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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 2018 TO SEPTEMBER 2018

PROJECT No.

GT/GDED/092/2017

AUTHORS

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DATE

OCTOBER 2018

REPORT No.

CSIR/NRE/WR/IR/2018/0084/C

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PREPARED FOR

Management Authority
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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 (12) bi-annual status quo reports. This document represents the twelfth (13th) such report. It covers the timeframe April 2018 to September 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 (aka 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 5th out of 8 after 2010, 2011, 2012 and 2014, and can be classified as an 'average' runoff year. The total 2018 half year (October 2017 to April 2018) discharge of 19.3 Mm^3 is slightly below the median discharge (20.8 Mm^3) for the same period in the last nine (9) years.

- The 2018 wet season rainfall amounted to 741 mm in the mine area and 593 mm at Sterkfontein Cave. These values are 7% and 0.5% higher, respectively, than the means of the last 8 years of record common to both stations. Total rainfall recorded at the HDS station during the 2018 hydrological year was 863 mm, which is above the 10 year average of 811 mm.

- Chemical analyses of rainwater in the south-western portion of the property confirm the very low salinity (specific electrical conductance or SEC ≤10 mS/m) of this water. The results represent a mixture of precipitation events over a period of ~3 months ending late-June 2018, and therefore are not representative of specific events. This influences especially the veracity of the pH values, which range from 5.1 to 6.6.

- 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 in the last 18 months, and in SEC values which show a decline in this period.

- The groundwater elevation in the south-western portion of the property (the Zwartkrans Basin) where the allogenic recharge component is greatest and reflects little change. 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.

- During September 2018, the discharge was measured at 6 out of the ten dolomitic springs in the study area. When compared to previous the discharge volumes previously measured by Hobbs (2011), the September 2018 readings were generally below these estimates. It should however be borne in mind that the discharge volumes exhibit seasonal variations and that the September 2018 measurements were taken at the end of the dry season.

- 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 period June 2016 to June 2018 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.

- 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 largely natural Skeerpoort River and the severely impacted Bloubank Spruit system. This is best evidenced by the B ecological category of the Skeerpoort River sites versus the 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 show that the river is in a seriously modified ecological state (E/F) and further reveal a decline in category from D at the lower site to E/F. A comparison with previous results however 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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A	**Description of the aquatic biomonitoring sites**
B	**Aquatic biomonitoring assessment results for February 2018**
C	**Toxicity testing results**

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
aka	also known as
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 (aka '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

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 (**Figure 1**) following the outcome of bid GT/GDED/092/2017. Since its inception in 2012, the monitoring programme has to date generated twelve (12) bi-annual status quo reports (Hobbs, 2012; 2013a; 2013b; 2014a; 2014b; 2015a; 2015b; 2016a; 2016b; 2017a; 2017b and Hobbs et al., 2018). This document represents the thirteenth (13th) such report. It covers the period April 2018 to September 2018.

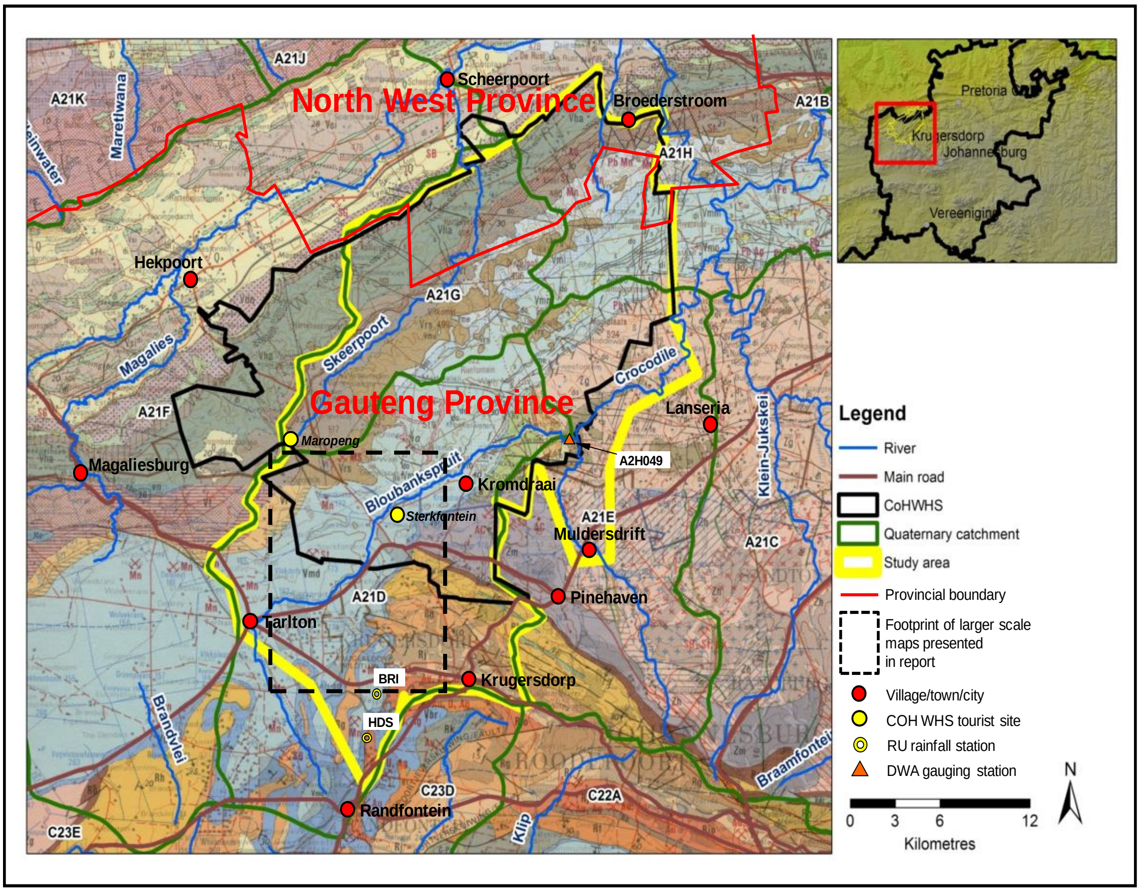

Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

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.

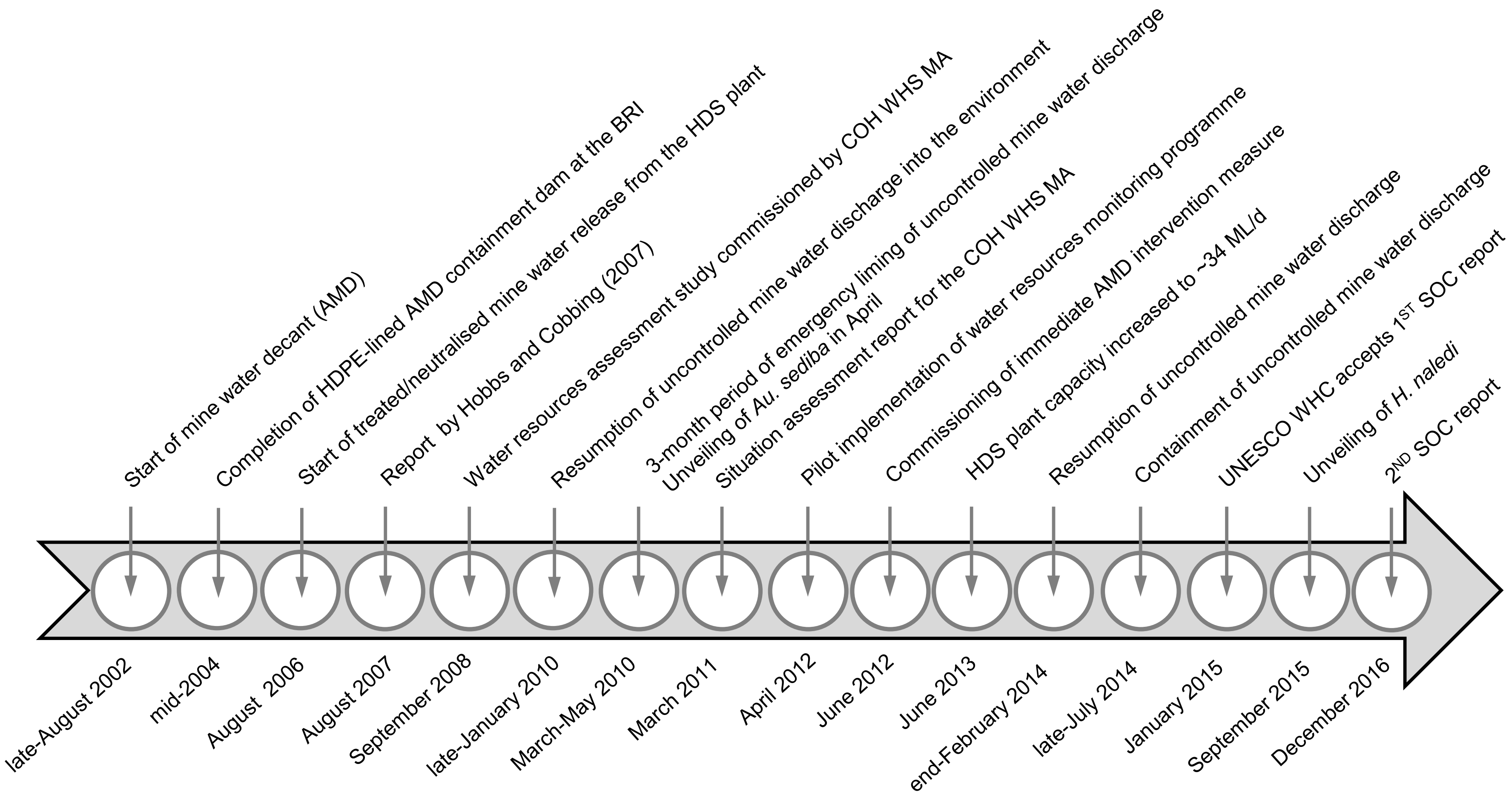

Figure 2 Timeline of key events relevant to the project and this report

3 RAINFALL

3.1 Quantity

The monthly precipitation record for the period October 2008 to September 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 total rainfall recorded at the HDS station during the 2018 hydrological year was 863 mm, which is above the 10 year average of 811 mm. The total rainfall recorded at the Sterkfontein Cave station during the period October 2017 to July 2018 was 696 mm. The 7 year average at this station is 684 mm. 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. The total 2017 wet season rainfall represents the maximum recorded at this station;
- the total wet season rainfall of the 2018 hydrological year (October 2017 to March 2018) at the HDS station was 741 mm;
- the total rainfall recorded at the HDS station during the 2018 hydrological year was 863 mm;
- at Sterkfontein Cave, 593 mm was recorded in the period October 2017 to March 2018 — this is 1 mm less than the 594 mm recorded in the same period a year earlier;

