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 2017 TO MARCH 2018

PROJECT No.

GT/GDED/092/2017

AUTHORS

P. Hobbs, L. Hill and P. McMillan

DATE

MARCH 2018

REPORT No.

CSIR/NRE/WR/ER/2018/0010/A

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PREPARED FOR

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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 eleven (11) bi-annual status quo reports. This document represents the twelfth (12^{th}) such report. It covers the timeframe April 2017 to March 2018.

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 (a.k.a. acid mine/rock drainage) rising in the Western Basin, and municipal effluent discharged from Mogale City's 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. The 40.6 Mm^3 closely approximates the median value of 41.4 Mm^3 for the last 8 years. The 2017 hydrological year therefore ranks 5^{th} out of 8 after 2010, 2011, 2012 and 2014, and can be classified as an 'average' runoff year.

- The 2018 wet season rainfall so far (excluding March) amounts to 601 mm in the mine area and 418 mm at Sterkfontein Cave. These values are 10% and 26% lower, respectively, than the means of the last 8 years of record common to both stations. The heavy widespread rainfall of 21, 22 and 23 March will no doubt erase this deficit, perhaps even turning the 2018 summer into one of the wetter (maybe even the wettest) in the last eight years.

- Chemical analyses of rainwater in the south-western portion of the property confirm the very low salinity (specific electrical conductance or SEC ≤15 mS/m) of this water. The results represent a mixture of precipitation events over a period of ~2 months ending early-December, and therefore are not representative of specific events. This influences especially the veracity of the pH values, which range from 6.4 to 7.5.

- The average 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 12 months, and in SEC 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 a slight decline that is most noticeable in the Sterkfontein Cave lake water level.

- 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 sulfate levels over the last year indicates that these have decreased slightly in the 'upstream' portion where ingress occurs, and increased slightly at the north-eastern discharge end of the Zwartkrans Basin.

- Severe bacteriological contamination from the municipal wastewater treatment works via the Blougat Spruit into the Bloubank Spruit is reflected in total coliform and *E. coli* values that routinely exceed a most probable number (MPN) count of 2419.6 per 100 mL. These counts on occasion reach values of 10's of thousand. It can be argued that the municipal wastewater poses an equally dire threat to the fitness for use of receiving surface water resources as does mine water. This threat extends into the Crocodile River as main stem of the Bloubank Spruit.

- The macroinvertebrate monitoring survey reveals the substantial difference in biotic condition between the nearly pristine Skeerpoort River and the severely impacted Bloubank Spruit system. This is best evidenced by the A and C ecological category of the Skeerpoort River sites versus the D and E/F category of the Bloubank Spruit sites. The Skeerpoort River results are similar to those reported in previous external studies, indicating little change in the health of this drainage. The Bloubank Spruit results reveal an improvement in category from E/F to D in a downstream direction. A comparison with previous results indicate a greater deterioration at the upstream site versus the marginal deterioration at the downstream site.

It is concluded that the water resources monitoring results documented in this report continues to confirm and consolidate the conceptual hydrophysical and hydrochemical model developed for the COH property in the situation assessment report. The inclusion of macroinvertebrate monitoring results adds to the rigour and substance of the water resources monitoring programme.

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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
ASPT	average score per taxon
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 (a.k.a. ‘the property’)
CoV	coefficient of variation
CPOM	coarse particulate organic matter
CSIR	Council for Scientific and Industrial Research
DWS	Department of Water & Sanitation [formerly the Department of Water Affairs (DWA)]
EC	electrical conductivity
EoP	end-of-pipe
FFG	functional feeding group
FPOM	fine particulate organic matter
HDS	high density sludge
IHAS	integrated habitat assessment system
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)
SASS	South African Scoring System
SD	standard deviation
SDM	synoptic discharge measurement
SEC	specific electrical conductance (electrical conductivity or EC @ 25°C)
SOC	State of Conservation
SRP	strategic research project
SS	Sibanye-Stillwater (formerly SibanyeGold and current owner of the original REGM)
TCTA	Trans-Caledon Tunnel Authority
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency
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 eleven (11) bi-annual status quo reports (Hobbs, 2012; 2013a; 2013b; 2014a; 2014b; 2015a; 2015b; 2016a; 2016b; 2017a; 2017b). This document represents the twelfth (12th) such report. It covers the period April 2017 to March 2018.

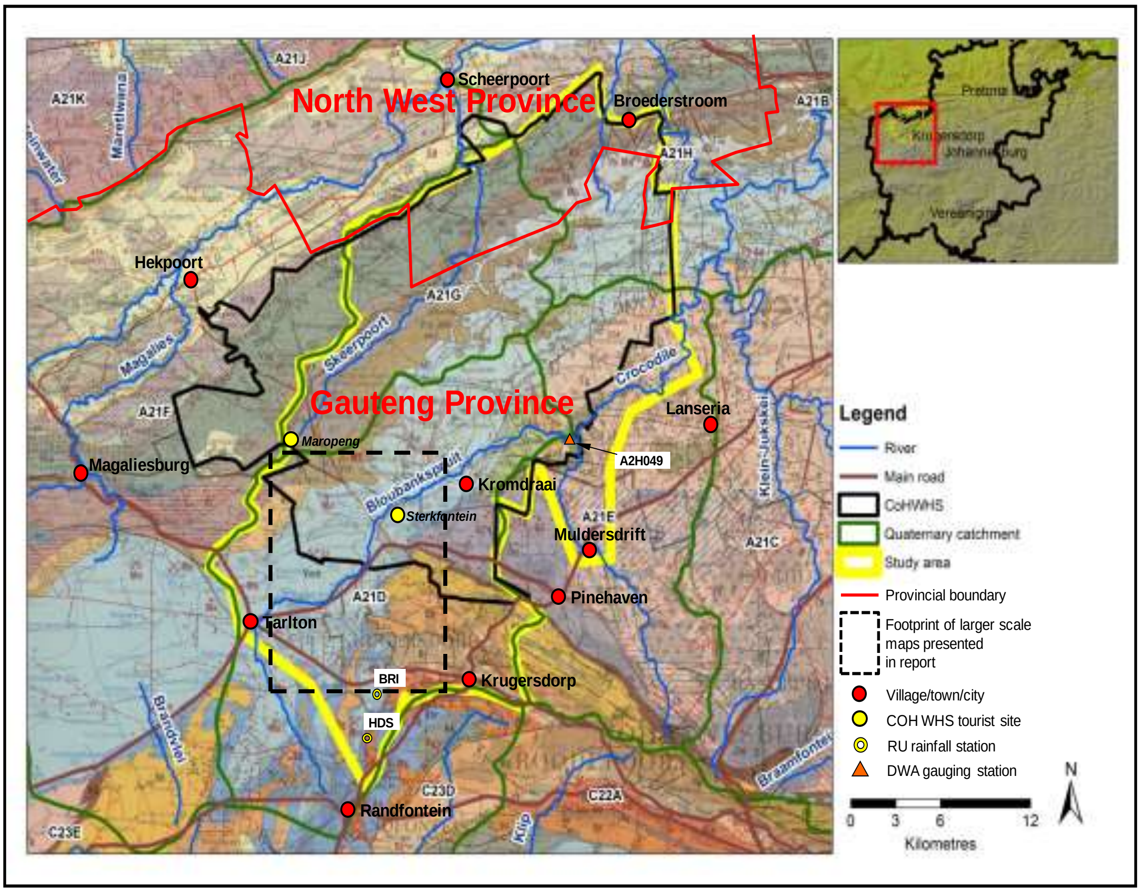

Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

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 41st session held in Vienna in mid-2017. The outcome of this examination 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. In this regard, the presentation of the results of an aquatic biomonitoring survey in this report (**Section 6**) represents the first time that the biotic condition of the major drainages on the property is addressed. Progress with the resolution of the WHC's specific concerns will be documented in forthcoming State of Conservation reports.

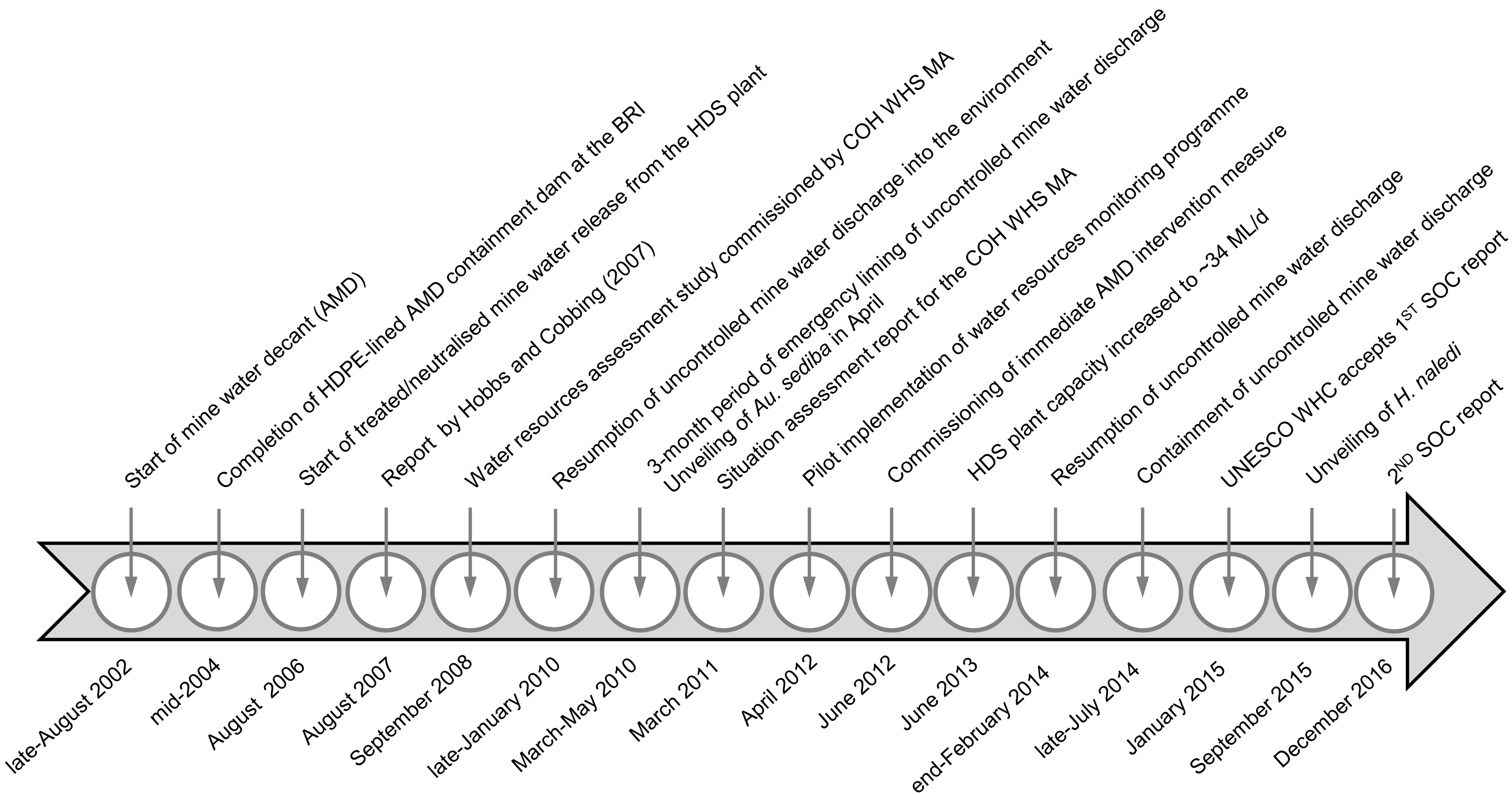

Figure 2 Timeline of key events relevant to the project and this report

3 RAINFALL

3.1 Quantity

The monthly precipitation record for the period October 2008 to February 2018 at the Sibanye-Stillwater (SS) [formerly Sibanye Gold (SG)] rainfall station HDS on the divide at the water treatment plant in the mine area, and station SC at the Sterkfontein Cave ~13 km to the north, 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 year (a_h) — 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, 418 mm was recorded in the period October 2017 to February 2018 — this is 172 mm less than the 590 mm recorded in the same period a year earlier, but the heavy widespread rainfall of 21, 22 and 23 March will no doubt erase this deficit, perhaps even turning the 2018 summer into one of the wetter (maybe even the wettest) in the last eight years;
- by comparison and similarly, the 601 mm recorded in the mine area is 221 mm less than the 822 mm recorded in the period October 2016 to February 2017, and will again most likely be erased by the late-March rainfall.

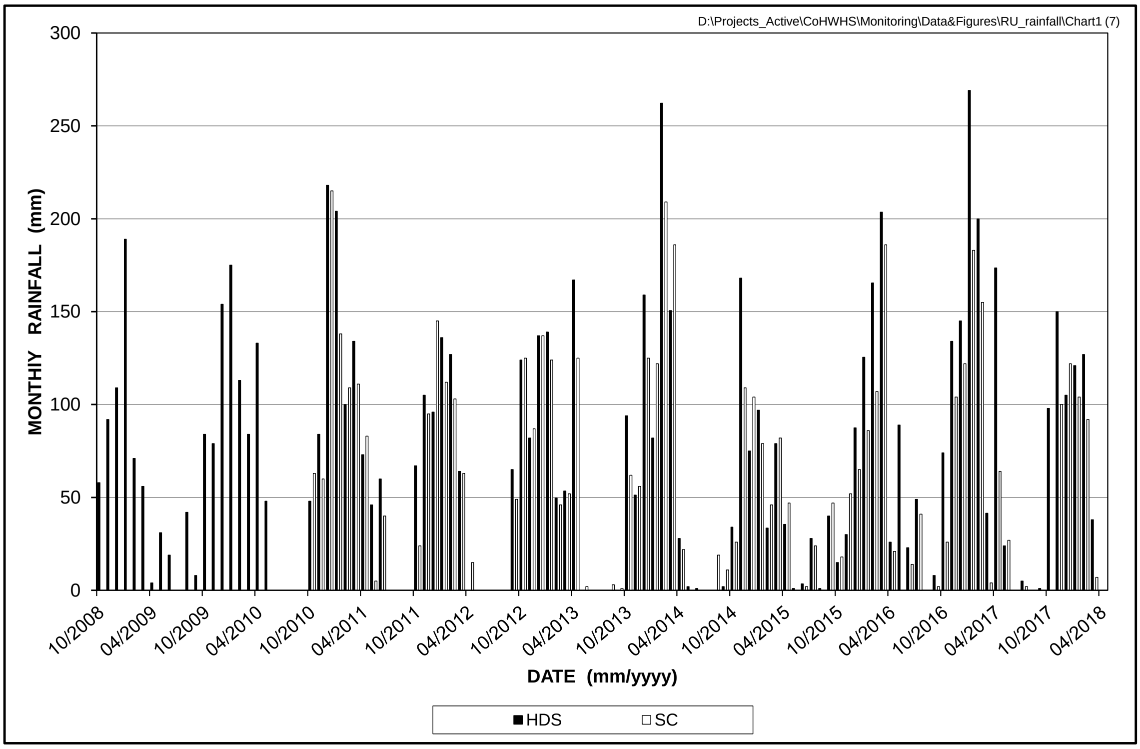

Figure 3 Monthly precipitation in the mine area (station HDS) from October 2008 to February 2018, and the contemporaneous record for the Sterkfontein Cave station from June 2010 to February 2018

The common monthly rainfall record for the HDS and Sterkfontein Cave stations is presented in **Figure 5**. The data set (n = 93) excludes months of no rainfall (n = 17) at both stations in order to remove the false correlation created by common null values, and shows a good correlation (R^2 = 0.84, p <0.01). Station SC experiences ~21% less rainfall on a monthly basis than station HDS.

