PROJECT TITLE

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

REPORT TITLE

WATER RESOURCES STATUS REPORT FOR THE PERIOD APRIL TO SEPTEMBER 2017

AUTHOR

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PREPARED BY

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SUMMARY

The Management Authority (MA) of the Cradle of Humankind World Heritage Site (COH WHS) appointed the CSIR to serve the water resources monitoring programme of the property following the outcome of bid GT/GDED/092/2017. A continuation of project BIQ005/2008 commissioned to develop a water resources monitoring programme for the property, the monitoring programme has since its inception in 2012 generated ten (10) bi-annual status quo reports to date. This document represents the eleventh (11th) such report. It covers the timeframe April to September 2017. As such, this report spans the period in which the MA ran the tender process of securing a service provider to continue with the programme following termination of the previous contract in March 2017.

An assessment of impacts on the water resources environment of the COH property takes a holistic view that includes 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 informs the State of Conservation (SOC) of the property. The SOC is a primary concern of UNESCO's World Heritage Centre. The current outcome is summarised as follows.

- Despite 2017 being the wettest hydrological year in the record for the mine area (Western Basin) spanning nine years, with a rainfall of 1067 mm, this did not translate into an abnormal catchment discharge, which since 2010 ranked only 5th out of 8 after 2010, 2011, 2012 and 2014, and can therefore be classified as moderate.

- The moderate annual discharge observed in the Bloubank Spruit system suggests that the mine water control and management measures implemented in the Western Basin have largely been successful in dealing with mine water decant and, as a result, in limiting the impact on the receiving water resources.

- The success of the mine water control and management measures was also manifested in the quality of mine water impacted surface water entering the karst terrane of the COH property, as evidenced in pH values which show a sustained increase of 1.5 to 2 pH units in the last 6 to 9 months, and in EC values which show a decline from 300 to 250 mS/m in this period.

- The groundwater elevation in the south-western portion of the property (the Zwartkrans Basin) where the allogenic recharge component is greatest, shows no material response to the exceptionally high rainfall of the 2017 hydrological year.

- Groundwater in the south-western portion of the property (the Zwartkrans Basin) continues to experience a compromised quality reflected in sulfate levels of up to ~2000 mg/L. A comparison of salinity (EC) levels over the last year, however, indicates these levels in ambient groundwater have stabilised also at the stations GP00314 and ZSp at the north-eastern (discharge) end of the Zwartkrans Basin.

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

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SYMBOLS, ACRONYMS & ABBREVIATIONS

~	approximately
>	greater than
<	less than
%	per cent (parts per hundred)
%ile	percentile
°C	degree(s) Celsius
Δh	change in head
a_h	hydrological year
AMD	acid mine drainage
amsl	above mean sea level
bc	below collar
bs	below surface
C_5	concentration exceeded 95% of the time (5%ile)
C_{95}	concentration exceeded 5% of the time (95%ile)
ca.	circa (about)
COH WHS	Cradle of Humankind World Heritage Site
CoV	coefficient of variation
CSIR	Council for Scientific and Industrial Research
DWS	Department of Water & Sanitation [formerly the Department of Water Affairs (DWA)]
EC	electrical conductivity
ENSO	El Niño Southern Oscilation
GWDMS	Groupwise Document Management System (internal to CSIR)
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
Q_{50}	discharge exceeded 50% of the time (50%ile or median)
REGM	Randfontein Estates Gold Mine
RU	Rand Uranium (earlier owner of the original REGM)
SD	standard deviation
SDM	synoptic discharge measurement
SS	Sibanye-Stillwater (formerly SibanyeGold, 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 (could also denote World Heritage Centre)
WWTW	wastewater treatment works

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1 INTRODUCTION, BACKGROUND & CONTEXT

The Management Authority (MA) of the Cradle of Humankind World Heritage Site (COH WHS) appointed the CSIR to serve the water resources monitoring programme of the property following the outcome of bid GT/GDED/092/2017. Since its inception in 2012, the monitoring programme has to date generated ten (10) bi-annual status quo reports (Hobbs, 2012; 2013a; 2013b; 2014a; 2014b; 2015a; 2015b; 2016a; 2016b; 2017a). This document represents the eleventh (11^{th}) such report. It covers the period April to September 2017.

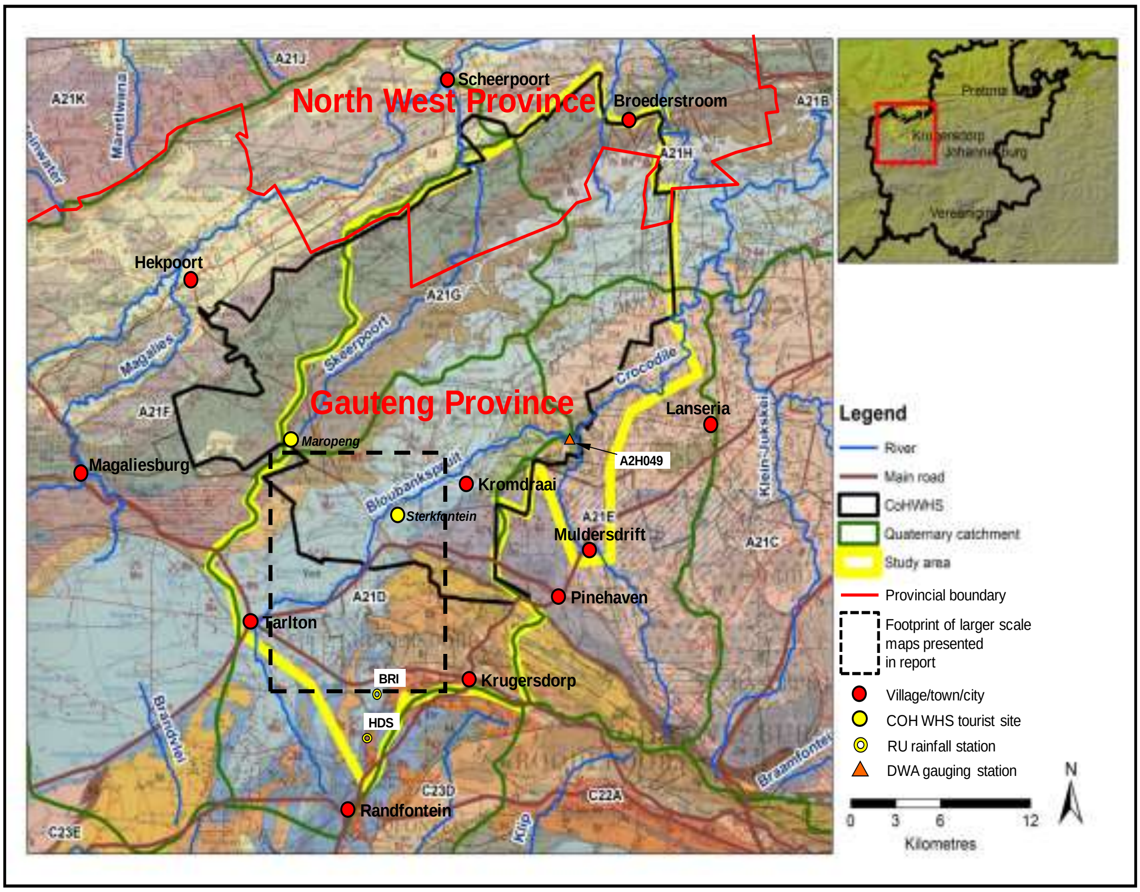

Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

2 TIMELINE OF KEY EVENTS

An updated timeline of key events since the start of mine water decant in 2002 and incorporating the reporting period, is presented in **Figure 2**. The most recent landmark event on the timeline is the completion of a State of Conservation (SoC) report (DEA, 2016) submitted to UNESCO's World Heritage Centre (WHC) for examination by the World Heritage Committee and presentation at its 41^{st} session held in Vienna in mid-2017. The outcome of this examination, expressed as a draft decision, is summarised in the **Annexure**. This sets out the concerns of the WHC for the property, and which need to be addressed and responded to in the monitoring programme going forward. Progress with the resolution of these concerns will be documented in State of Conservation (SOC) reports.

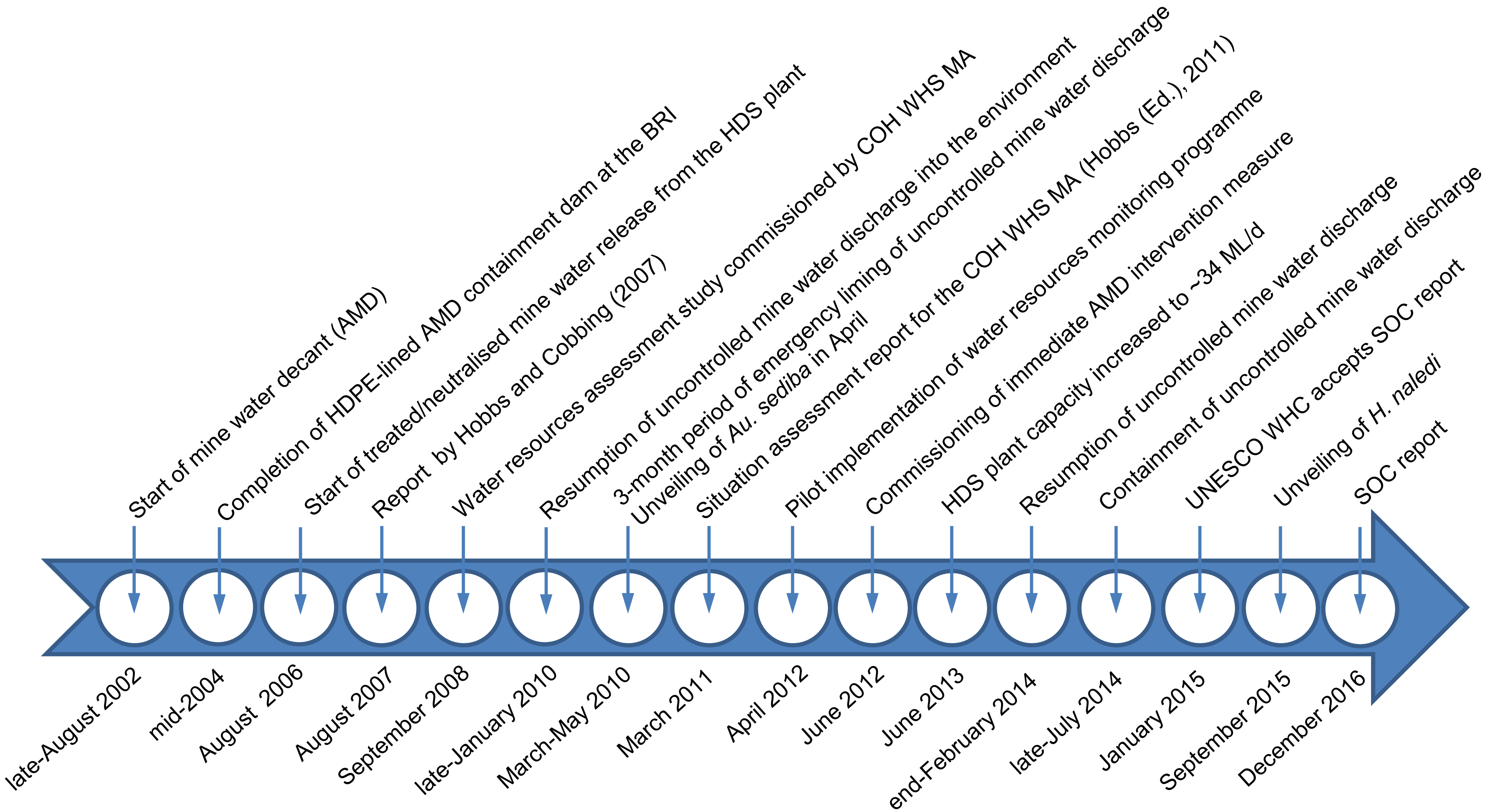

Figure 2 Timeline of key events relevant to the project and this report

3 RAINFALL

The monthly precipitation record for the period October 2008 to September 2017 at the Sibanye-Stillwater (SS) [formerly Sibanye Gold (SG)] rainfall station HDS at the water treatment plant in the mine area, and station SC at the Sterkfontein Cave, is shown in **Figure 3**. The wet (summer) season precipitation record in the mine area is compared to that at Sterkfontein Cave in **Figure 4**. These comparisons reveal the following:

- the very wet mid-summer period of the 2017 hydrological (a_h) year — in November 2016 to February 2017, 748 mm was recorded at the HDS station, representing ~87% of the total 2017 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) at this locality in the past seven years after a_h 2014 (760 mm) and a_h 2011 (696 mm); and
- the wet early winter season of a_h 2017 experienced in the mine area, when in the order of 200 mm was experienced in April and May 2017, and ~90 mm was experienced at Sterkfontein Cave in this time.