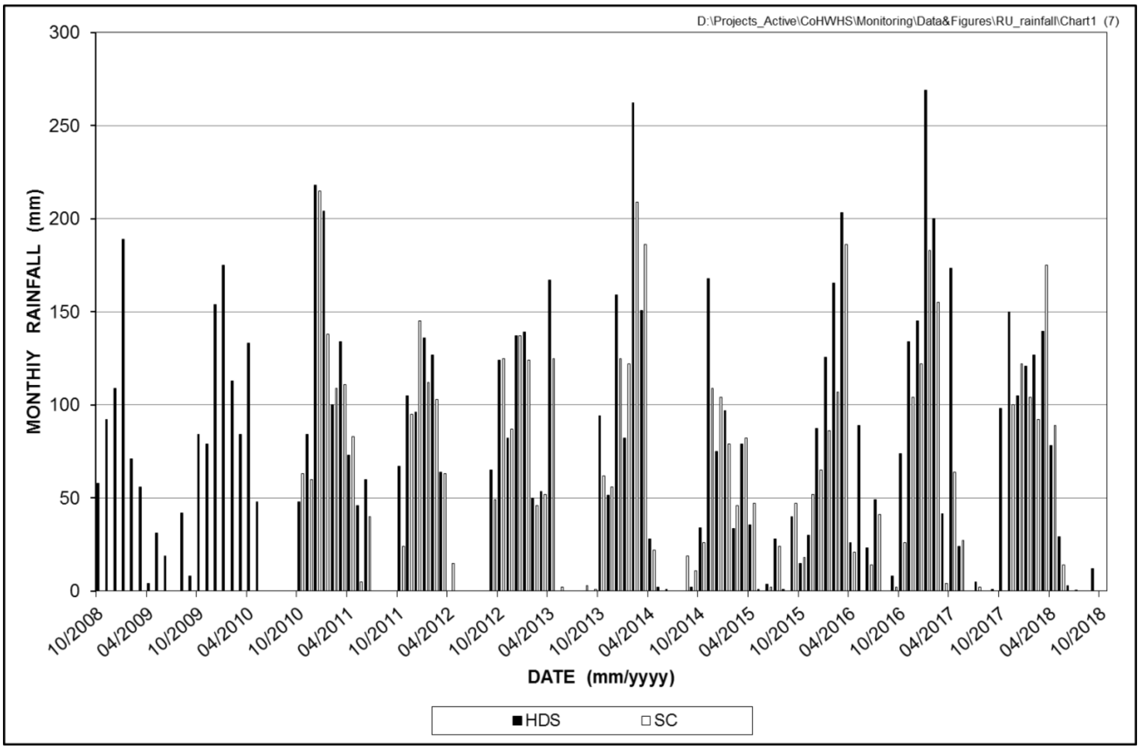

Figure 3 Monthly precipitation in the mine area (station HDS) from October 2008 to September 2018, and the contemporaneous record for the Sterkfontein Cave station from June 2010 to July 2018

The common monthly rainfall record for the HDS and Sterkfontein Cave stations is presented in **Figure 5**. The data set (n = 99) excludes months of no rainfall (n = 18) 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.

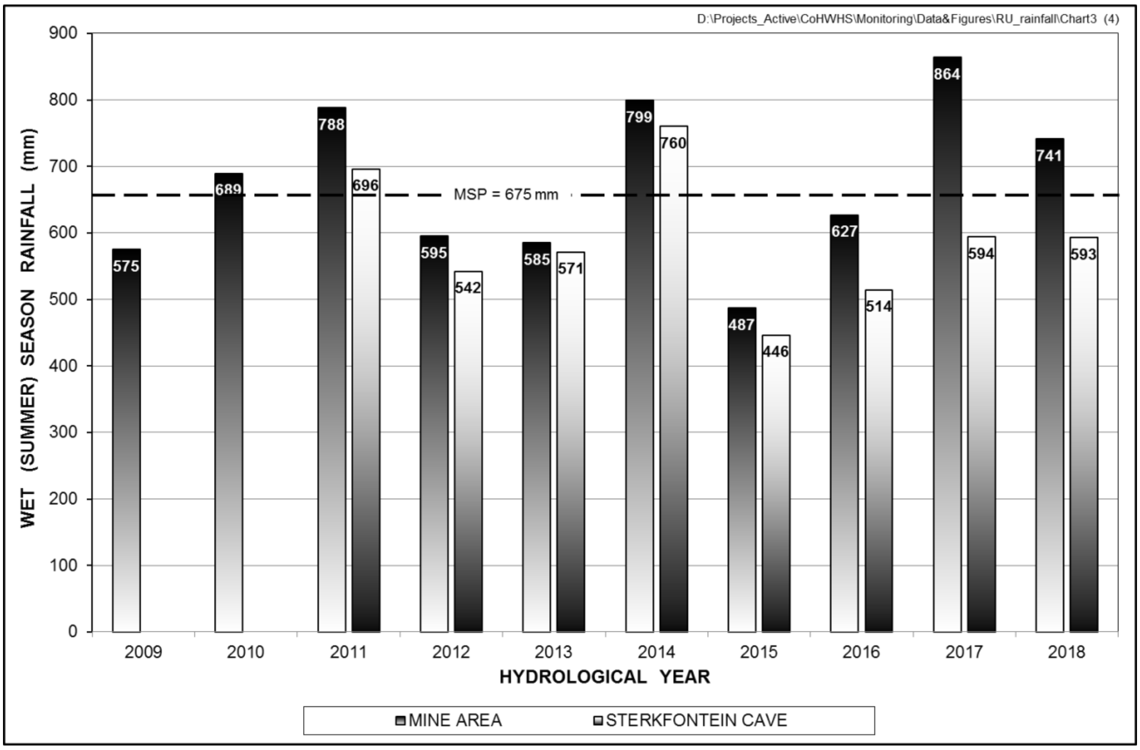

Figure 4 Total wet season (summer) rainfall in the mine area (HDS station) in the past ten hydrological years, also showing the comparison with that for the available contemporaneous Sterkfontein Cave record; MSP denotes mean summer precipitation

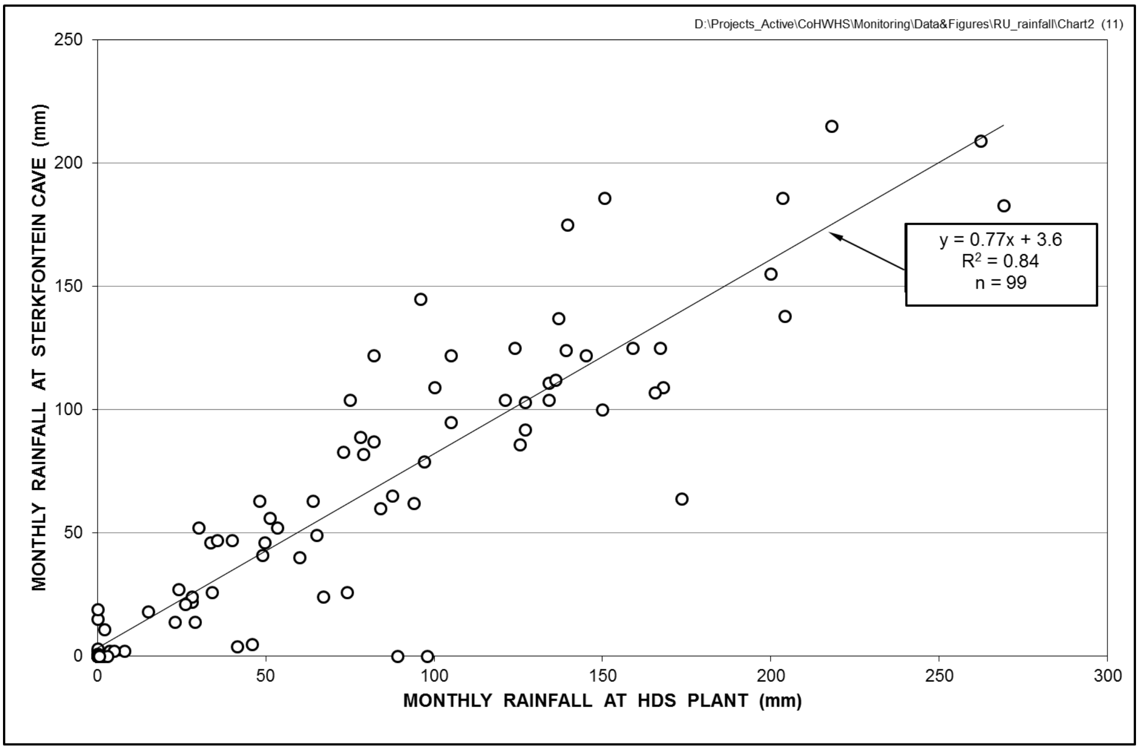

Figure 5 Correlation of monthly rainfall at Sterkfontein Cave with that at the HDS mine water treatment plant in the mine area for the period of common record June 2010 to July 2018

3.2 Quality

The chemical composition of rainwater in the south-western portion of the property is reflected in the samples obtained from 4 totalling rainfall stations. 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 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-March to late-June 2018

Variable/analyte	Unit	Rainfall Station			
		HDS[1]	GP00303[2]	GP00301[3]	SC[4]
Specific electrical conductance*	mS/m @ 25°C	4	3	3	7
pH*	$-\log_{10}\alpha_{H+}$	6.2	5.1	6.6	6.6
Calcium	mg Ca/L	1.5	0.7	0.5	0.3
Magnesium	mg Mg/L	0.3	0.2	0.7	0.4
Sodium	mg Na/L	0.3	0.2	0.1	0.5
Potassium	mg K/L	0.2	0.2	0.6	0.4
Chloride	mg Cl/L	<2.0	<2.0	<2.0	<2.0
Sulfate	mg SO_4/L	9.9	7.5	3.9	12
Total alkalinity	mg $CaCO_3$/L	3.2	<2.5	5.7	12
Nitrate + nitrite	mg N/L	1.1	1.3	0.6	<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 DWS gauging station A2H029 measures the discharge from the Bloubank Spruit system, and is located about 700 m upstream of the system's confluence with the Crocodile River (**Figure 1**). The 46-year discharge record from 1972 to 2018 for this catchment (Quaternary A21D) provides the monthly statistics reported in

Table 2. The record is extended and updated as frequently as possibly when data are obtained from the station and processed by the DWS.

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 previous 8 years. Only discharge records for the first (October to December 2017) and second (January to April 2018) quarters of the 2018 hydrological year are currently available. **Figure 6** shows total annual discharge in Mm^3 only for complete hydrological years up to 2017. 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, and the total 2018 half year discharge of 19.3 Mm^3 is slightly below the median discharge (20.8 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 April 2018 (latest data as at October 2018)

Variable	Month											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	44	44	45	45	46	46	46	44	45	45	44	44
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	0.902	1.075	1.190	0.998	0.964	0.961	0.921	0.803
Mean	1.903	1.909	2.305	2.749	2.705	3.050	2.459	2.297	2.103	2.086	1.961	1.823
Median	1.684	1.745	2.092	2.513	2.296	2.550	2.060	1.925	1.797	1.695	1.676	1.574
95%ile	3.799	2.952	4.488	5.320	6.280	7.729	5.309	4.882	4.115	4.058	3.658	3.508
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	1.909	1.910	2.187	1.296	1.197	0.976	0.944	0.876	0.882
CoV (%)	48.9	43.7	47.7	69.5	70.6	71.7	52.7	52.1	46.4	45.3	44.7	48.4

