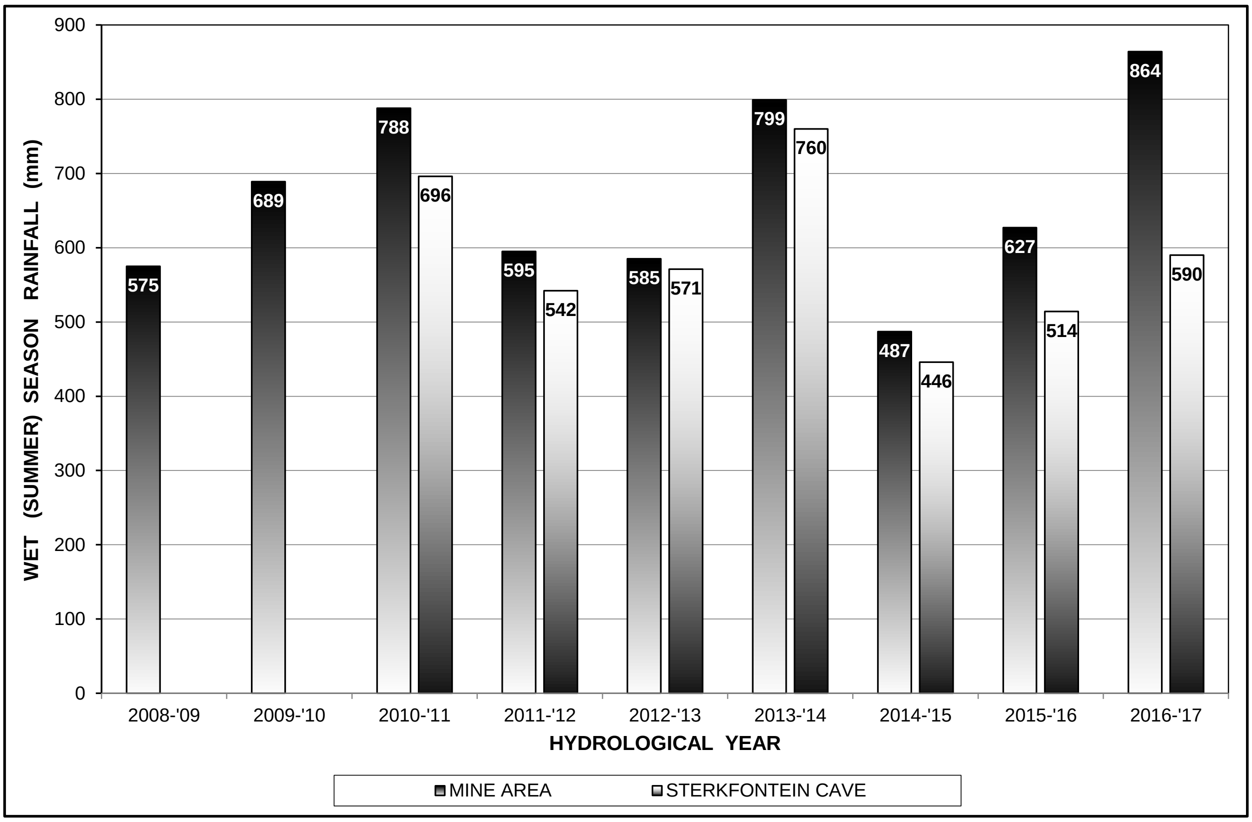


Figure 4 Total wet season (summer) rainfall in the mine area (HDS station) in the past nine hydrological years, also showing the comparison with that for the available contemporaneous Sterkfontein Cave record

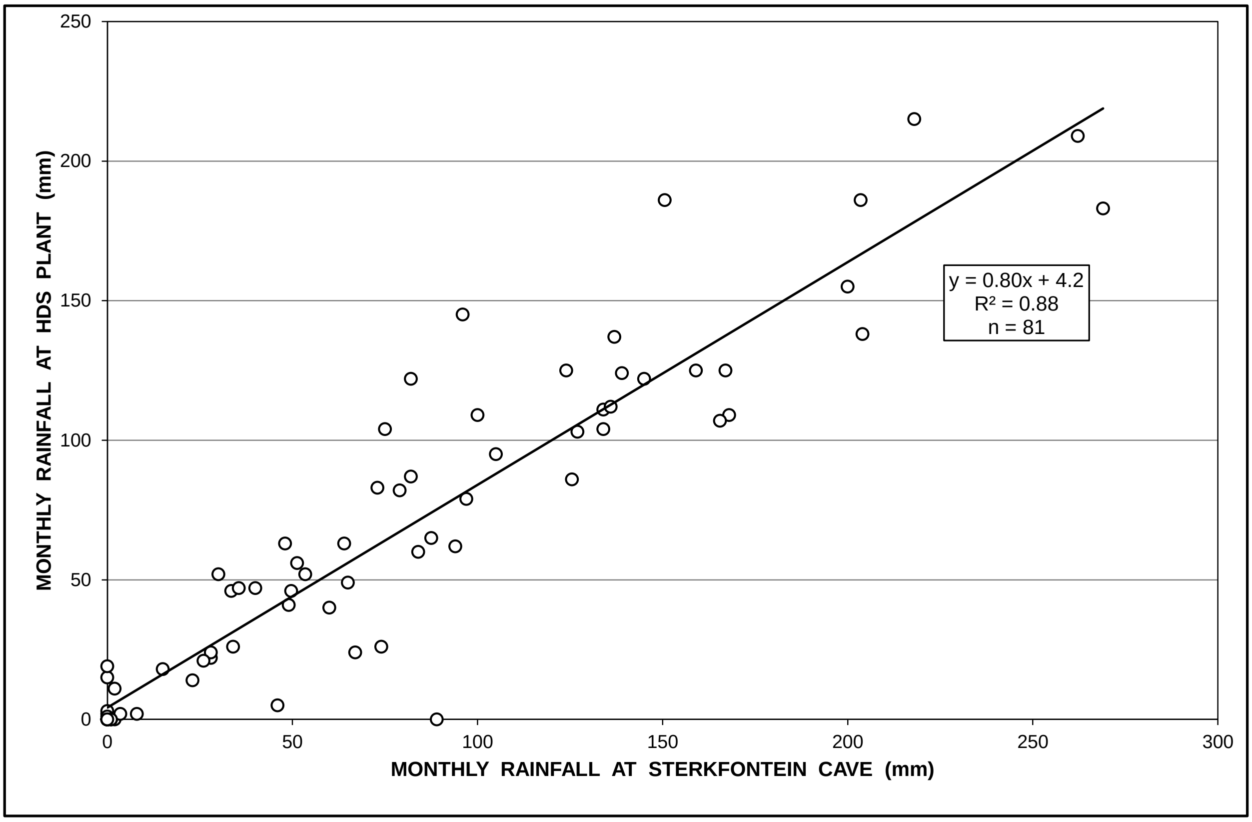


Figure 5 Correlation of monthly rainfall at Sterkfontein Cave with that at the HDS plant in the mine area

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 January 2017

Variable	**Month**											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	43	43	44	44	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	0.789	0.860	1.043	1.097	0.899	1.058	1.185	0.992	0.960	0.959	0.918	0.802
Mean	1.872	1.886	2.274	2.696	2.645	3.009	2.403	2.270	2.083	2.060	1.936	1.804
Median	1.676	1.743	2.066	2.419	2.087	2.512	1.986	1.888	1.772	1.668	1.609	1.561
95%ile	3.824	2.952	4.501	5.355	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	0.920	0.830	1.093	1.914	1.915	2.228	1.297	1.198	0.978	0.939	0.871	0.883
CoV (%)	49.1	44.0	48.1	71.0	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

Latest available data as at 27 March 2017 is complete to January 2017

The discharge per hydrological year shown in **Figure 6** indicates that the 2015–’16 hydrological year produced a modest discharge 34.3 Mm^3. Further, that the 2016–’17 hydrological year is likely to produce an even smaller discharge. The recent discharge pattern at station A2H049 as discussed in Hobbs (2016b) is therefore likely to continue, i.e. with Quaternary catchment A21D discharging at well below the median and mean of 42.7 and 44.5 Mm^3/a, respectively, recorded in the last seven hydrological years since 2009–’10.

The instantaneous monthly flow pattern at station A2H049 for the complete record period October 1972 to January 2017 is shown in **Figure 7**. The record reveals a consistent instantaneous low flow, or base discharge, in the order of 0.8 to 1 m^3/s since 2010. This is driven in roughly equal proportions by autogenic sources in the form of high-yielding karst springs, and allogenic sources in the form of treated/neutralised mine water from the Western Basin with a subordinate contribution of municipal wastewater effluent from the Percy Stewart Wastewater Treatment Works.

Although the comparatively constant base discharge maintained since October 2014 appears to testify to the subdued precipitation experienced in the region in the past few years, the comparatively wet 2016–’17 summer season (**Section 3**) shows no effect on the discharge regime at station A2H049 as at January 2017. It is probable that the high rainfall experienced on the subcontinental divide through the Western Basin in January (269 mm) and February (200 mm) of 2017, will only manifest an impact on catchment discharge in the late summer (February, March and possibly April) of 2017.

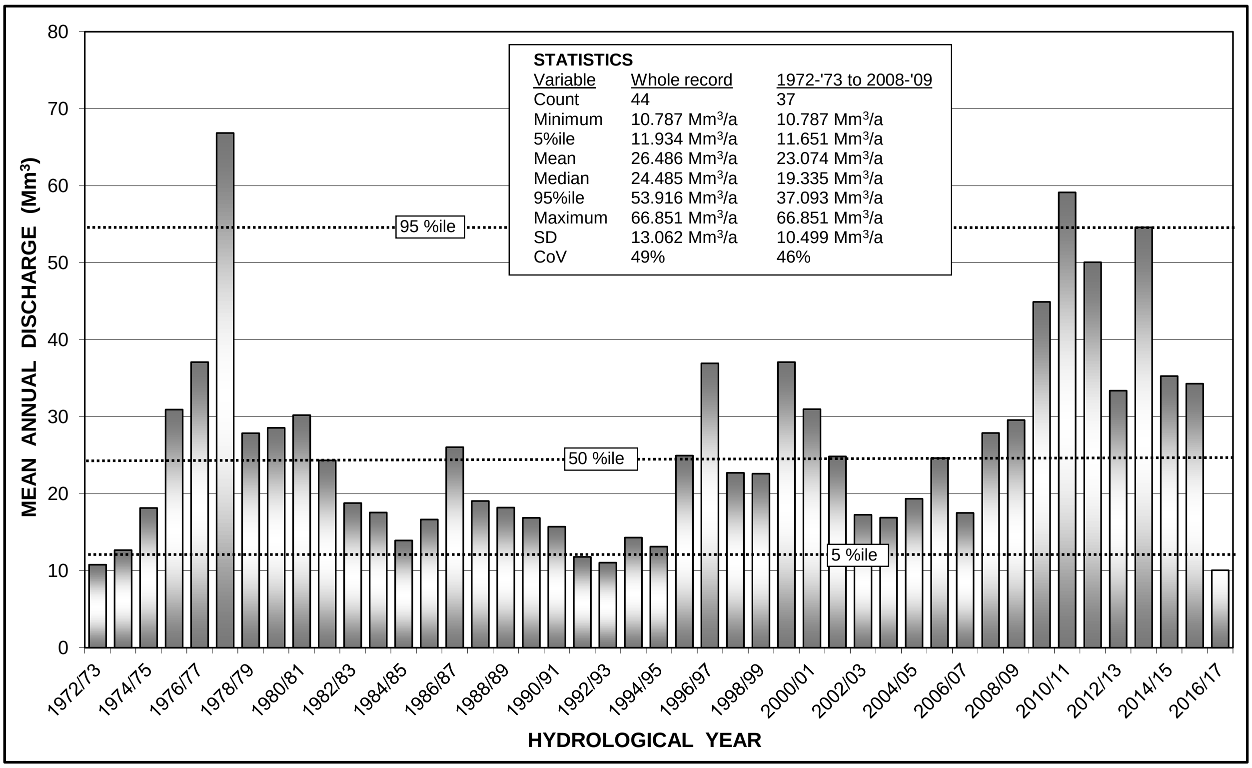


Figure 6 Graph of Bloubank Spruit annual discharge gauged at station A2H049 since October 1972; note hydrological year 2016/17 is incomplete, as data only extends to January 2017