The total a_h 2017 rainfall of 1067 mm makes this the wettest year in the record spanning nine (9) years. The next wettest year was 2011 with 967 mm.

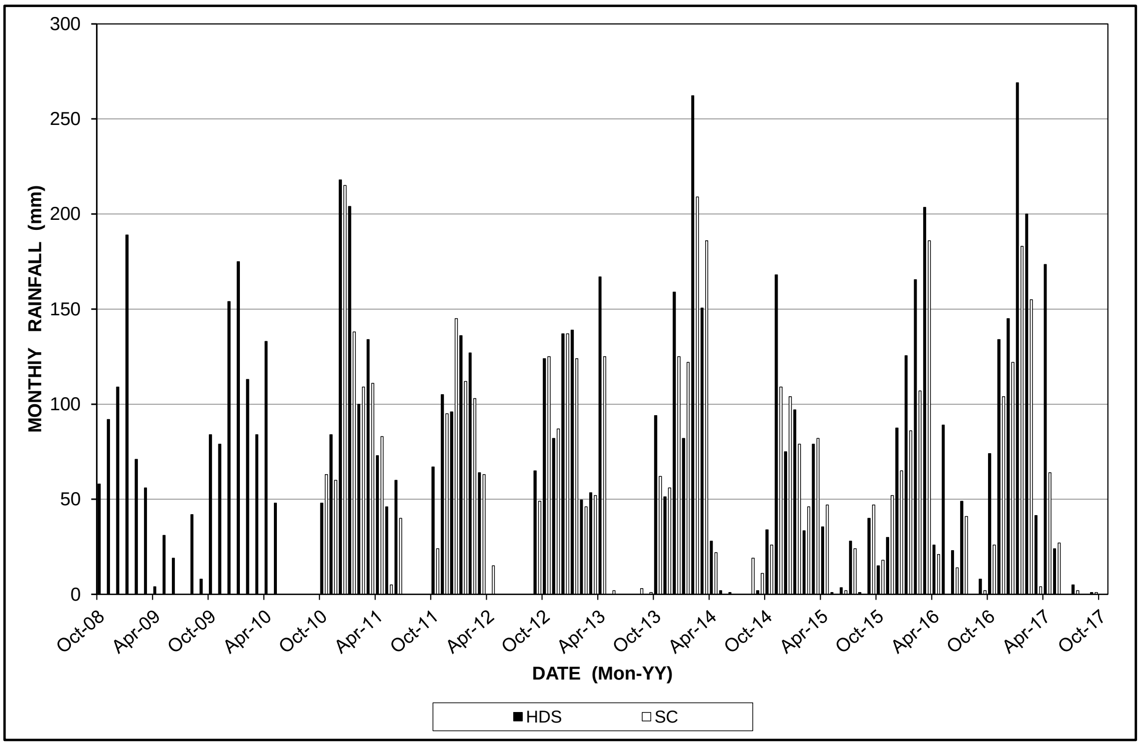

Figure 3 Monthly precipitation at the SS rainfall monitoring station HDS in the mine area from October 2008 (a_h 2009) to September 2017 (a_h 2017), and the available contemporaneous record for the Sterkfontein Cave station from June 2010 (a_h 2010) to September 2017

The common monthly rainfall record for the HDS and Sterkfontein Cave stations is presented in **Figure 5**. The data set excludes months of no rainfall at both stations in order to remove the false correlation created by common null values.

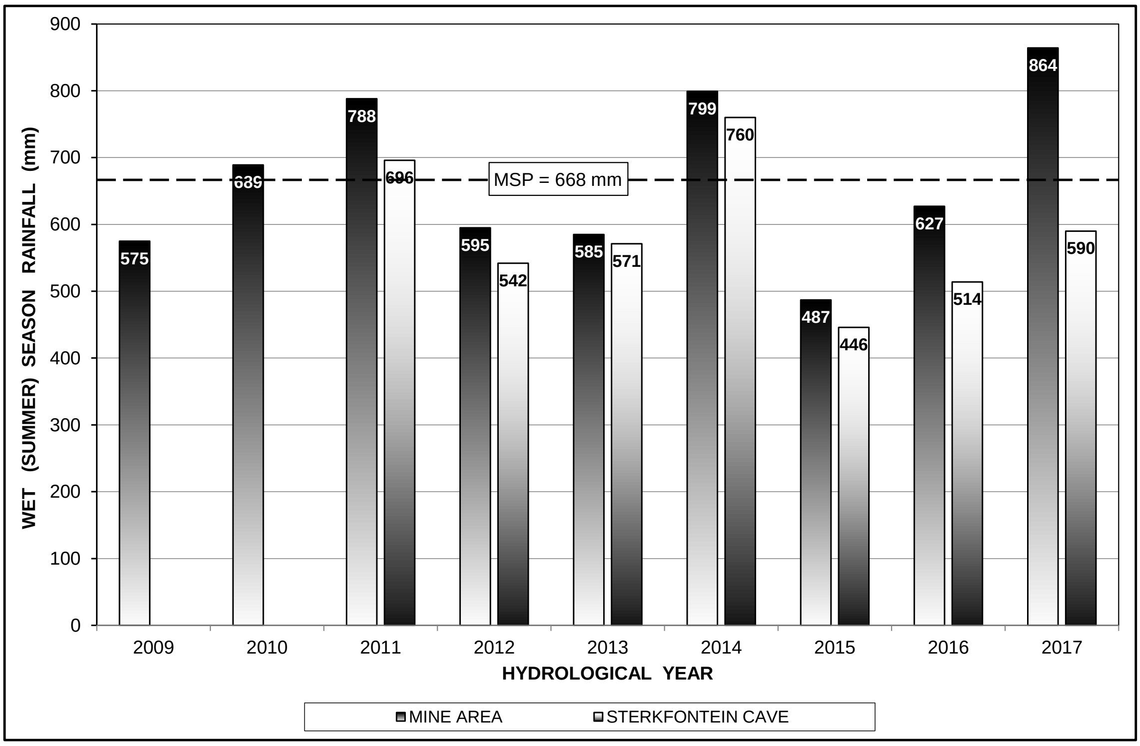

Figure 4 Total wet season (summer) rainfall in the mine area (HDS station) in the past nine hydrological years, also showing the comparison with that for the available contemporaneous Sterkfontein Cave record; MSP denotes mean summer precipitation

Figure 5 shows a good correlation (R^2 = 0.82, p <0.01). Station SC experiences ~22% less rainfall on a monthly basis than does station HDS on the watershed ~13 km to the south.

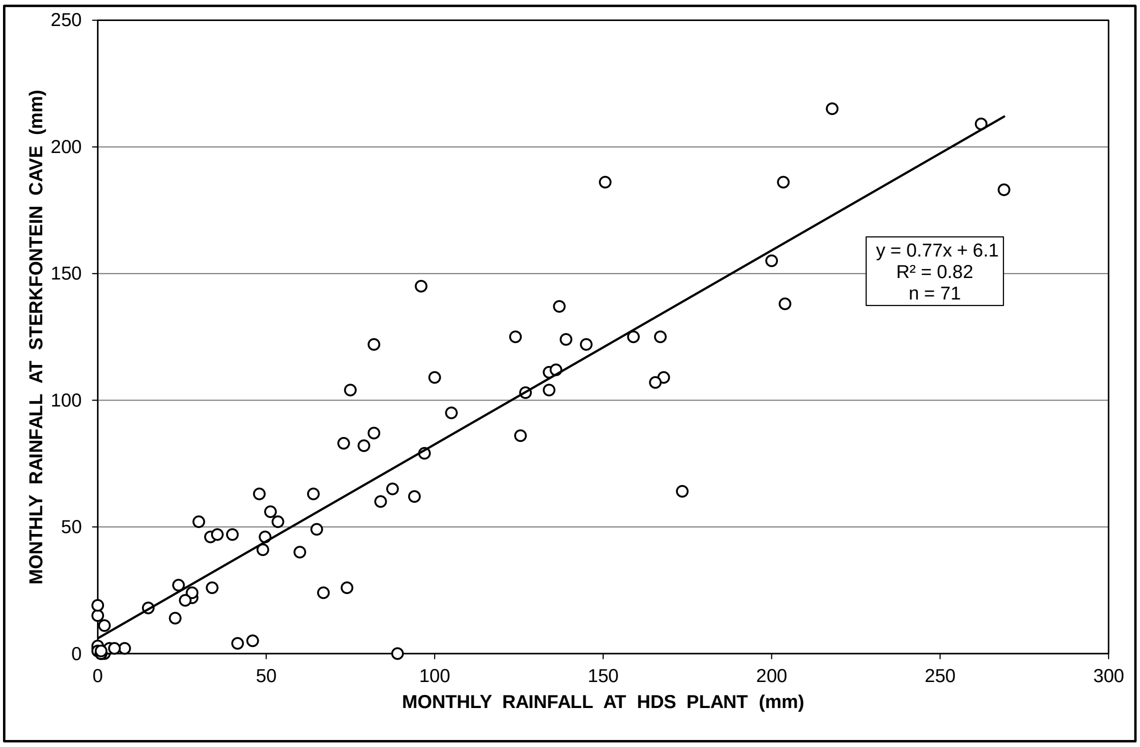

Figure 5 Correlation of monthly rainfall at Sterkfontein Cave with that at the HDS mine water treatment plant in the mine area for the period of common record June 2010 to September; data set (n = 71) excludes months of no rainfall (n = 17) at both stations

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 ~45-year discharge record for this catchment (Quaternary A21D) provides the monthly statistics reported in **Table 1**.

Table 1 Statistical analysis of Bloubank Spruit monthly discharge data gauged at station A2H049 in the period October 1972 to September 2017

Variable	Month											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	43	43	44	44	45	45	45	44	45	45	44	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	0.901	1.066	1.187	0.998	0.964	0.961	0.921	0.802
Mean	1.874	1.886	2.276	2.745	2.702	3.031	2.436	2.297	2.103	2.086	1.961	1.804
Median	1.676	1.743	2.066	2.471	2.222	2.534	1.987	1.925	1.797	1.695	1.676	1.561
95%ile	3.824	2.952	4.501	5.355	6.328	7.863	5.355	4.882	4.115	4.058	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	0.921	0.830	1.094	1.931	1.932	2.208	1.301	1.197	0.976	0.944	0.876	0.883
CoV (%)	49.1	44.0	48.1	70.4	71.5	72.8	53.4	52.1	46.4	45.3	44.7	49.0

All units are Mm^3 unless otherwise indicated.
Analysis excludes months with missing and station rating exceedance data, but includes unaudited (recent) and estimated data

The discharge per hydrological year shown in **Figure 6** indicates that the 2017 hydrological year produced a modest discharge of 37.9 Mm^3. The recent discharge pattern at station A2H049 as discussed in Hobbs (2017a) is therefore likely to continue, i.e. with Quaternary catchment A21D discharging at below the median and mean of 41.4 and 43.7 Mm^3/a, respectively, recorded in the last eight hydrological years since 2010.