- *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*

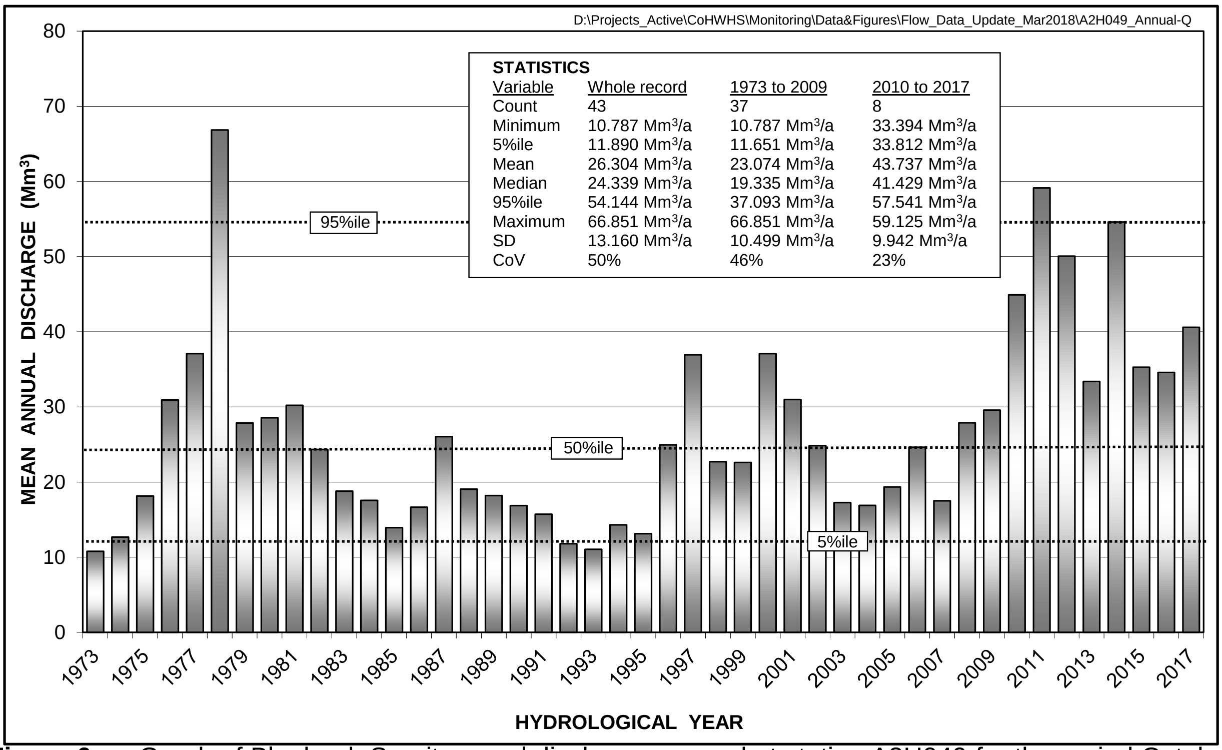

Figure 6 Graph of Bloubank Spruit annual discharge gauged at station A2H049 for the period October 1972 (a_h 1973) to September 2017 (a_h 2017)

The instantaneous monthly flow pattern at station A2H049 for the complete available record period October 1972 to April 2018 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 ten 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**), implying that the rainfall associated with this discharge was rather spread out over the hydrological year rather than concentrated in a few months, to significantly impact on the observed discharge.

For the 2018 hydrological year, based on the currently available records from October 2017 to April 2018 the highest mean monthly instantaneous discharge was about 1.45 m^3/s.

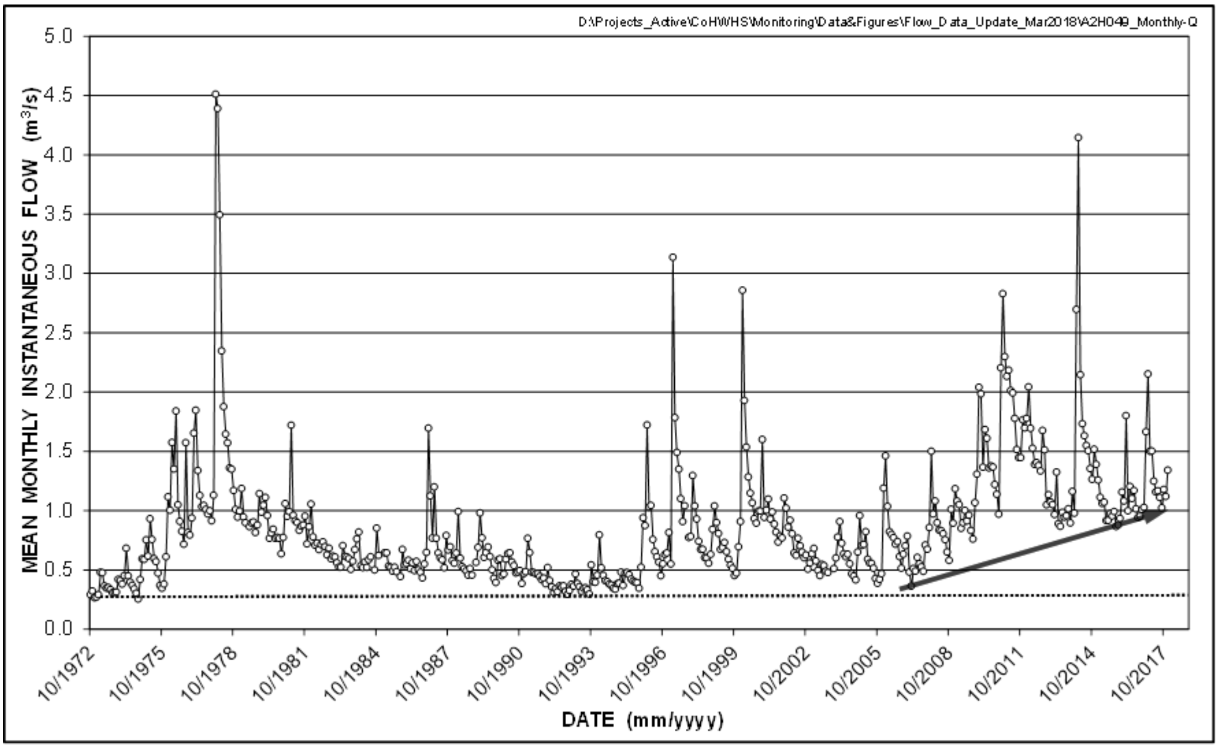

Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to April 2018 (latest data as at October 2018)

4.1.2 Surface Water Fluxes

The magnitude of surface water loss to predominantly the karst aquifer is quantified by the difference in measured streamflow discharge at stations F11S12 (Brickworks Dam), at the lower end of the Tweelopie Spruit, and at MRd, about 3.9 km further downstream on the Riet Spruit (**Figure 10**). **Figure 10** shows the location of the surface water quantity and quality monitoring stations.

The 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 was assumed to have been an indication of an increased discharge from the mine water treatment plant. Equally notable was that the December 2017 discharge (21.5 ML/d) at station MRd (the surface ‘outflow’) was also significantly high, again emphasising 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).

Updated records for June and October 2018 indicate losses of 8 ML/d and 1.8 ML/d (**Figure 8**), respectively mainly as a result of reduced measured flows at F11S12. Thus, the estimated losses are far less compared to the December 2017 record and indicate better correlation with the Period 3 data set (**Figure 8**). This could most likely be attributed to possible decreased discharge from the mine water treatment plant and the fact that 2018 has been a hydrologically drier year than 2017 as confirmed by the reduced instantaneous mean monthly discharge (**Figure 7**).

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.

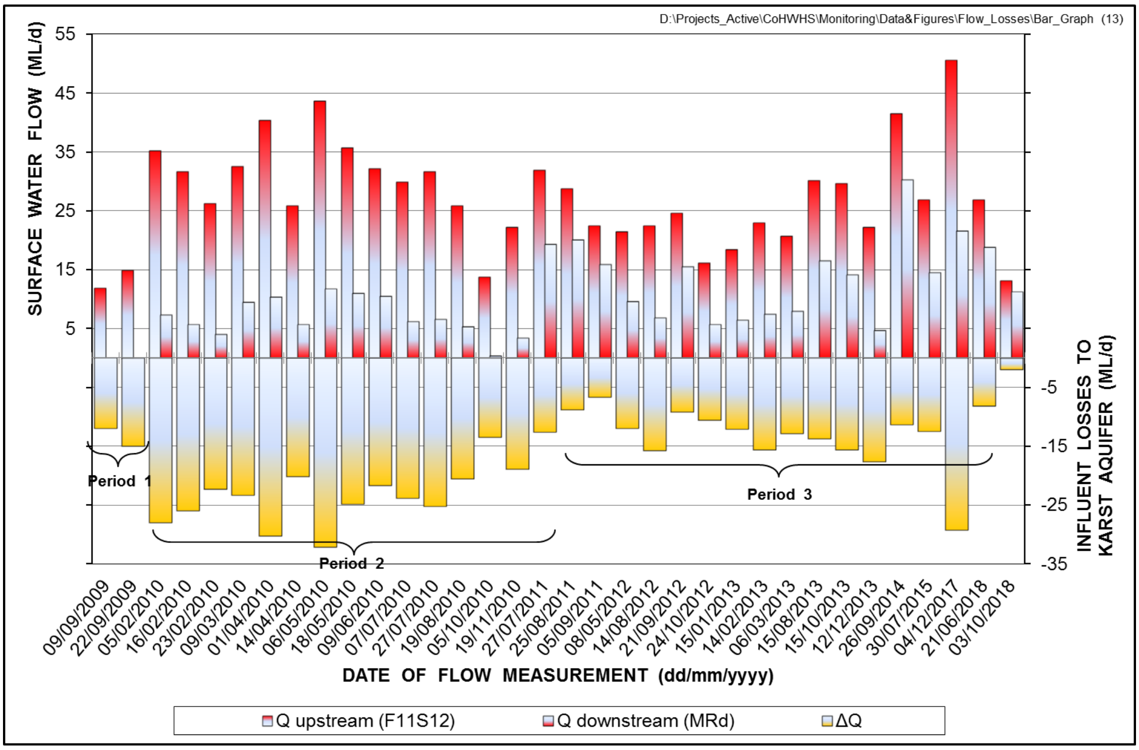

Figure 8 Graph of streamflow and influent losses to the karst aquifer in the lower Riet Spruit valley

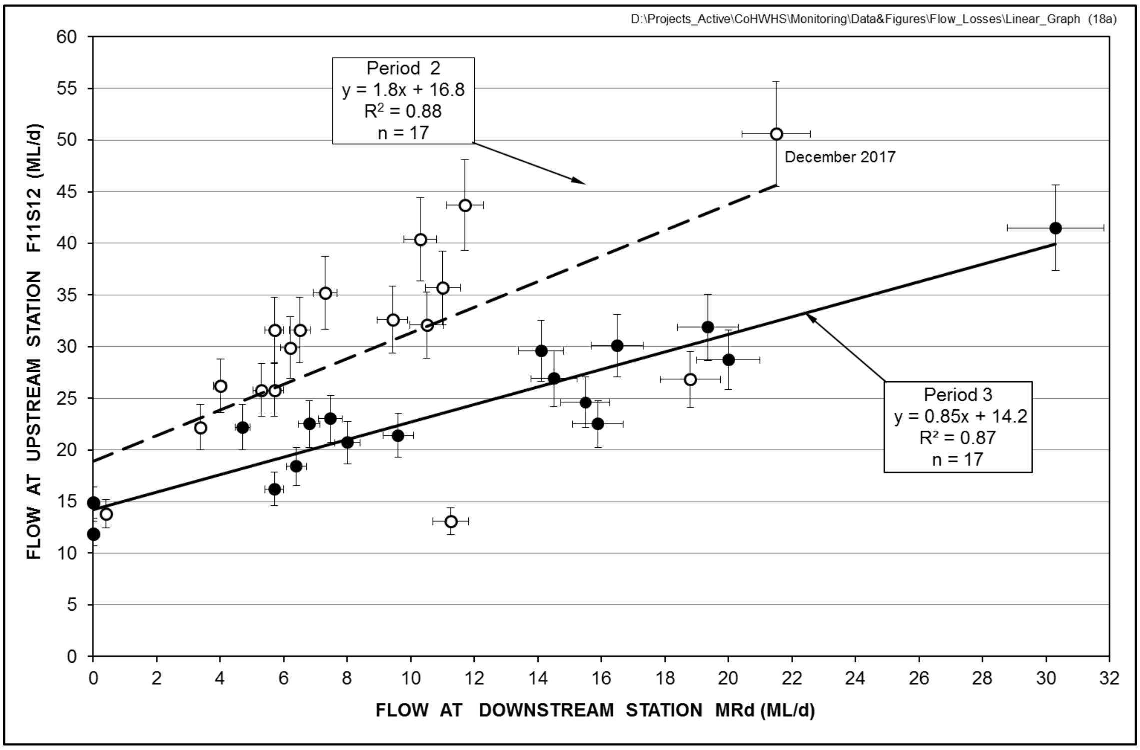

Figure 9 Correlation of streamflow at stations F11S12 and MRd in the lower Riet Spruit valley, with vertical error bars denoting ±10% at F11S12 and horizontal bars ±5% at MRd