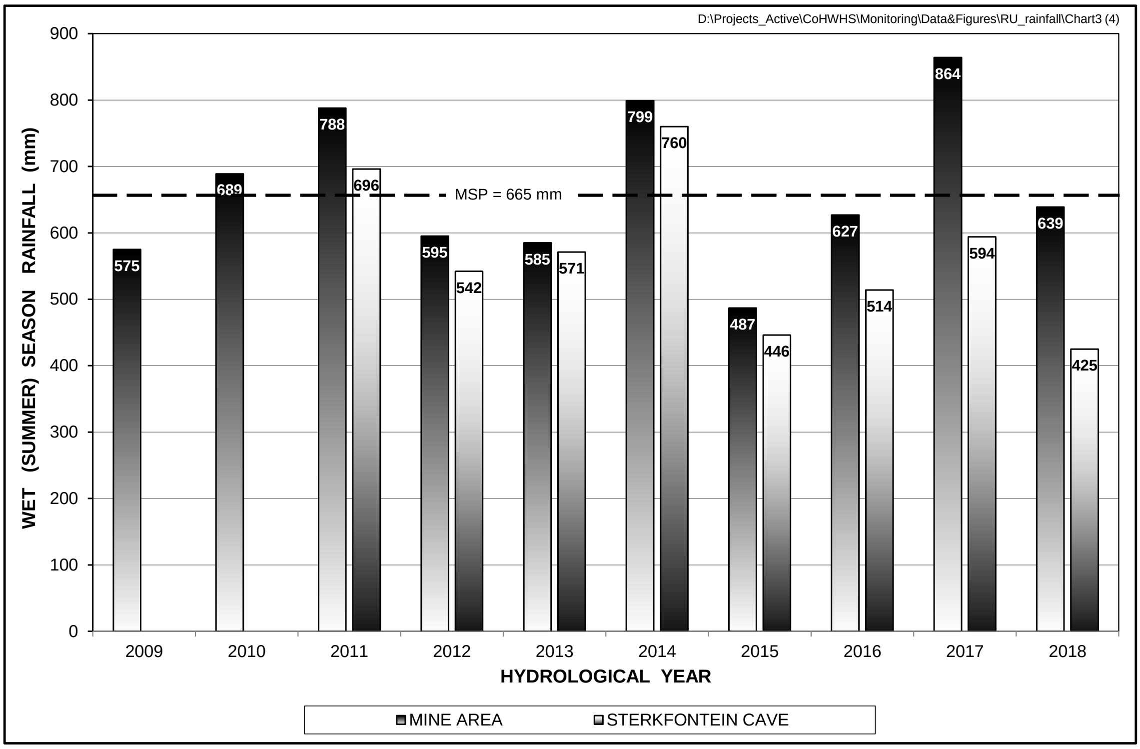

Figure 4 Total wet season (summer) rainfall in the mine area (HDS station) in the past ten hydrological years (2018 excludes March), also showing the comparison with that for the available contemporaneous Sterkfontein Cave record; MSP denotes mean summer precipitation

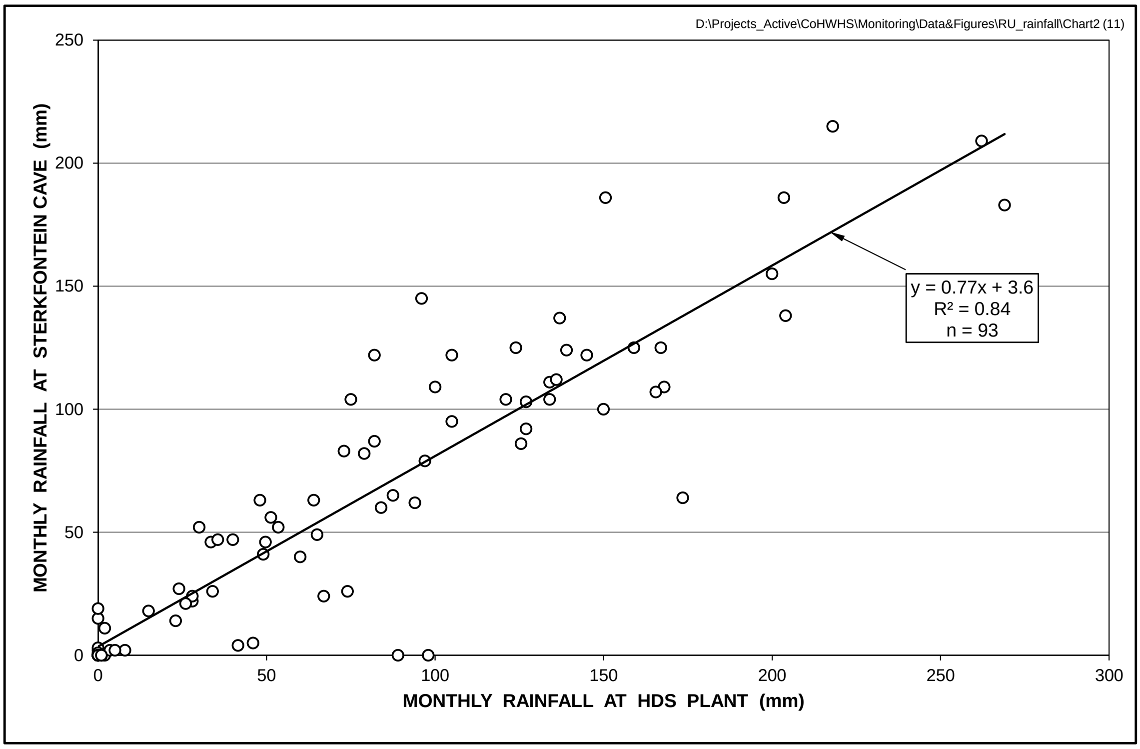

Figure 5 Correlation of monthly rainfall at Sterkfontein Cave with that at the HDS mine water treatment plant in the mine area for the period of common record June 2010 to February 2018

3.2 Quality

The chemical composition of rainwater in the south-western portion of the property is reflected in the samples obtained from four (4) totalling rainfall stations (**Figure 27**). The stations are operated and maintained by the Department of Water and Sanitation (DWS). They have a rainfall equivalent capacity of ~450 mm, and are therefore typically emptied every 2 to 4 months depending on season. These circumstances dictate that the chemistry of the collected rainwater represents a mixture of that contributed by the various precipitation events in the period of collection. The results are therefore not representative of specific events, a factor that cautions against the typicality of the laboratory-determined pH values. The most recent water chemistry results are presented in **Table 1**. These mainly confirm the very low salinity of rainwater in the region. Inter-station differences in total dissolved solids, sulfate and total alkalinity levels are not readily explained on the basis of the current understanding of temporal rainwater quality and distribution in the region.

Table 1 Composite rainwater chemistry in the south-western portion of the property in the period late-October to early-December 2017

Variable/analyte	**Unit**	**Rainfall Station**			
		HDS[1]	**GP00303**[2]	**GP00301**[3]	**SC**[4]
Total dissolved solids	mg/L	19	19	77	96
Specific electrical conductance*	mS/m @ 25°C	3	3	12	15
pH*	$-\log_{10}\alpha_{H+}$	6.6	6.4	7.5	7.0
Calcium	mg Ca/L	1.4	0.7	1.0	3.2
Magnesium	mg Mg/L	0.1	0.2	0.3	1.1
Sodium	mg Na/L	<0.1	<0.1	<0.1	1.3
Potassium	mg K/L	1	1	2.9	2.2
Chloride	mg Cl/L	<0.5	<0.5	0.8	3.1
Sulfate	mg SO_4/L	6.4	7.4	10	18
Total alkalinity	mg $CaCO_3$/L	5.1	3.6	35	38
Nitrate + nitrite	mg N/L	1.1	0.9	0.4	<0.1

* Laboratory values
1 At the high density sludge plant in the mine area
2 At monitoring borehole GP00303, Vlakplaats 160IQ, Tarlton
3 At monitoring borehole GP00301, Sterkfontein 173IQ
4 At Sterkfontein Cave

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 2**.

The discharge per hydrological year shown in **Figure 6** indicates that the 2017 hydrological year produced a modest discharge of 40.6 Mm^3. This is similar to the median value of 41.4 Mm^3 for the last 8 years. Discharge for only the first quarter (October to December 2017) of the 2018 hydrological year is available. The total 2018 1st quarter discharge (9.6 Mm^3) is marginally greater than the median discharge (9.3 Mm^3) for the same period in the last nine (9) years.

Table 2 Statistical analysis of Bloubank Spruit monthly discharge data gauged at station A2H049 in the period October 1972 to December 2017 (latest data as at March 2018)

Variable	Month											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	44	44	45	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	0.792	0.867	1.044	1.097	0.901	1.066	1.187	0.998	0.964	0.961	0.921	0.802
Mean	1.903	1.909	2.305	2.745	2.702	3.031	2.436	2.297	2.103	2.086	1.961	1.804
Median	1.684	1.745	2.092	2.471	2.222	2.534	1.987	1.925	1.797	1.695	1.676	1.561
95%ile	3.799	2.952	4.488	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	0.930	0.834	1.099	1.931	1.932	2.208	1.301	1.197	0.976	0.944	0.876	0.883
CoV (%)	48.9	43.7	47.7	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

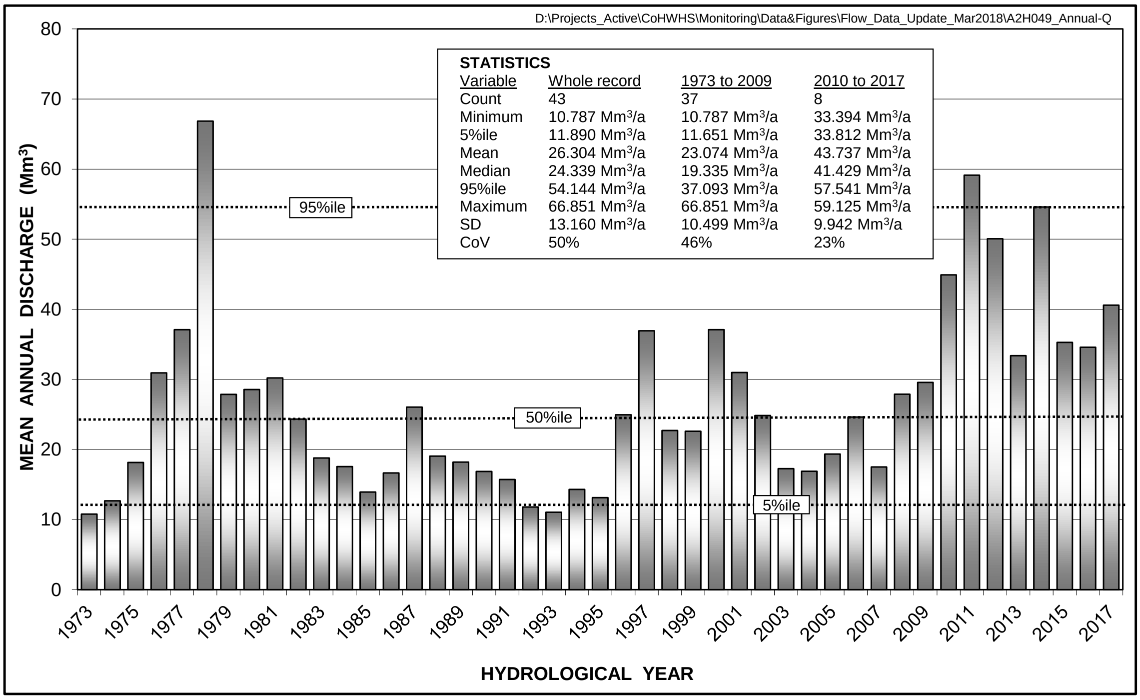

Figure 6 Graph of Bloubank Spruit annual discharge gauged at station A2H049 for the period October 1972 (a_h 1973) to September 2017 (a_h 2017)

The instantaneous monthly flow pattern at station A2H049 for the complete available record period October 1972 to December 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.

Despite 2017 being the wettest year in the last nine years, it only produced the 3rd greatest instantaneous 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**). As reported by Hobbs (2017b), this suggests that the rainfall associated with this discharge was spread out over the hydrological year rather than concentrated in a few months.

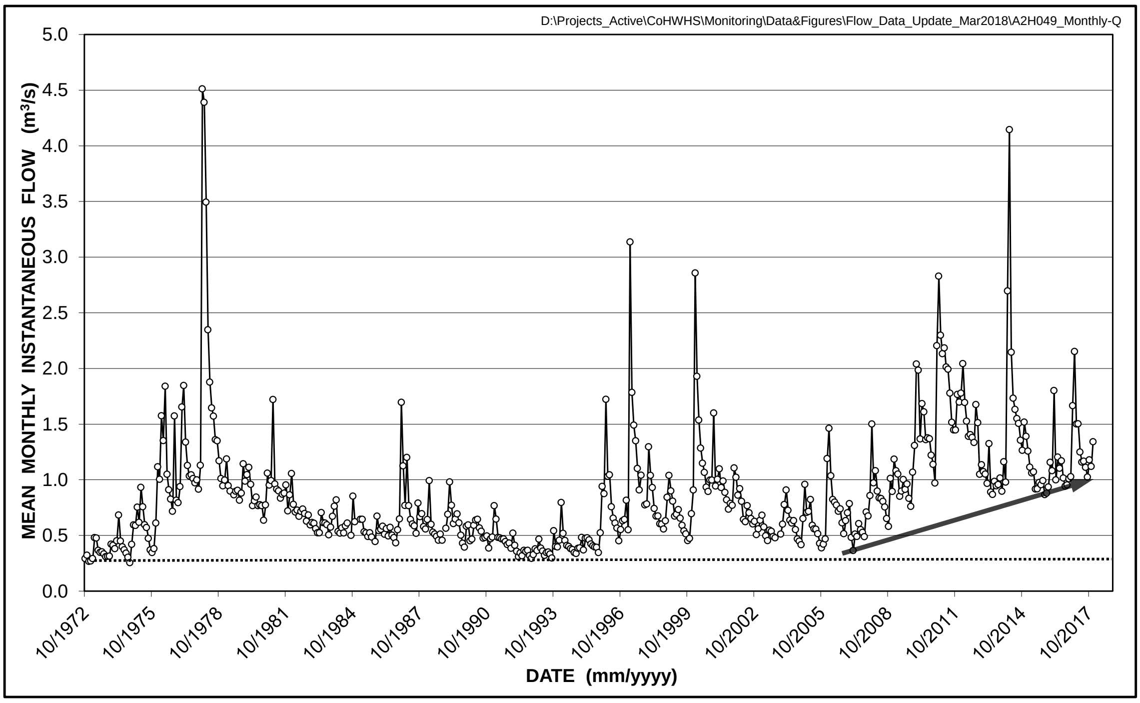

Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to December 2017 (latest data as at March 2018)

4.1.2 Surface Water Fluxes

Streamflow 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 10**) quantify the magnitude of surface water loss to the karst aquifer. The updated record of these measurements (**Figure 8**) shows a recent loss of 29.1 ML/d. This is similar in magnitude to the losses experienced in Period 2 of the record, and exceed by 60% the greatest loss experienced in Period 3. The correlation with the Period 2 data set is confirmed in **Figure 9**. It is also notable that the December 2017 discharge (50.6 ML/d) at station F11S12 (the surface 'inflow') is the greatest measured in the complete record. This might indicate an increased discharge from the mine water treatment plant. Equally notable is that the December 2017 discharge (21.5 ML/d) at station MRd (the surface 'outflow') is also the greatest in the whole record. This again emphasises the increasing importance of the treated/neutralised mine water contribution as an allogenic component of downstream surface flow in the Bloubank Spruit system recognised by Hobbs (2017a).