The instantaneous monthly flow pattern at station A2H049 for the complete record period October 1972 to September 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 very wet 2017 summer season (**Section 3**) is reflected at the end of the hydrograph. Despite this being the wettest year in the last nine years, the hydrograph reflects only the third greatest discharge (~2.2. m^3/s) after the 4.1 m^3/s of 2014 and the 2.8 m^3/s of 2010 (**Figure 7**). This indicates that the rainfall pattern driving this discharge was spread out over the hydrological year rather than concentrated in a few months.

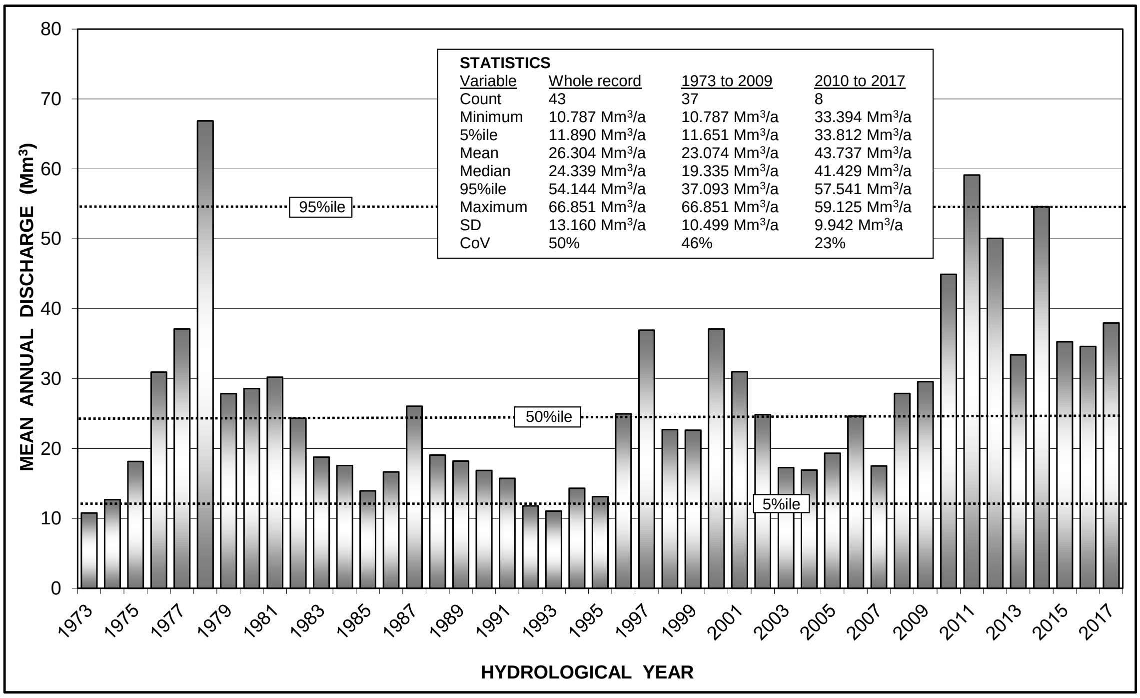

Figure 6 Graph of Bloubank Spruit annual discharge gauged at station A2H049 for the period October 1972 (a_h 1973) to September 2017 (a_h 2017)

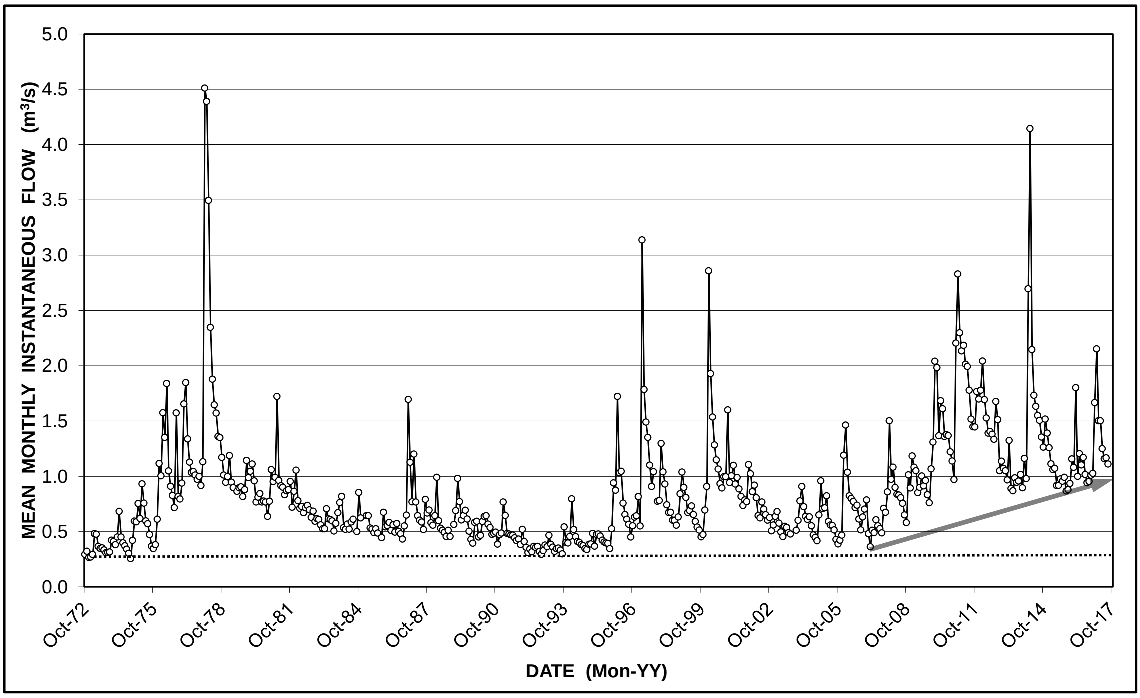

Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 (a_h 1973) to September 2017 (a_h 2017)

The subregional and regional temporal discharge regime of the Bloubank Spruit system in the context of the regionally significant Hartbeespoort Dam is addressed by Hobbs (2017b). The most salient observation in this regard is that the substantial mine water discharges in the past 6 years, i.e. since the periodic uncontrolled escape of raw water to the environment in early-2010, manifest no discernible difference in the proportional discharge contribution of the Bloubank Spruit in either a subregional or a regional context.

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. No such measurements were carried out in the reporting period, and the information reported in the previous status quo report (Hobbs, 2017a) inform this aspect.

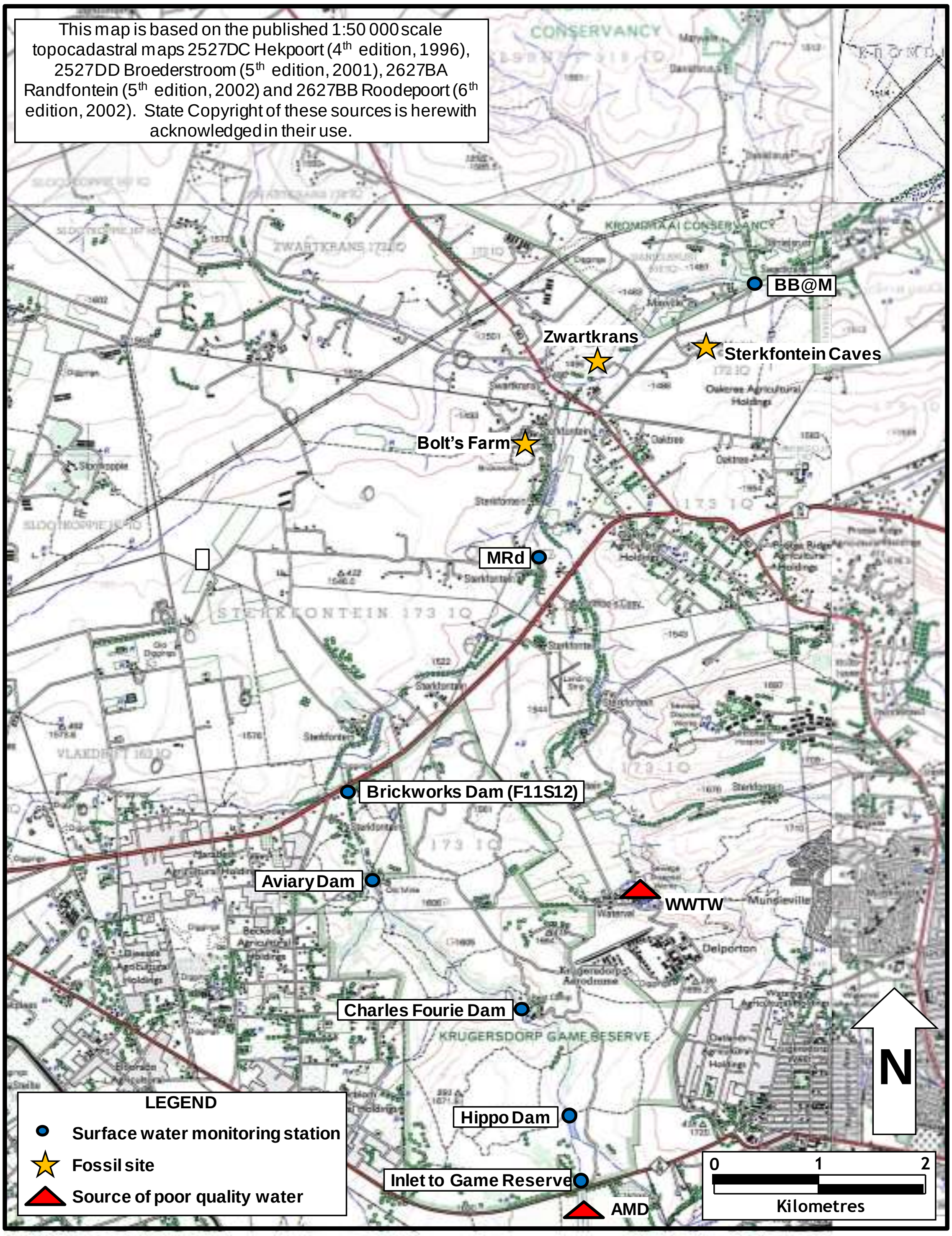

Figure 8 Locality map of surface water quantity and quality monitoring stations

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-Stillwater 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 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 9** (pH), **Figure 10** (EC), **Figure 10** (SO_4), **Figure 12** (Fe), **Figure 13** (Mn) and **Figure 14** (U).

The patterns revealed in **Figure 9** to **Figure 14** 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 covered by this report is the recovery of the mine water treatment and manangement measures to 'operationally optimal' levels. This follows the excursion in the 2017 summer of mine water discharges to poorer (suboptimal) levels because of copious decant volumes. The recovery is most pronounced in the pH values (**Figure 9**), which show a sustained increase in the last 6 to 9 months, and the EC values (**Figure 10**), which show a decline in this period.

The difference between pH values recorded at the Hippo Dam and F11S12 stations is particularly distinct in the last 6 to 9 months of the record. The difference amounts to between 1.5 and 2 pH units, being lower at the downstream F11S12 station. This is unequivocal evidence of hydrolysis in the stream reach between the Hippo Dam and station F11S12 even under circumstances where the discharge from the mine area comprised mainly treated/neutralised mine water with very low iron levels (**Figure 12**). Manganese (**Figure 13**) is the only other of the graphed variables that shows a distinct excursion in the most recent period.