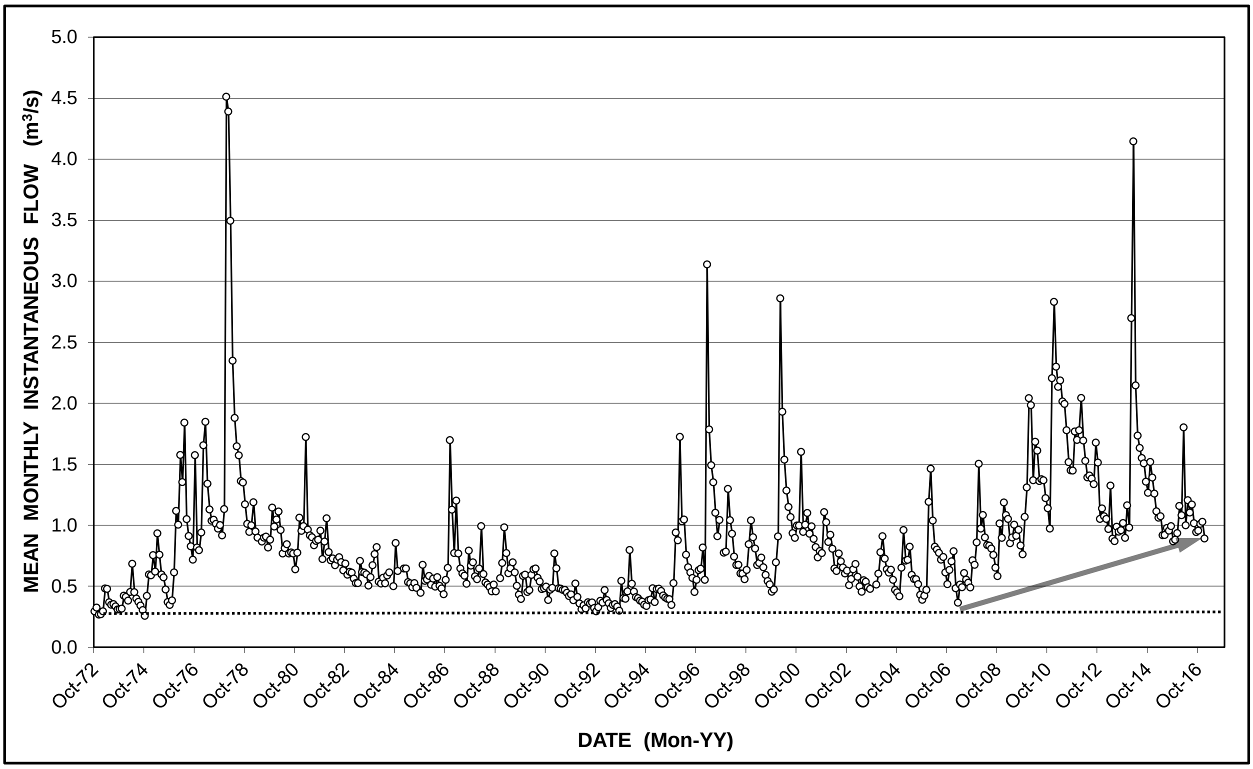
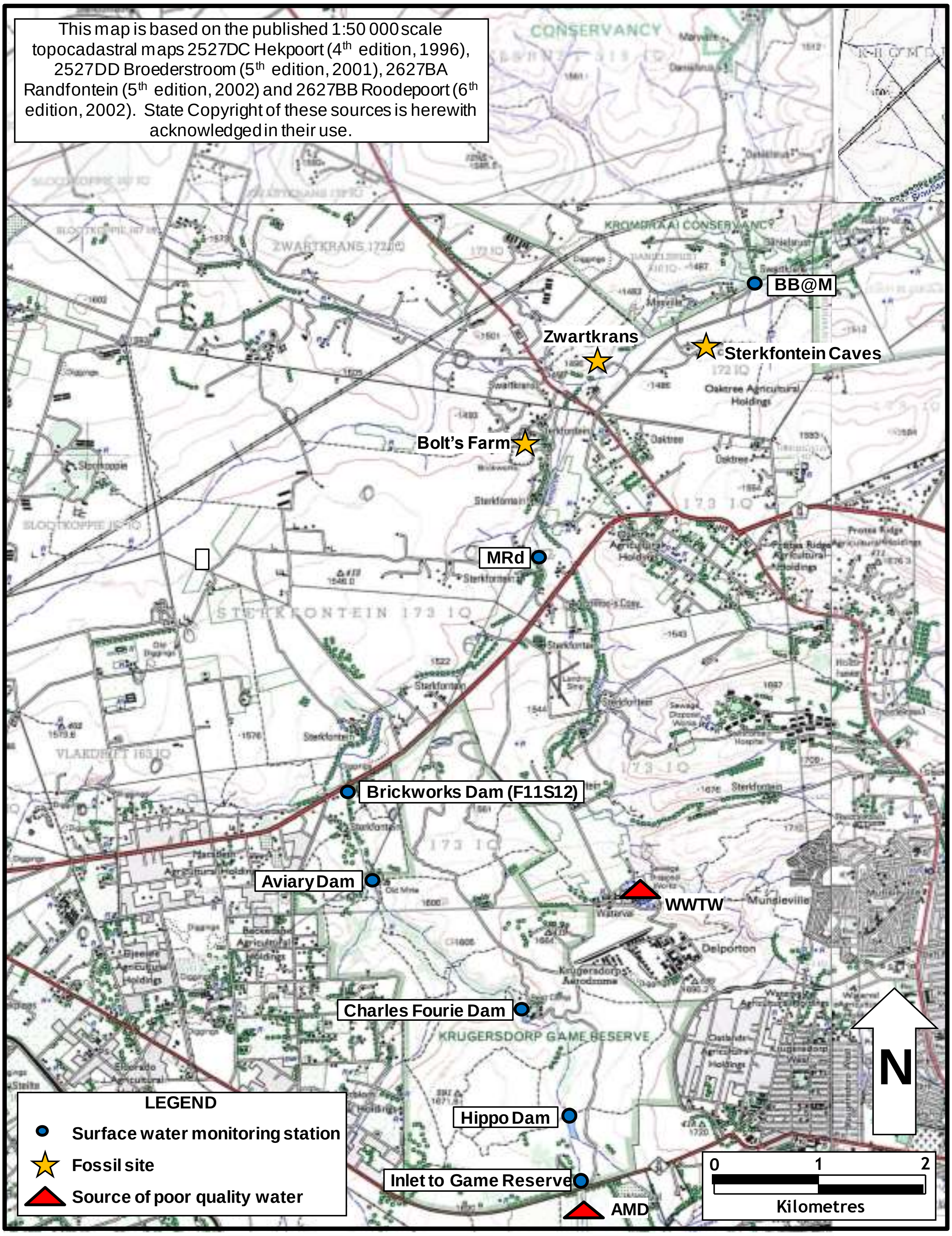


Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to January 2017

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), 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.

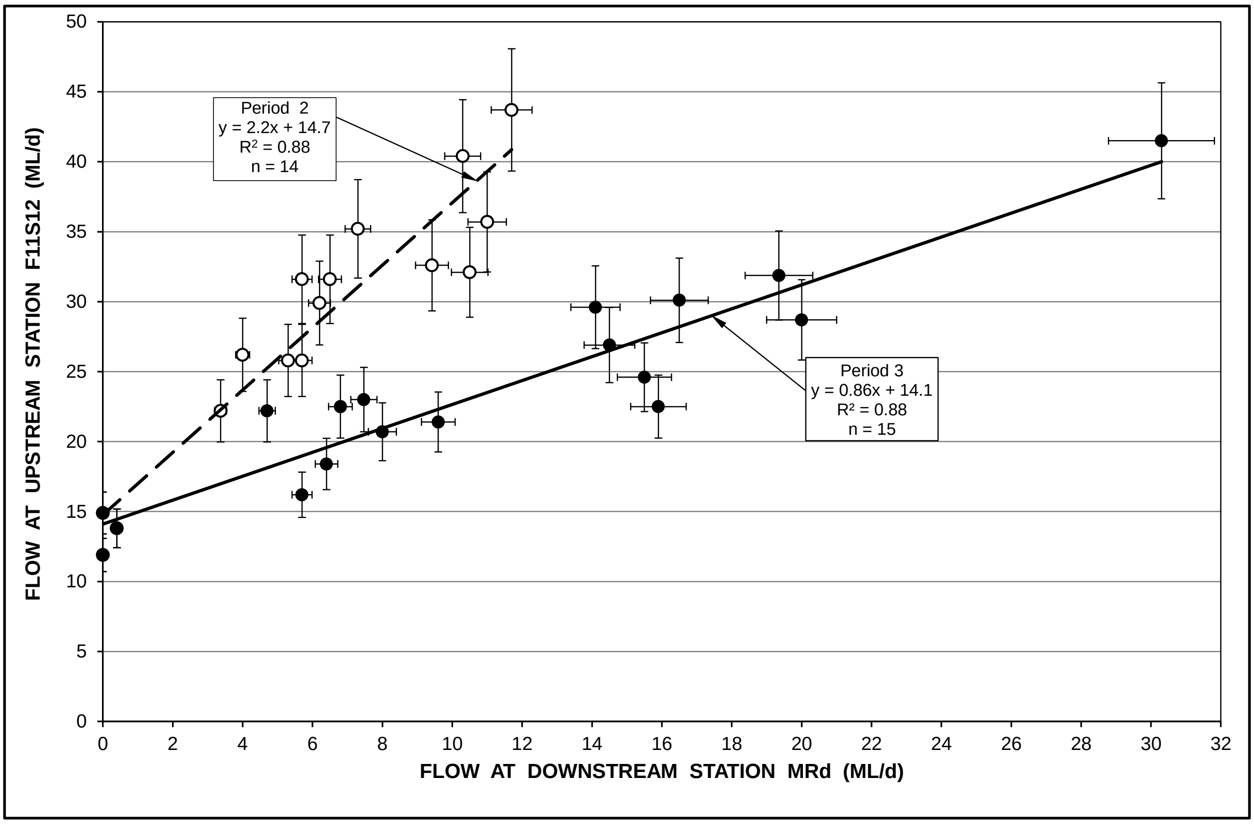


Figure 9 Correlation of streamflow at stations F11S12 and MRd in the Riet Spruit valley, with vertical error bars denoting ±10% at F11S12 and horizontal bars ±5% at MRd

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. More significant 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.