4.2 Chemical Hydrology

4.2.1 Mine Water Impact

4.2.1.1 Tweelopie Spruit / 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 (**Figure 10**) 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. The monitoring of the variables pH, electrical conductivity (EC) and sulfate (SO_4) dates back to May 2004. The results for two of these stations, namely the (upstream) Hippo and (downstream) Brickworks (F11S12) dams, are presented in **Figure 11** (pH), **Figure 12** (SEC), **Figure 13**

(SO_4), **Figure 14** (Fe), **Figure 15** (Mn) and **Figure 16** (U). The 'upstream' and 'downstream' positions of these stations renders the results of the other three stations superfluous for the purposes of this report.

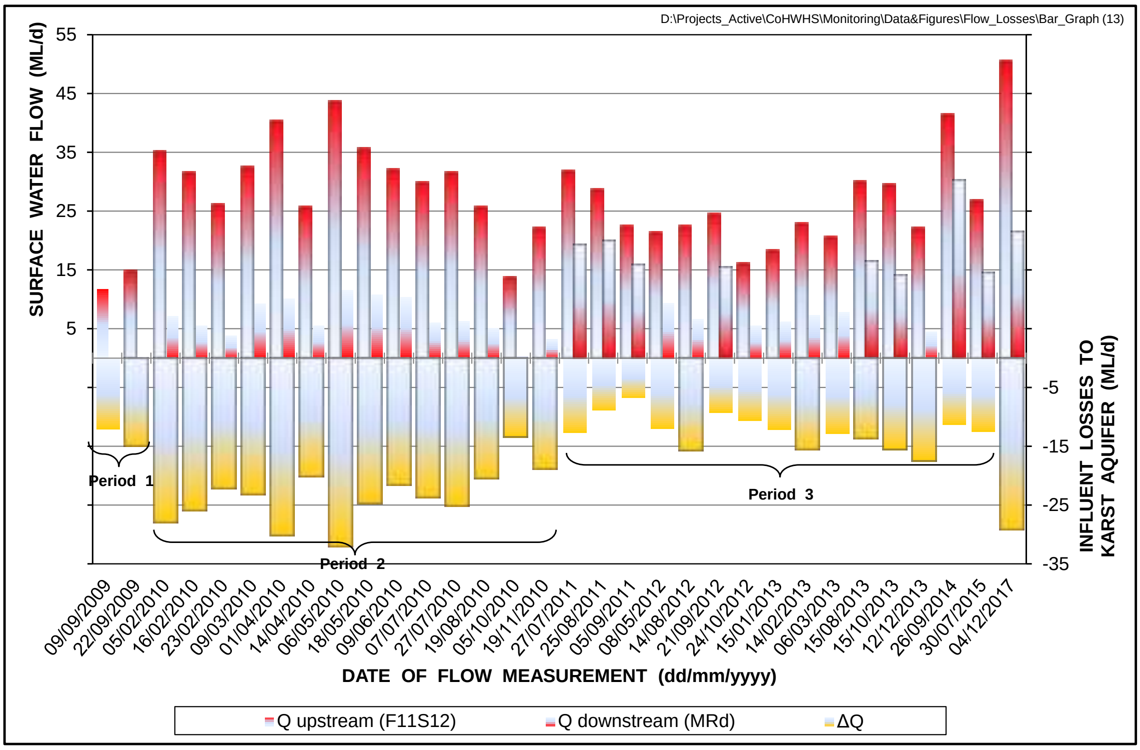

Figure 8 Graph of streamflow and influent losses to the karst aquifer in the lower Riet Spruit valley

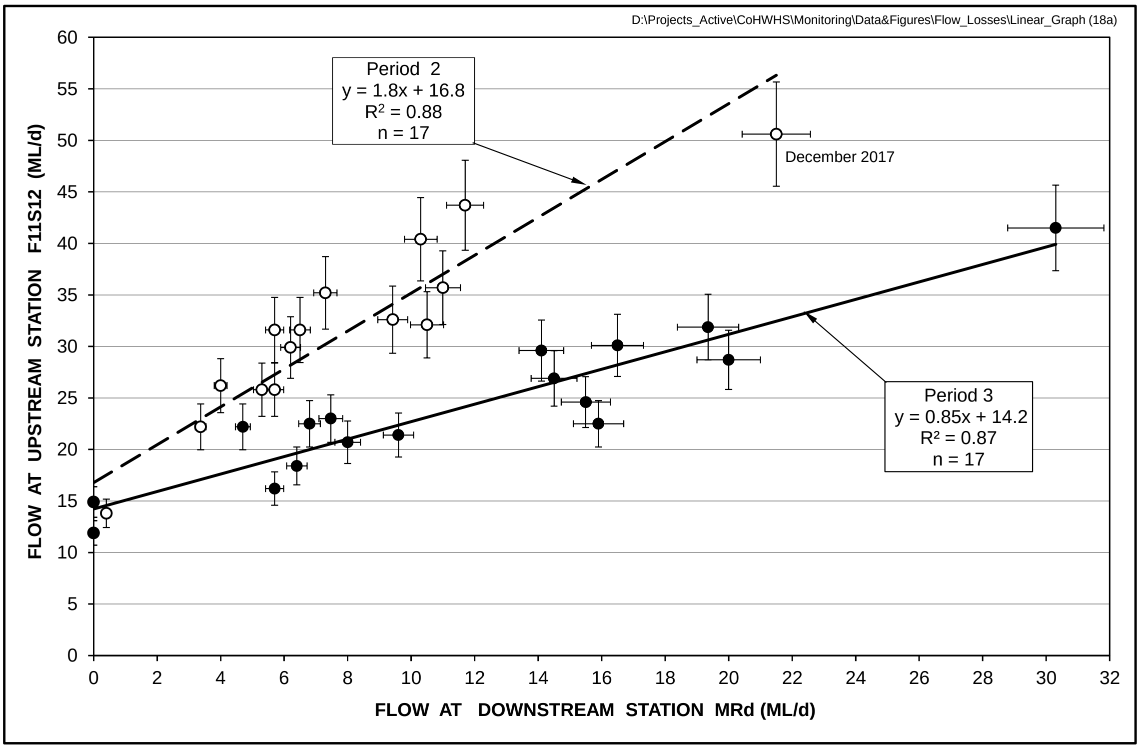

Figure 9 Correlation of streamflow at stations F11S12 and MRd in the lower Riet Spruit valley, with vertical error bars denoting ±10% at F11S12 and horizontal bars ±5% at MRd

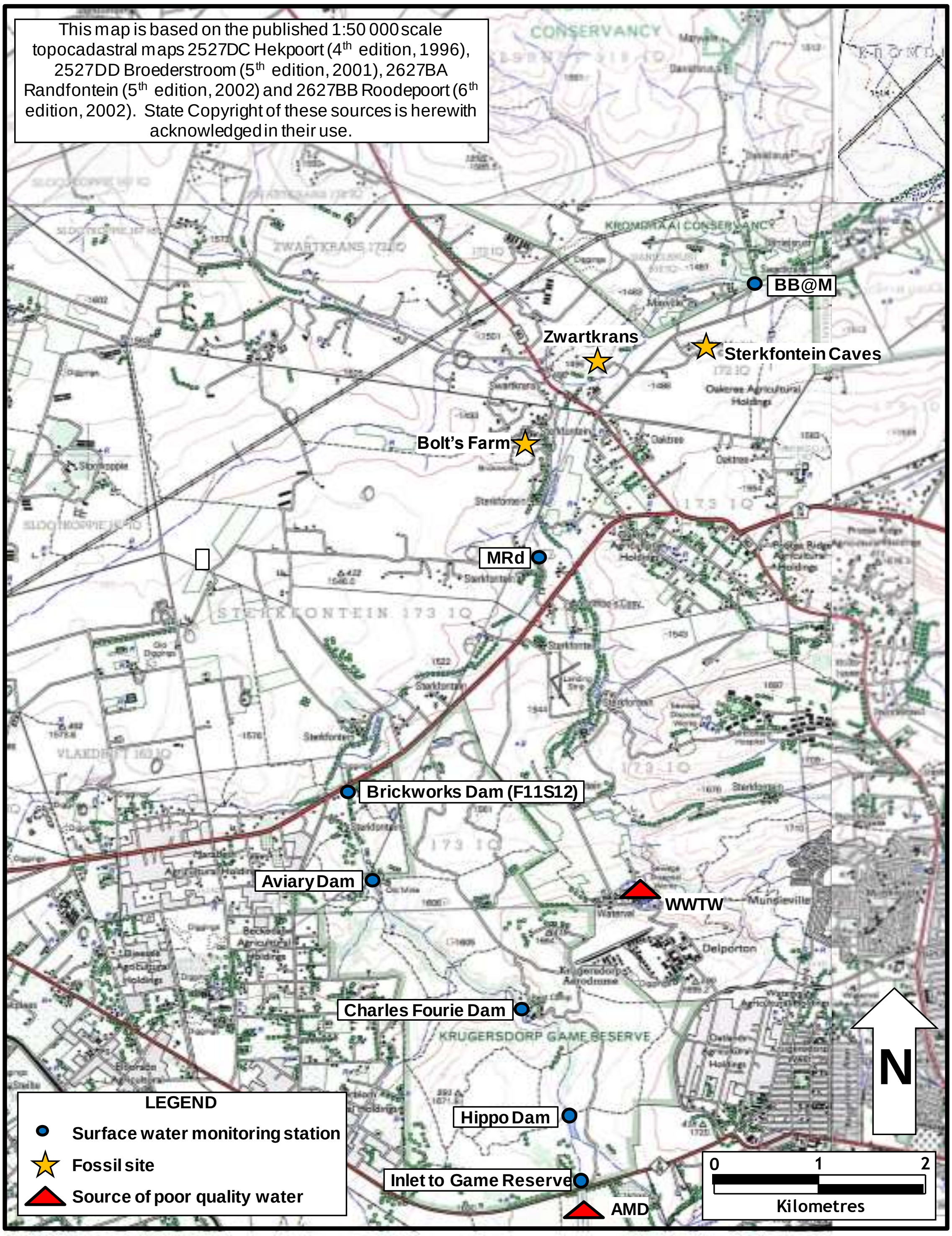

Figure 10 Locality map of surface water quantity and quality monitoring stations

The patterns revealed in **Figure 11** to **Figure 16** reflect the temporal variation and trend in the respective variable values in surface water as it flows 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 management 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 11**), which show a sustained increase in the last 12 months, and the SEC values (**Figure 12**), 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 18 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 two stations even under circumstances where the discharge from the mine area comprised mainly treated/neutralised mine water with very low iron levels (**Figure 14**). Manganese (**Figure 15**) remains 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 11** to **Figure 16** is presented in **Table 3**. 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 did not manifest 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, the recent efficacy of which is reflected in the median and 95%ile values in period E– that consistently show the lowest values across the five periods of analysis.

4.2.1.2 Bloubank Spruit

The statistical overview of synoptic surface water chemistry data for DWS flow gauging station A2H049 at the lower end of the Bloubank Spruit system presented in previous reports such as this, has been amended to bring out substantial temporal changes in variable-specific values. The revised overview presented in **Table 4** eliminates the favourable bias imposed by the long-term whole record data set on the statistics for the much shorter more recent period of mine water impact. For example, the whole record median SO_4 value of 85 mg/L (see Hobbs, 2017b) is similar to the 84 mg/L for the period August 2002 to January 2010, and substantially less than the 266 mg/L of the period since January 2010 (**Table 4**). Further validation for this amendment is provided by **Figure 21**.

Table 4 reflects statistics for a 'pre-impact' period (August 2002 to January 2010) and a 'post-impact' period (February 2010 to September 2017). None of the variables/analytes reported for either the 'pre-impact' or the 'post-impact' periods exceed the respective SANS (2015a; 2015b) health-related limits 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.

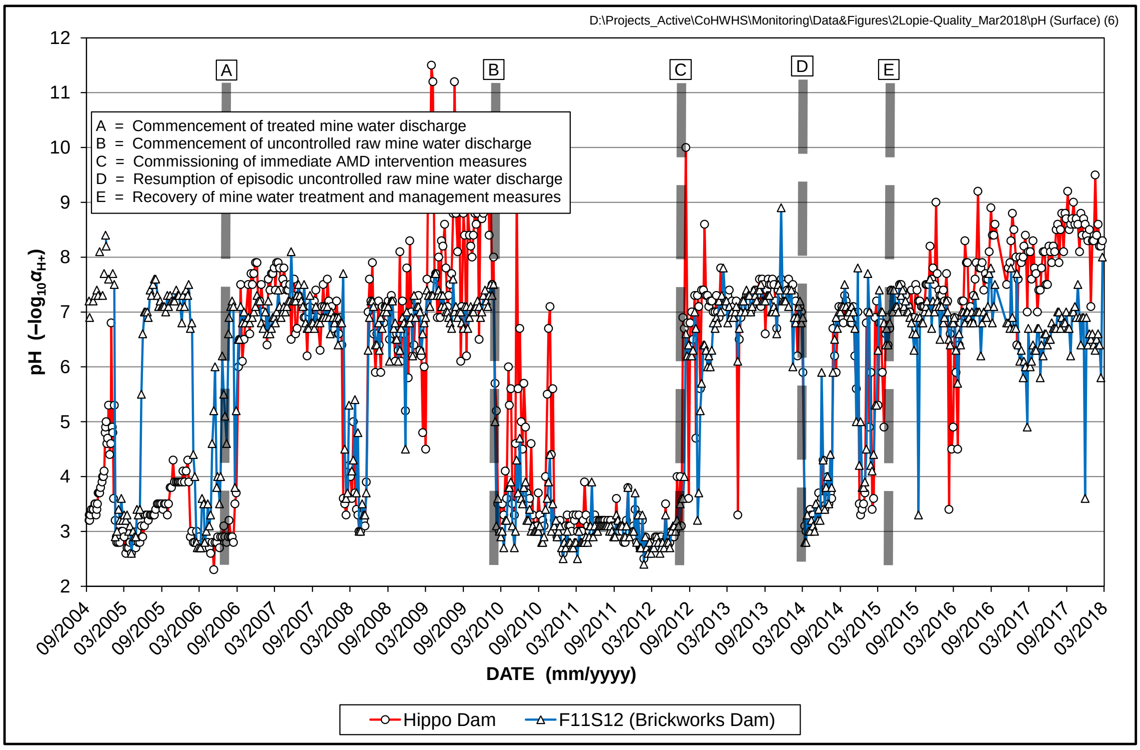

Figure 11 pH pattern of Tweelopie Spruit surface water in the period September 2004 to February 2018