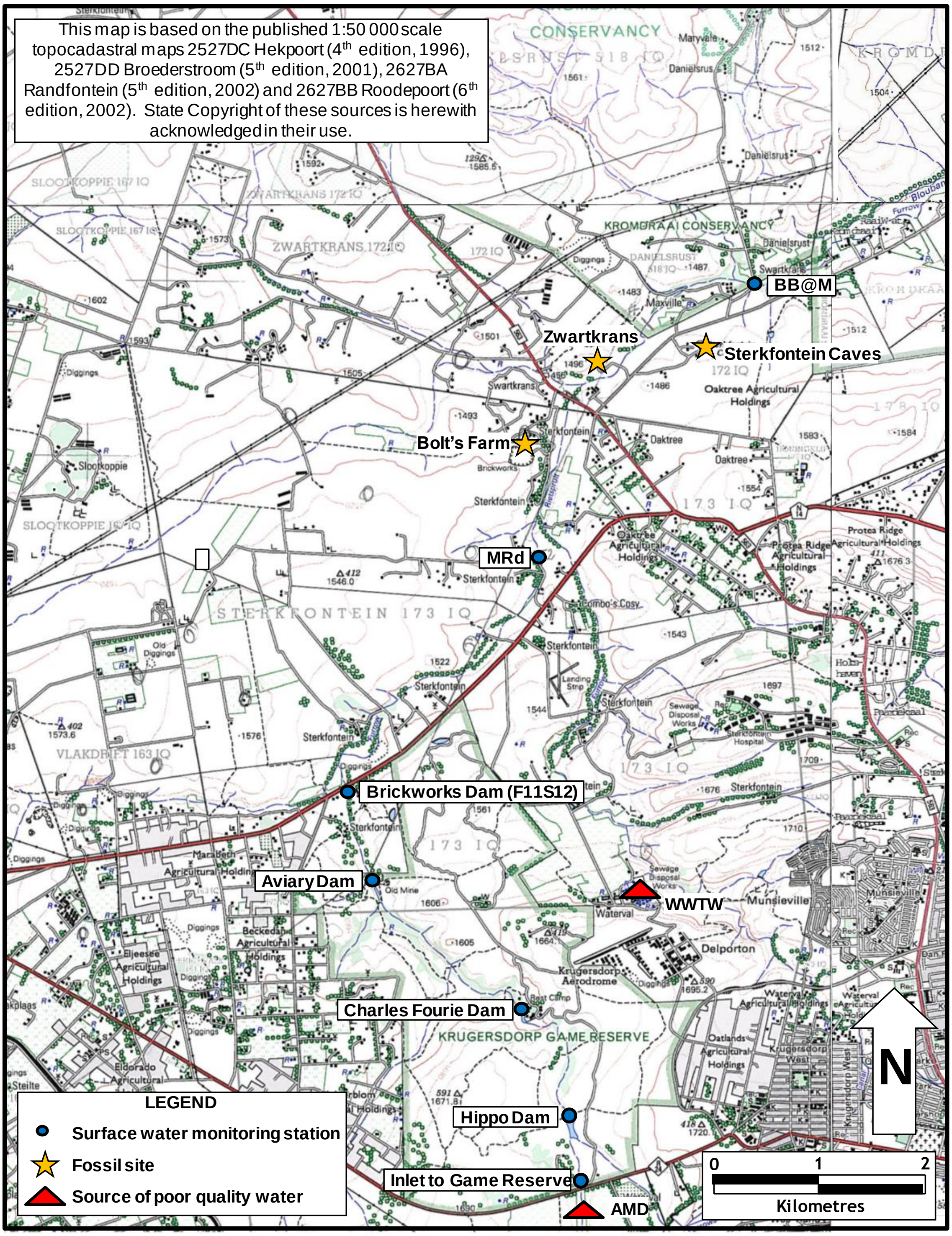

Figure 10 Locality map of surface water quantity and quality monitoring stations

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 18 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 are 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 December 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.

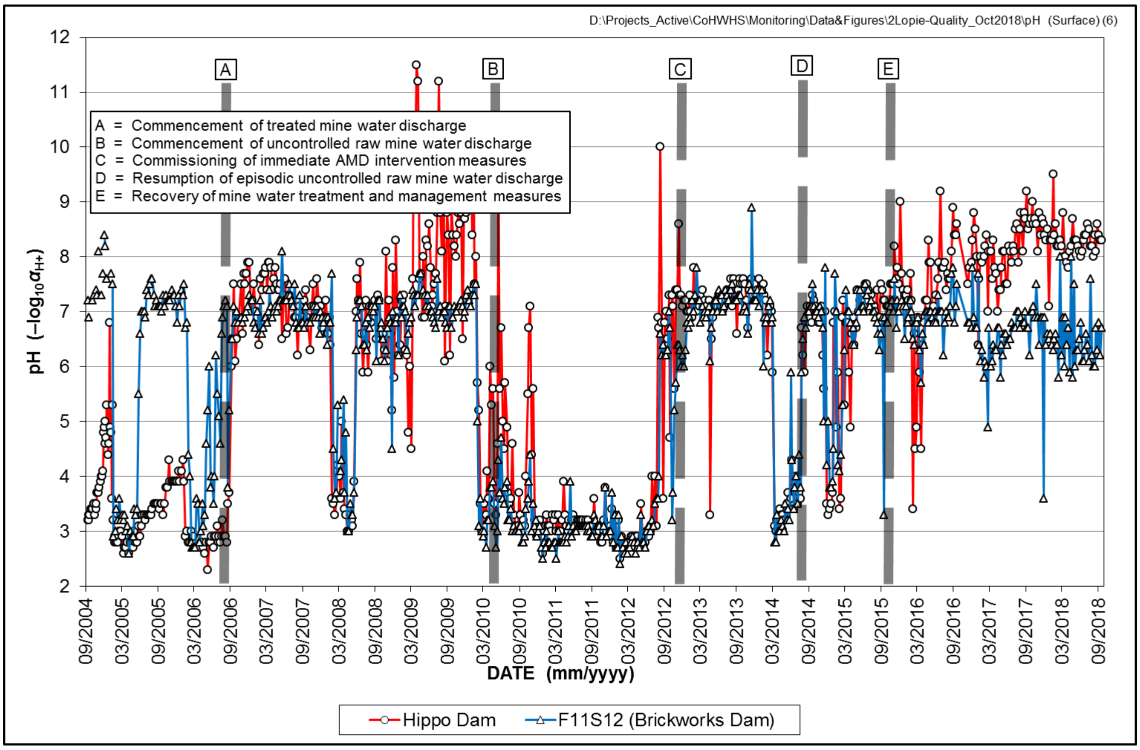

Figure 11 pH pattern of Tweelopie Spruit surface water in the period September 2004 to September 2018

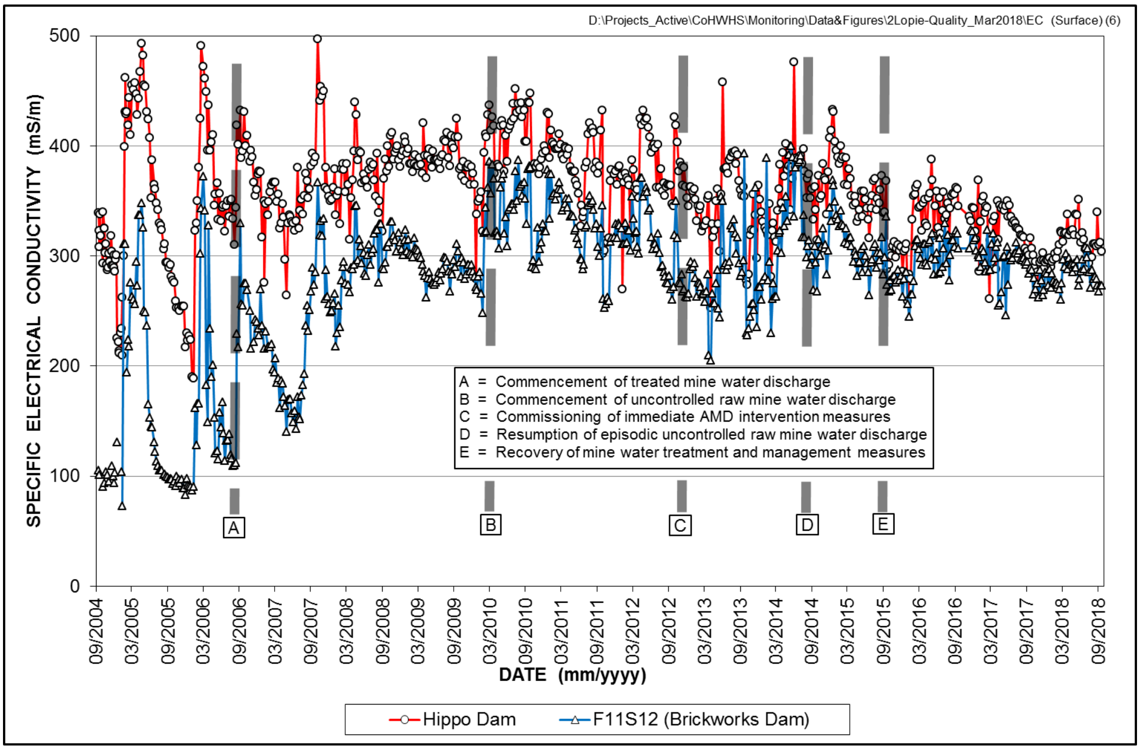

Figure 12 Specific electrical conductivity pattern of Tweelopie Spruit surface water in the period September 2004 to September 2018