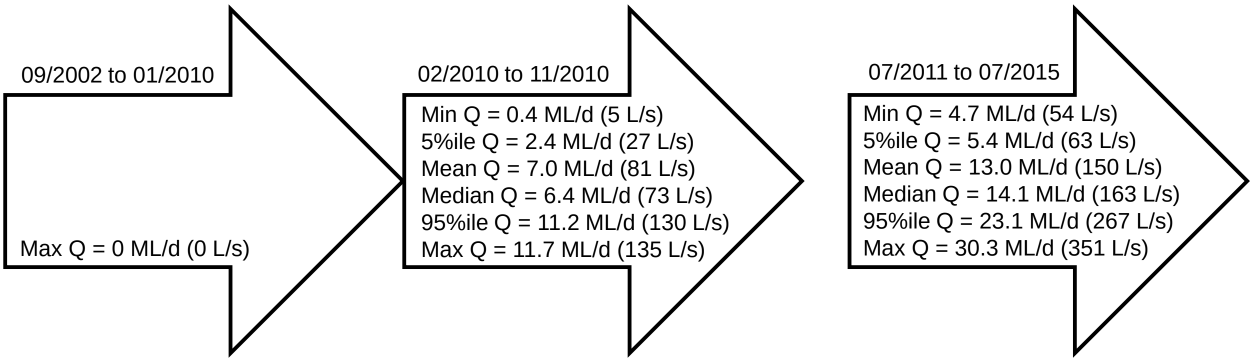


Figure 10 Episodic progression of surface flow measured at station MRd since the start of mine water decant

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 of 5.8 to 6.4 for the most recent portion of the F11S12 record (**Figure 11**). This is attributed to hydrolysis in the stream reach between the Hippo Dam and station F11S12 under circumstances where iron-rich raw mine water contributed moderately to the total mine water discharge comprising mainly treated/neutralised mine water. These circumstances in turn are attributed to the comparatively wet 2016–’17 summer season (**Section 3**). Manganese (**Figure 15**) is the only other of the graphed variables that shows a distinct excursion in the most recent 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 again only been necessary to update the information for period D–. The salient differences between the data sets previously described by Hobbs (2016b) remain unaffected by the updated record, and are therefore not repeated here.

---

[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.

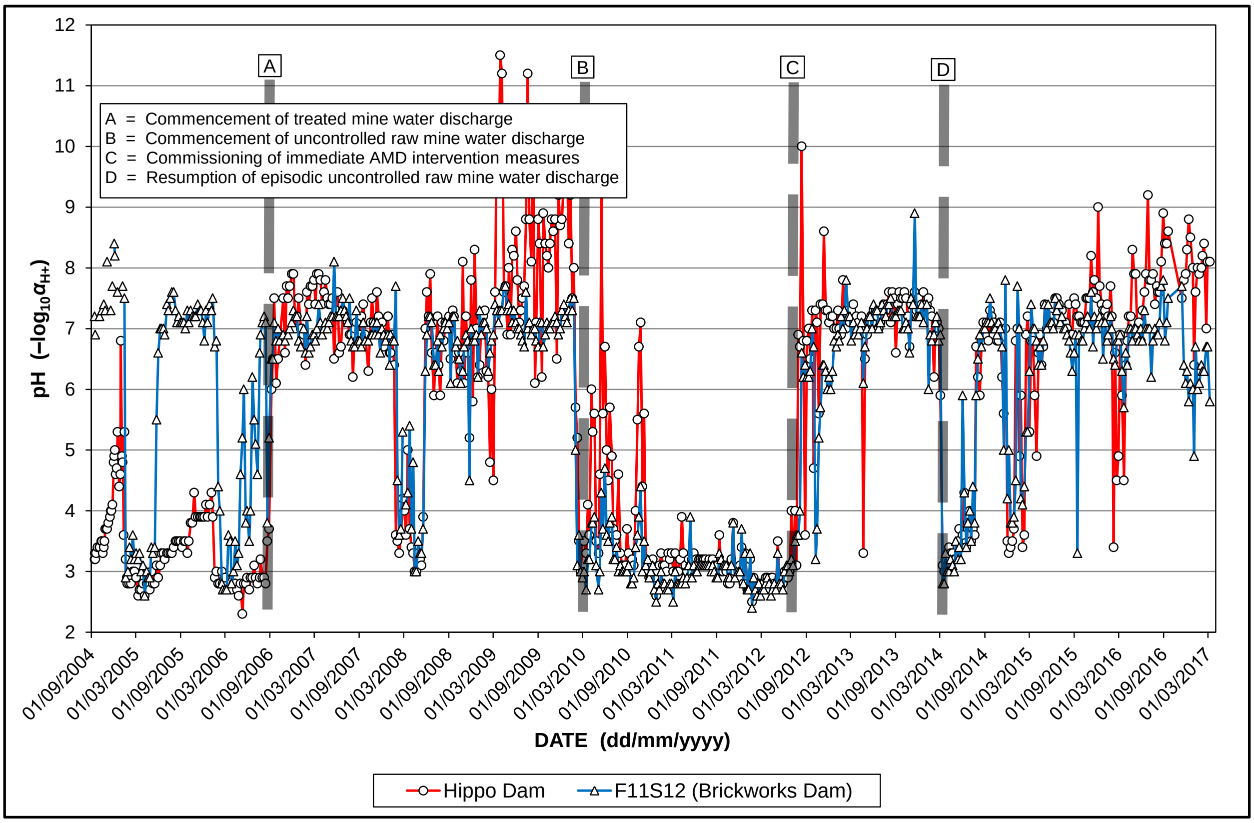


Figure 11 Pattern of pH of Tweelopie Spruit surface water in the period September 2004 to March 2017

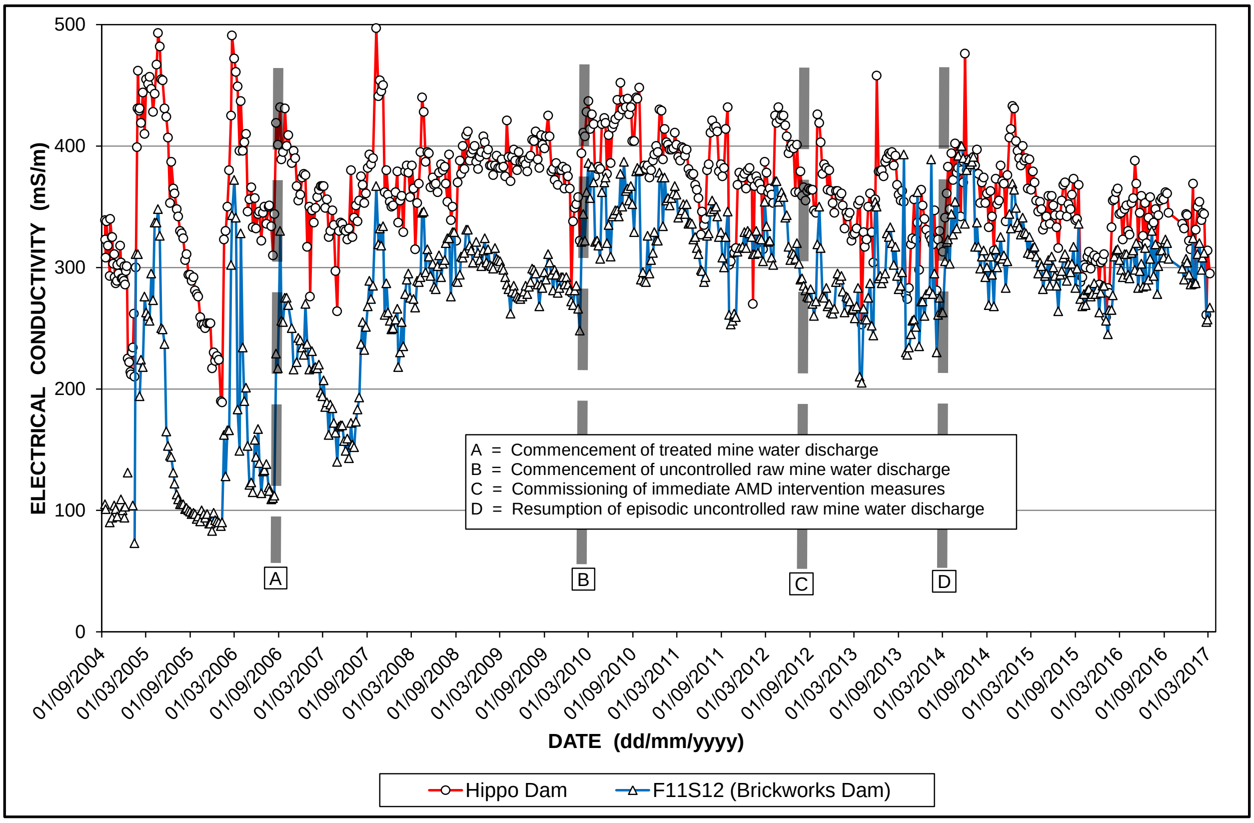


Figure 12 Pattern of electrical conductivity of Tweelopie Spruit surface water in the period September 2004 to March 2017

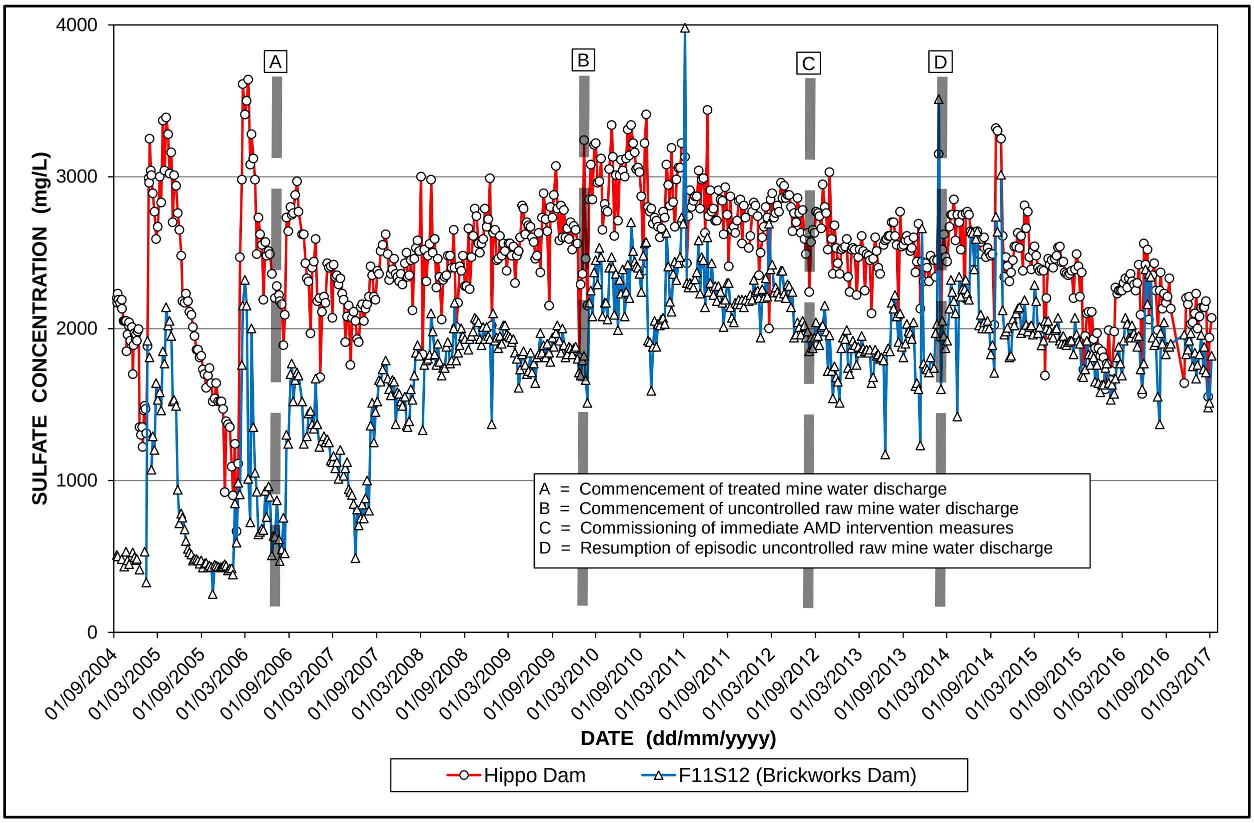


Figure 13 Pattern of sulfate in Tweelopie Spruit surface water in the period September 2004 to March 2017