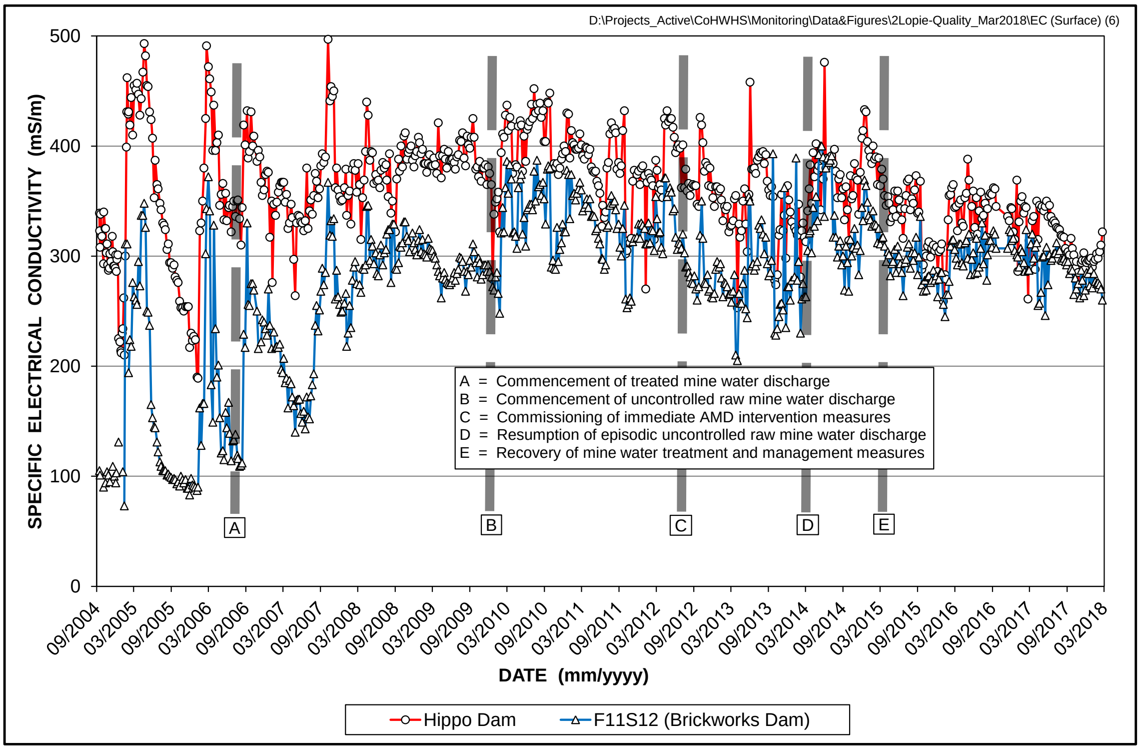

Figure 12 Specific electrical conductivity pattern of Tweelopie Spruit surface water in the period September 2004 to February 2018

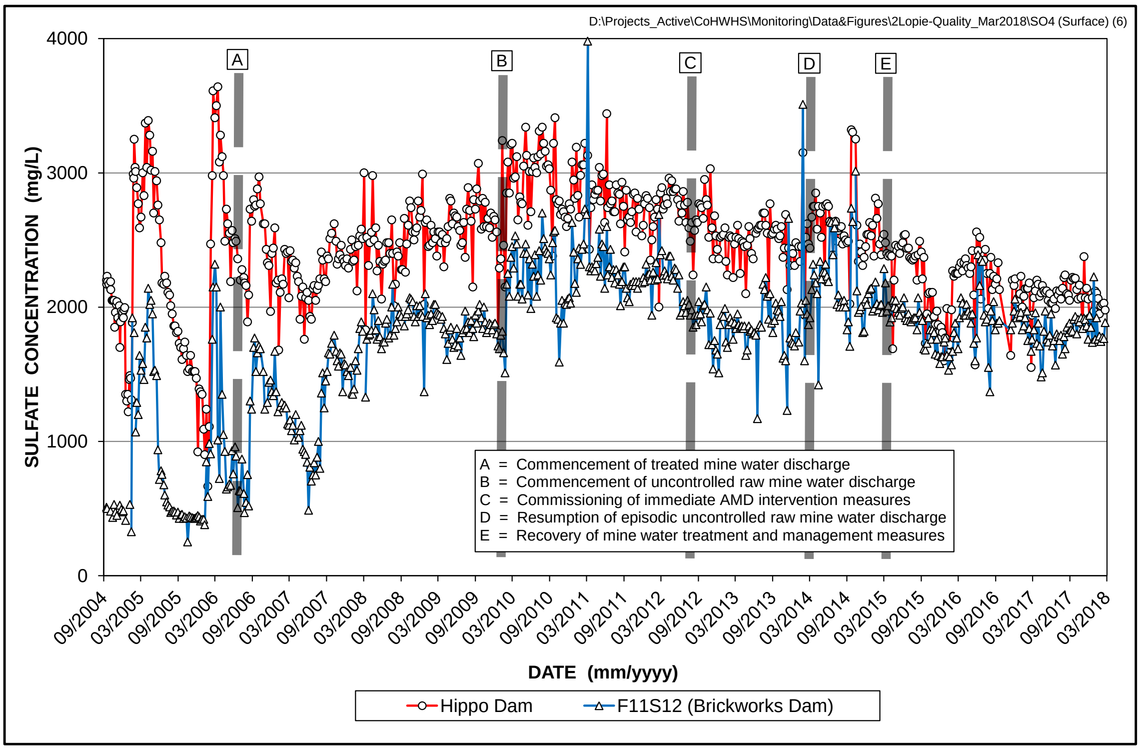

Figure 13 Sulfate pattern of Tweelopie Spruit surface water in the period September 2004 to February 2018

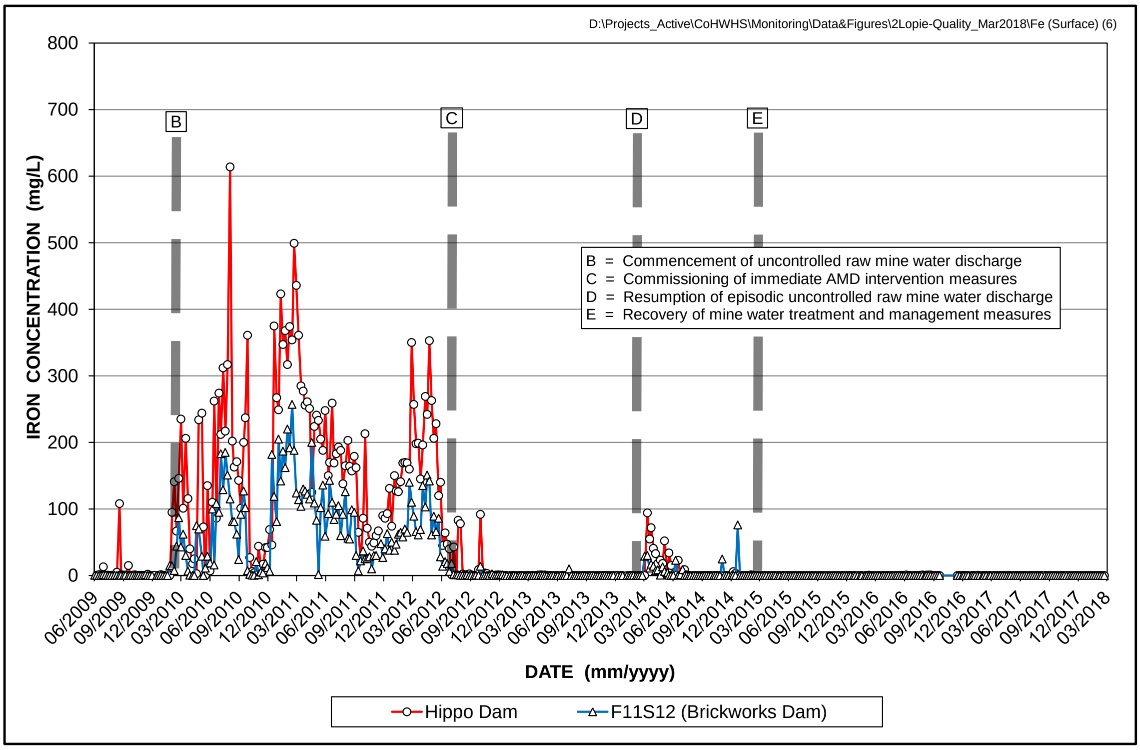

Figure 14 Iron pattern of Tweelopie Spruit surface water in the period June 2009 to February 2018

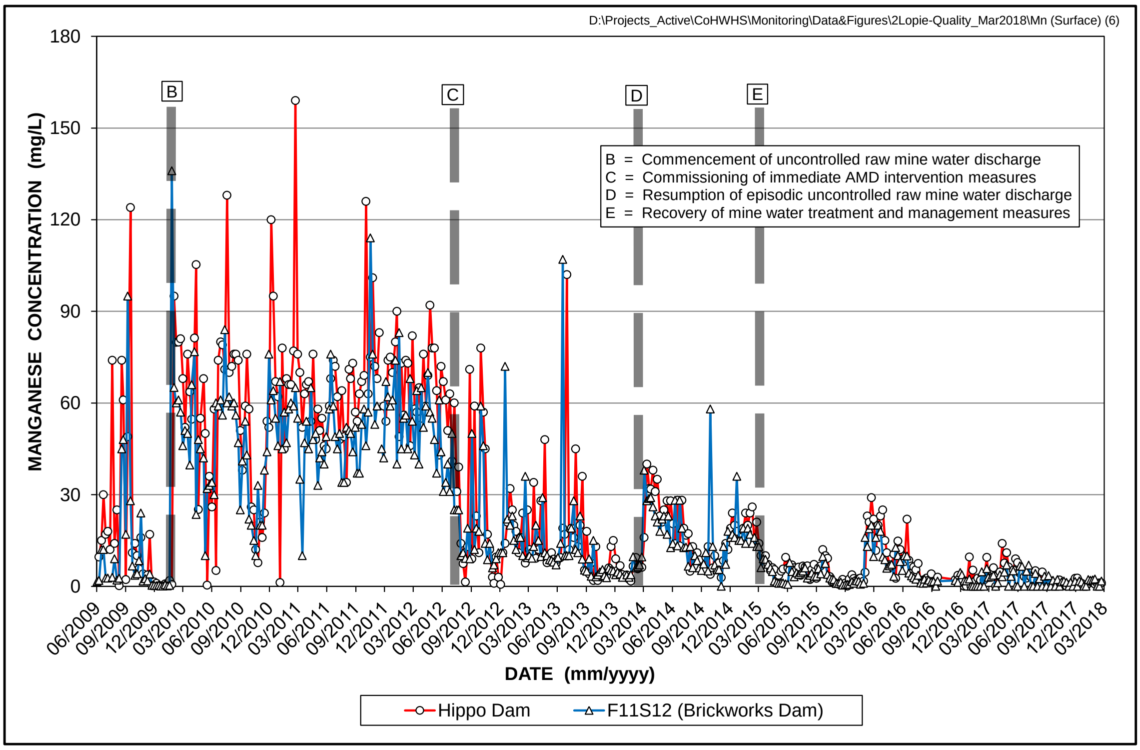

Figure 15 Manganese pattern in Tweelopie Spruit surface water in the period June 2009 to February 2018

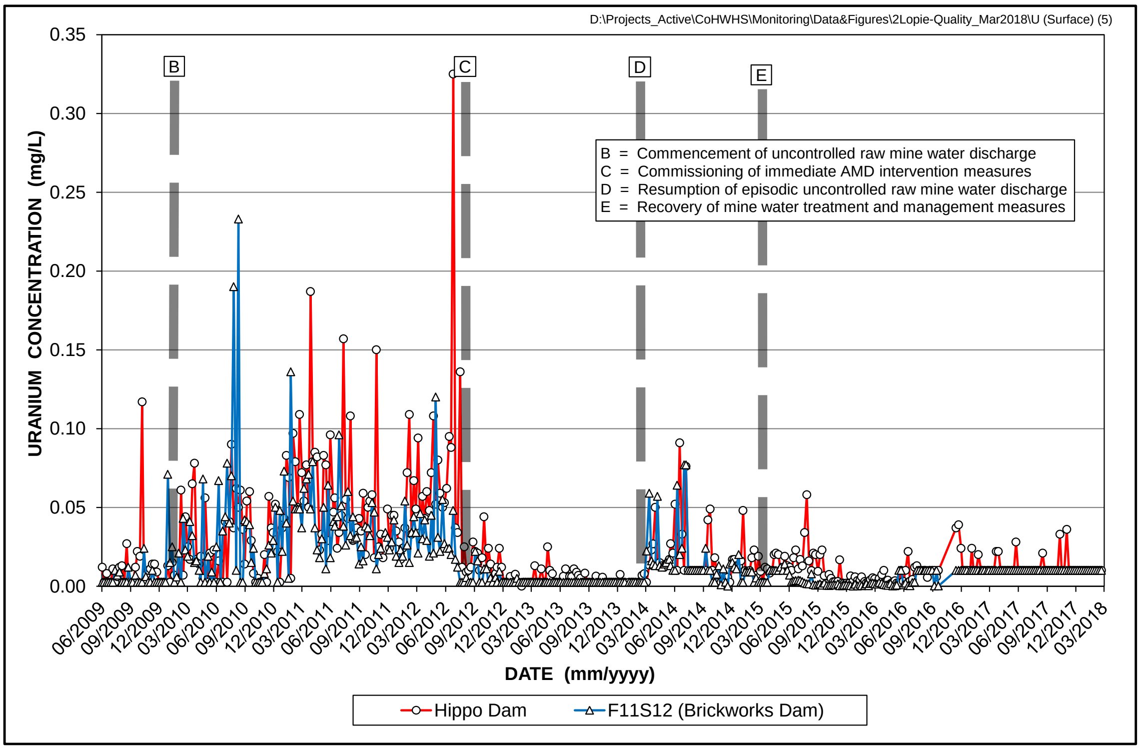

Figure 16 Uranium pattern in Tweelopie Spruit surface water in the period June 2009 to February 2018

Table 3 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	144	173	128	83	57	151
	5%ile	3.6	2.8	5.9	3.2	6.4	3.9	2.7	5.3	3.0	6.0
	Mean	—	—	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	4.9	7.7	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	0.6
	CoV (%)	22.0	30	11	32	12	14	14	13	32	9
SEC (mS/m)	n	175	129	83	57	144	172	128	83	57	151
	Mean	374	391	350	376	327	268	332	281	329	293
	Median	379	393	354	377	332	283	330	276	323	294
	95%ile	426	438	395	417	365	329	378	350	391	320
	SD	32	33	34	28	26.2	48	29	34	34	18
	CoV (%)	9	8	10	7	8	18	9	12	10	6
SO_4 (mg/L)	n	176	128	82	56	144	171	128	83	56	151
	Mean	2448	2846	2520	2585	2144	1636	2264	1879	2137	1845
	Median	2460	2815	2525	2541	2134	1760	2240	1870	2075	1848
	95%ile	2828	3220	2770	2950	2459	2015	2593	2148	2640	2065
	SD	262	226	193	231	209	349	245	268	274	155
	CoV (%)	11	8	8	9	10	21	11	14	13	8
Fe (mg/L)	n	33	129	83	57	133	33	128	82	57	126
	Mean	4.7	168.4	2.5	8.9	0.08	0.3	72.9	0.47	4.9	0.02
	Median	0.4	163.0	0.03	0.10	0.03	0.2	64.0	0.08	0.04	0.01
	95%ile	13.8	365.2	3.1	52.6	0.40	0.8	186.3	1.00	25.7	0.05
	SD	18.8	116.2	13.10	19.5	0.15	0.3	57.7	1.9	12.2	0.02
	CoV (%)	399	69	528	220	192	94	79	407	2518	123
Mn (mg/L)	n	34	129	83	57	132	33	128	83	57	123
	Mean	18.1	62.7	16.5	17.3	5.6	10.3	50.3	14.4	16.1	4.3
	Median	9.8	65.0	11.0	16.0	3.7	2.7	50.0	10.0	14.0	3.1
	95%ile	74.0	95.0	56.1	32.6	20.5	46.2	76.0	45.0	30.4	13.0
	SD	27.6	23.5	18.0	9.1	5.6	19.4	17.6	15.8	9.9	4.1
	CoV (%)	153	38	109	53	100	188	35	110	61	97

(1) 09/2006 – 01/2010 (2) 02/2010 – 07/2012 (3) 08/2012 – 02/2014 (4) 03/2014 – 03/2015 (5) 04/2015 – 02/2018