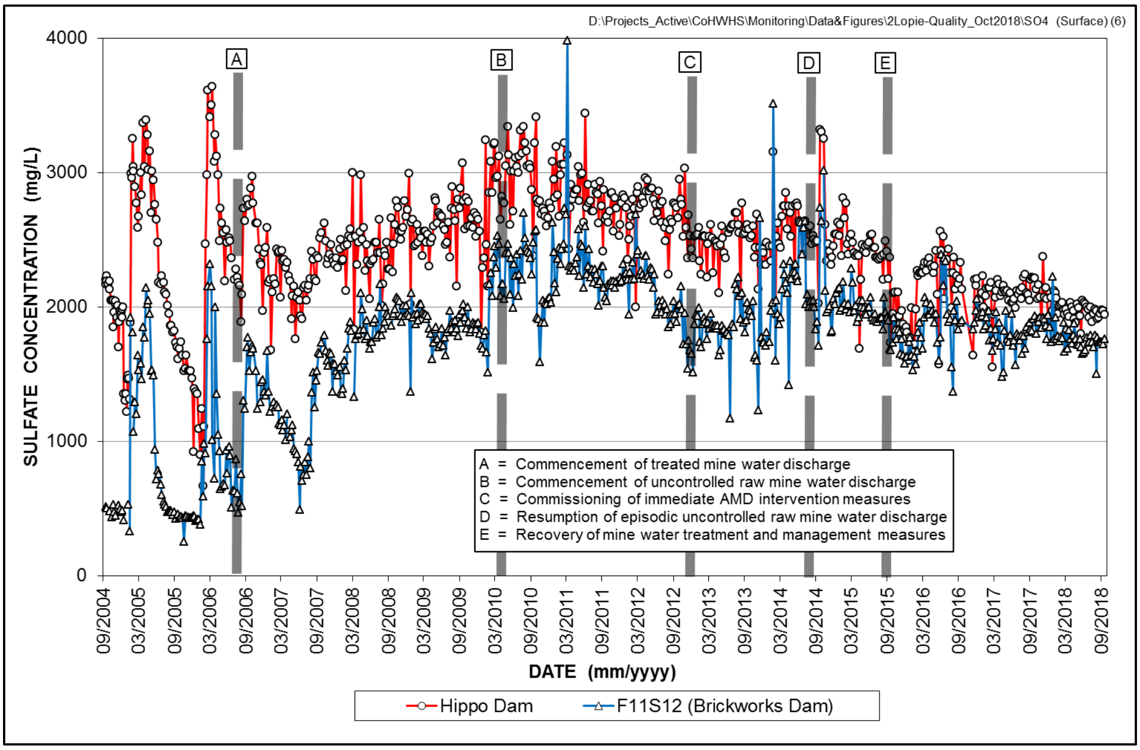

Figure 13 Sulfate pattern of Tweelopie Spruit surface water in the period September 2004 to September 2018

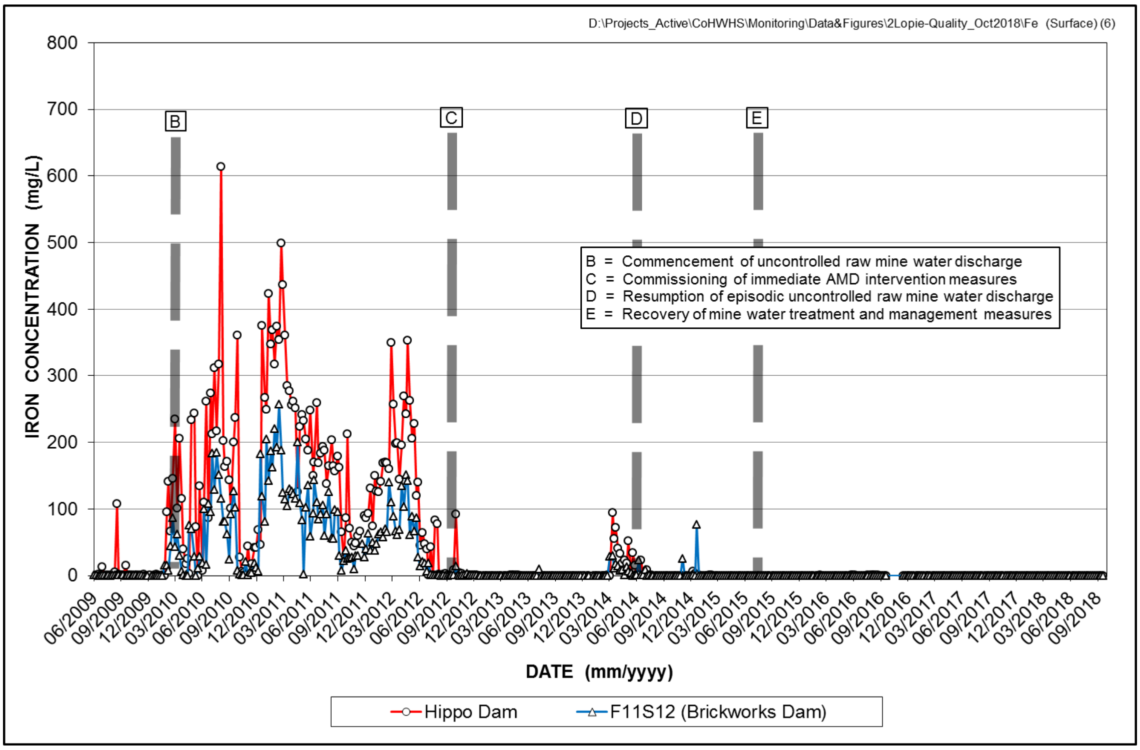

Figure 14 Iron pattern of Tweelopie Spruit surface water in the period June 2009 to February 2018

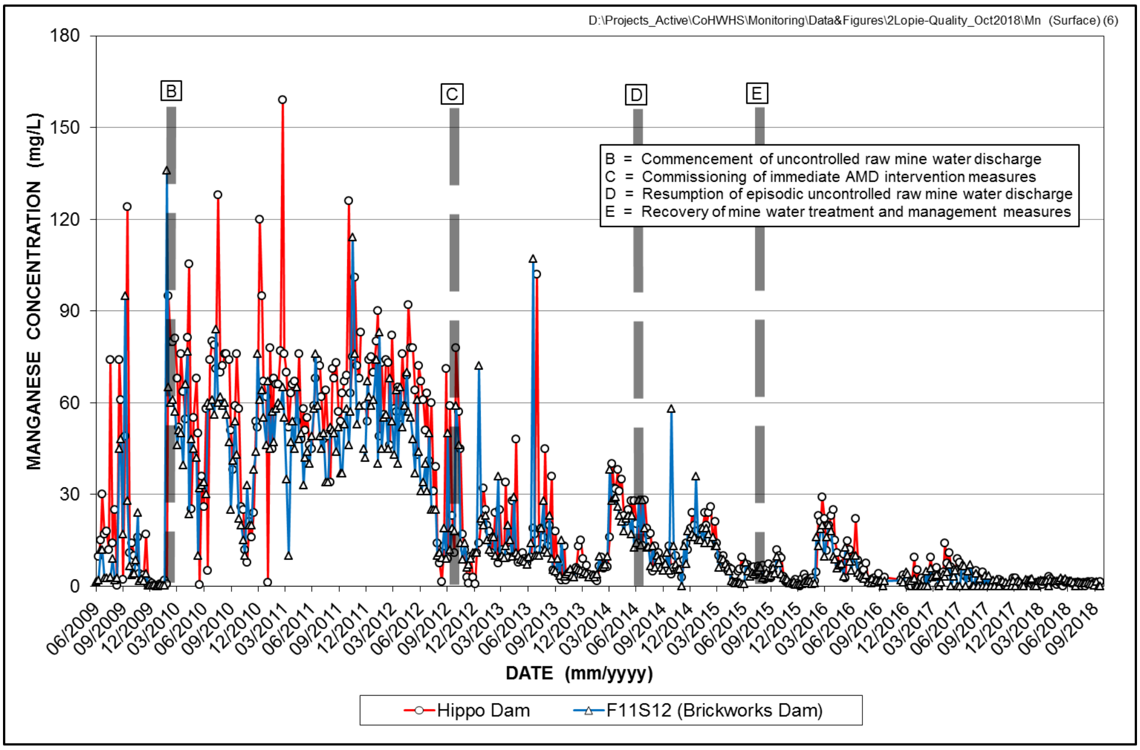

Figure 15 Manganese pattern in Tweelopie Spruit surface water in the period June 2009 to February 2018

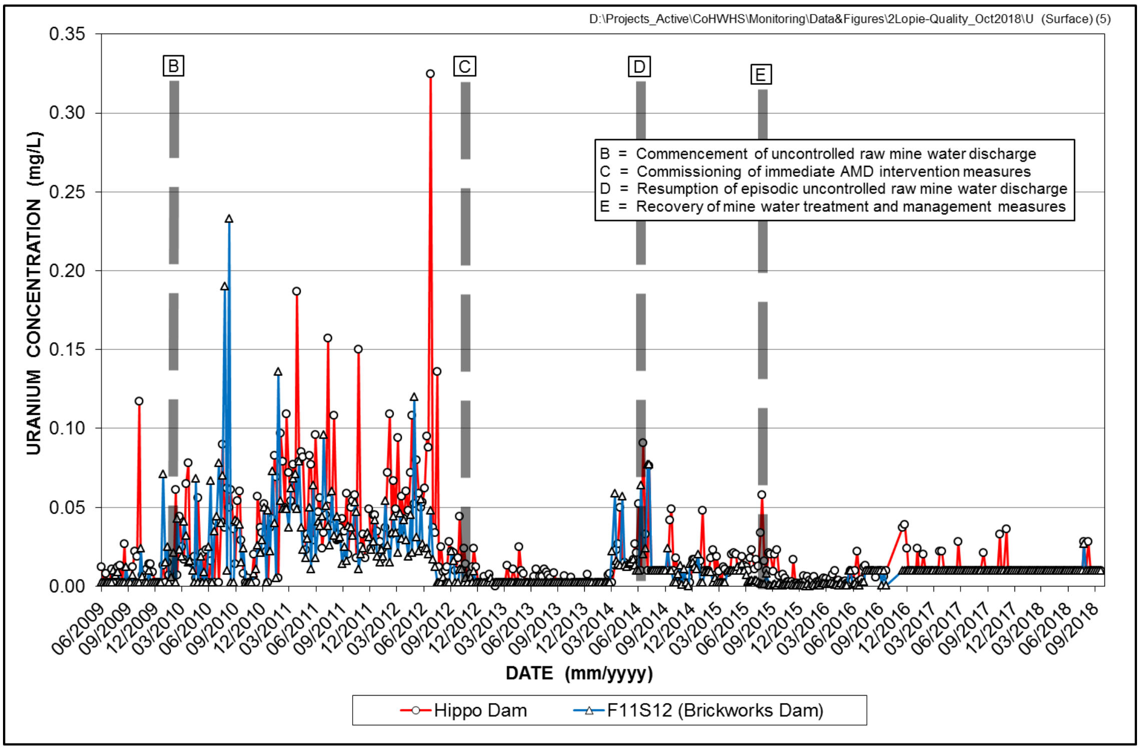

Figure 16 Uranium pattern in Tweelopie Spruit surface water in the period June 2009 to February 2018

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	174	173	128	83	57	151
	5%ile	3.6	2.8	5.9	3.2	6.6	3.9	2.7	5.3	3.0	6.0
	Mean	—	—	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	4.9	7.9	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	0.8	0.9	0.4	0.9	1.7	0.6
	CoV (%)	22.0	30	11	32	10.8	14	14	13	32	9
SEC (mS/m)	n	175	129	83	57	174	172	128	83	57	151
	Mean	374	391	350	376	325.6	268	332	281	329	293
	Median	379	393	354	377	324.5	283	330	276	323	294
	95%ile	426	438	395	417	362.0	329	378	350	391	320
	SD	32	33	34	28	24.7	48	29	34	34	18
	CoV (%)	9	8	10	7	7.6	18	9	12	10	6
SO_4 (mg/L)	n	176	128	82	56	174	171	128	83	56	151
	Mean	2448	2846	2520	2585	2112.2	1636	2264	1879	2137	1845
	Median	2460	2815	2525	2541	2100.0	1760	2240	1870	2075	1848
	95%ile	2828	3220	2770	2950	2443.5	2015	2593	2148	2640	2065
	SD	262	226	193	231	203.8	349	245	268	274	155
	CoV (%)	11	8	8	9	9.7	21	11	14	13	8
Fe (mg/L)	n	33	129	83	57	160	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	0.04	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	0.14	0.3	57.7	1.9	12.2	0.02
	CoV (%)	399	69	528	220	182.4	94	79	407	2518	123
Mn (mg/L)	n	34	129	83	57	160	33	128	83	57	123
	Mean	18.1	62.7	16.5	17.3	4.8	10.3	50.3	14.4	16.1	4.3
	Median	9.8	65.0	11.0	16.0	2.7	2.7	50.0	10.0	14.0	3.1
	95%ile	74.0	95.0	56.1	32.6	15.2	46.2	76.0	45.0	30.4	13.0
	SD	27.6	23.5	18.0	9.1	5.3	19.4	17.6	15.8	9.9	4.1
	CoV (%)	153	38	109	53	111.1	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 – 09/2018