A statistical analysis of the data associated with each of the periods of record A–B, B–C, C–D, D–E and E– defined by the divisions recognised in **Figure 9** to **Figure 14** for each of the Hippo Dam and F11S12 stations is presented in **Table 2**. The result provides a quantitative measure of the variable-specific differences between each period at each station as well as between stations. The excursions to a poorer quality discharge associated with the B–C and the D–E periods is reflected in the median values of all the variables (with the possible exception of iron) at both stations. This observation suggests that the very wet 2017 hydrological year has not manifested a similarly adverse impact on the quality of mine water discharges to the environment as was associated with the 2010, 2011 and 2014 hydrological years. The most likely driver of these circumstances is the mine water control and management measures implemented in the Western Basin.

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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.

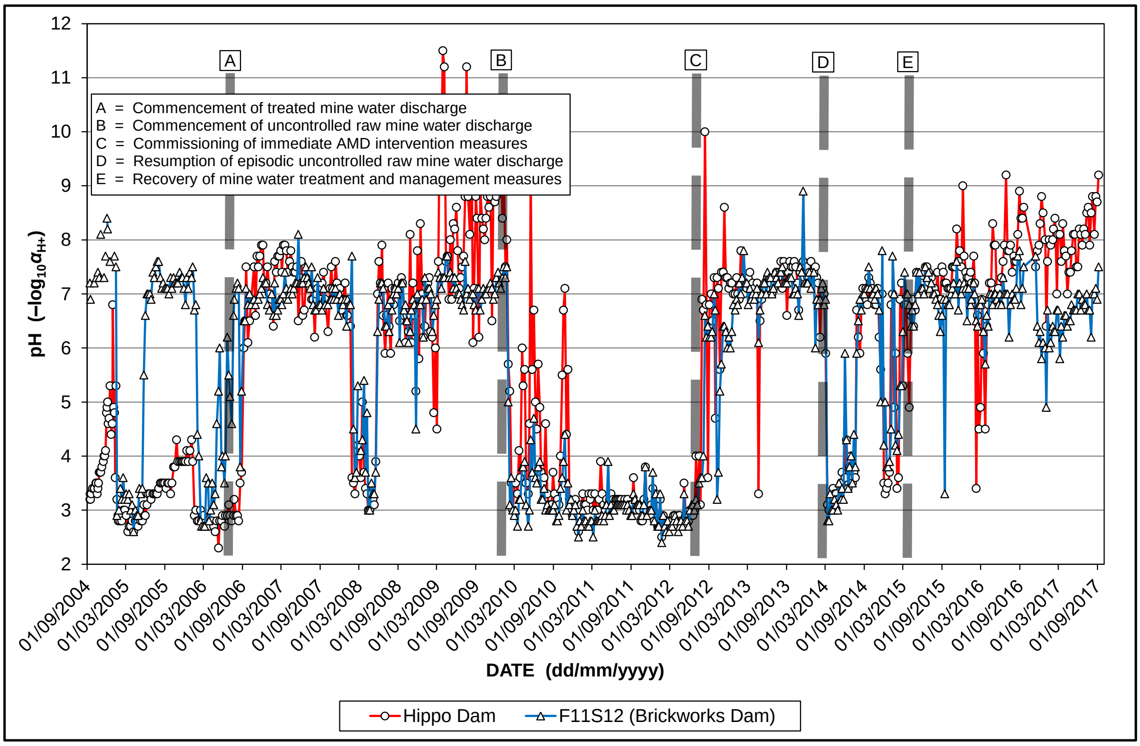

Figure 9 Pattern of pH of Tweelopie Spruit surface water in the period September 2004 to September 2017

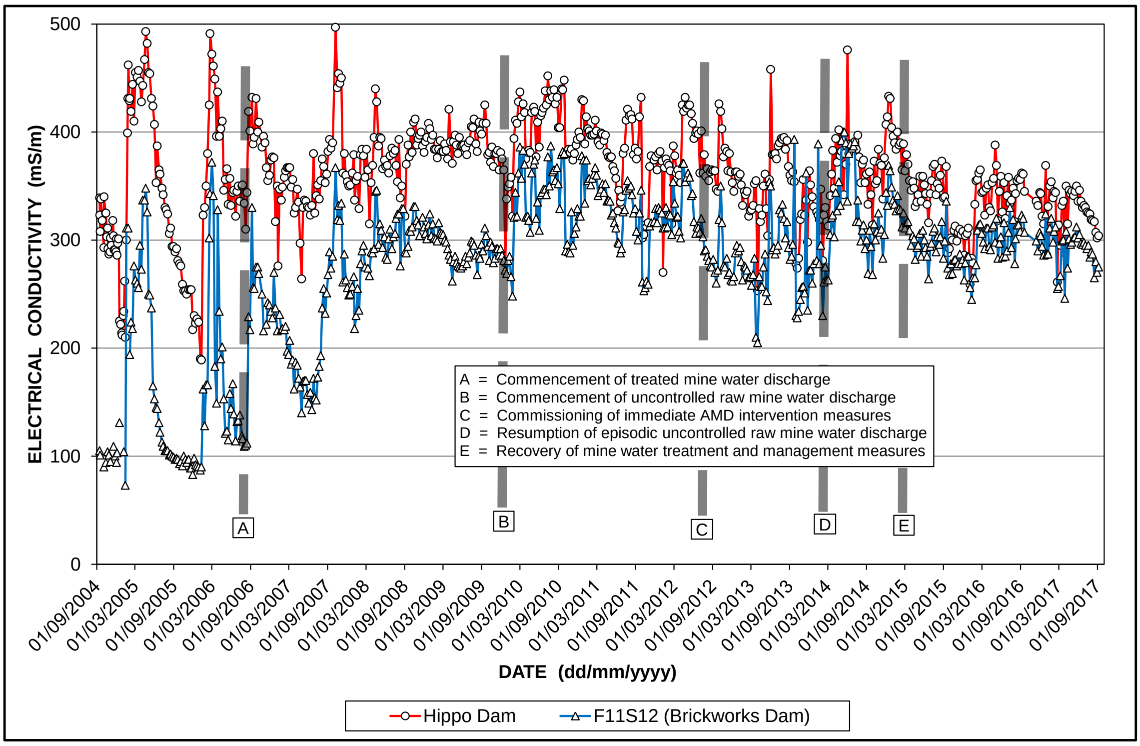

Figure 10 Pattern of electrical conductivity of Tweelopie Spruit surface water in the period September 2004 to September 2017

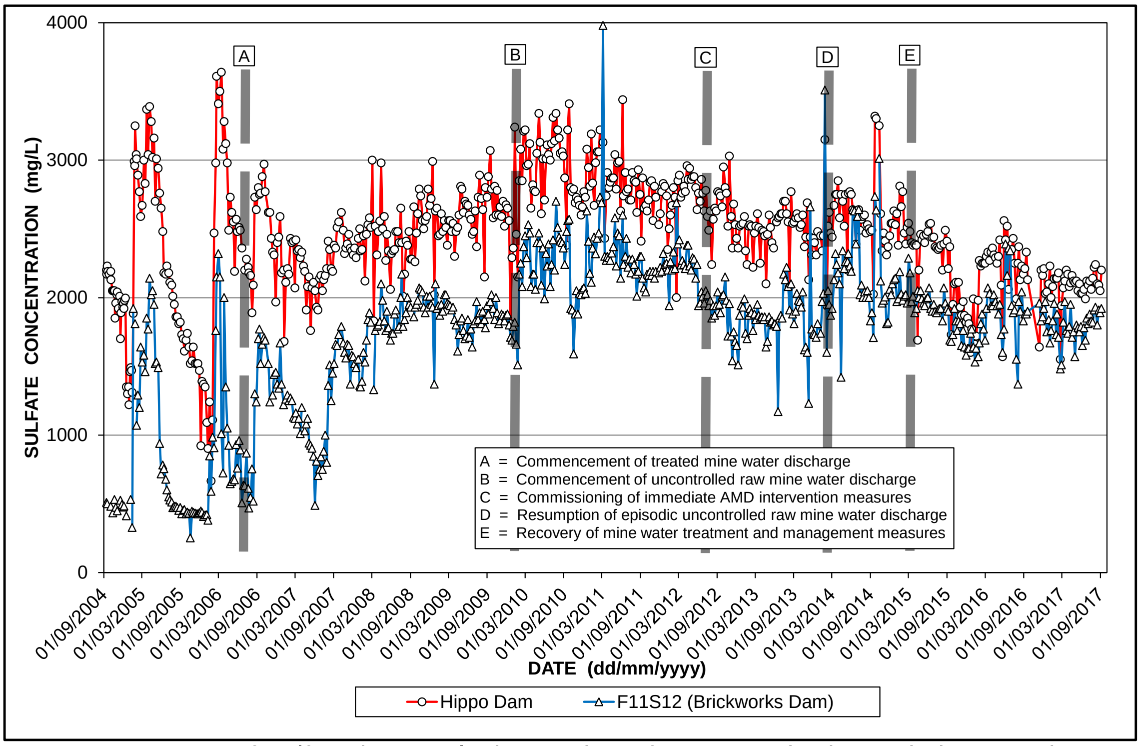

Figure 11 Pattern of sulfate in Tweelopie Spruit surface water in the period September 2004 to September 2017

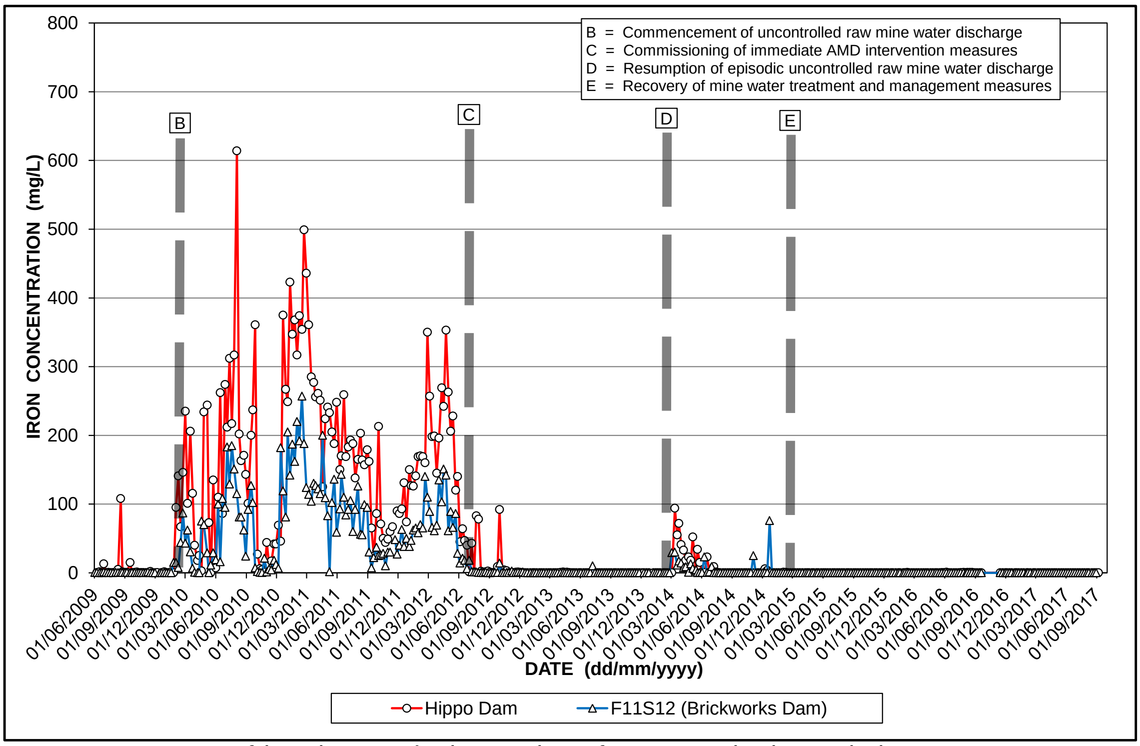

Figure 12 Pattern of iron in Tweelopie Spruit surface water in the period June 2009 to September 2017