Table 4 Synoptic overview of Bloubank Spruit water chemistry at station A2H049 in the periods August 2002 to January 2010 and February 2010 to September 2017 (latest data as at March 2018)

Variable	Statistical Parameter														SANS (2015a)[1]
	Period August 2002 to January 2010							Period February 2010 to September 2017							
	n	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	**n**	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	
pH ($-\log_{10}\alpha_{H+}$)	251	7.7	—	8.1	8.4	0.2	2	174	7.6	—	8.2	8.5	0.3	4	5.0–9.7
SEC (mS/m)	232	51.1	61.2	62.3	66.8	5.0	8	172	61.1	89.2	87.6	122.4	21.8	25	<170
TDS (mg/L)	137	347.6	438.5	448.9	479.3	41.5	9	114	468.6	660.6	632.0	920.3	156.9	24	<1200
Ca (mg/L)	172	40.1	51.3	52.1	57.7	5.31	10	169	53.6	90.6	90.4	147.7	30.1	33	n.s.
Mg (mg/L)	171	23.3	30.2	30.4	34.9	4.8	16	169	28.3	42.8	43.3	58.9	10.3	24	n.s.
Na (mg/L)	185	19.1	27.5	27.7	34.0	4.7	17	141	27.5	39.4	36.7	55.1	9.1	23	<200
K (mg/L)	173	1.4	2.4	2.4	3.4	0.7	27	143	2.8	3.9	3.7	5.6	8.0	22	n.s.
Cl (mg/L)	175	29.2	36.2	36.3	43.5	4.8	13	172	30.9	38.5	38.0	45.3	5.5	14	<300
SO_4 (mg/L)	191	63.4	85.8	83.9	110.0	15.1	18	164	94.7	260.8	266.3	460.3	125.3	48	<500
HCO_3 (mg/L)	185	146.1	188.1	190.2	216.1	21.1	11	167	89.6	139.8	141.9	180.8	27.3	20	n.s.
NO_3+NO_2 (mg N/L)	214	3.294	4.740	4.414	7.085	1.190	25	166	3.378	5.483	5.408	8.145	1.485	27	<11
PO_4 (mg P/L)	247	0.043	0.189	0.158	0.451	0.131	69	169	0.005	0.101	0.064	1.262	0.132	131	n.s.
Si (mg/L)	247	4.93	5.84	5.83	6.69	0.60	10	166	4.9	5.7	5.6	6.6	0.7	12	n.s.
Fe (mg/L)	69	0.006	0.035	0.014	0.120	0.056	163	61	0.004	0.019	0.013	0.072	0.121	126	<2
Mn (mg/L)	69	0.001	0.049	0.002	0.146	0.226	459	61	.001	0.162	0.002	0.050	0.855	526	<0.5
Al (mg/L)	65	0.001	0.060	0.014	0.091	0.262	437	60	0.003	0.019	0.007	0.057	0.026	139	<0.3

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

4.2.2 Municipal Wastewater Impact

The Blougat Spruit is the conduit for municipal wastewater effluent into the COH property. The reticence of local government to provide water quality data for wastewater released to the Blougat Spruit from the municipal wastewater treatment works (WWTW) has been documented previously (e.g. Hobbs, 2016a; 2016b; 2017a). Water samples collected ~1 km downstream of the WWTW end-of-pipe (EoP) provide a measure of the bacteriological contamination in the Blougat Spruit from this facility. This impact extends into the Bloubank Spruit in its passage through the south-eastern portion of the property.

The severity of the bacteriological contamination is reflected in total coliform and *E. coli* values that routinely exceed a most probable number (MPN) count of 2419.6 per 100 mL. These counts on occasion reach values of 10’s of thousand. It can be argued that the municipal wastewater poses an equally dire threat to the fitness for use of receiving surface water resources as does mine water. This threat extends into the Crocodile River as main stem of the Bloubank Spruit.

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 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. This is readily attributable to the very high salt loads experienced in the 2011 hydrological year. Similar conditions (albeit slightly more muted) prevailed in the subsequent period (August 2012 to September 2017) as indicated in **Figure 17** (text box). An evaluation of the subregional and regional temporal salt loads delivered to Hartbeespoort Dam is presented by Hobbs (2017c).

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-2010. 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 September 2017) exhibits a substantially higher median value of 933 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 a trebling of the SO_4 concentration (from ~120 mg/L to ~360 mg/L) between mid-2010 and mid-2014, followed by a period of comparatively consistent rising concentrations from 360 to 450 mg/L to the end of the record. These circumstances are confirmed by the load and concentration statistics presented in the text boxes.

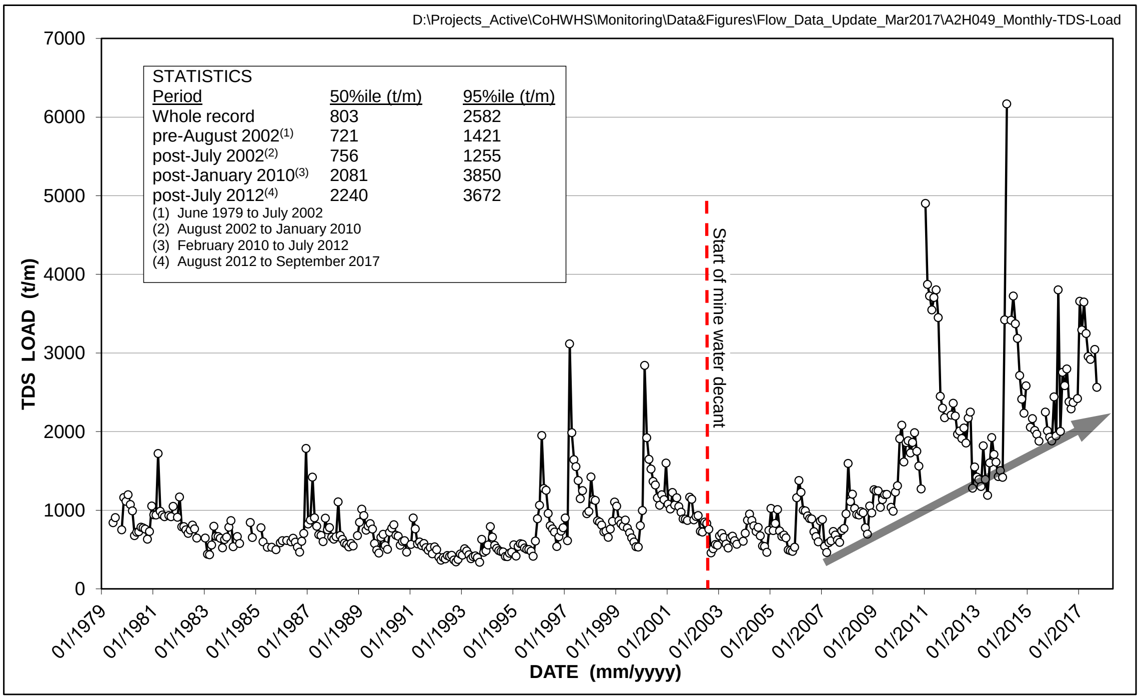

Figure 17 Long-term (June 1979 to September 2017) monthly TDS load pattern and trend in the Bloubank Spruit at station A2H049

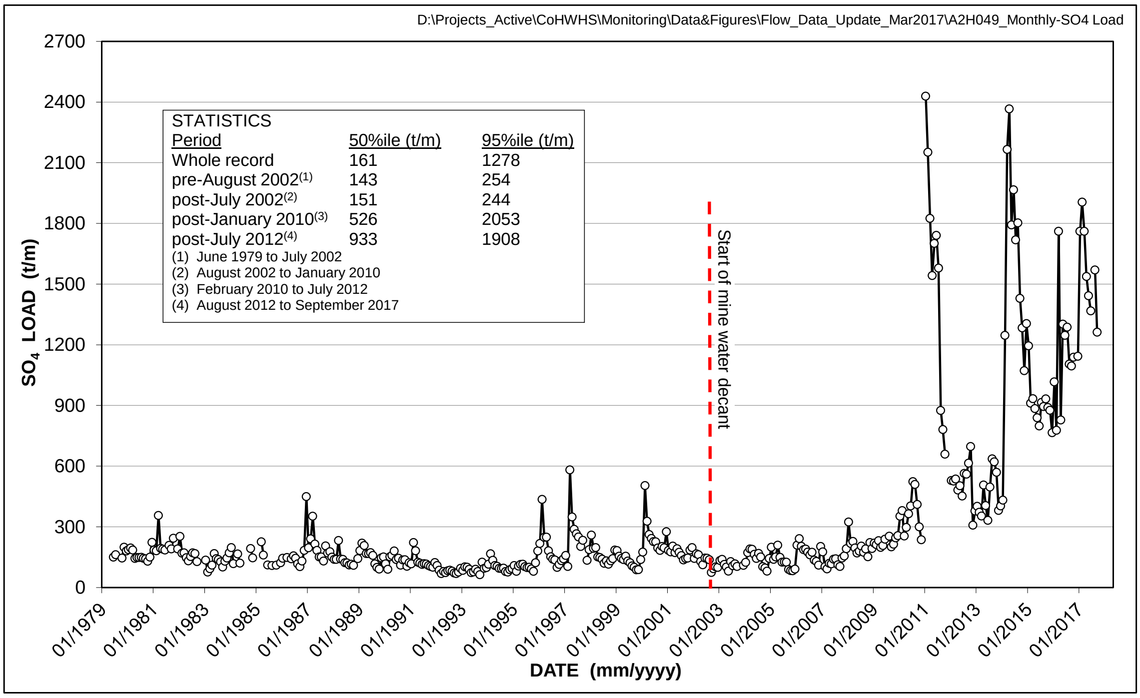

Figure 18 Long-term (June 1979 to September 2017) monthly SO_4 load pattern and trend in the Bloubank Spruit at station A2H049

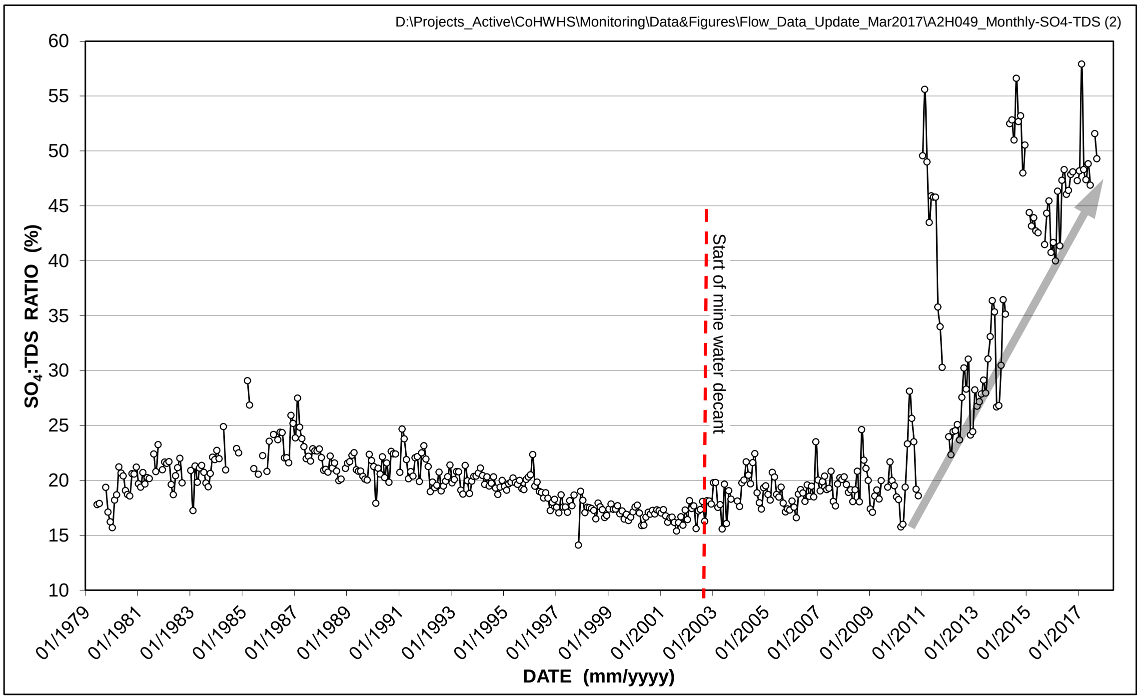

Figure 19 Long-term (June 1979 to September 2017) trend in the SO_4:TDS ratio at station A2H049

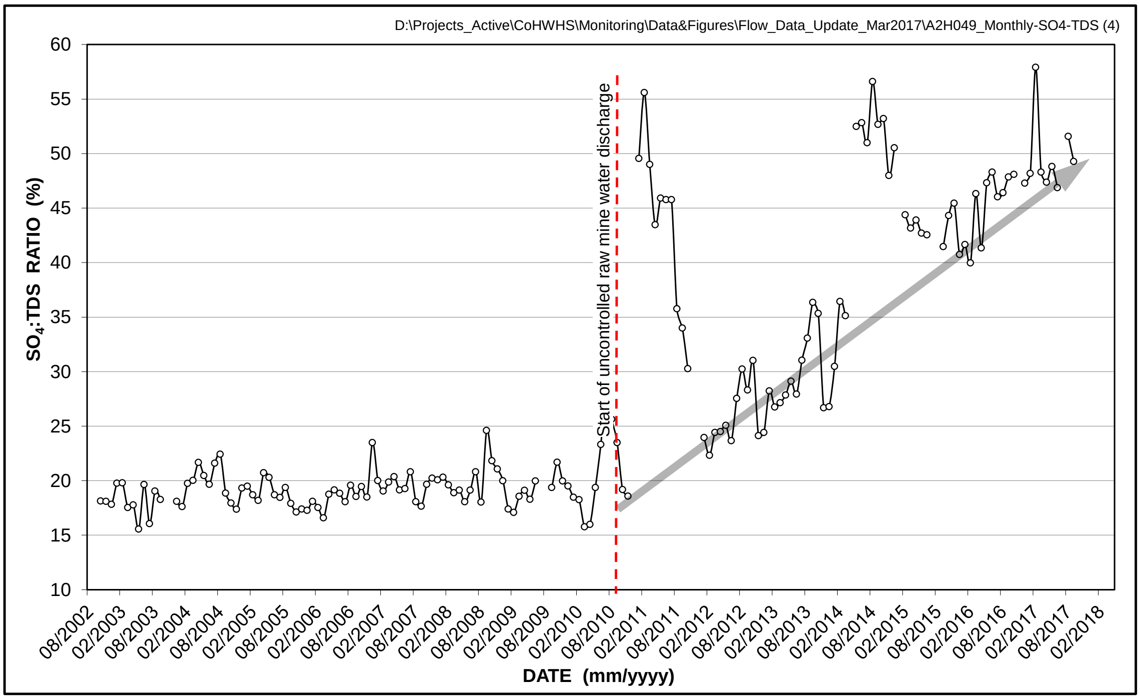

Figure 20 Pattern and trend of the SO_4:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin in mid-2002

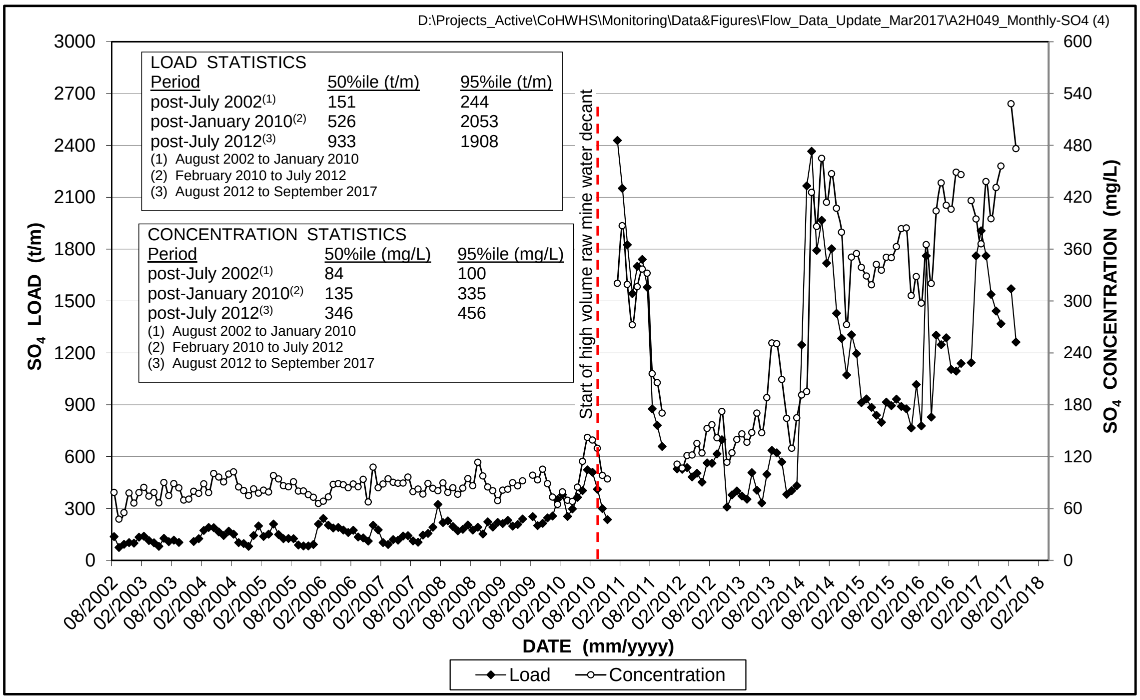

Figure 21 Monthly SO_4 concentration and load pattern and trend in the Bloubank Spruit at station A2H049 since mid-2002

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 22.** 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 brought out by the use of 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 22** reflect little change in the southern segment in the reporting period. A decline in groundwater level elevations in the central and especially the northern segments is evident. The lake water level in Sterkfontein Cave at the north-eastern discharge end of the Zwartkrans Basin most clearly reflects this decline as shown in **Figure 23**.