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

Variable	Statistical Parameter														SANS (2015a)[1]
	Period August 2002 to January 2010							Period February 2010 to December 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	192	7.541	8.151	8.227	8.5	0.301	4	5.0–9.7
SEC (mS/m)	232	51.1	61.2	62.3	66.8	5.0	8	190	61.335	92.022	94.05	126.055	22.845	25	<170
TDS (mg/L)	137	347.6	438.5	448.9	479.3	41.5	9	131	473.598	690.914	677.717	977.231	170.463	25	<1200
Ca (mg/L)	172	40.1	51.3	52.1	57.7	5.31	10	187	54.06	95.236	93.7	153.37	32.58	34	n.s.
Mg (mg/L)	171	23.3	30.2	30.4	34.9	4.8	16	187	28.405	43.917	44.514	59.783	10.602	24	n.s.
Na (mg/L)	185	19.1	27.5	27.7	34.0	4.7	17	159	28.13	41.065	38.84	56.94	9.813	24	<200
K (mg/L)	173	1.4	2.4	2.4	3.4	0.7	27	161	2.9	4.064	3.838	5.8	0.989	24	n.s.
Cl (mg/L)	175	29.2	36.2	36.3	43.5	4.8	13	190	31.093	38.735	38.355	45.414	5.341	14	<300
SO_4 (mg/L)	191	63.4	85.8	83.9	110.0	15.1	18	182	96.368	277.641	302.96	473.821	131.077	47	<500
HCO_3 (mg/L)	185	146.1	188.1	190.2	216.1	21.1	11	185	88.258	136.208	138.232	178.958	27.141	20	n.s.
NO_3+NO_2 (mg N/L)	214	3.294	4.740	4.414	7.085	1.190	25	183	3.404	5.504	5.399	8.128	1.465	27	<11
PO_4 (mg P/L)	247	0.043	0.189	0.158	0.451	0.131	69	187	0.005	0.096	0.062	0.262	0.127	132	n.s.
Si (mg/L)	247	4.93	5.84	5.83	6.69	0.60	10	190	4.942	5.629	5.546	6.625	0.623	11	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	0.024	126	<2
Mn (mg/L)	69	0.001	0.049	0.002	0.146	0.226	459	61	0.001	0.162	0.002	0.05	0.855	528	<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	137	<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 prevailed in the subsequent period (August 2012 to March 2018) 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 March 2018) exhibits a substantially higher median value of 1017 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 ~380 mg/L) between mid-2010 and mid-2014, followed by a period of comparatively consistent rising concentrations from 360 to 415 mg/L to the end of the record. These circumstances are confirmed by the load and concentration statistics presented in the text boxes

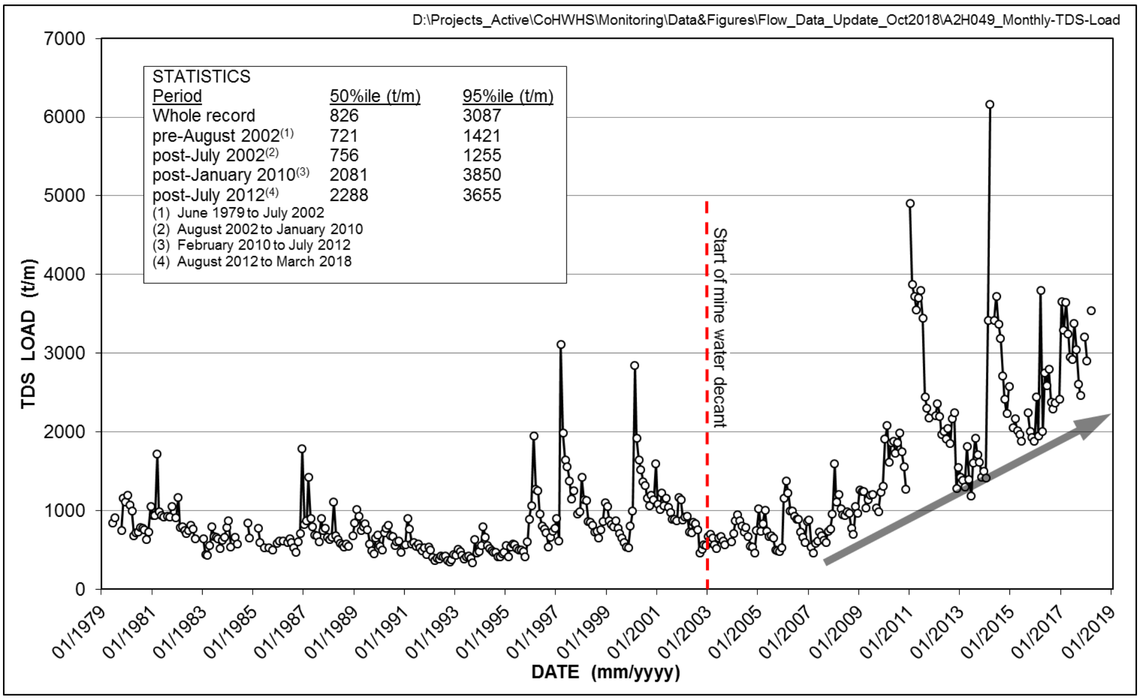

Figure 17 Long-term (June 1979 to March 2018) monthly TDS load pattern and trend in the Bloubank Spruit at station A2H049

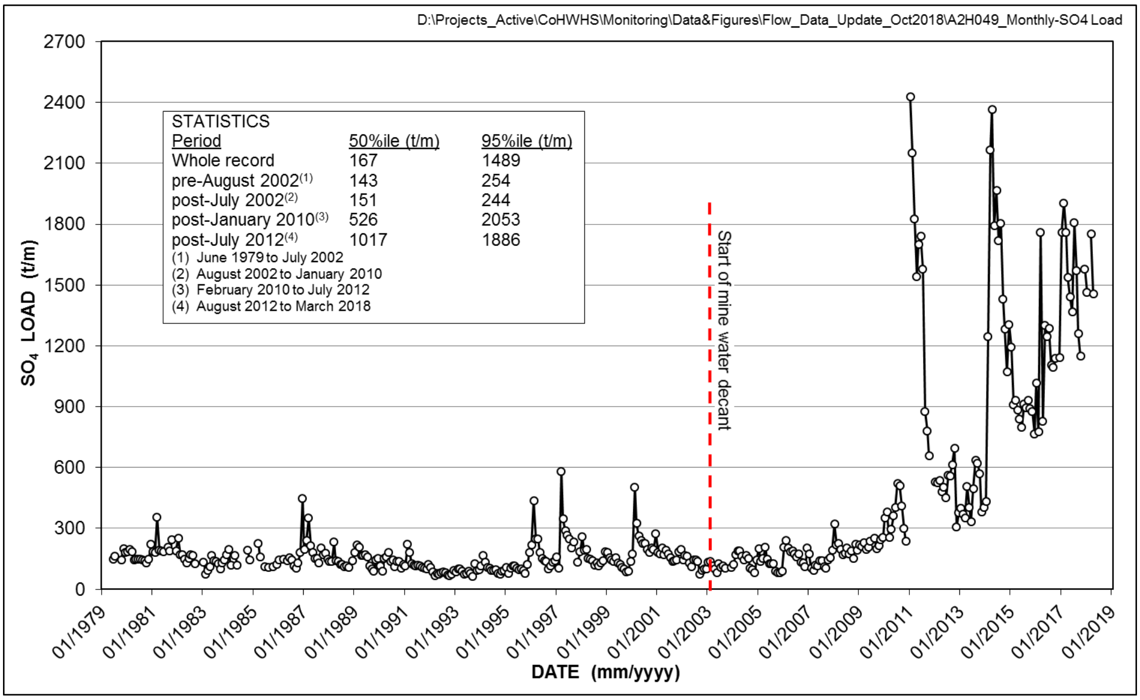

Figure 18 Long-term (June 1979 to March 2018) monthly SO_4 load pattern and trend in the Bloubank Spruit at station A2H049

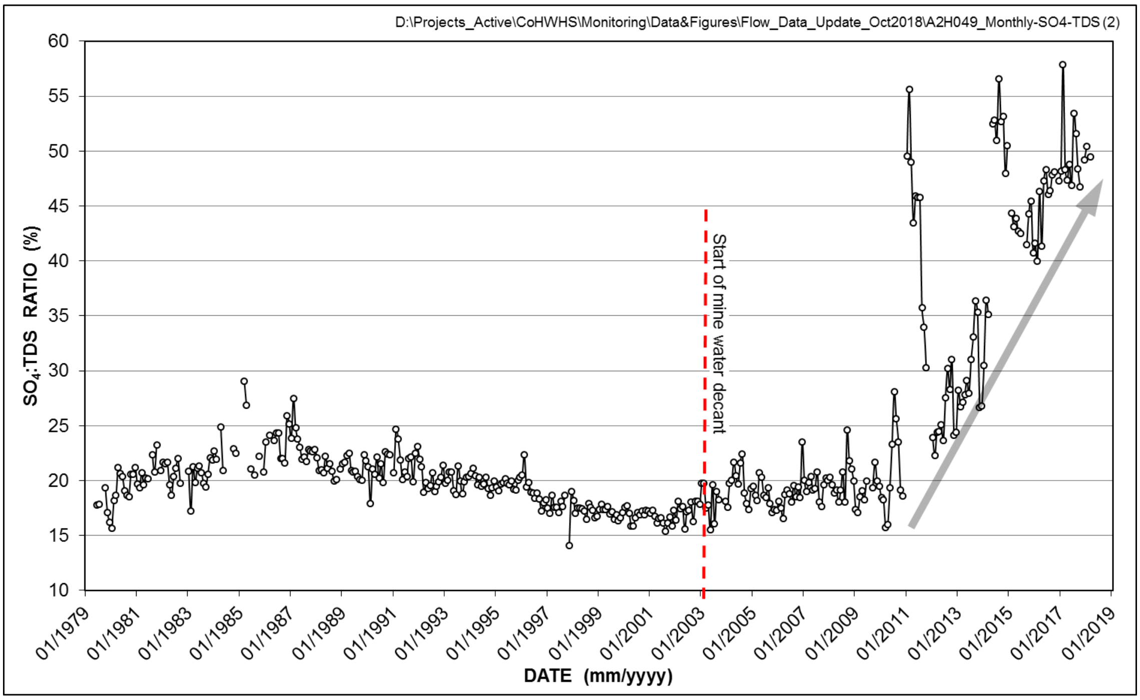

Figure 19 Long-term (June 1979 to March 2018) trend in the SO_4:TDS ratio at station A2H049