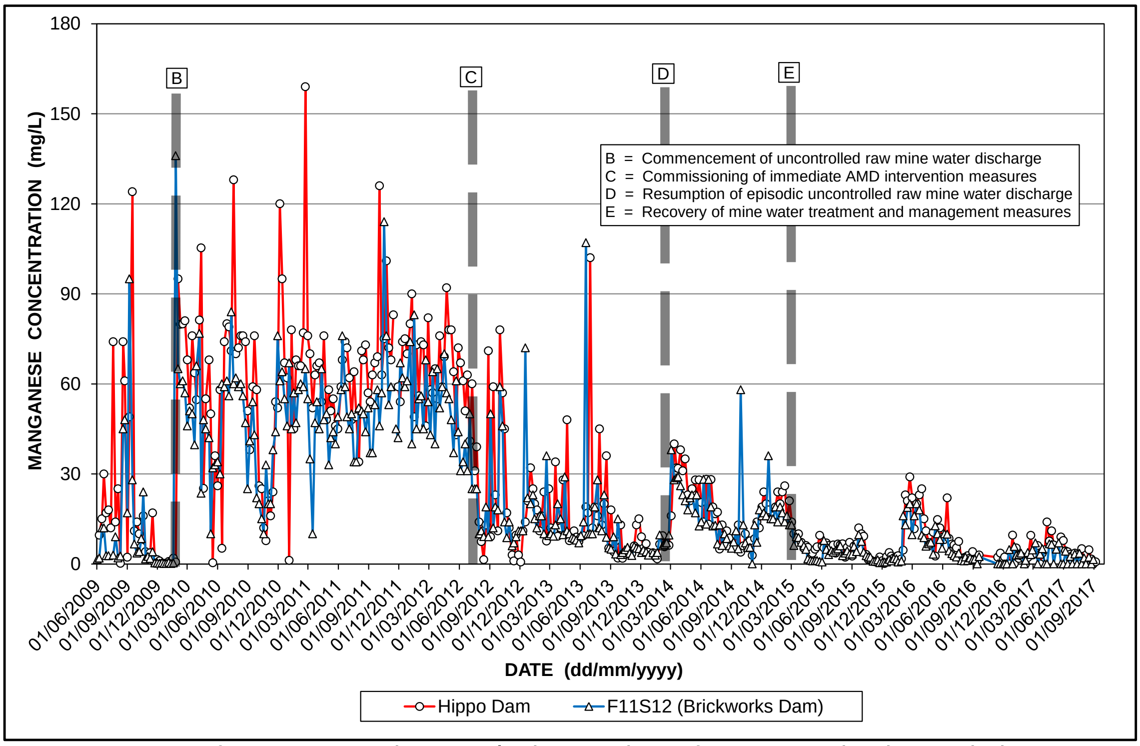

Figure 13 Pattern of manganese in Tweelopie Spruit surface water in the period June 2009 to September 2017

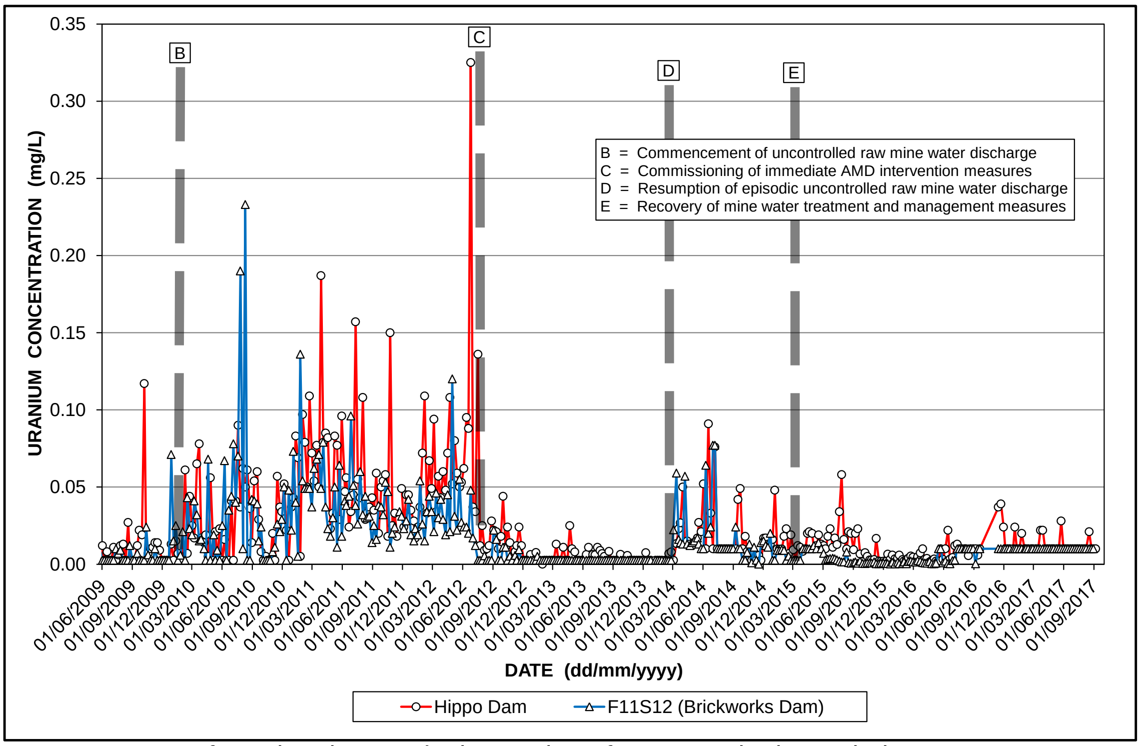

Figure 14 Pattern of uranium in Tweelopie Spruit surface water in the period June 2009 to September 2017

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—E(4)	E—(5)	A—B(1)	B—C(2)	C—D(3)	D—E(4)	E—(5)
pH ($-\log_{10}\alpha_{H+}$)	n	176	129	83	57	120	173	128	83	57	120
	5%ile	3.6	2.8	5.9	3.2	6.4	3.9	2.7	5.3	3.0	6.0
	Mean	—	—	—	—	—	—	—	—	5.2	6.8
	Median	7.2	3.2	7.2	4.9	7.5	6.9	3.0	7.0	5.0	6.8
	95%ile	9.3	5.7	7.6	7.1	8.8	7.4	3.9	7.4	7.4	7.5
	SD	1.5	1.0	0.8	1.6	0.9	0.9	0.4	0.9	1.7	0.5
	CoV (%)	22.0	30	11	32	12	14	14	13	32	8
EC (mS/m)	n	175	129	83	57	120	172	128	83	57	151
	Mean	374	391	350	376	333	268	332	281	329	307
	Median	379	393	354	377	338	283	330	276	323	305
	95%ile	426	438	395	417	368	329	378	350	391	383
	SD	32	33	34	28	24.4	48	29	34	34	30
	CoV (%)	9	8	10	7	7	18	9	12	10	10
SO_4 (mg/L)	n	176	128	82	56	120	171	128	83	56	150
	Mean	2448	2846	2520	2585	2159	1636	2264	1879	2137	1960
	Median	2460	2815	2525	2541	2165	1760	2240	1870	2075	1940
	95%ile	2828	3220	2770	2950	2461	2015	2593	2148	2640	2390
	SD	262	226	193	231	220	349	245	268	274	257
	CoV (%)	11	8	8	9	10	21	11	14	13	13
Fe (mg/L)	n	33	129	83	57	114	33	128	82	57	146
	Mean	4.7	168.4	2.5	8.9	0.08	0.3	72.9	0.47	4.9	1.9
	Median	0.4	163.0	0.03	0.10	0.02	0.2	64.0	0.08	0.04	0.02
	95%ile	13.8	365.2	3.1	52.6	0.4	0.8	186.3	1.00	25.7	12.5
	SD	18.8	116.2	13.10	19.5	0.16	0.3	57.7	1.9	12.2	8.0
	CoV (%)	399	69	528	220	201	94	79	407	2518	416
Mn (mg/L)	n	34	129	83	57	113	33	128	83	57	143
	Mean	18.1	62.7	16.5	17.3	6.3	10.3	50.3	14.4	16.1	9.4
	Median	9.8	65.0	11.0	16.0	5.1	2.7	50.0	10.0	14.0	6.1
	95%ile	74.0	95.0	56.1	32.6	21.4	46.2	76.0	45.0	30.4	27.8
	SD	27.6	23.5	18.0	9.1	5.7	19.4	17.6	15.8	9.9	9.0
	CoV (%)	153	38	109	53	91	188	35	110	61	96

(1) 09/2006 – 01/2010 (2) 02/2010 – 07/2012 (3) 08/2012 – 02/2014 (4) 03/2014 – 03/2015 (5) 04/2015 – 09/2017

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 C_5 (95%ile) level and, in the case of pH, also at the C_{95} (5%ile) level. This record is scrutinised in **Section 4.3**.

Table 3 Synoptic overview of Bloubank Spruit water chemistry at station A2H049 in the period May 1979 (start of monitoring) to February 2017 (latest data as at November 2017)

Variable	Statistical Parameter							SANS
	n	5%ile	Mean	Median	95%ile	SD	CoV (%)	(2015a)(1)
pH ($-\log_{10}\alpha_{H+}$)	1070	7.4	—	8.2	8.5	0.3	4.1	5.0–9.7
EC (mS/m)	1173	51.2	64.0	61.1	102.0	21.2	33	<170
TDS (mg/L)	899	356.0	463.5	451.0	711.9	102.6	22	<1200
Ca (mg/L)	987	43.7	58.8	54.0	105.7	20	33	n.s.
Mg (mg/L)	986	25.4	33.9	32.8	50.3	7.0	21	n.s.
Na (mg/L)	955	10.1	23.7	22.7	42.6	9.5	40	<200
K (mg/L)	962	0.7	2.1	1.9	4.2	1.1	51	n.s.
Cl (mg/L)	993	20.3	32.6	32.5	42.3	6.3	19	<300
SO_4 (mg/L)	986	65.6	112.3	85.1	349.6	84.0	75	<500
HCO_3 (mg/L)	986	143.3	189.0	194.3	219.3	26.3	14	n.s.
NO_3+NO_2 (mg N/L)	1032	3.029	4.654	4.458	6.855	1.730	37	<11
PO_4 (mg P/L)	1061	0.005	0.093	0.055	0.313	0.109	117	n.s.
Si (mg/L)	1064	5.04	5.94	5.93	6.82	0.80	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 15**) and SO_4 (**Figure 16**) load pattern and trend manifested at station A2H049. The long-term monthly trend in the TDS load delivered by the Bloubank Spruit (**Figure 15**) indicates an increasing salt load (as indicated by the visually inserted arrow) since early-2007. The text box in **Figure 15** 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. This is readily attributable to the very high salt loads experienced in the 2011 hydrological year. Similar conditions (albeit slightly more muted) have prevailed in the subsequent period (August 2012 to January 2017) as indicated in **Figure 15** (text box). An evaluation of the subregional and regional temporal salt loads delivered to Hartbeespoort Dam is presented by Hobbs (2017b). The most salient observation in this regard is that moderately saline poor-quality mine water actively draining from the Western Basin exhibits a negligible impact on the TDS load reporting to Hartbeespoort Dam, irrespective of the volume of mine water discharge.

The long-term monthly trend in the SO_4 load delivered by the Bloubank Spruit (**Figure 16**) mimics the TDS load pattern (**Figure 15**) 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 February 2017) exhibits a substantially higher median value of 903 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 17** and **Figure 18**, which reflect more recent SO_4**:**TDS ratio values in the range 45 to 50%.