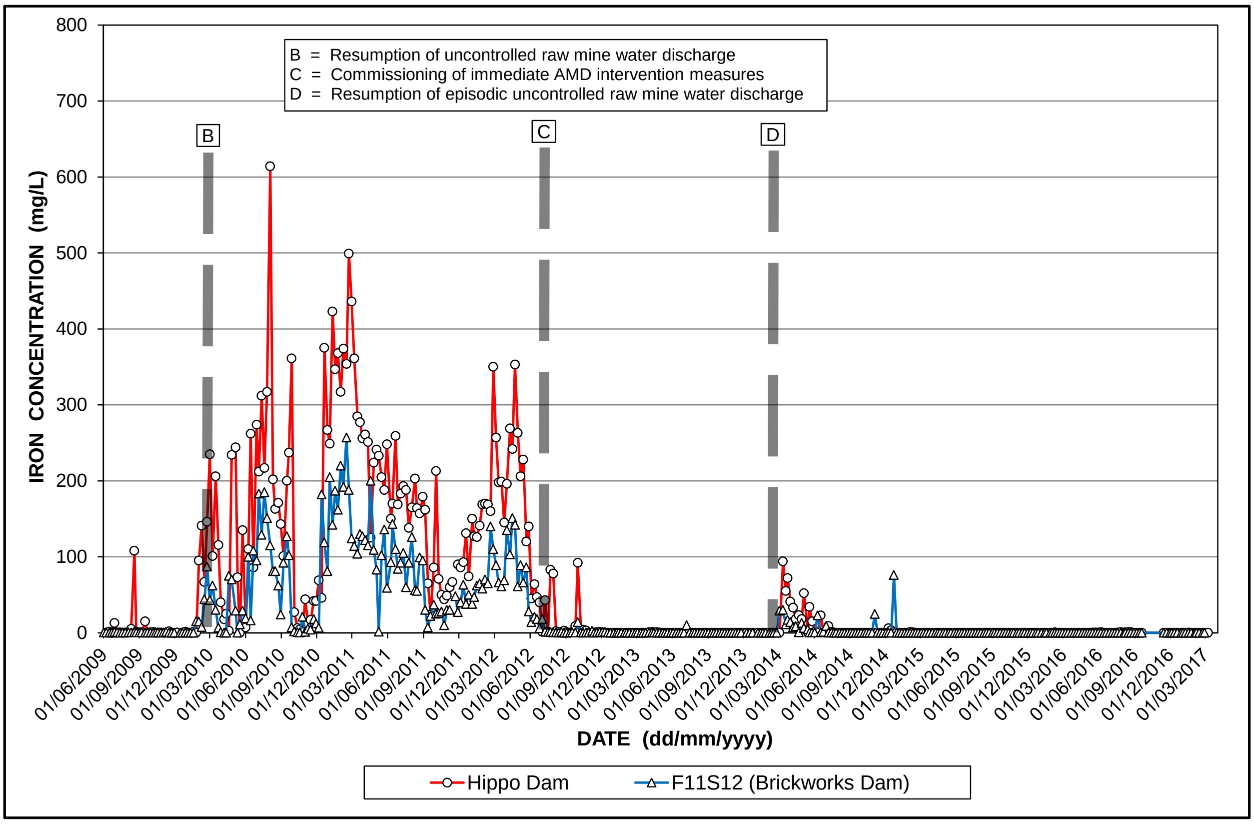


Figure 14 Pattern of iron in Tweelopie Spruit surface water in the period June 2009 to March 2017

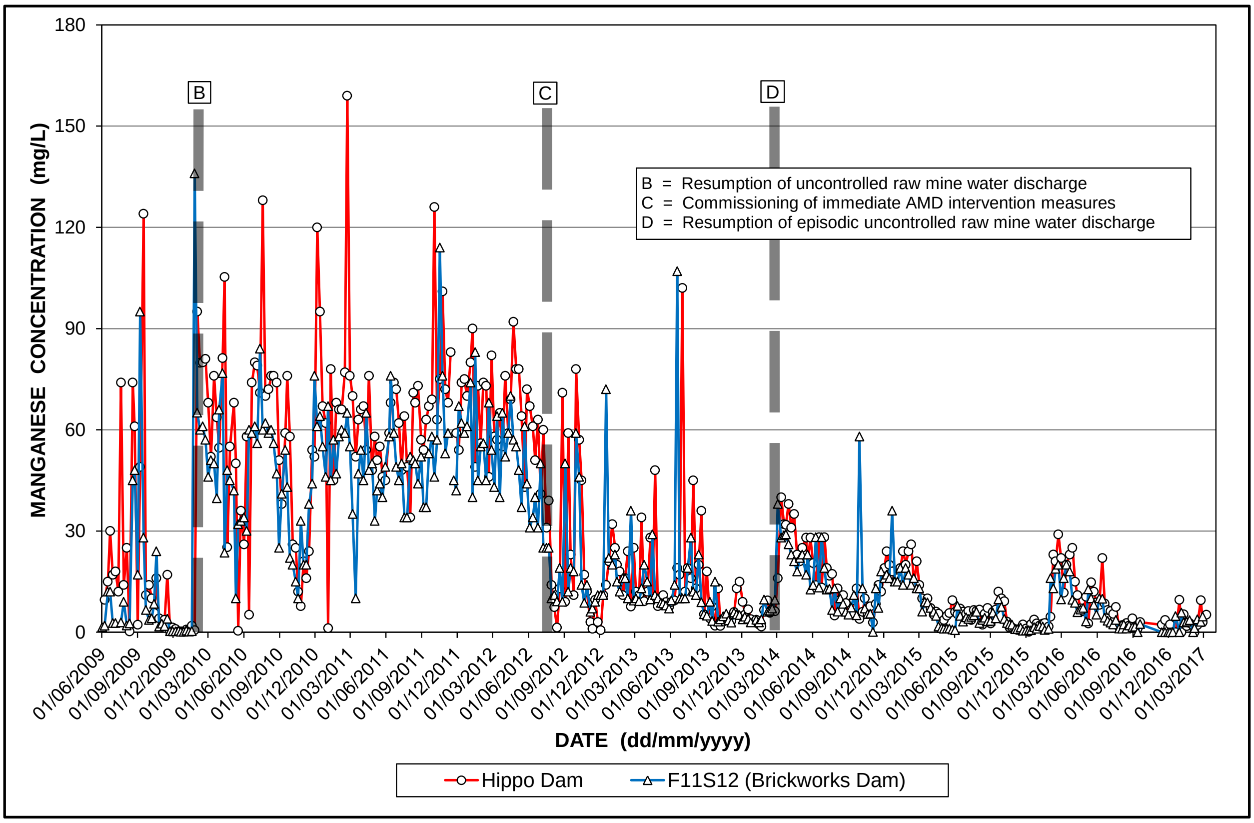


Figure 15 Pattern of manganese in Tweelopie Spruit surface water in the period June 2009 to March 2017

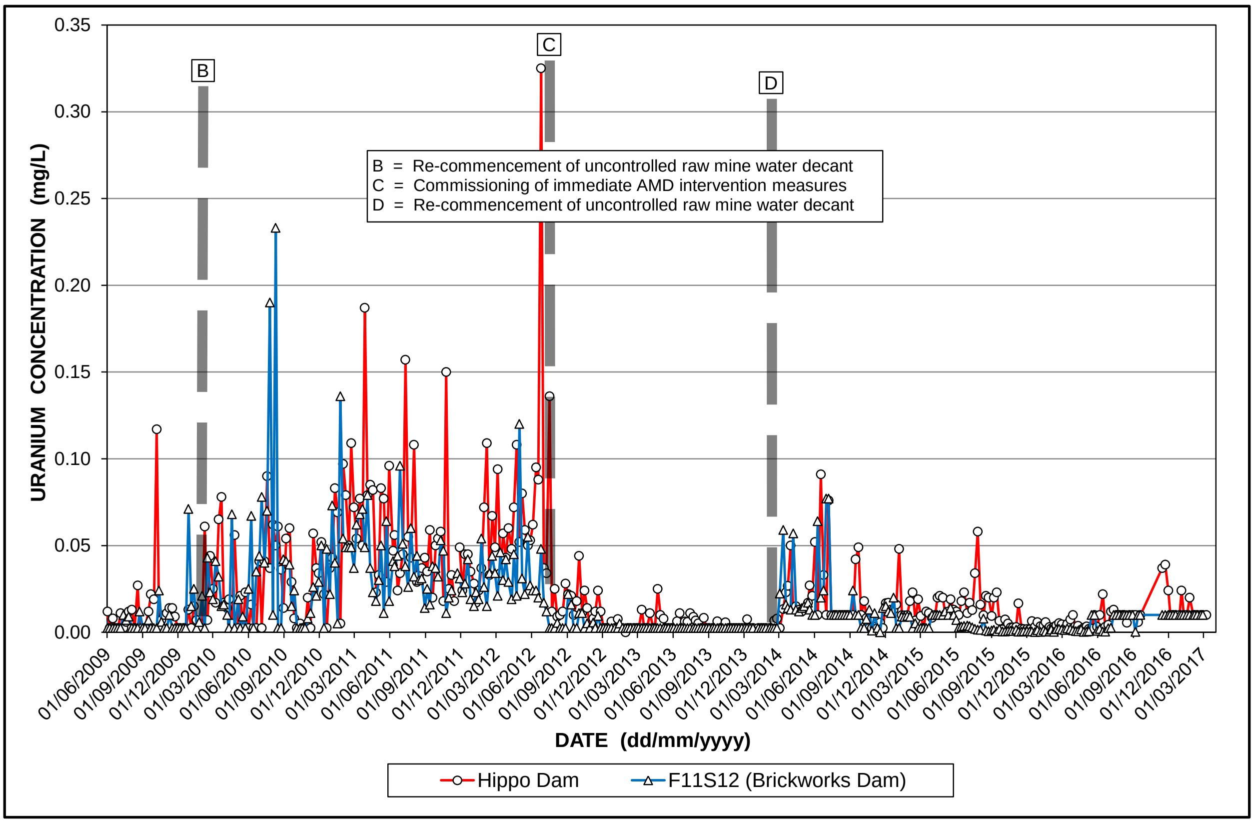


Figure 16 Pattern of uranium in Tweelopie Spruit surface water in the period June 2009 to March 2017

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	151	173	128	83	151
	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	7.1	6.9	3.0	7.0	6.8
	95%ile	9.3	5.7	7.6	8.4	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	25.4	14.1	13.7	13.0	21.9
EC (mS/m)	n	175	129	83	151	172	128	83	151
	Mean	374	391	350	350	268	332	281	307
	Median	379	393	354	352	283	330	276	305
	95%ile	426	438	395	399	329	378	350	383
	SD	32	33	34.1	33	48	29	34	30
	CoV (%)	8.5	8.4	9.7	9.5	18.0	8.7	12.2	9.9
SO_4 (mg/L)	n	176	128	82	150	171	128	83	150
	Mean	2 448	2 846	2 520	2 326	1 636	2 264	1 879	1 973
	Median	2 460	2 815	2 525	2 365	1 760	2 240	1 870	1 940
	95%ile	2 828	3 220	2 770	2 756	2 015	2 593	2 148	2 500
	SD	262	226	193	312	349	245	268	294
	CoV (%)	10.7	7.9	7.6	13.4	21.3	10.8	14.3	14.9
Fe (mg/L)	n	33	129	83	147	33	128	82	146
	Mean	4.7	168.4	2.490	3.5	0.3	72.9	0.466	1.9
	Median	0.4	163.0	0.030	0.03	0.2	64.0	0.075	0.02
	95%ile	13.8	365.2	3.090	23.0	0.8	186.3	1.000	12.5
	SD	18.8	116.2	13.146	12.8	0.3	57.7	1.896	8.0
	CoV (%)	399	69	528	367	94	79	407	416
Mn (mg/L)	n	34	129	83	147	33	128	83	143
	Mean	18.1	62.7	16.5	10.8	10.3	50.3	14.4	9.4
	Median	9.8	65.0	11.0	7.2	2.7	50.0	10.0	6.1
	95%ile	74.0	95.0	56.1	28.2	46.2	76.0	45.0	27.8
	SD	27.6	23.5	18.0	9.1	19.4	17.6	15.8	9.0
	CoV (%)	153	38	109	84	188	35	110	96