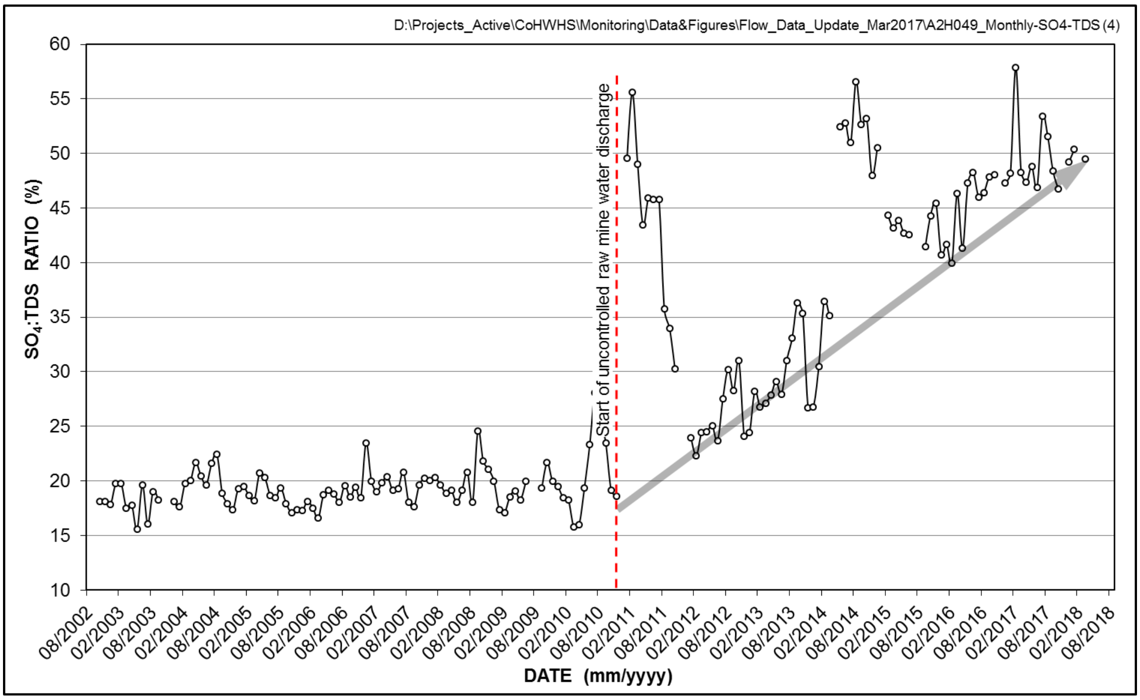

Figure 20 Pattern and trend of the SO_4:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin in mid-2002

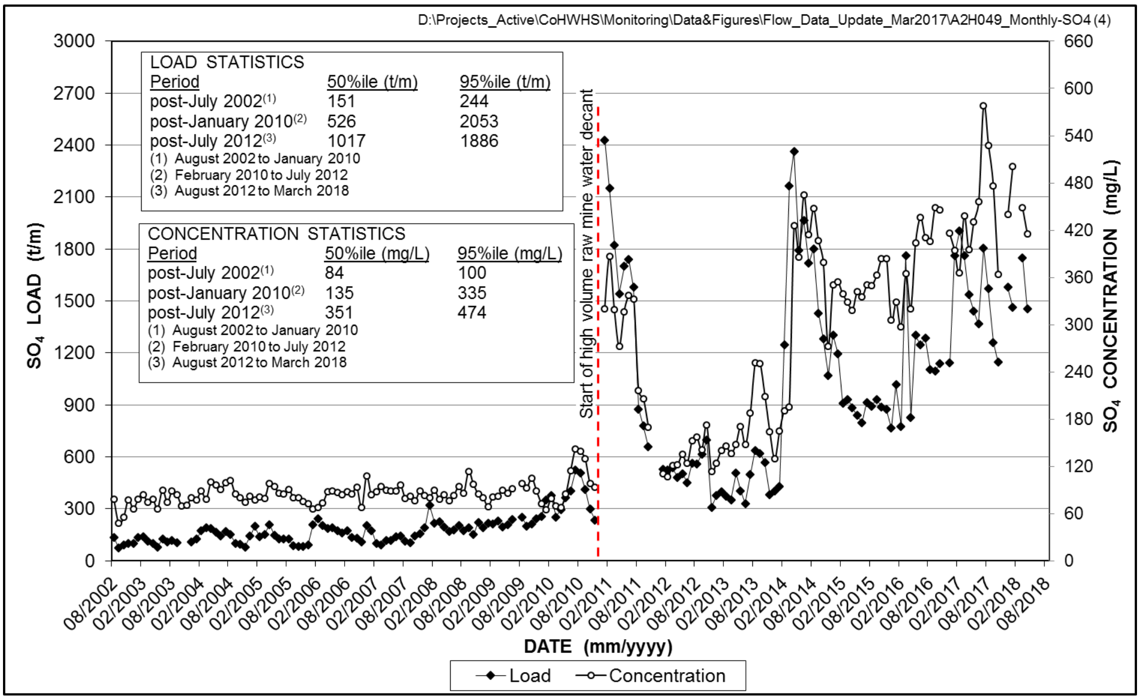

Figure 21 Monthly SO_4 concentration and load pattern and trend in the Bloubank Spruit at station A2H049 since mid-2002

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 locations 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**.

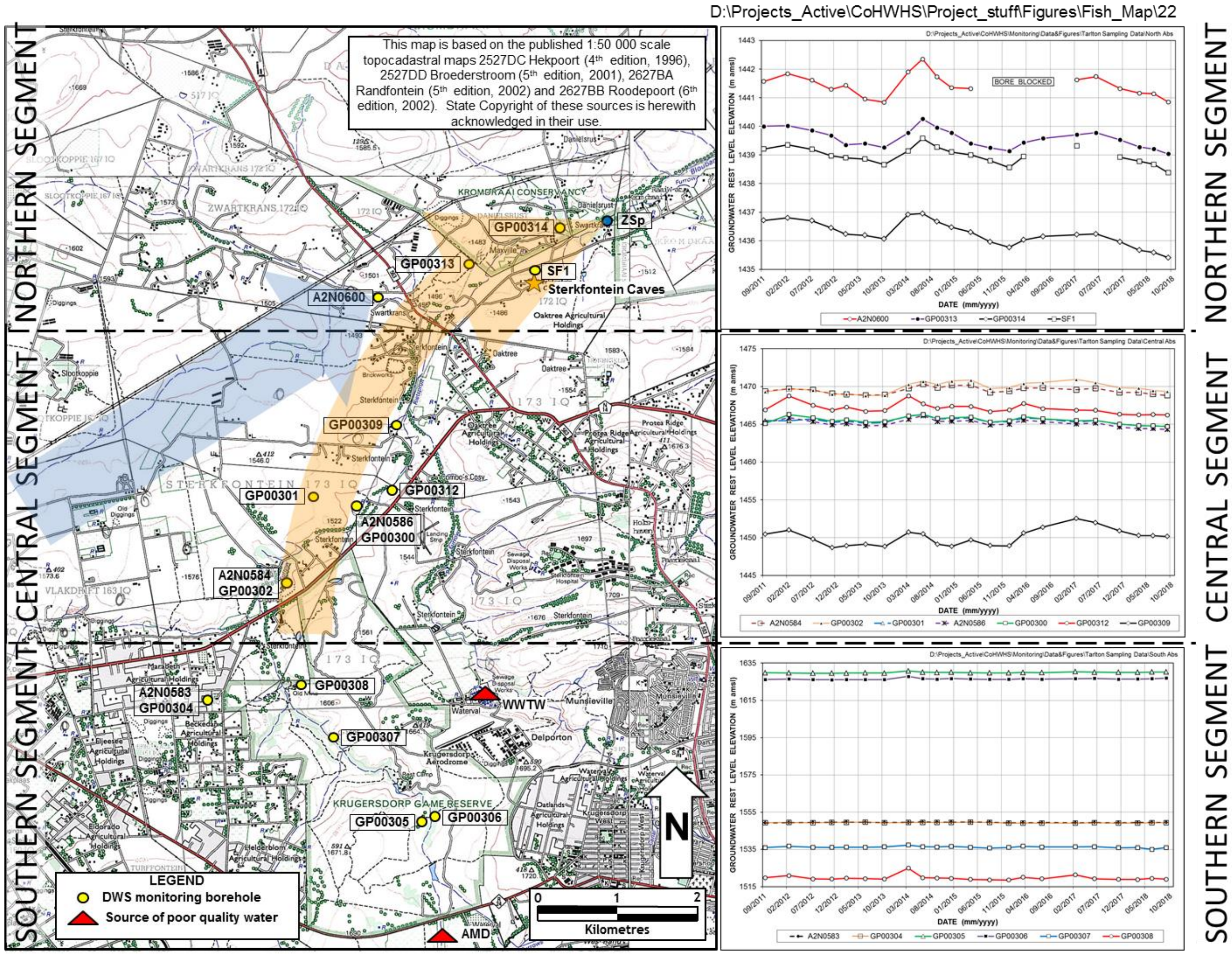

Figure 22 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

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. The groundwater level recorded in September 2018 represents the lowest elevation recorded since mid-2010, i.e. 1438.38 mamsl.

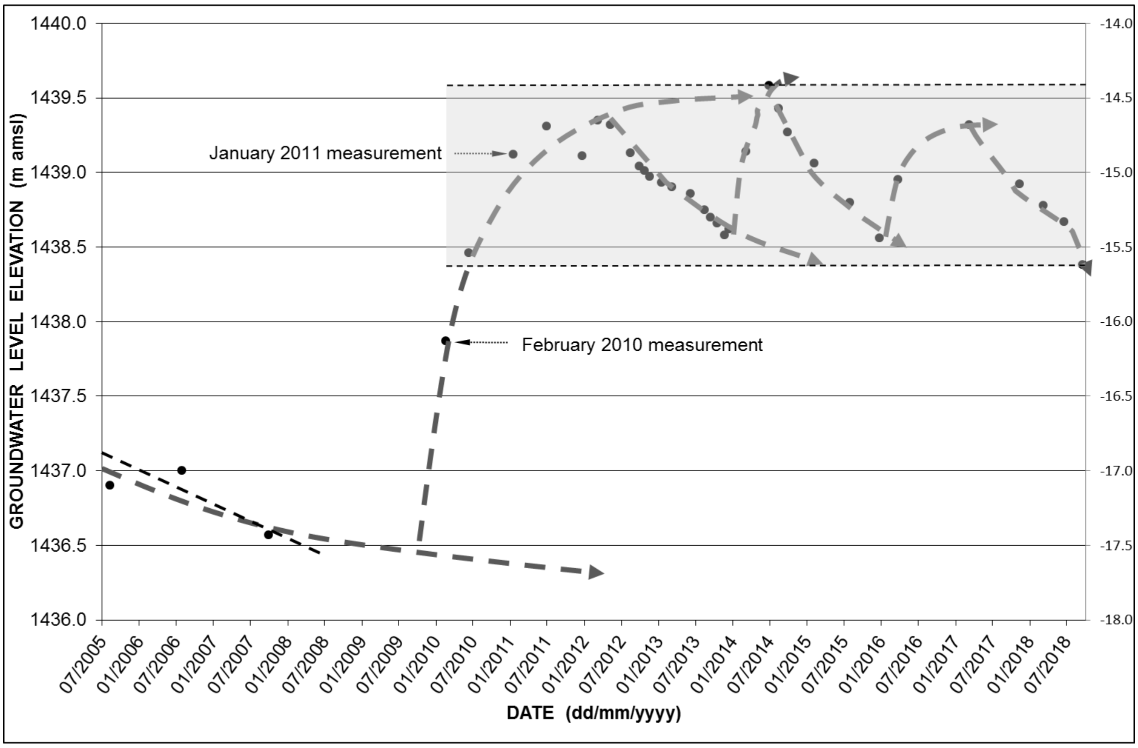

Figure 23 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the lake water level in Sterkfontein Cave; shaded area denotes magnitude of fluctuation since mid-2010

5.1.4 Discharge from the Dolomitic Springs

The discharge from the dolomitic springs in the COH WHS is measured every six months. The bi-annual measurement frequency targets the end of the wet (typically March/April) and dry (typically September/October) seasons, as appropriate measurement times. This is to assess the variation of the possible contributions of the spring discharge to the flow in the river systems, to add to the limited currently available spring discharge database and to allow for the identification of any future impact. For the September 2018 monitoring, flow was measured at six (**Table 5**) of the ten identified springs. The Cradle, Aquamine, Tweefontein and Nash springs were identified and water samples were collected from them, however the discharge was not measured. This was because no suitable cross-sectional area for measurement could be identified in the vicinity of these spring sites.