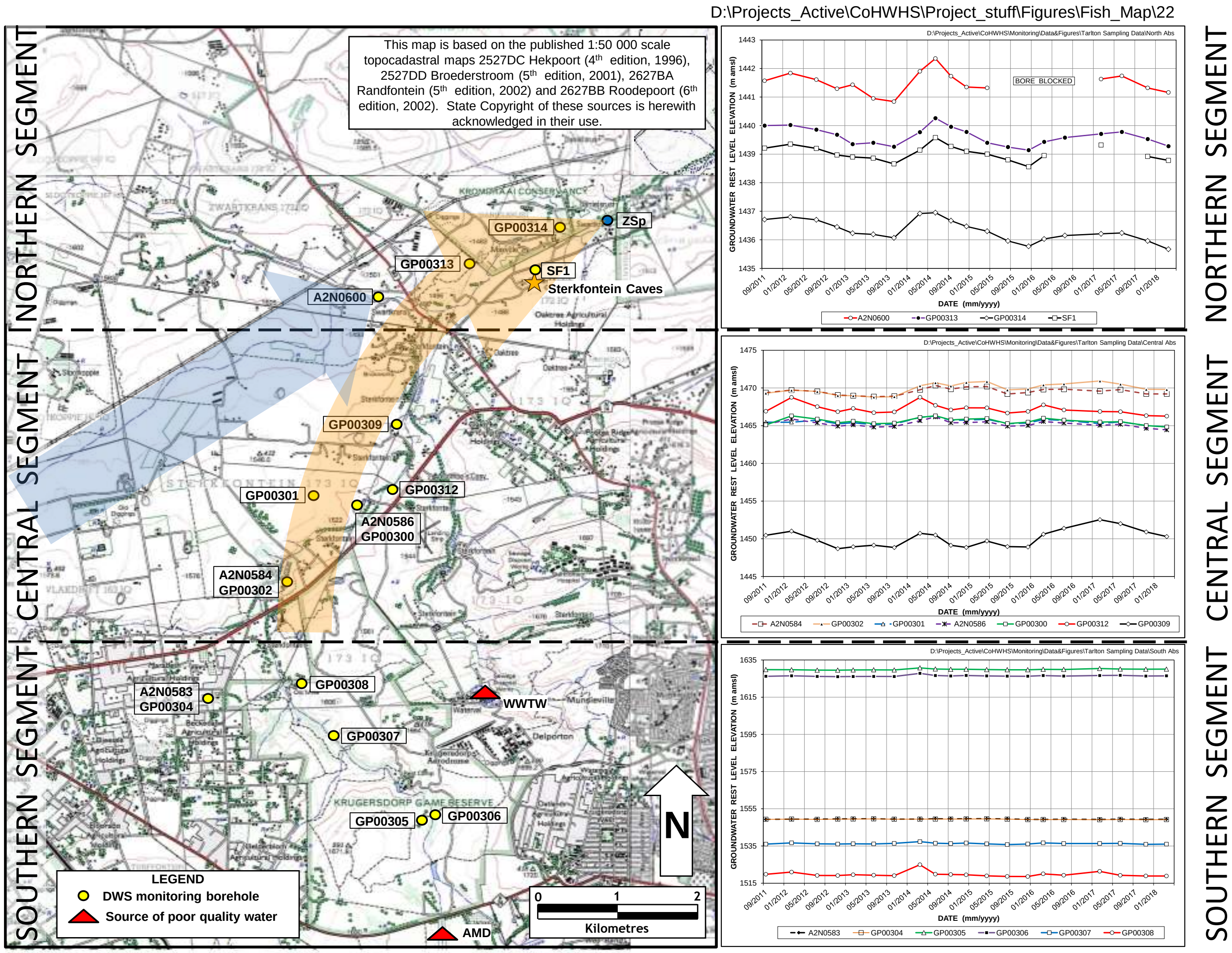

Figure 22 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

5.1.3 Sterkfontein Cave Water Level

The international significance of Sterkfontein Cave as the flagship fossil site on the property focuses attention on any perceived impact to this site. The substantial rise of ~3 m in the cave water level through 2010 to early-2012 drew attention to the hydrostatic behaviour of the cave water level, and is discussed in detail by Hobbs and de Meillon (2017).

The cave water level response in the last 13 years is illustrated in **Figure 23**. The hydrograph shows that the fluctuation since mid-2010 has amounted to ~1 m, varying in the elevation range 1439 ± 0.5 m above mean sea level (amsl). It is postulated that the cave lake will maintain this position into the future because of sustained greater discharge in the upper tributaries of the Bloubank Spruit (the Tweelopie/Riet Spruit system and the Blougat Spruit) driving allogenic groundwater recharge of mine water and municipal wastewater, respectively, in the Zwartkrans Basin.

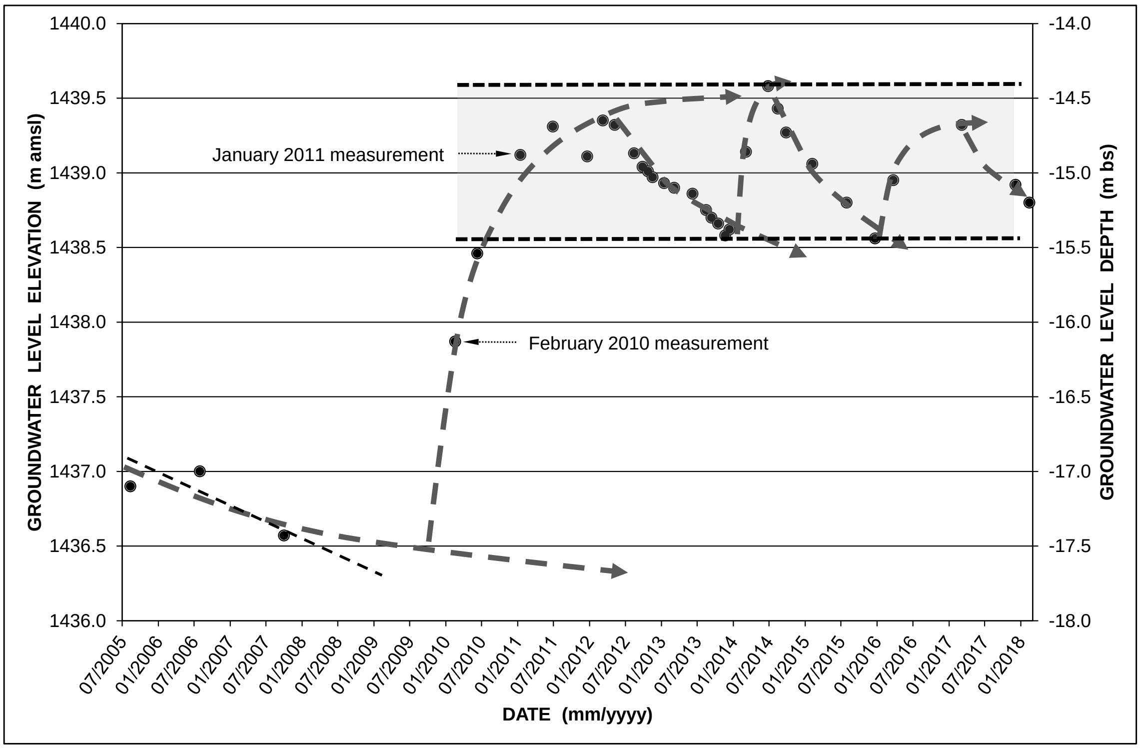

Figure 23 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the lake water level in Sterkfontein Cave; shaded area denotes magnitude of fluctuation since mid-2010

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 24** and **Figure 25**. 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 outcome 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

The most recent pH and SEC values generated by the monitoring programme in the Zwartkrans Basin must be viewed with caution as in most instances they are associated with 'grab' samples obtained manually with a bailer because of failure of the sampling pump. The caution pertains to the known measure of vertical chemical stratification that exists in the water column of a number of the monitoring boreholes. The stratification is generally characterised by a layer of fresher (lower salinity) groundwater (of varying bore-to-bore thickness but up to 10 m) overlying more saline groundwater.

The magnitude of the mine water impact on the karst aquifer in the Zwartkrans Basin is illustrated in **Figure 24** and **Figure 25** with the aid of bar graphs for the chemical variables pH and SEC respectively.

The bar graphs in **Figure 24** reflect the more recent 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 7.0 to 7.8.

The bar graphs in **Figure 25** 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 slightly increased 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 with the exception of the Zwartkrans Spring, 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 26**.

The extent of the mine water impact on the karst aquifer of the Zwartkrans Basin is shown in **Figure 26**, and provides an indication of the sulfate trend at each monitoring station in terms of up, stable or down in the recent past, by comparing the July 2016, February 2017 and November 2017 values. The comparison indicates that sulfate levels in ambient groundwater have remained stable at the south-western (ingress) end of the impacted zone, and are still increasing at the north-eastern (discharge) end.