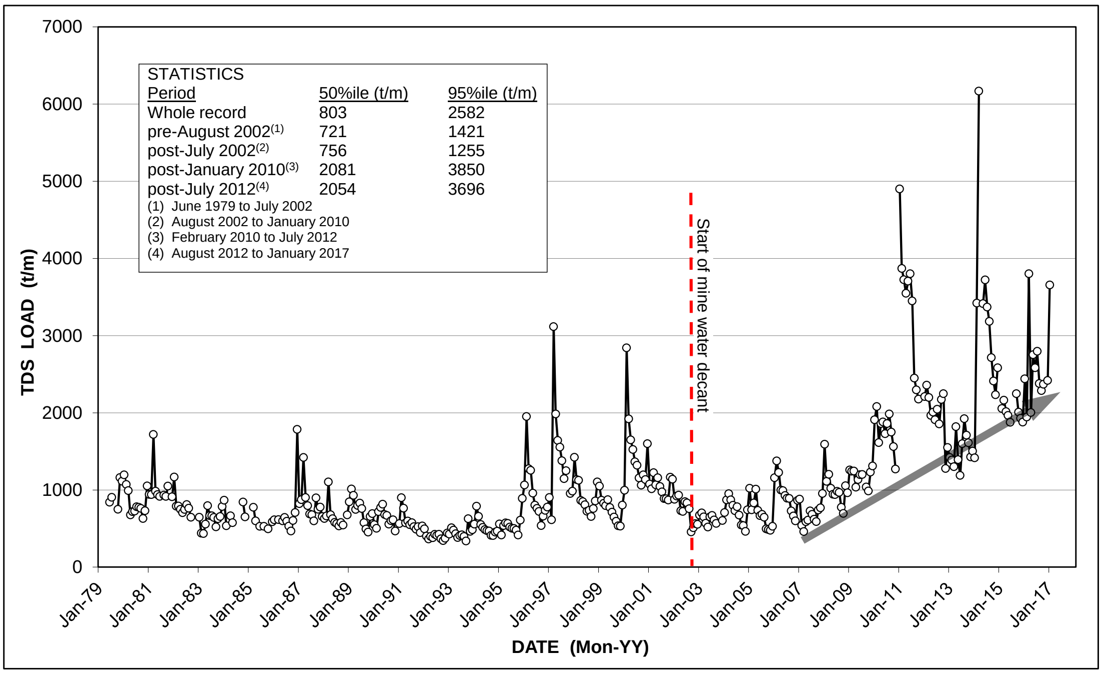

Figure 15 Long-term (June 1979 to January 2017) monthly TDS load pattern and trend in the Bloubank Spruit at station A2H049

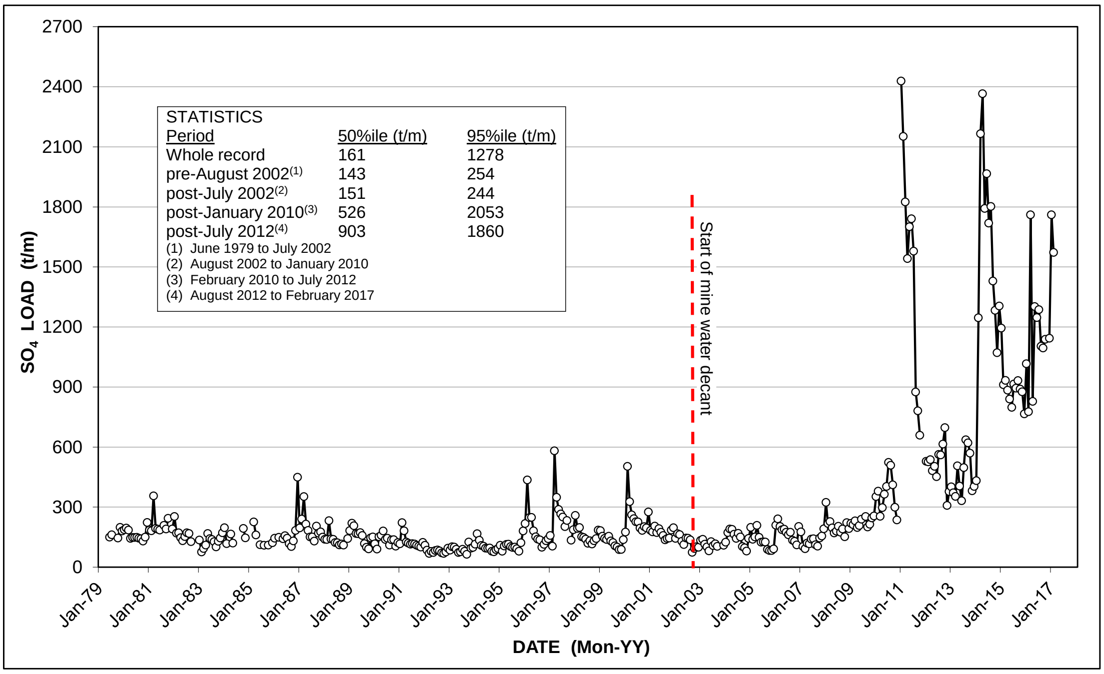

Figure 16 Long-term (June 1979 to February 2017) monthly SO_4 load pattern and trend in the Bloubank Spruit at station A2H049

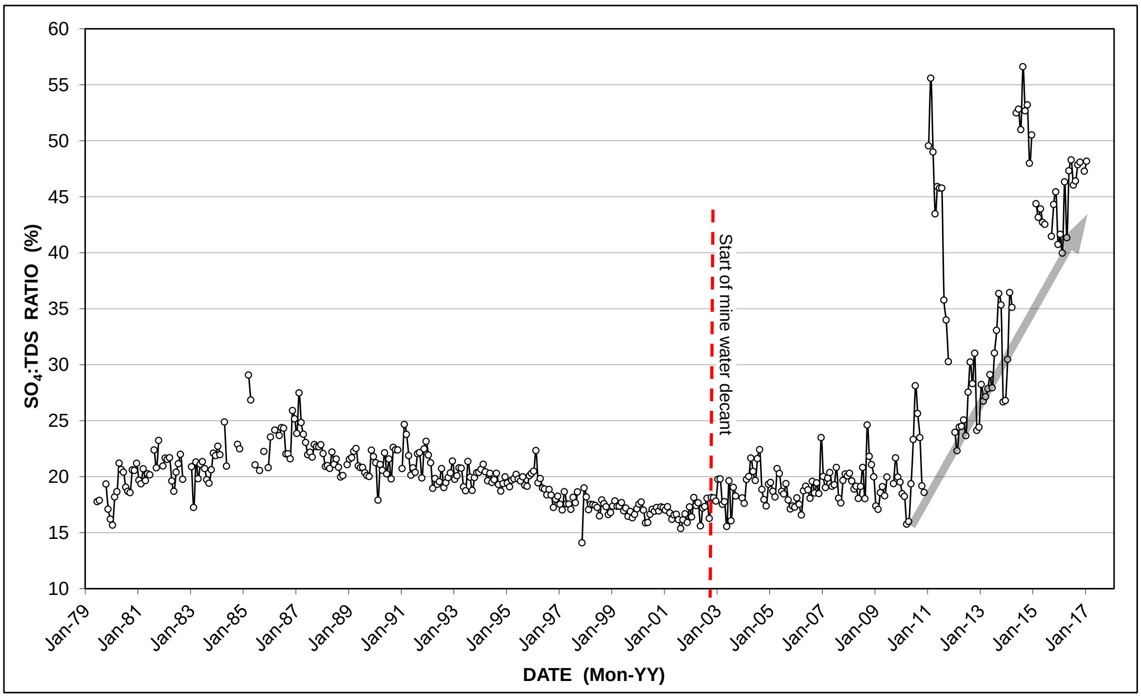

Figure 17 Long-term (June 1979 to January 2017) trend in the SO_4:TDS ratio at station A2H049

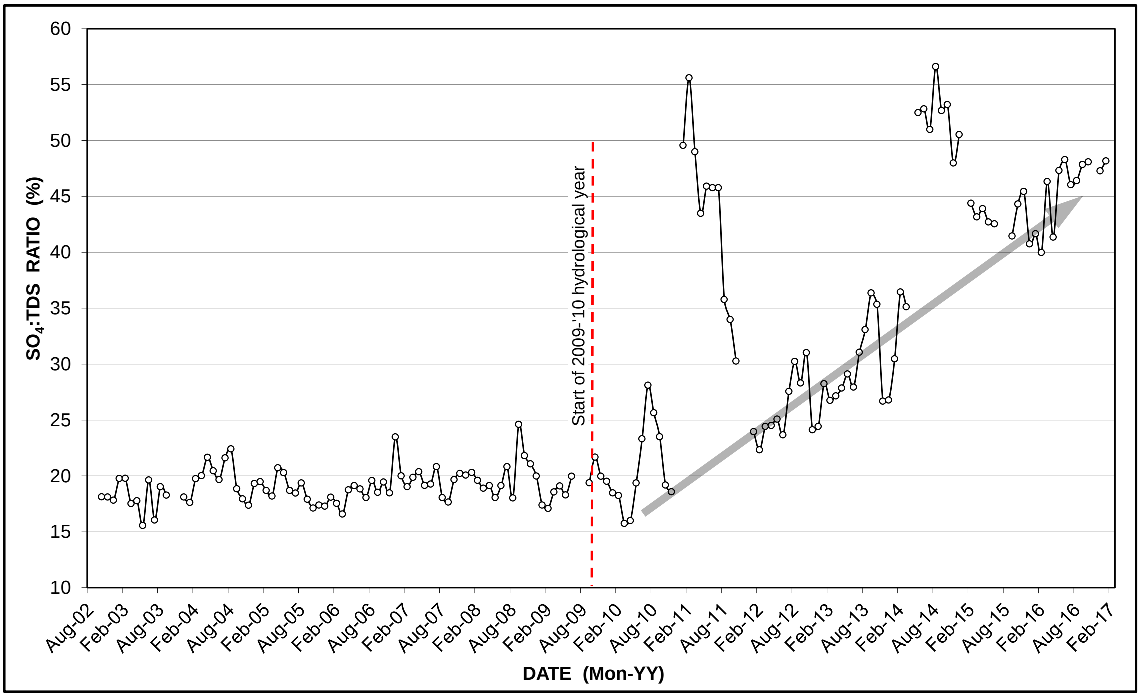

Figure 18 Pattern and trend of the SO_4:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin in mid-2002

The closer inspection in **Figure 19** 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 SO_4 concentration in the range ~350 to ~450 mg/L for the last part of the record (since August 2014) explains the contemporary higher sulfate loads.