(1) 09/2006 – 01/2010 (2) 02/2010 – 07/2012 (3) 08/2012 – 02/2014 (4) 03/2014 – 03/2017

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
	n	5%ile	Mean	Median	95%ile	SD	CoV (%)	(2015a)$^{(1)}$
pH ($-\log_{10}\alpha_{H+}$)	1 058	7.4	—	8.2	8.5	0.3	4	5.0–9.7
EC (mS/m)	1 161	51.2	63.4	61.0	96.3	20.6	33	<170
TDS (mg/L)	887	355.3	458.1	450.6	640.2	91.6	20	<1 200
Ca (mg/L)	975	43.7	57.9	54.0	99.7	18.1	31	n.s.
Mg (mg/L)	974	25.3	33.8	32.7	49.2	6.7	20	n.s.
Na (mg/L)	943	10.0	23.4	22.6	38.9	9.0	38	<200
K (mg/L)	950	0.7	2.1	1.9	4.1	1.0	50	n.s.
Cl (mg/L)	981	20.2	32.5	32.4	42.1	6.3	19	<300
SO_4 (mg/L)	974	65.6	108.6	84.8	332.4	77.7	72	<500
HCO_3 (mg/L)	974	143.4	189.4	194.7	219.4	26.2	14	n.s.
NO_3+NO_2 (mg N/L)	1 020	3.027	4.644	4.449	6.855	1.735	37	<11
PO_4 (mg P/L)	1 049	0.005	0.093	0.055	0.315	0.110	118	n.s.
Si (mg/L)	1 052	5.05	5.95	5.94	6.82	0.81	14	n.s.
Fe (mg/L)	130	0.004	0.027	0.014	0.115	0.045	167	<2
Mn (mg/L)	130	0.001	0.102	0.002	0.146	0.608	596	<0.5
Al (mg/L)	125	0.003	0.040	0.010	0.091	0.190	475	<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 SO_4 (**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 arrow) 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 October 2016) as indicated in **Figure 17** (text box).

The long-term monthly trend in the 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 October 2016) exhibits a substantially higher median value of 890 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, but with lower maximum values, i.e. less variability. This is confirmed in **Figure 19** and **Figure 20**, which reflect more recent SO_4**:**TDS ratio values in the range 45 to 50%.

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 concentrations. These circumstances are confirmed by the load and concentration statistics presented in the text boxes. The median SO_4 concentration of 328 mg/L for the most recent period explains the contemporary higher sulfate loads.

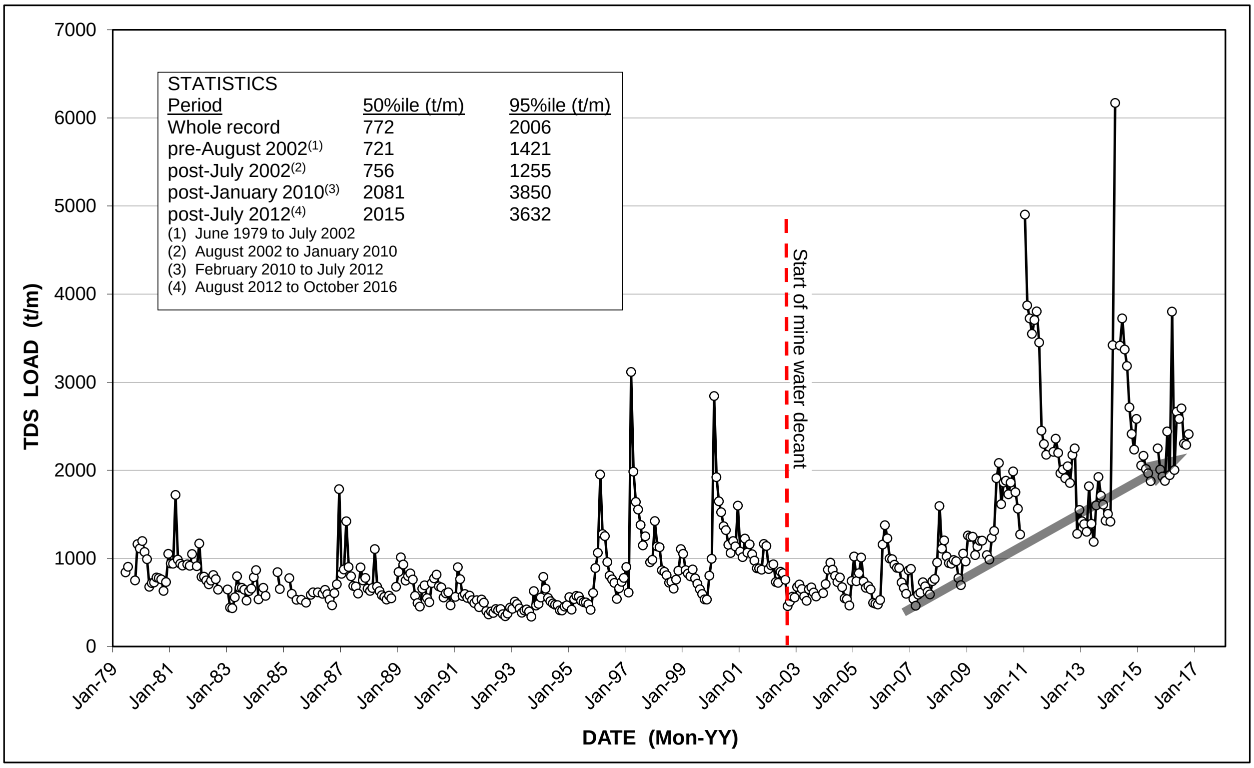


Figure 17 Long-term (June 1979 to October 2016) monthly TDS load pattern and trend in the Bloubank Spruit at station A2H049

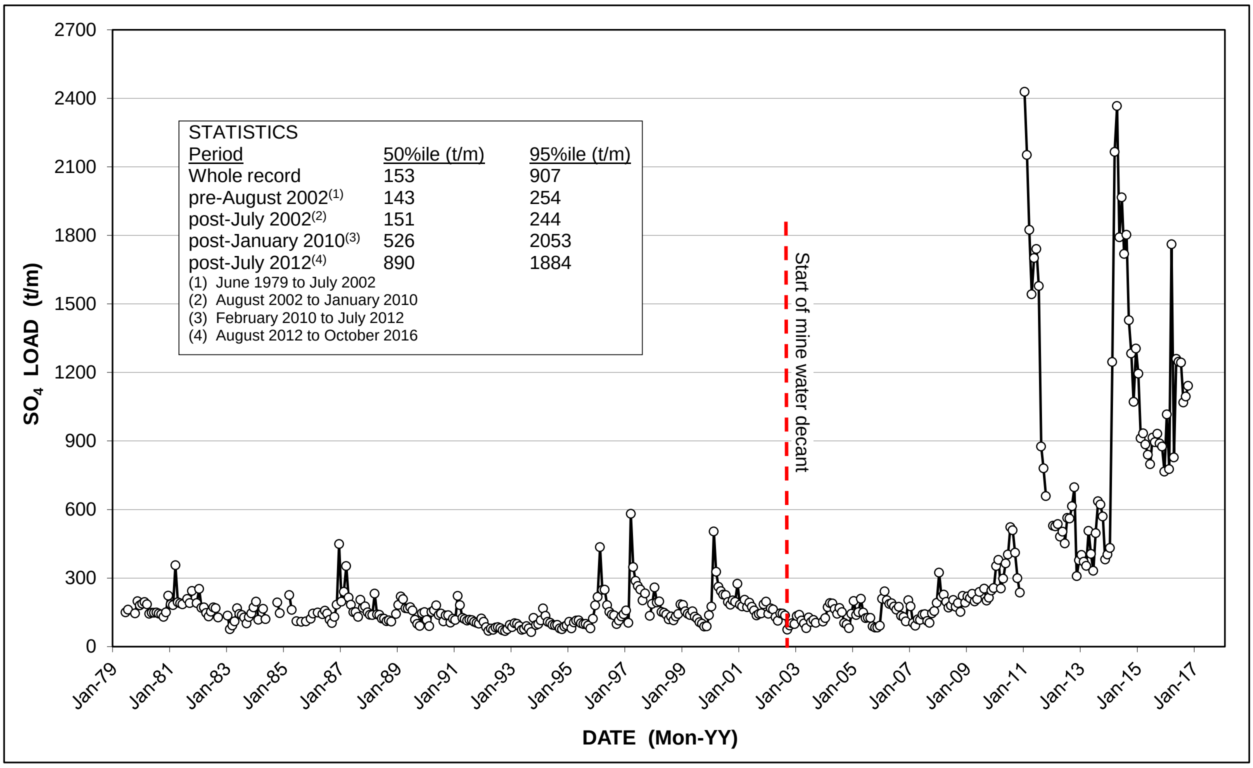


Figure 18 Long-term (June 1979 to October 2016) monthly SO_4 load pattern and trend in the Bloubank Spruit at station A2H049

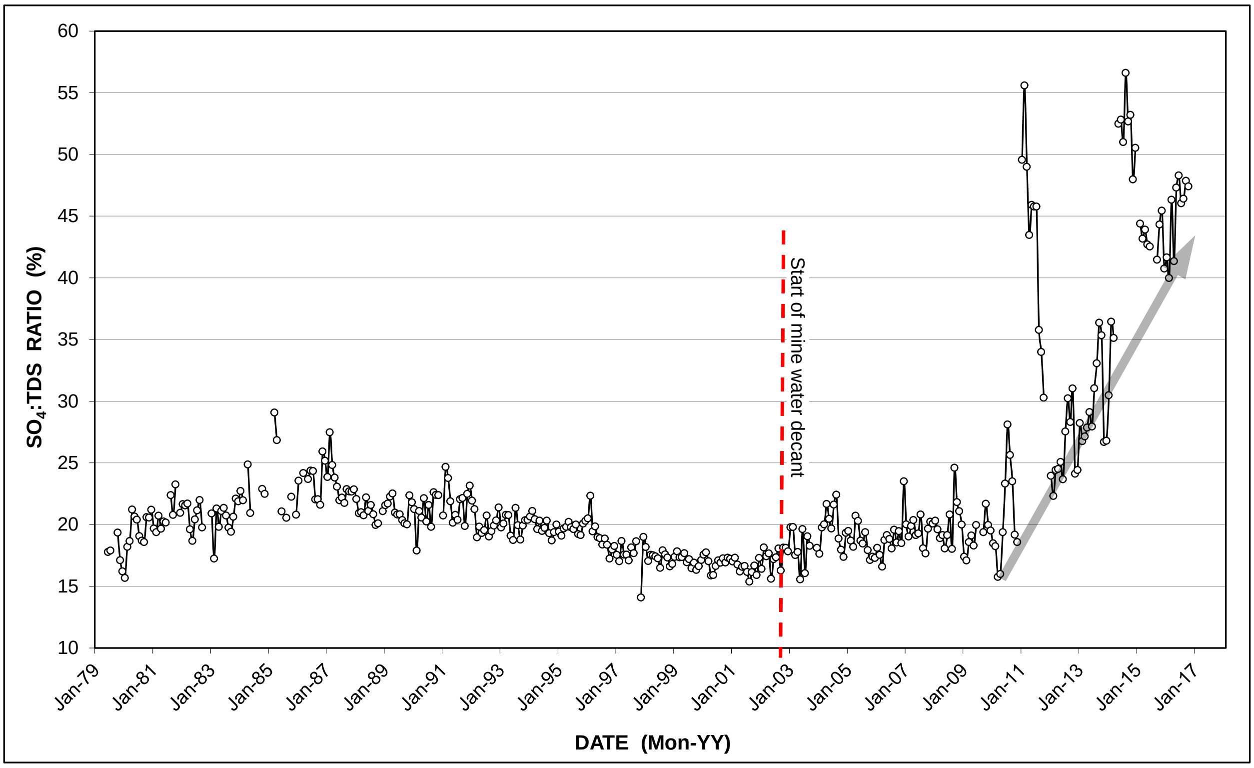


Figure 19 Long-term (June 1979 to October 2016) trend in the SO$_4$:TDS ratio at station A2H049