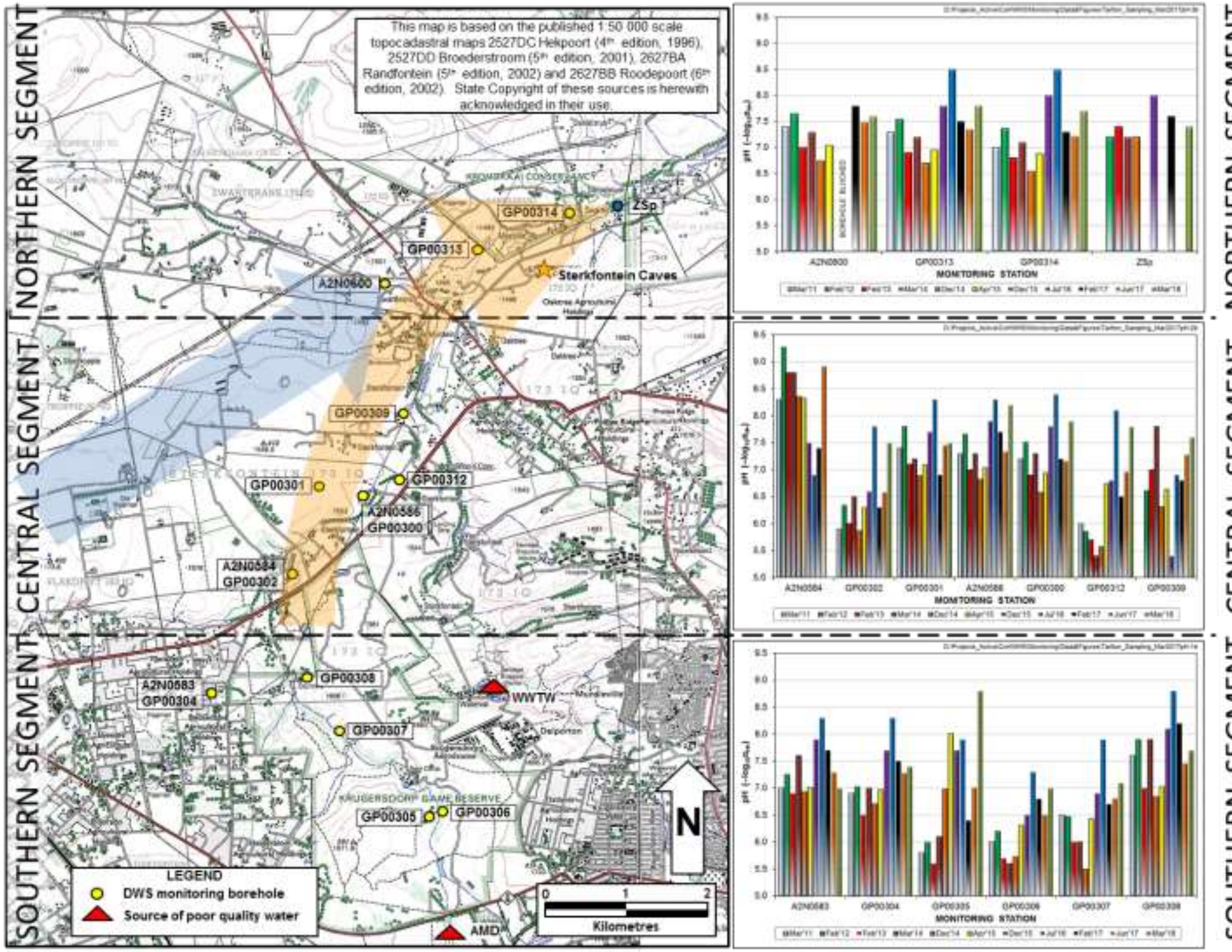

Figure 24 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

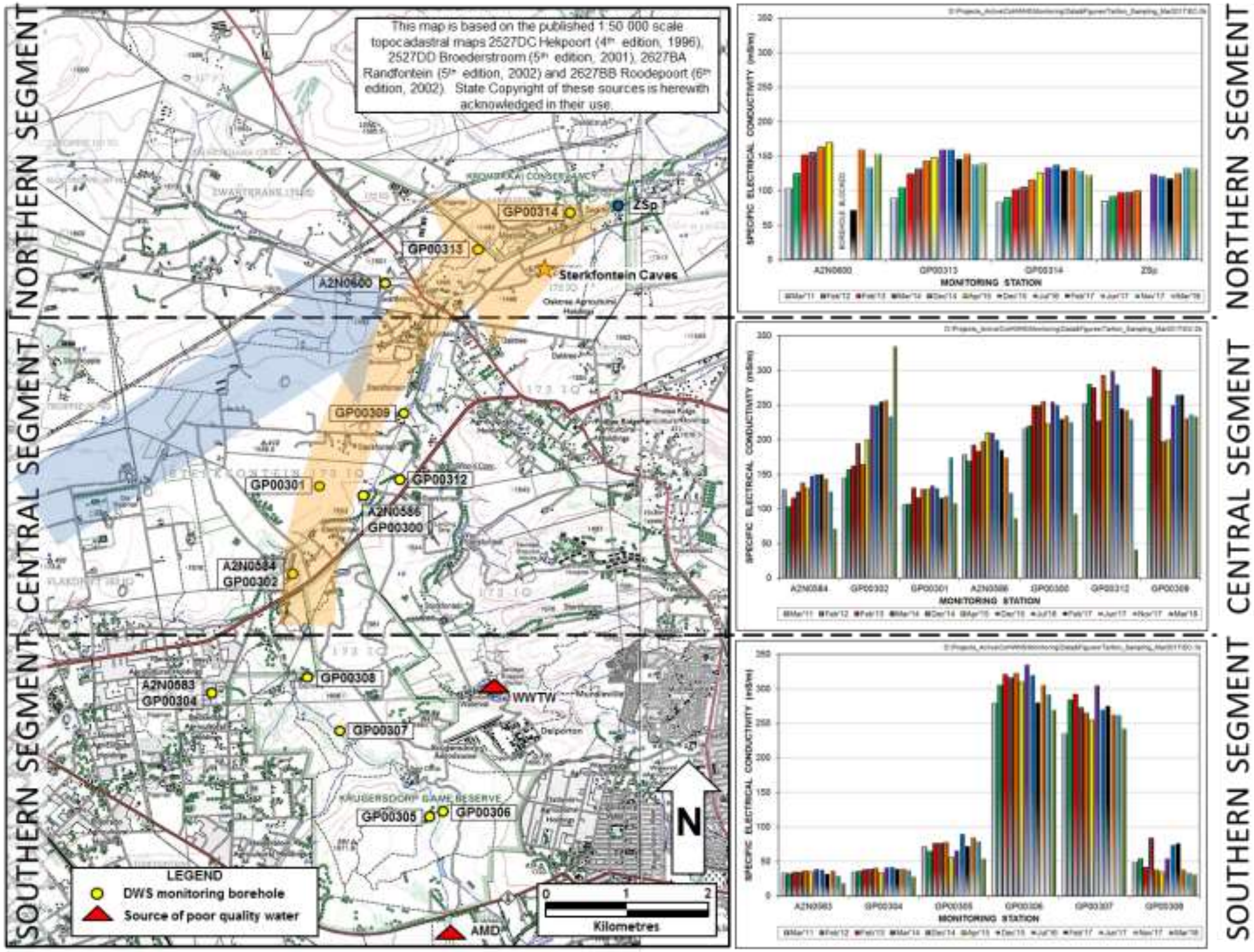

Figure 25 Distribution of DWS monitoring boreholes with SEC pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

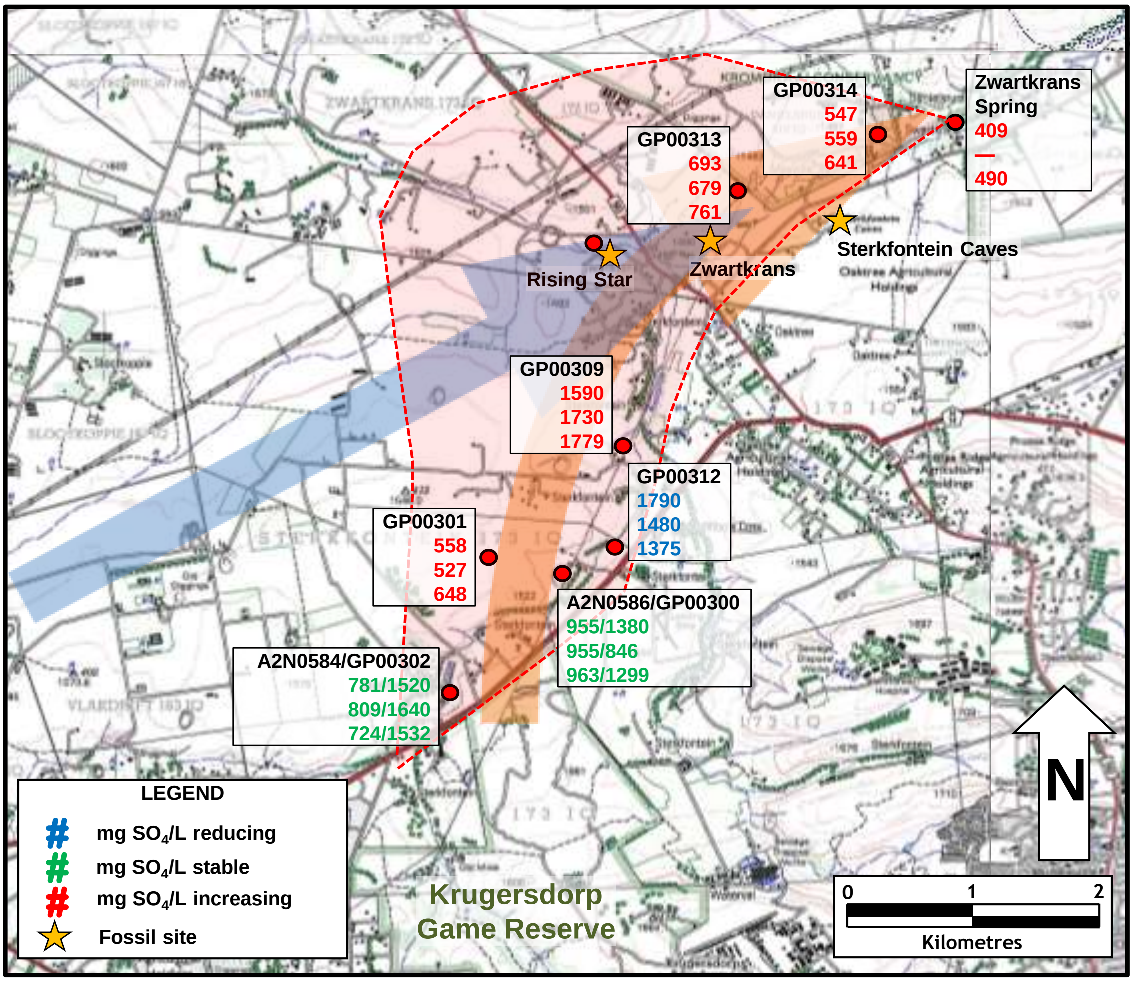

Figure 26 Distribution of sulfate levels in groundwater of the Zwartkrans Basin in July 2016 (1st value), February 2017 (2nd value) and November 2017 (3rd value), also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow), the postulated footprint (shaded area) of a mine water impact in the karst aquifer, and SEC trend as INCREASING (red text), STABLE (green text) or REDUCING (blue text)

6 RIVER HEALTH

In accordance with the SLA that governs project GT/GDED/092/2017, the water resources monitoring programme now includes an assessment of river health on the property on the basis of macroinvertebrate biomonitoring and toxicity screening assays. The assessment targets two sites on the nearly pristine Skeerpoort River and two sites on the impacted Bloubank Spruit (**Figure 27)**.

In the case of the springwater-driven Skeerpoort River, the ‘upper’ site is located on a small (short) perennial tributary at a distance of ~125 m downstream from a major karst spring, and the ‘lower’ site at a position ~4000 m further downstream where the river has left the dolomitic substrate and traverses sedimentary strata (mainly shale). In the case of the Bloubank Spruit, both the ‘upstream’ and ‘downstream’ sites experience the combined impact of mine water and municipal wastewater discharges. The difference is that the upper site is located before the first substantial springwater (Zwartkrans Spring) input, and the lower site after the last substantial springwater (Kromdraai Spring) input.

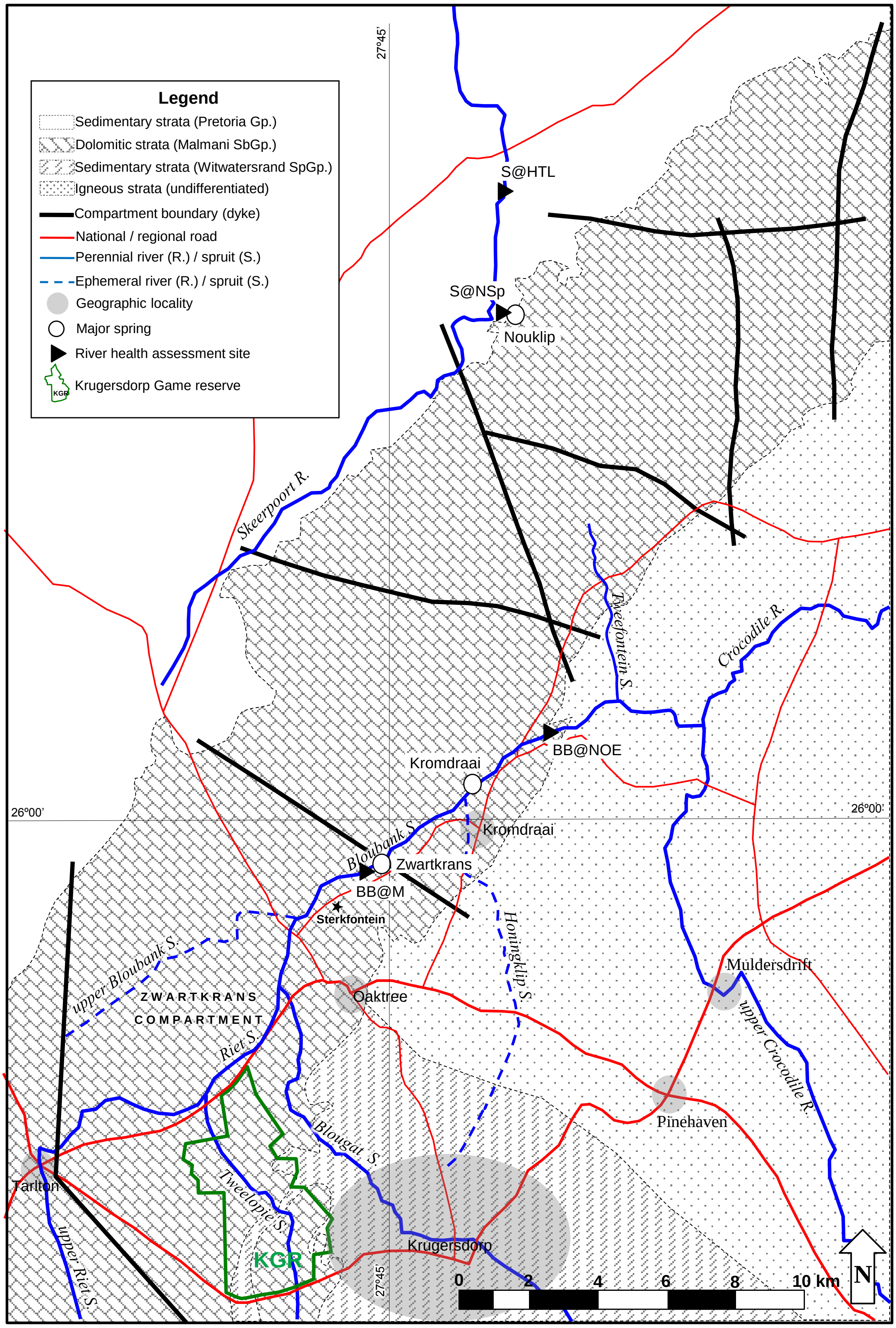

Figure 27 Map showing sites of relevance to the river health assessment

The sites on the Bloubank Spruit replicate two of those surveyed earlier as part of a CSIR Strategic Research Project (SRP) assessment of the biotic response in streams of the Western Basin that receive neutralised acid mine drainage. The outcome of this project is reported in Hill et al. (2014).

The Skeerpoort River sites ostensibly represent undisturbed natural conditions for reference purposes, but the lower site is located ~120 m downstream of a weir and adjacent to a trout farm that discharges into the river. The lower site has been surveyed on numerous occasions in the past (Fourie et al., 2014 and references therein). No published material is available for the aquatic ecosystem status of the upper site, and it is not known whether this drainage has been surveyed before. In any event, this site represents as natural a condition of a springwater-driven headwater stream in a karst landscape as can be found in the COH.

In three instances therefore, a useful comparison of current conditions with earlier conditions can be made. Future surveys at the upper site on the Skeerpoort River will develop a record for this locality.

6.1 Assessment & Data Analysis

The assessment entailed the application of the IHAS (McMillan, 1998) and SASS5 (Dickens and Graham, 2002) procedures to evaluate respectively the instream habitat quality and associated benthic macroinvertebrate integrity at each site. Together, the procedures have proven in countless studies nationally their efficacy in assessing aquatic macroinvertebrate diversity as a function of instream habitat and water quality. Impairment of either habitat or water quality reduces biodiversity and, therefore, results in a 'poorer' river condition (generically referred to as river health) when compared to the natural (or reference) condition. A description of the survey sites is given in **Annexure A**. River health is classified according to the criteria set out in **Annexure B**.

A further aspect incorporated in the survey was the adjudication of functional feeding group (FFG) criteria as described by Cummins et al. (2005). This is not yet widely accepted or applied in South Africa.

6.2 Macroinvertebrate Biomonitoring Results

6.2.1 Current Assessment Outcome

The full set of results (including the functional feeding group results) obtained for each of the surveyed sites are presented in **Annexure C**. The synthesis of these results is presented as a synoptic assessment in **Table 5**, and the results discussed in **Section 6.4**. Unsurprisingly, the Skeerpoort River scores as an A category at the lower (downstream) site, and the Bloubank Spruit as an E/F category improving to a D category at the downstream site. The upstream Skeerpoort River site (S@NSp) on the Groot Spruit scores as a C category for reasons discussed in S**ection 6.4**.

Table 5 Synoptic river health assessment outcome for February 2018 (from **Annexure C**)

SITE	Date	Ecological category	Condition	Description
S@NSp	27/02/2018	**C**	Fair	Moderately modified
S@HTL	13/02/2018	**A**	Natural	Unmodified natural
BB@M	13/02/2018	**E/F**	Seriously modified	Seriously modified
BB@NOE	13/02/2018	**D**	Poor	Largely modified

6.2.2 Comparison with Historical Results

6.2.2.1 Skeerpoort River

The study by Fourie et al. (2014) provides a comparatively recent assessment against which to gauge the present river condition. This is provided in **Table 6**, which shows similar results and suggests no discernible temporal change in ecological category.

Table 6 Comparison of present biomonitoring results for site S@HTL with those of the Fourie et al. (2014) "site B" results

COMPARATIVE SCORES							
SASS5		Taxa		Mean ASPT		IHAS	
Jan 2014[1]	Feb 2018[2]	Jan 2014[1]	Feb 2018[2]	Jan 2014[1]	Feb 2018[2]	Jan 2014[1]	Feb 2018[2]
~200[3]	185	~34[3]	27	~6[3]	6.9		72%

[1] From Fourie et al. (2014)
[2] From **Annexure C**
[3] Approximate value interpolated from bar graph in Fourie et al. (2014)

6.2.2.2 Bloubank Spruit

The study by Hill et al. (2014) provides a similarly quite recent assessment against which to gauge the present river condition. This is provided in **Table 7** (site BB@M) and **Table 8** (site BB@NOE).