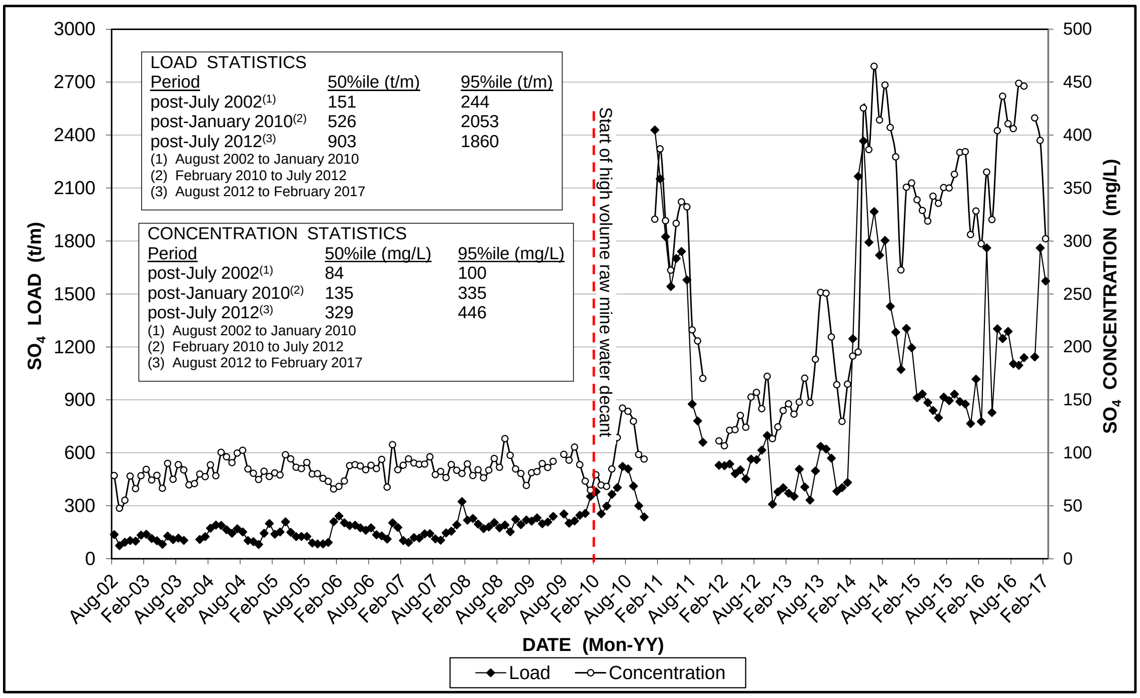

Figure 19 Monthly SO_4 concentration and load pattern and trend in the Bloubank Spruit at station A2H049 since mid-2002

5 GROUNDWATER HYDROLOGY

5.1 Physical Hydrogeology

5.1.1 Monitoring Framework

An inspection of the more recent potentiometric response in DWS monitoring boreholes located downstream of the mine area is presented in **Figure 20.** 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 Subregional Groundwater levels

The groundwater hydrographs presented in **Figure 20** reflect little change in the reporting period.

5.1.3 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 (Hobbs and de Meillon, 2017).

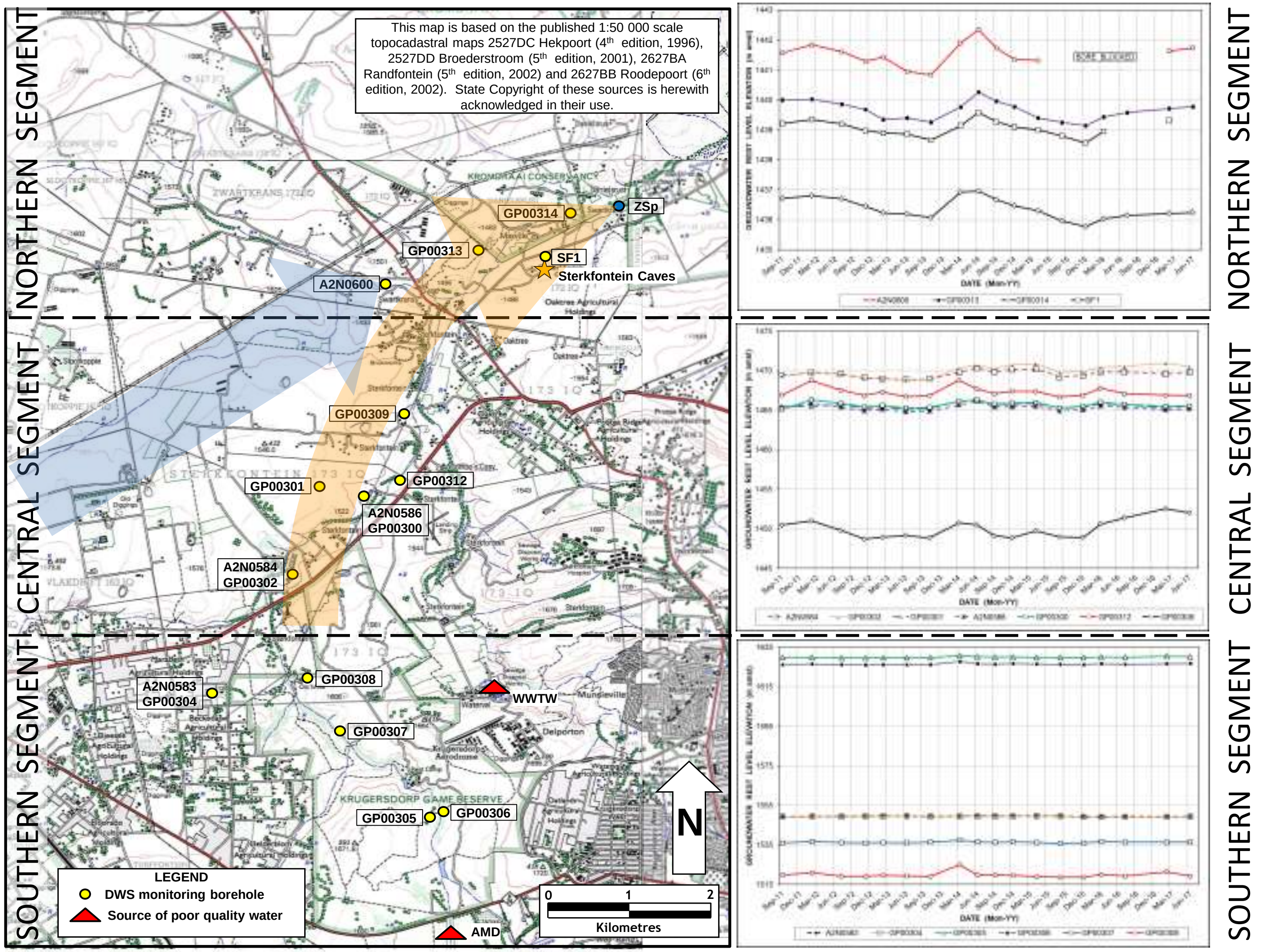

Figure 20 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

The cave water level as represented by the groundwater rest level measured in borehole SF1 on the cave property was not monitored in the reporting period. **Figure 21** therefore reflects the situation as at the end of the previous reporting period (Hobbs, 2017a). It is expected that water level would have dropped slightly in the reporting period.

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 Basin. This is premised on the greater sustained discharge of treated/neutralised mine water associated with the immediate and short-term AMD control and management interventions in the Western Basin (DWA, 2011).

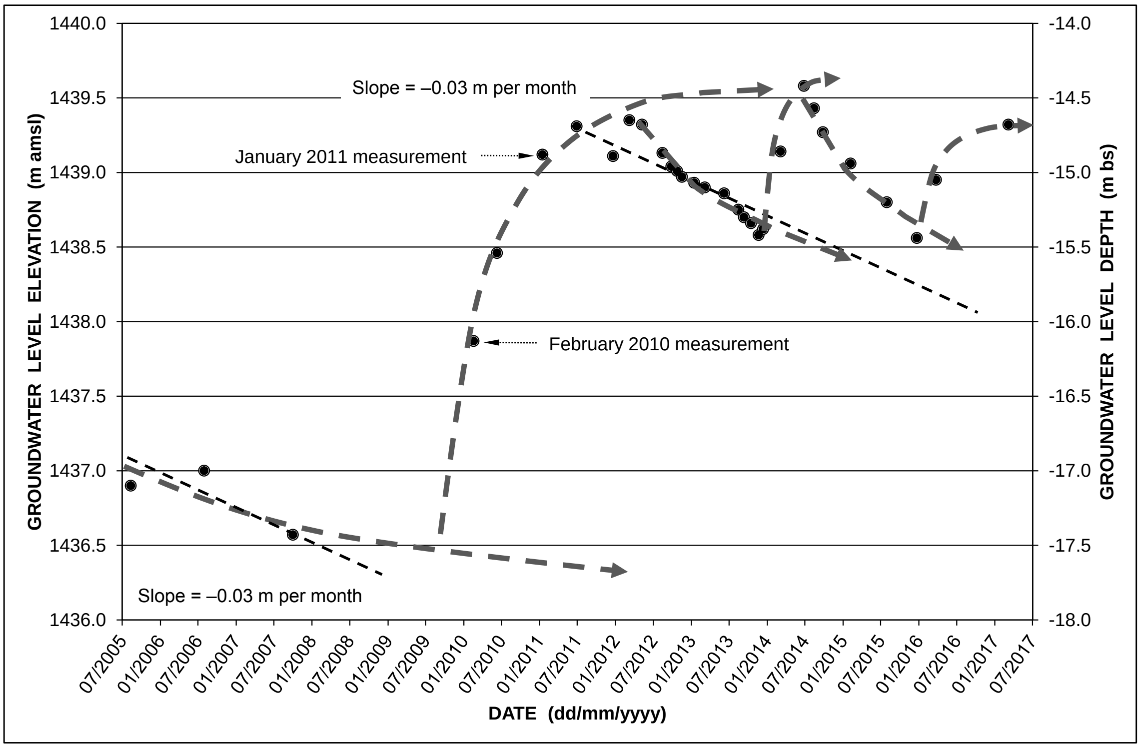

Figure 21 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the lake water level in Sterkfontein Cave

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 22** and **Figure 23**. 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, 2017a). The groundwater chemistry data generated by the monitoring programme in the Zwartkrans Basin 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 22** and **Figure 23** with the aid of bar graphs for the chemical variables pH and EC respectively.

The bar graphs in **Figure 22** 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 (February 2017) values, but remain in the range 6.5 to 8. The pH values in the central segment bracket the range 6.5 to 7.5, and those in the northern segment the range 7.3 to 7.8.

The bar graphs in **Figure 23** 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. The recent salinity is constrained to the range 200 to 250 mS/m. In the northern segment, 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 recent salinity is constrained to the range 100 to 150 mS/m.

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 24**. The latter figure provides an indication of the extent of this impact, as well as the salinity (EC) trend at each monitoring station in terms of up, stable or down in the recent past, by comparison of the July 2016, February 2017 and June 2017 values. The comparison indicates the salinity levels in ambient groundwater have stabilised in the last year even at the stations GP00314 and ZSp at the north-eastern (discharge) end of the Zwartkrans Basin.

6 OBSERVATIONS AND CONCLUSIONS

The karst environment of a portion of the Zwartkrans Basin 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 2017 summer season experienced a high rainfall of ~864 mm, but this has yet to translate into an abnormal catchment discharge as at January 2017.