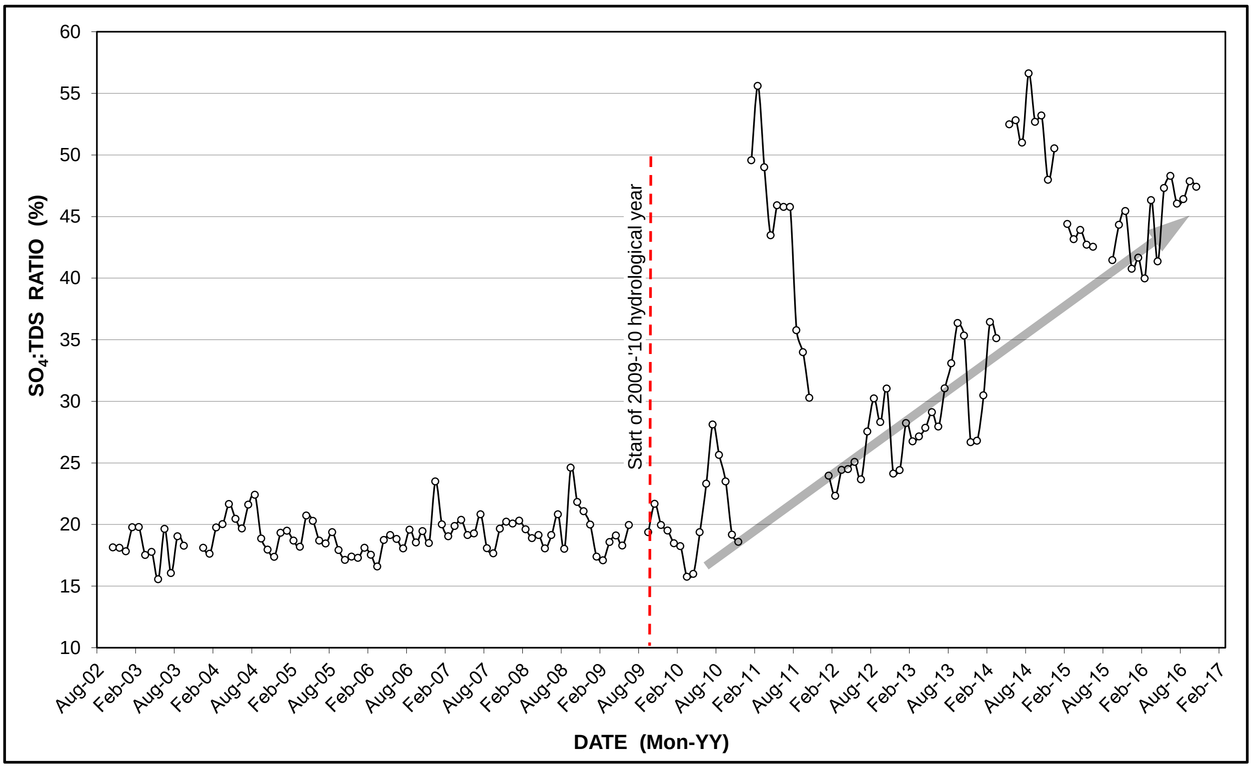


Figure 20 Pattern and trend of the SO$_4$:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin in mid-2002

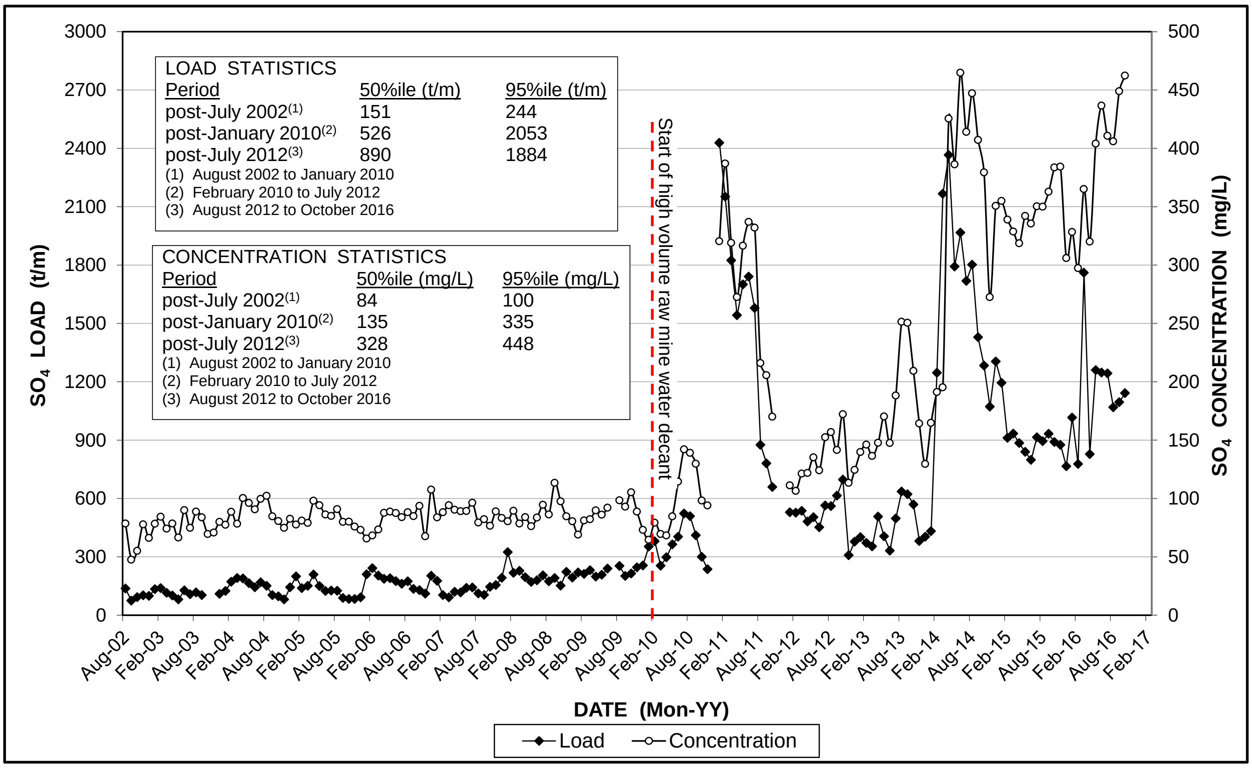


Figure 21 Monthly SO_4 concentration and load pattern and trend in the Bloubank Spruit at station A2H049 since mid-2002

4.4 Municipal Wastewater Impact

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

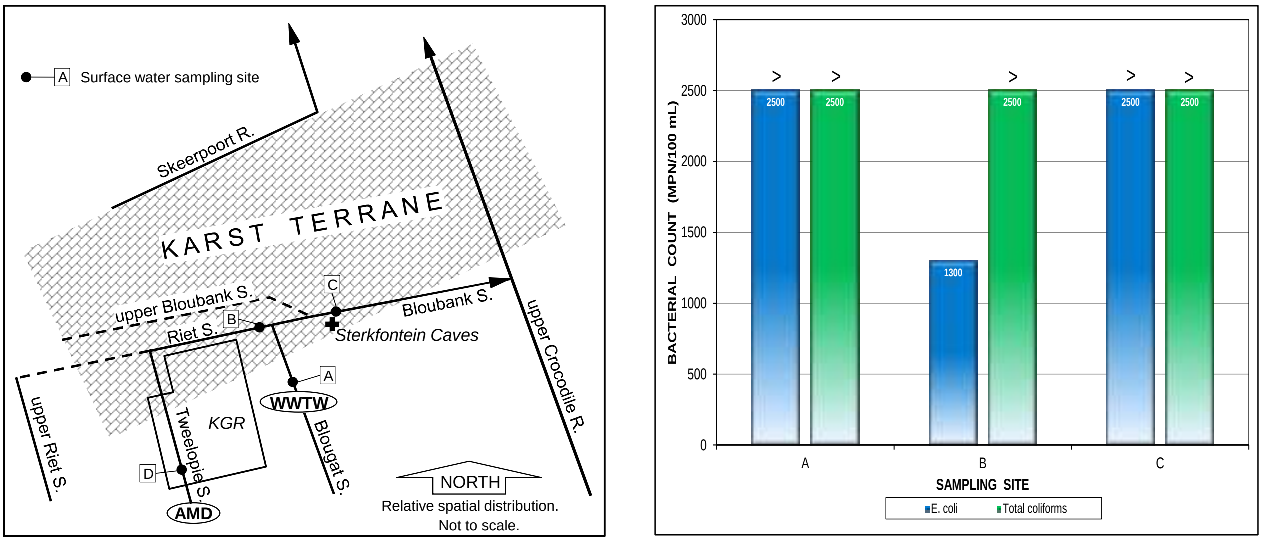


Figure 22 Schematic diagram showing the position of the surface water bacteriological sampling sites A, B and C (left), and histogram of the associated results (right)

An indication of the impact of the WWTW on the downstream receiving water environment in July 2016 is reflected in the bacteriological results (*E. coli* and total coliform counts) reported by Hobbs (2016b). A similar sampling exercise carried out in March 2017 produced the results shown in **Figure 22**. It is worth repeating that sampling station A on the Blougat Spruit receives municipal wastewater effluent discharged from the Percy Stewart WWTW, station B on the Riet Spruit receives mainly mine water effluent via the Tweelopie Spruit, and station C on the Bloubank Spruit receives the aggregate contribution from stations A and B. The results indicate that the *E. coli* levels at stations A and C substantially exceed those at station B. It is also important to note that the bacteriological contamination at the level of 2500 MPN/100 mL represents the maximum countable limit in each undiluted sample. As shown by Hobbs (2016b), levels above this limit, i.e. >2500 MPN/100 mL, reach counts approaching 10 000 MPN/100 mL at station C. These levels far exceed the limit of nil counts per 100 mL (i.e. not detected) set by the SANS (2015a; 2015b) guideline for drinking water.