Table 7 Comparison of present biomonitoring results for site BB@M with those of the Hill et al. (2014) study

COMPARATIVE SCORES							
SASS5		Taxa		Mean ASPT		IHAS	
Mar 2013[1]	Feb 2018[2]	Mar 2013[1]	Feb 2018[2]	Mar 2013[1]	Feb 2018[2]	Mar 2013[1]	Feb 2018[2]
52	27	13	8	4.0	3.4	74%	67%

[1] From Hill et al. (2014) [2] From **Annexure C**

Table 8 Comparison of present biomonitoring results for site BB@NOE with those of the Hill et al. (2014) study

COMPARATIVE SCORES							
SASS5		Taxa		Mean ASPT		IHAS	
Mar 2013[1]	Feb 2018[2]	Mar 2013[1]	Feb 2018[2]	Mar 2013[1]	Feb 2018[2]	Mar 2013[1]	Feb 2018[2]
60	57	10	12	6.0	4.8	55%	53%

[1] From Hill et al. (2014) [2] From **Annexure C**

6.2.3 Grootvlei Spruit (Skeerpoort River headwater tributary)

It is unknown whether site S@NSp has been surveyed before. If it has, the results are not available to the CSIR. The inclusion of this site in the survey aims to assess the veracity of site S@HTL as a reference site for the COH property even though it is located downstream of the karst area.

Table 9 Comparison of present biomonitoring results for sites S@NSp and S@HTL

COMPARATIVE SCORES							
SASS5		Taxa		Mean ASPT		IHAS	
S@NSp[(1)]	S@HTL[(2)]	S@NSp[(1)]	S@HTL[(2)]	S@NSp[(1)]	S@HTL[(2)]	S@NSp[(1)]	S@HTL[(2)]
105	185	18	27	5.8	6.9	71%	72%

[1] Surveyed on 27/02/2018 [2] Surveyed on 13/02/2018

6.3 Toxicity Testing Results

Freshwater toxicity screening tests with *Daphnia magna* were performed on surface water samples collected at the ‘downstream’ Skeerpoort River site (S@HTL) and at the two sites (BB@M and BB@NOE) on the Bloubank Spruit. For the purpose of this study, acute 48 hour *D. magna* tests were conducted under static conditions to establish the short-term toxicity potential of water samples from the selected sites. The test conditions and test acceptability criteria are summarised in **Table D.1** of **Annexure D**.

Physicochemical parameters were measured at the start and the end of the tests with a hand-held Hach HQ 40D multi-parameter (temperature, pH, electrical conductivity and dissolved oxygen) meter. The results are summarised in **Table D.2** (**Annexure D**). The results for the *D. magna* toxicity tests are summarised in **Table D.3**. The tests were accepted as no mortality (≤10%) was observed in the Control. At the end of the exposure period (48 hours), slight acute toxicity was observed in sample BB@NOE (i.e. 15% mortality) while no acute toxicity was detected in test samples S@HTL and BB@M.

6.4 Observations

The geomorphological differences between the Skeerpoort River sites suggest that the upper site (S@NSp) represents conditions that are closer to an undisturbed natural aquatic environment for a springwater-driven stream in the COH karst landscape. It is therefore informative to compare the survey results between these sites taking cognisance of the following. With a longer reach of water upstream, other activities such as microbial activity at high temperatures (Arimoro, 2007) can produce fine particulate organic matter (FPOM). The comparatively short distance of site S@NSp from its perennial source indicates a limiting factor in this regard.

6.4.1 Site S@HTL

A good diversity of invertebrates and all functional feeding groups are represented. There is a large predominance of collector-gatherers and predators, while shredders in particular are under-represented (only 1 shredder was found). Scored as an A category, the results compare fairly well with the January 2014 results of Fourie et al. (2014). The site is considered a good selection to serve as a reference site for the Skeerpoort River system.

6.4.2 Site S@NSp

Although the survey results categorise the site as a C, it is borderline a category B as an ASPT score of 5.9 (compared to the assessed score of 5.8) would make the difference. Even then, it would still represent one category lower than site S@HTL. In the vicinity of the spring itself, the stream channel shows evidence of recent flooding[1], which conditions might easily affect the invertebrate sampling scores. Of the 130 individual invertebrates captured, no collector-filterers were present, and only one shredder. It will be important to keep this site on the list of those surveyed.

[1] Heavy rainfall in early-December 2018 caused widespread flooding of stream channels and erosional damage to access roads on the John Nash Nature Reserve property (pers. comm., H. Visser).

It should be noted that shredders process coarse particulate organic matter (CPOM) (>1 mm) mainly from leaves and other vegetation and debris (Stumpf et al., 2009). This results in fine particulate organic matter (FPOM), which is the main food source of collector-filterers.

6.4.3 Site BB@M

The current (February 2018) results are somewhat lower than the 2013 results, although feeding group and taxa dominance remain the same. With only 8 taxa found, it is not that surprising to find no shredders or scrapers in the sample. A little more surprising is that only 8 individual predators were captured from 3 of the 8 taxa. The site scores as a category E/F.

6.4.4 Site BB@NOE

The results from the current sampling are similar to those found previously. The river shows improvement from the upstream site (BB@M) with a one better category level of D. There is also a similar trend in feeding groups to the upstream site, with no shredders or scrapers found, and only 21 individual predators, although these are from 6 (50%) of the sampled taxa.

7 DISCUSSION & CONCLUSIONS

The karst environment of a portion of the Zwartkrans Basin in the south-western quadrant of the property continues to reflect a slight reduction in SO_4 levels in the ‘upstream’ reaches and an increase in the ‘downstream’ reaches in the November 2017 monitoring results compared to the February 2017 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:

- 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. The 40.6 Mm^3 closely approximates the median value of 41.4 Mm^3 for the last 8 years. The 2017 hydrological year therefore ranks 5th out of 8 after 2010, 2011, 2012 and 2014, and can be classified as an ‘average’ runoff year.

- The 2018 wet season rainfall so far (excluding March) amounts to 601 mm in the mine area and 418 mm at Sterkfontein Cave. These values are 10% and 26% lower, respectively, than the means of the last 8 years of record common to both stations. The heavy widespread rainfall of 21, 22 and 23 March will no doubt erase this deficit, perhaps even turning the 2018 summer into one of the wetter (maybe even the wettest) in the last eight years.

- Chemical analyses of rainwater in the south-western portion of the property confirm the very low salinity (specific electrical conductance or SEC ≤15 mS/m) of this water. The results represent a mixture of precipitation events over a period of ~2 months ending early-December, and therefore are not representative of specific events. This influences especially the veracity of the pH values, which range from 6.4 to 7.5.

- The average 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 12 months, and in SEC 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 a slight decline that is most noticeable in the Sterkfontein Cave lake water level.

- Groundwater in the south-western portion of the property continues to experience a compromised quality reflected in sulfate levels of up to ~2000 mg/L. A comparison of sulfate levels over the last year indicates that these have decreased slightly in the 'upstream' portion where ingress occurs, and increased slightly at the north-eastern discharge end of the Zwartkrans Basin.

- Severe bacteriological contamination from the municipal wastewater treatment works via the Blougat Spruit into the Bloubank Spruit is reflected in total coliform and *E. coli* values that routinely exceed a most probable number (MPN) count of 2419.6 per 100 mL. These counts on occasion reach values of 10's of thousand. It can be argued that the municipal wastewater poses an equally dire threat to the fitness for use of receiving surface water resources as does mine water. This threat extends into the Crocodile River as main stem of the Bloubank Spruit.

- The macroinvertebrate monitoring survey reveals the substantial difference in biotic condition between the nearly pristine Skeerpoort River and the severely impacted Bloubank Spruit system. This is best evidenced by the A and C ecological category of the Skeerpoort River sites versus the D and E/F category of the Bloubank Spruit sites. The Skeerpoort River results are similar to those reported in previous external studies, indicating little change in the health of this drainage. The Bloubank Spruit results reveal an improvement in category from E/F to D in a downstream direction. A comparison with previous results indicate a greater deterioration at the upstream site versus the marginal deterioration at the downstream site. The river health survey and monitoring adds considerable value to the water resources status quo assessment.

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.

8 ACKNOWLEDGEMENTS

The compilation of this report has been made possible in part by the continued assistance of DWS staff Messrs Theo Moolman and Nico de Meillon in the collection of field data. The services of the DWS staff Ms's Marica Erasmus and Elna Vermaak (Resource Quality Information Services), Ms Busisiwe Sekgomane (PDA Requests), Ms Shouneez Chaka (GeoRequests) 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 as well as Ms Karen du Plessis 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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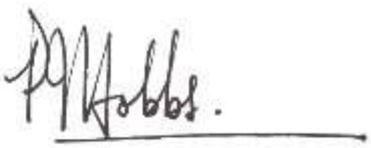

PJ Hobbs (Pr.Sci.Nat.)
SENIOR RESEARCH HYDROGEOLOGIST

L Hill (MSc.)
SENIOR AQUATIC SCIENTIST

ANNEXURE A

DESCRIPTION OF THE AQUATIC BIOMONITORING SURVEY SITES

A.1 GENERAL

All four sites are located Western Bankenveld ecoregion. Site S@HTL, however, is considered a transitional location as it is located close to the boundary with the Bushveld Basin ecoregion to the north.

A.2 S@HTL

This is located on the Skeerpoort River approximately 50 metres downstream of a small trout farm. Nevertheless, much of the surrounding area is natural and undisturbed. The sampling area comprises a pool of slow-moving/still water, leading to a narrower region of faster-flowing riffles. Most habitats are well represented, although there was a lack of sandy areas. When the bottom mud was disturbed, there was a slightly unpleasant odour.

A.3 S@NSp

This is located on a spring-fed tributary (the Groot Spruit) of the Skeerpoort River some 4000 m upstream from site S@HTL. The survey site itself is located ~120 m downstream of the Nouklip Spring, and would therefore count as a headwater site. Spring discharge at the time of surveying was measured at 105 ± 10 L/s (~9100 m^3/d). The habitat is varied and adequate, and large areas of the riverbed are sandy. The surrounding area is largely undisturbed, natural vegetation.

A.4 BB@M

The upstream site on the Bloubank Spruit was originally immediately downstream of the causeway over the stream at Makiti. Although there is excellent habitat abundance and diversity, concern exists for the impact of the causeway and culverts on the morphology of the site. The site has therefore been moved ~350 m downstream where more natural conditions prevail, but maintains its position upstream of the Zwartkrans Spring, i.e located upstream of the first major groundwater discharge into the Bloubank Spruit. A significant difference between the ‘old’ and the ‘new’ sites is the abundance of a sandy substrate and absence of riffles at the ‘old’ site, compared to the abundance of riffles and moderate sandy substrate at the ‘new’ site.

A.5 BB@NOE

Site BB@NOE is located on the Bloubank Spruit ~7400 m downstream of site BB@M. This position places it downstream of the last major groundwater discharge (that from the Kromdraai and Plover’s Lake springs) into the Bloubank Spruit. This site appears to be turbid, even when the upstream site BB@M is clear. There is a trout farm upstream of the site. The habitat at the site is inferior to the upstream site in that it is mostly bedrock and large stones. There is little sand, and the overhanging vegetation is often limited.

ANNEXURE B

RIVER HEALTH CLASSIFICATION (Dallas, 2007)

BIOLOGICAL BAND / ECOLOGICAL CATEGORY	BAND / CATEGORY NAME	DESCRIPTION
A	Natural	Unmodified natural
B	Good	Largely natural with few modifications
C	Fair	Moderately modified
D	Poor	Largely modified
E/F	Seriously modified	Seriously modified

ANNEXURE C

AQUATIC BIOMONITORING ASSESSMENT RESULTS FOR FEBRUARY 2018

SITE	PHYSICO-CHEMICAL VARIABLES			SCORES						DOMINANCE		Shannon Diversity Index
	Temp. (°C)	pH	SEC[1] (mS/m)	SASS5	Taxa	ASPT[2]	IHAS[3] (%)	Highest sensitivity	Total invertebrates	Feeding group	Taxa	
S@NSp[6]	21.7[4]	7.1[4]	30[4]	105	18	5.8	71	12	130	Predators	*Baetidae*	2.31
S@HTL[7]	21.5[4] 20.1[5]	5.9[4] 8.3[5]	31[4] 30.8[5]	185	27	6.9	72	13	683	Collector-Gatherers	*Tricorythidae*	2.36
BB@M[8]	23.6[4] 20.1[5]	7.3[4] 7.7[5]	180[4] 187[5]	27	8	3.4	67	6	219	Collector-Filterers	*Simulidae*	1.43
BB@NOE[9]	21.8[4] 20.1[5]	7.6[4] 8.0[5]	127[4] 125[5]	57	12	4.8	58	12	234	Collector-Gatherers	*Baetidae*	1.72

1 Electrical conductivity instrument-adjusted to specific electrical conductance @ 25°C
2 Average score per taxon
3 Integrated habitat assessment system
4 Field value (see **Table 5** for date of survey)
5 Laboratory value
6 Skeerpoort River tributary (Grootspruit) downstream of the Nouklip Spring (25.8745° S; 27.7838° E)*
7 Skeerpoort River on the Highland Trout Lodge property (25.8435° S; 27.7838° E)*
8 Bloubank Spruit downstream of the Makiti causeway (26.0085° S; 27.7441° E)*
9 Bloubank Spruit at the Nedbank Olwazini Estate property (25.9788° S; 27.8005° E)*
* Truncated to 4 decimals to prevent unsolicited casual visitation on private property

ANNEXURE D

TOXICITY TESTING RESULTS

Table D.1. Summary of test conditions and test acceptability criteria for *Daphnia magna* acute toxicity tests with effluents and receiving waters (Slabbert, 2004)

Summary of toxicity test	
Test system	*Daphnia* test
Test species	*Daphnia magna*
Age of test organisms	Less than 48h old
Trophic level	Grazer
Toxicity level	Acute toxicity
Test procedure	USEPA, 2002
Summary of test conditions for the *Daphnia magna* acute toxicity test	
Test type	Static-renewal
Water temperature	20 ºC ± 1 ºC; or 25 ºC ± 1 ºC
Light quality	Ambient laboratory illumination
Photoperiod	8 hours dark: 16 hours light
Feeding regime	Feed algae and commercial fish flakes while in holding prior to test
Aeration	None
Size of test chamber	50 ml
Volume of test sample	25 ml
Number of test organisms per chamber	5
Number of replicate chambers	4
Total number of test organisms per sample	20
Control and dilution water	Moderately hard, reconstituted water
Test duration	48 hours
Effect measured	Percentage lethality (no movement on gentle prodding), calculated in relation to control
Test acceptability	90% or greater survival in control
Interpretation	Lethality >10% indicates toxicity, provided that control lethality is ≤10%

Table D.2. Results of the *D. magna* screening assays expressed as percent mortality after 24 and 48 hours

Sample	Time (hrs)	Mortality (No. of organisms)	Mortality (%)
CONTROL	24	0	0
	48	0	0
HTC (S@HTL)	24	0	0
	48	0	0
BB@NOE	24	1	5
	48	3	15
BB@M	24	0	0
	48	1	5

Table D.3. Physicochemical parameters per sample measured at the start and end of the tests

Sample	Time (hrs)	Temperature (°C)	pH	SEC (mS/m)	Dissolved oxygen (mg/L)
CONTROL	0	20.0	8.10	21.3	7.24
	48	20.1	8.01	23.7	7.04
HTC (S@HTL)	0	20.1	8.31	30.8	7.59
	48	20.0	7.73	43.8	6.05
BB@NOE	0	20.2	7.96	124.7	6.73
	48	20.0	8.22	138.7	6.35
BB@M	0	20.2	7.72	187.2	6.68
	48	20.1	7.76	201.9	6.66