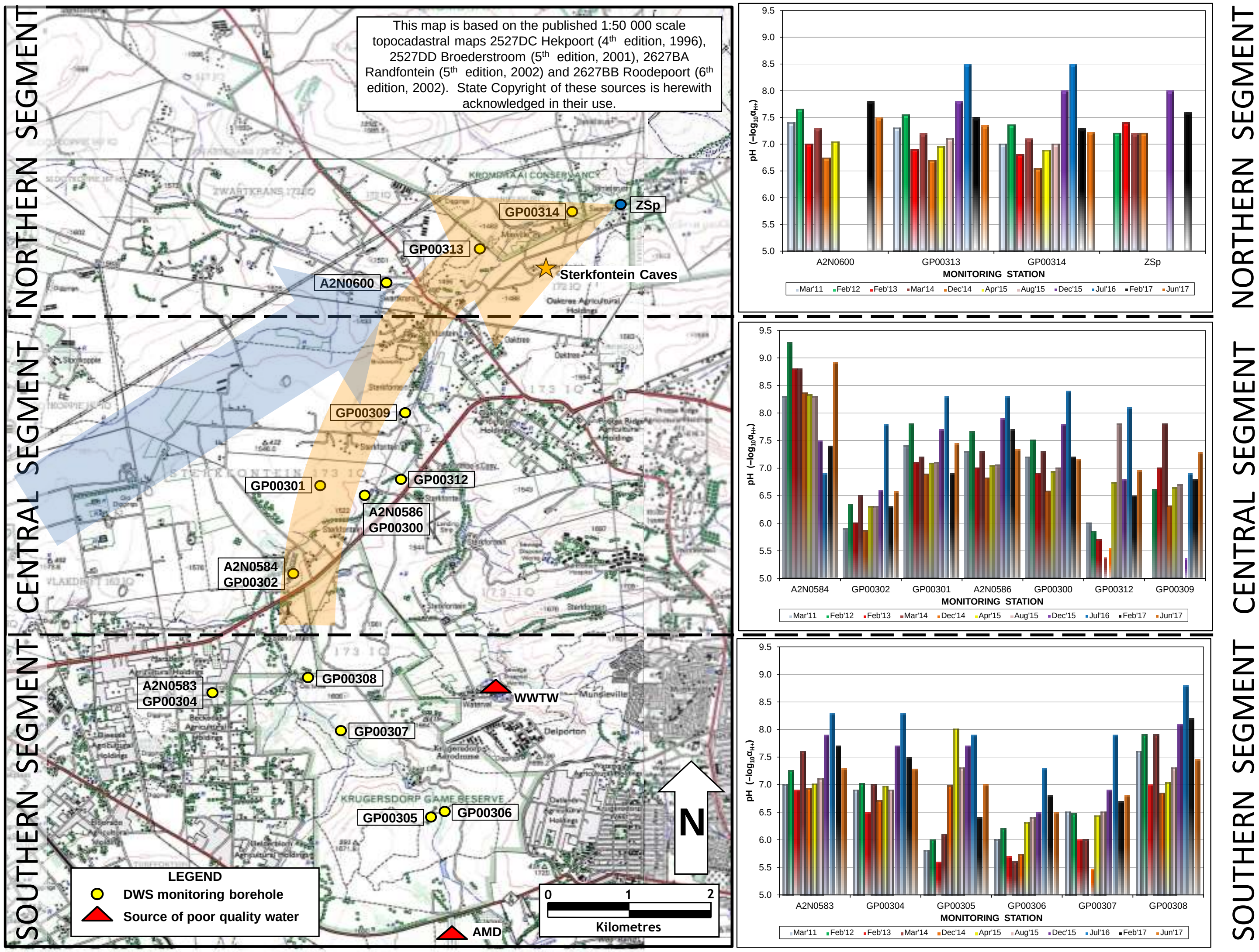

Figure 22 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

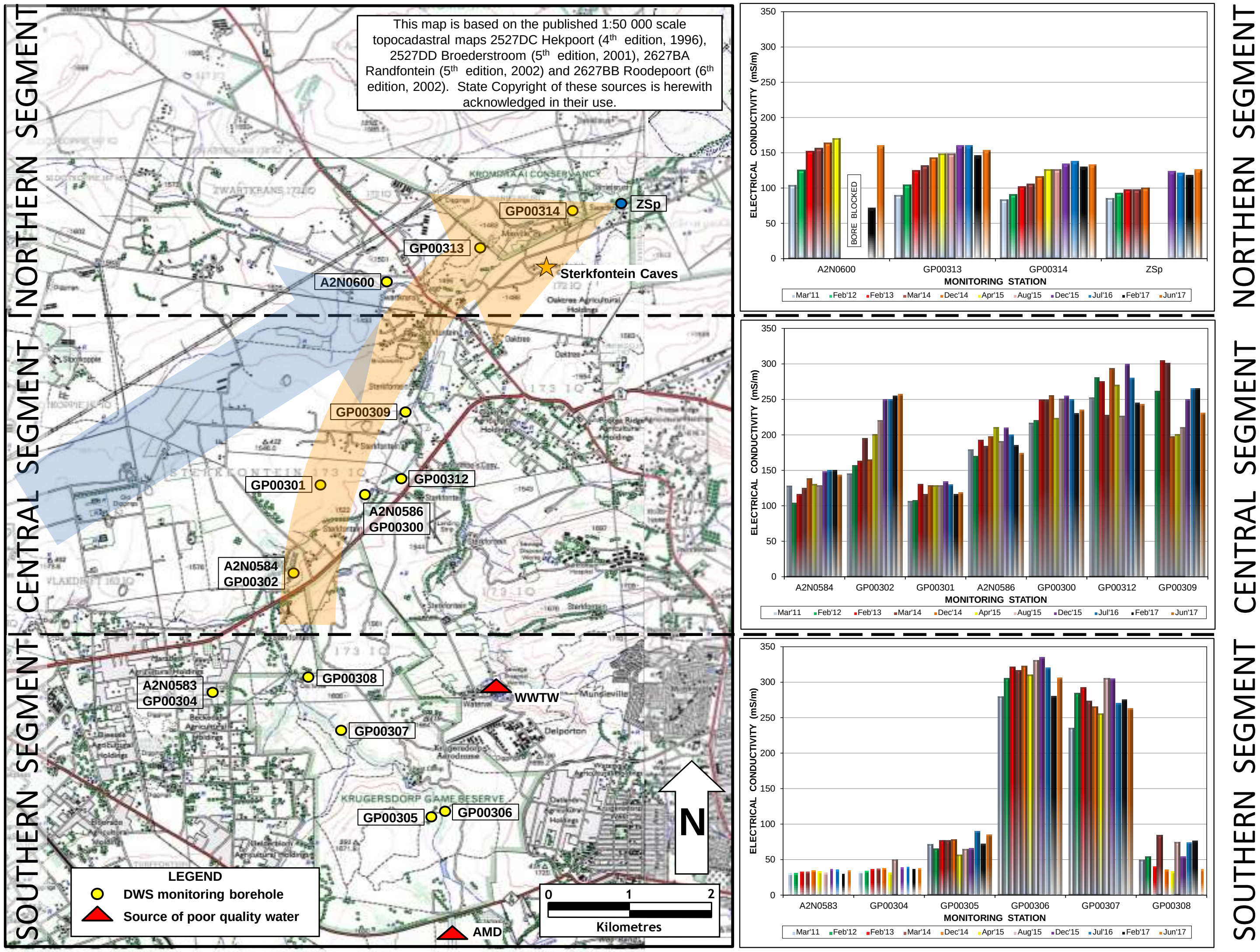

Figure 23 Distribution of DWS monitoring boreholes with EC pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

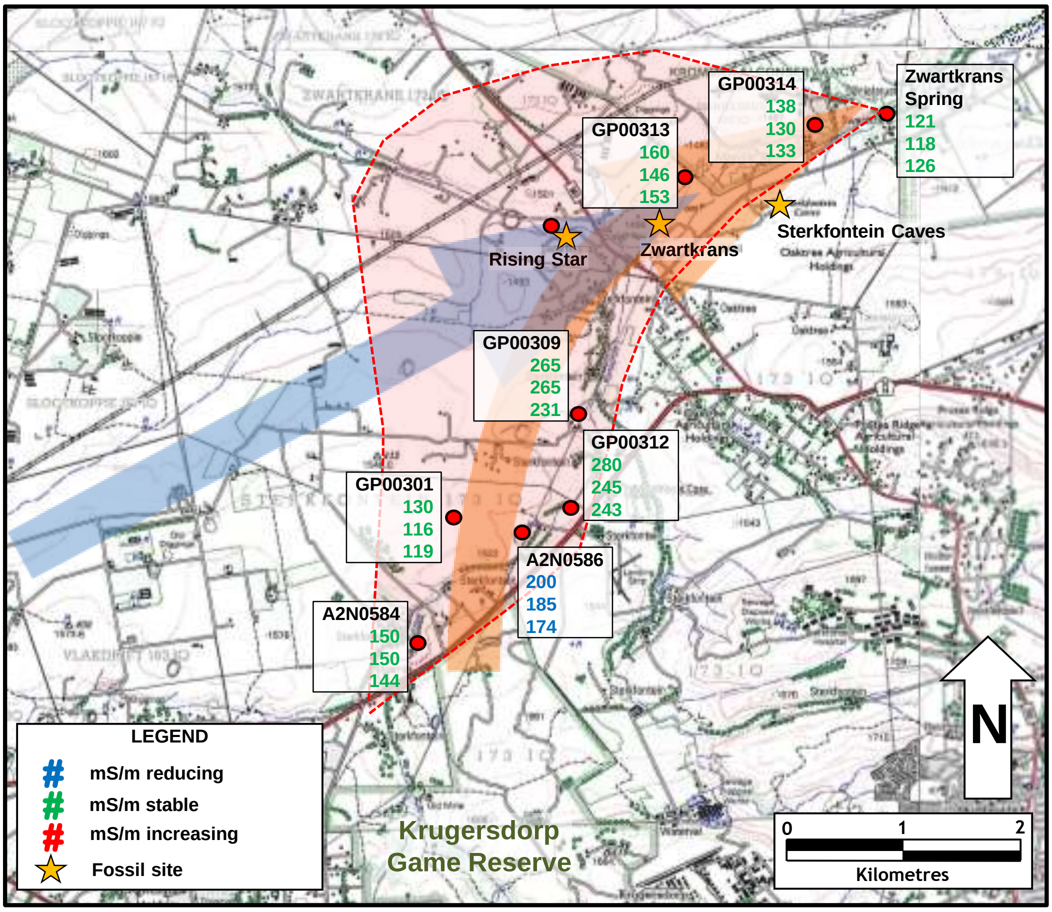

Figure 24 Distribution of salinity (EC) levels in groundwater of the Zwartkrans Basin in July 2016 (1st value), February 2017 (2nd value) and June 2017 (3rd value), also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow), the postulated footprint (shaded area) of a mine water impact in the karst aquifer, and EC trend as INCREASING (red text), STABLE (green text) or REDUCING (blue text)

- The 2017 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 2010.

- 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 Basin.

- The groundwater elevation in the south-western portion of the property (the Zwartkrans Basin) 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 Basin) 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 24**).

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 has been made possible in part by the continued collection of field data by the DWS field personnel Messrs Theo Moolman and Nico de Meillon. The services of the DWS staff Ms Marica Erasmus (Resource Quality Information Services), Ms Busisiwe Sekgomane (PDA Requests) and Ms Edeline Mashabela (Hydstra Support) in the provision of water resources monitoring data is also recognised and appreciated. Messrs Johan Wagner and Gerardo Pretorius of Sibanye-Stillwater, and Mr Themba Ngomane of the Trans-Caledon Tunnel Authority, are thanked for the provision of mine water and rainfall data associated with the mine area. 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.

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ANNEXURE

EXCERPT FROM DOCUMENT WHC/1/17/41.COM/7B

Draft Decision: 41 COM 7B.72

The World Heritage Committee,

1. *Having examined Document WHC/17/41.COM/72,*

2. *Recalling Decision **39 COM 7B.44**, adopted at its 39th session (Bonn, 2015),*

3. *Notes that the water monitoring programme has been effective in confirming that the main areas of high water pollution are located in the south west part of the property, but expresses concern that the polluted effluent from the current water treatment plant continues to present a high risk to fossil sites;*

4. *Also notes the arrangements for water management within the property, and reiterates its request to the State Party to provide more detailed information on:*
   a) *Water quality targets,*
   b) *The overall management framework of the property, including an update on the State Party's engagement with stakeholders;*

5. *Requests the State Party to prepare a risk prevention strategy for the vulnerable fossil sites and submit it to the World Heritage Centre, for review by the Advisory Bodies;*

6. *Welcomes the approval in principle given in May 2016 for the development of the second phase of the Western Basin treatment work project, which will improve the quality of water effluent, thus reducing the threat to the fossil remains, and also reiterates its request to the State Party to submit the design specifications for the project and an Environmental Impact Assessment (EIA) to the World Heritage Centre for review by the Advisory Bodies, as soon as they are available, and by **1 December 2017** at the latest, and before the parameters of the project have been determined and a construction contract awarded, in order that the review can inform the project;*

7. *Also requests the State Party to submit to the World Heritage Centre, by **1 February 2018**, a progress report, and by **1 December 2018**, an updated report on the state of conservation of the property and the implementation of the above, for examination by the World Heritage Committee at its 43rd session in 2019.*