5 GROUNDWATER HYDROLOGY

5.1 Physical Hydrogeology

5.1.1 Groundwater Levels

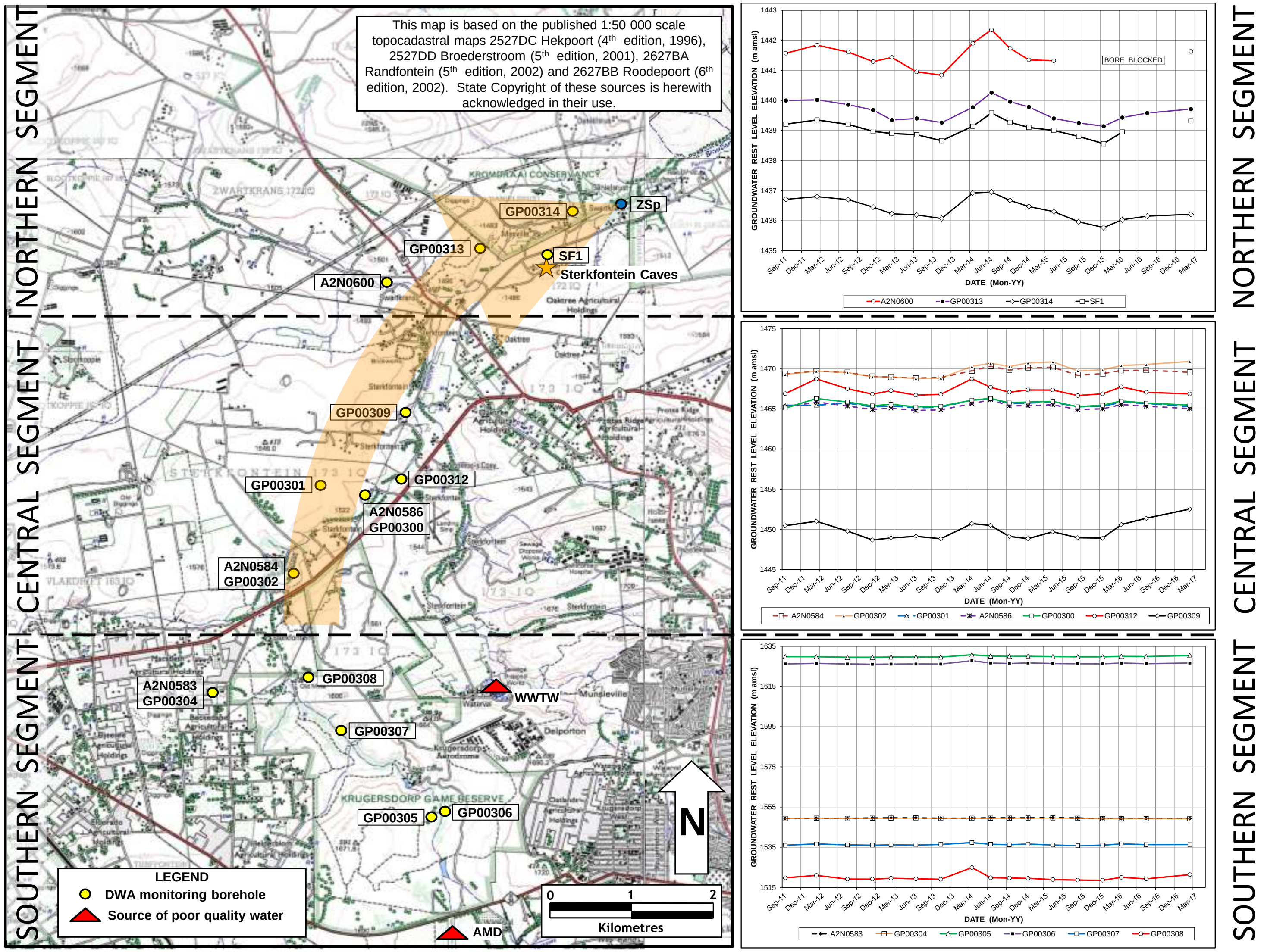
An inspection of the more recent potentiometric response in DWS monitoring boreholes located downstream of the mine area is presented in **Figure 23.** The boreholes are grouped into a southern, a central and a northern segment to distinguish between their relative location in the downstream receiving 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 Cave Water Level

The international significance of Sterkfontein Cave 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 cave to successively higher elevations. These circumstances focussed attention on the hydrostatic behaviour of the cave water level.

Figure 24 reveals that the recent cave water level again approached its maximum elevation of ~1439.5 m amsl in March 2017 after the previous maximum in late-2014. This response is also evident in the potentiometric heads of monitoring boreholes in the central and northern segments (**Figure 23**), and is readily attributed to the comparatively wet summer of the 2016–’17 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, 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).



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

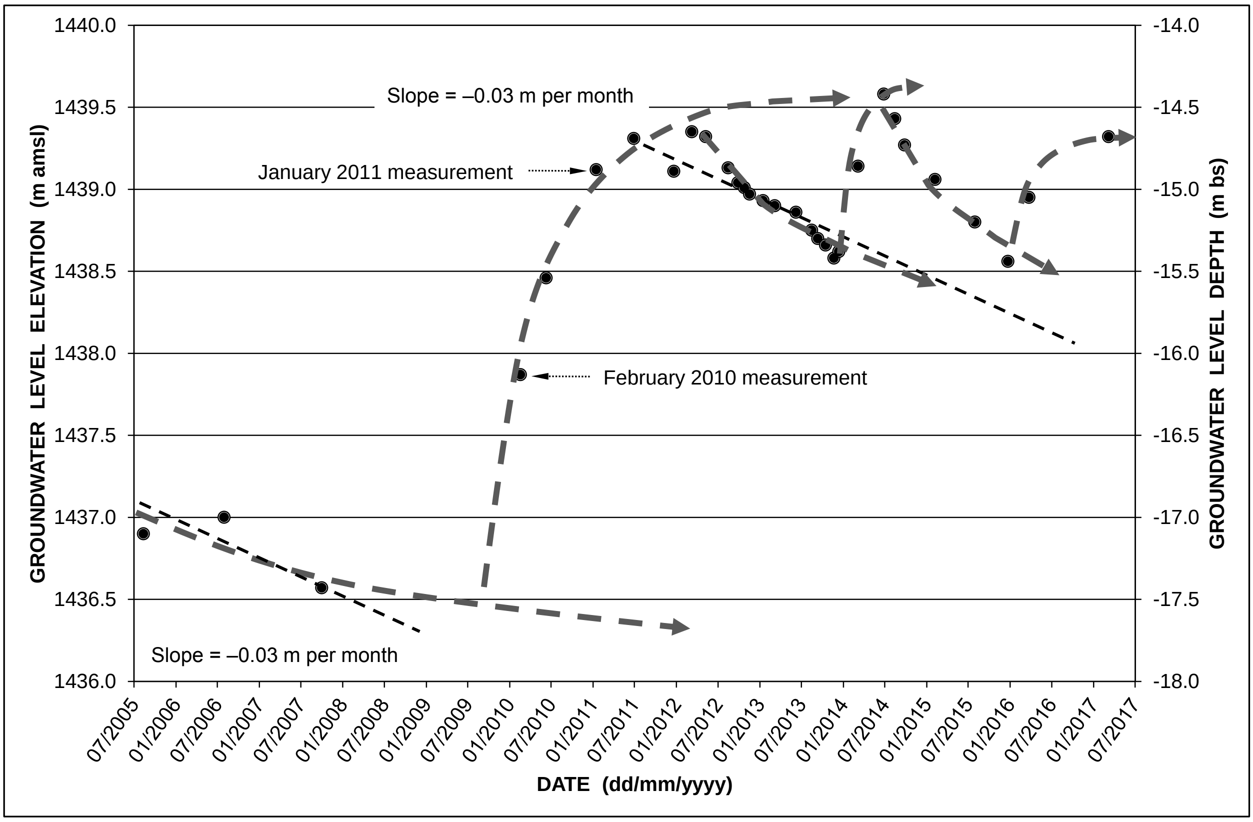


Figure 24 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the lake water level in Sterkfontein Cave

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 25** and **Figure 26**. 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 hydrochemical 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, 2016b). 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 25** and **Figure 26** 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 25** 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. In the southern segment, the most recent pH values are all slightly lower than the previous (July 2016) values, but remain bracketed in the range 6.5 to 8. pH values in the central segment are bracketed in the range 6.5 to 7.5, and those in the northern segment in the range 7.3 to 7.8.

The bar graphs in **Figure 26** reflect the elevated salinity adjacent to the Tweelopie Spruit in the southern segment, as well as the recent reduction in salinity at each of the stations GP00306 and GP00307 in this segment. The central segment reveals a general progressive increase in salinity from south to north, and in all instances either a similar or reduced recent individual salinity compared to earlier results. In the northern segment, however, the spatial salinity trend along the flow path is a declining one, also at each of the stations individually compared to slightly earlier results.

The patterns described above reflect 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 27**. The latter figure provides an indication of the extent of this impact, as well as the SO_4 trend at each monitoring station in terms of up, stable or down in the recent past, by comparison of the December 2015, July 2016 and February 2017 values. The only conclusive trend revealed by the comparison is the increasing trend at stations GP00314 and ZSp at the north-eastern (discharge) end of the Zwartkrans Compartment. This is still interpreted as reflecting the passage of a "slug" of AMD-impacted groundwater through the aquifer toward the Zwartkrans Spring.

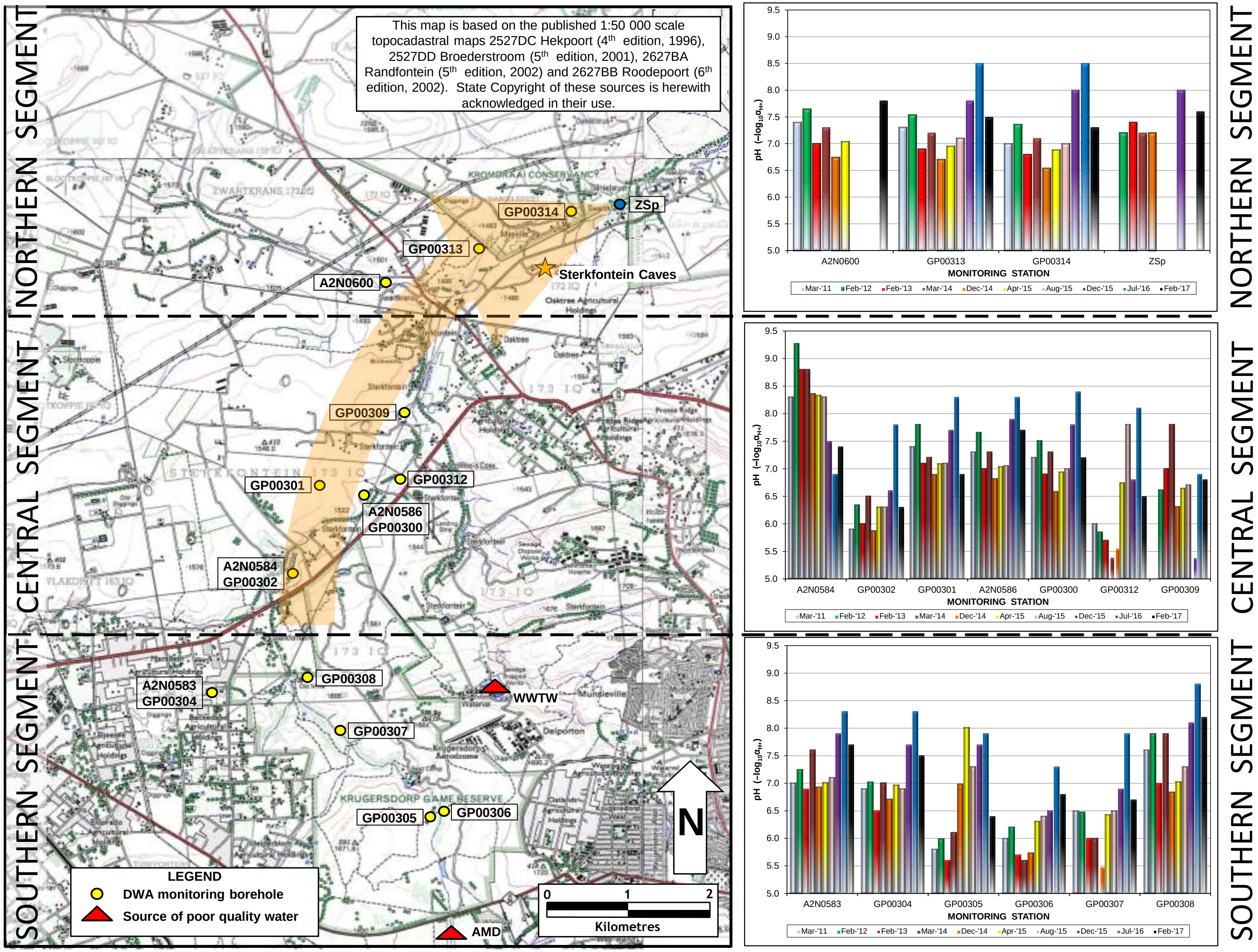
The Zwartkrans Spring water chemistry continues to show an increase, albeit at a gradually reducing rate, in the sulfate concentration. The February 2017 value of 9.62 meq/L (462 mg/L) represents an increase of 13% over the 8.52 meq/L (409 mg/L) of December 2015.

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 2016–'17 summer season experienced a comparatively high rainfall of ~864 mm, but this has yet to translate into an abnormal catchment discharge as at January 2017.

- The 2016–'17 hydrological year is likely to produce a smaller runoff than the ~34 Mm^3 of the previous hydrological year. The recent discharge pattern at station A2H049 is therefore likely to continue, i.e. with Quaternary catchment A21D discharging at well below the median and mean of 42.7 and 44.5 Mm^3/a, respectively, recorded in the last seven hydrological years since 2009–'10.



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 pH pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow

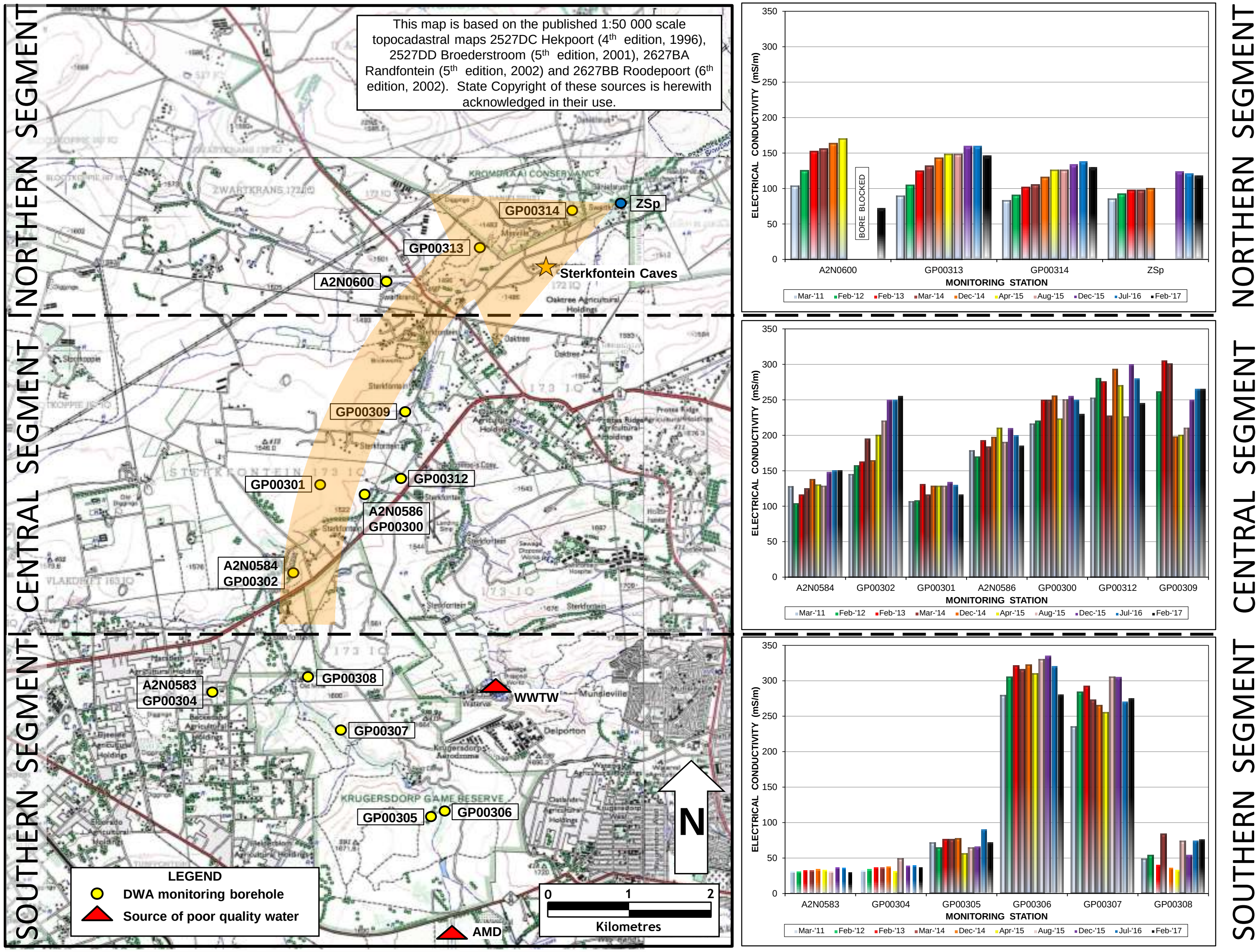


Figure 26 Distribution of DWS monitoring boreholes with EC pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow

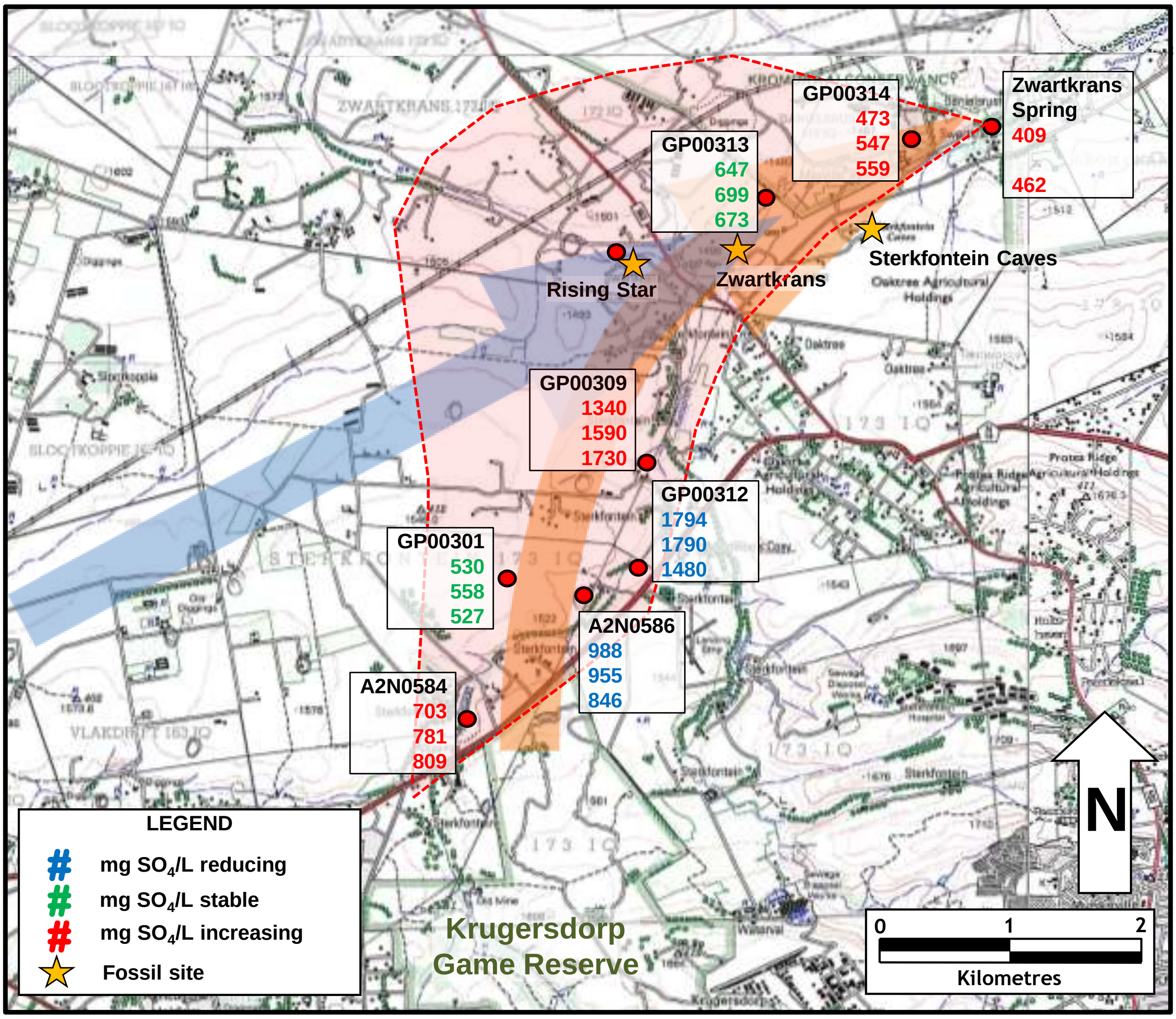


Figure 27 Distribution of SO_4 concentrations in groundwater of the Zwartkrans Compartment in December 2015 (1st value), July 2016 (2nd value) and February 2017 (3rd value), also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow), the postulated footprint (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)

- The return to ‘more normal’ pre-2010 discharge water quality in the downstream receiving hydrologic environment observed previously 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 ~1750 mg/L in mine water impacted surface water entering the karst environment of the Zwartkrans Compartment.

- Faecal coliform (*E. coli*) bacteria counts continue to reflect unacceptably high levels (>2500 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. By comparison, *E. coli* levels in the mine water impacted surface water amount to ~1300 MPN/100 mL.

- 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 summer rains. This is also reflected in the lake water level in Sterkfontein Cave, which again has approached its maximum elevation of ~1439.5 m amsl.

- 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 (**Figure 27**).

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 Theo Moolman and Nico de Meillon in the collection of field data. The services of the DWS staff Marica Erasmus (Resource Quality Services) and Jane Boshomane (Hydrological Services) in the provision of water resources monitoring data is also recognised and appreciated. Karen du Plessis of Sibanye Gold is thanked for the provision of rainfall data collected by this mining house. 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.

DEA 2016. *State of Conservation report for the fossil hominid sites of South Africa World Heritage Site (the Sterkfontein, Swartkrans, Kromdraai and environs component) (C 915 BIS).* Department of Environmental Affairs. 10 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.

DWS 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. 2016a. *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.

Hobbs, P.J. 2016b. *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 2016.* Report no. CSIR/NRE/WR/ER/2016/0073/A. Council for Scientific & Industrial Research. Pretoria. 37 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.

PJ Hobbs.

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

ANNEXURE

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

Variable/analyte	**Unit**	**Sampling Station**					
		Tweelopie Spruit (Site D in Fig. 22)		**Riet Spruit (Site B in Fig. 22)**		**Bloubank Spruit (Site C in Fig. 22)**	
Date	mm/yyyy	07/2016	02/2017	07/2016	02/2017	07/2016	02/2017
Temperature*	°C	14.9	22.8	—	20.9	—	—
Electrical conductivity*	mS/m	24.5	289	—	251	—	—
Electrical conductivity	mS/m	335	300	295	290	160	115
pH*	$-\log_{10}\alpha_{H+}$	6.8	7.3	—	6.5	—	—
pH	$-\log_{10}\alpha_{H+}$	7.6	7.3	4.8	4.3	8.0	7.4
Calcium	mg Ca/L	647	628	533	573	170	260
Magnesium	mg Mg/L	109	96	94	90	58	60
Sodium	mg Na/L	152	150	118	135	81	88
Potassium	mg K/L	164	16	12	14	7.4	9.7
Chloride	mg Cl/L	59	68	52	67	57	56
Sulfate	mg SO_4/L	2090	2020	1740	1840	679	845
Total alkalinity	mg $CaCO_3$/L	30	39	3.1	<0.5	88	69
Nitrate + nitrite	mg N/L	1.2	2.1	6.7	7.4	8.8	9.3
Silica	mg Si/L	2.1	2.3	1.9	2.4	4.8	4.6
Aluminium (total)	mg Al/L	0.07	0.02	0.06	0.10	0.10	0.12
Iron (total)	mg Fe/L	0.10	0.11	0.08	0.23	0.26	0.24
Manganese (total)	mg Mn/L	3.8	3.8	1.9	2.7	0.73	0.82
E. coli	MPN/100 mL	35	—	461	1300	9330	>2419
Total coliforms	MPN/100 mL	517	—	>2419	>2419	32 550	>2419

* Field values

MPN most probable number