Table 5 Dolomitic spring discharge measured between 25 and 27 September 2018

Spring	**Compartment**	**Measured Discharge**		**Spring Discharge**		**Previous Discharge Volume** [1]	
		(m^3/s)	**(ML/d)**	**(m^3/s)**	**(ML/d)**	**(m^3/s)**	**(ML/d)**
Zwartkrans (upstream)	Zwartkrans	1.01	86.91	0.04	3.4	~0.1	~8.6
Zwartkrans (downstream)		1.05	90.31				
Plover's Lake	Krombank	0.04	3.52	0.05	4.03	~0.06	~5.2
Plover's Lake (culvert)		0.01	0.51				
Kromdraai (upstream)	Krombank	1.11	95.88	0.13	10.79	~0.28	~24.1
Kromdraai (downstream)		1.24	106.67				
Danielsrust	Danielsrust	0.04	3.56	0.04	3.56	~0.03	~2.4
Nouklip	Diepkloof	0.18	15.65	0.18	15.65	~0.14	~12.4
Broederstroom	Broederstroom	0.01	0.91	0.01	0.91	~0.02	~1.8

[1] after Hobbs (2011)

The Zwartkrans spring occurs along the Bloubank Spruit. It should be noted that at the time of discharge determination of this spring, there was continuous direct abstraction from the spring by nearby residents. This therefore implies that the actual contribution of the spring to the river flow, and the consequent discharge determined, may have been compromised, leading to a possible under-estimation.

The highest discharges were recorded at the Nouklip and Kromdraai springs, respectively yielding 15.65 ML/d and 10.79 ML/d. When compared to previous the discharge volumes previously measured by Hobbs (2011), the September 2018 readings were generally below these estimates. It should however be borne in mind that the discharge volumes exhibit seasonal variations and that the September 2018 measurements were taken at the end of the dry season.

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 pH and SEC values generated by the monitoring programme in the Zwartkrans Basin during March 2018 must be viewed with caution as 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, in a spatial context, from south to north within the central and northern segments. The pattern reflected by individual stations however shows variability, with some exhibiting a decreasing trend and others exhibiting an increasing trend. The magnitude of this variability is however not significant. The spatial pattern evident in the central segment is heavily influenced by proximity to the influent (losing) reach of the Riet Spruit. pH values in the central segment bracket the range 6.5 to 8, and those in the northern segment the range 7.0 to 8. In the southern segment, the most recent pH values are in the range 7.0 to 8.5. Again, the more recent pH pattern at individual stations exhibits variability.

The bar graphs in **Figure 25** reflect the elevated salinity adjacent to the Tweelopie Spruit in the southern segment, as well as the recent reducing trend 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 salinity of groundwater in this segment may be influenced by the proximity to the influent (losing) reach of the Riet Spruit. 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, November 2017, March 2018 and June 2018 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. A significant reduction in the sulfate concentrations were evident during March 2018 at some of the monitoring points located at the south-western end of the impacted zone. The reason for this is not currently discernible.

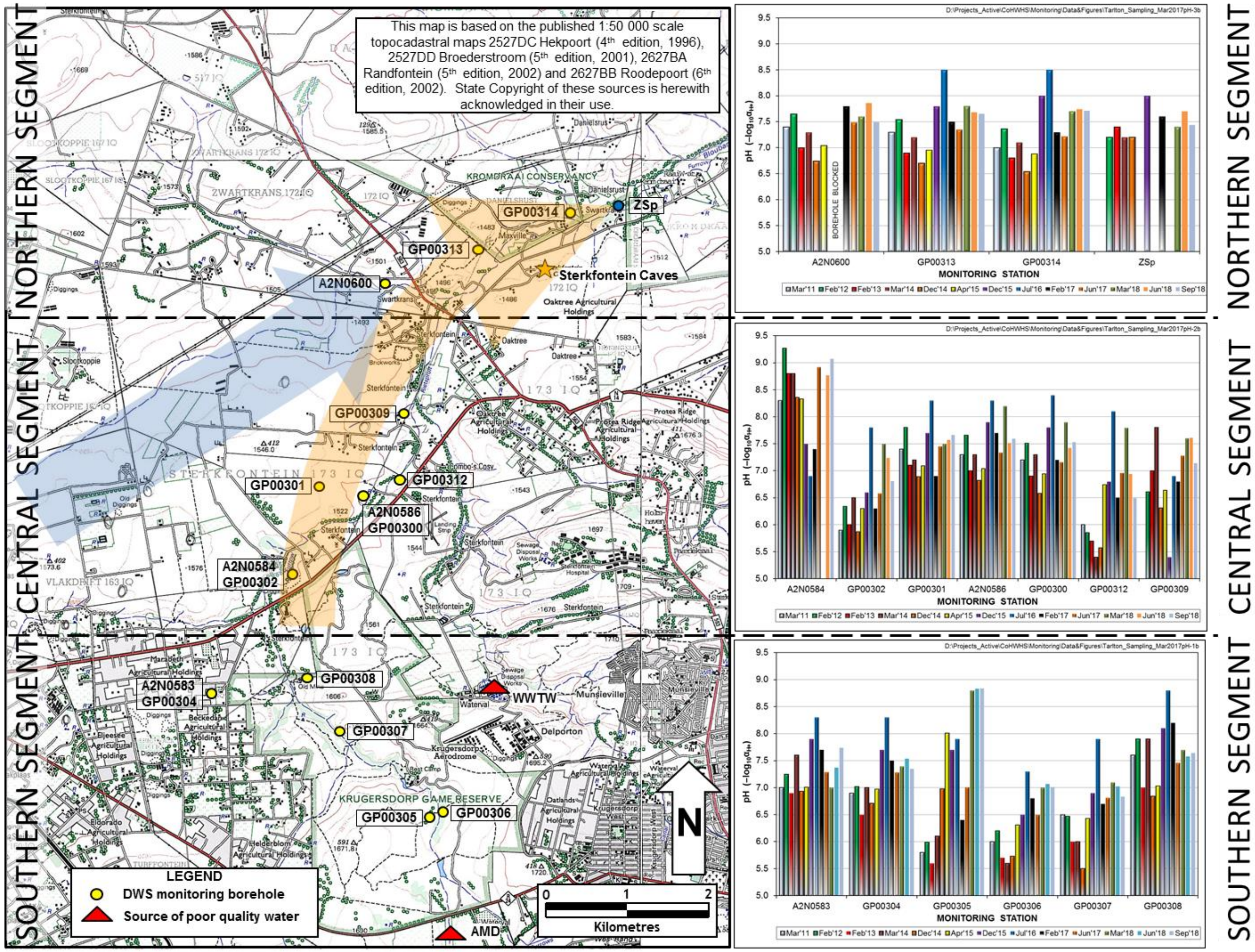

Figure 24 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

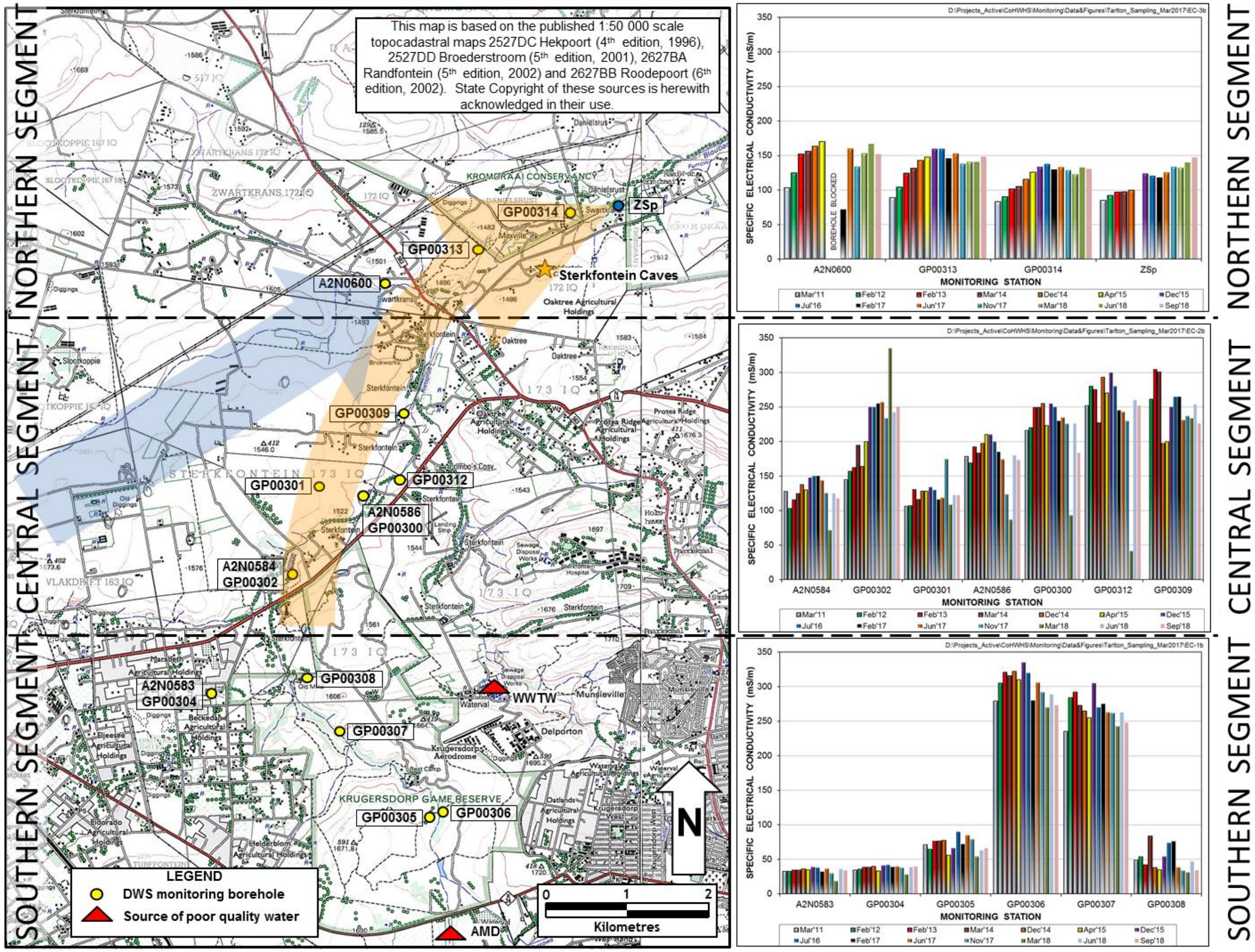

Figure 25 Distribution of DWS monitoring boreholes with SEC pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

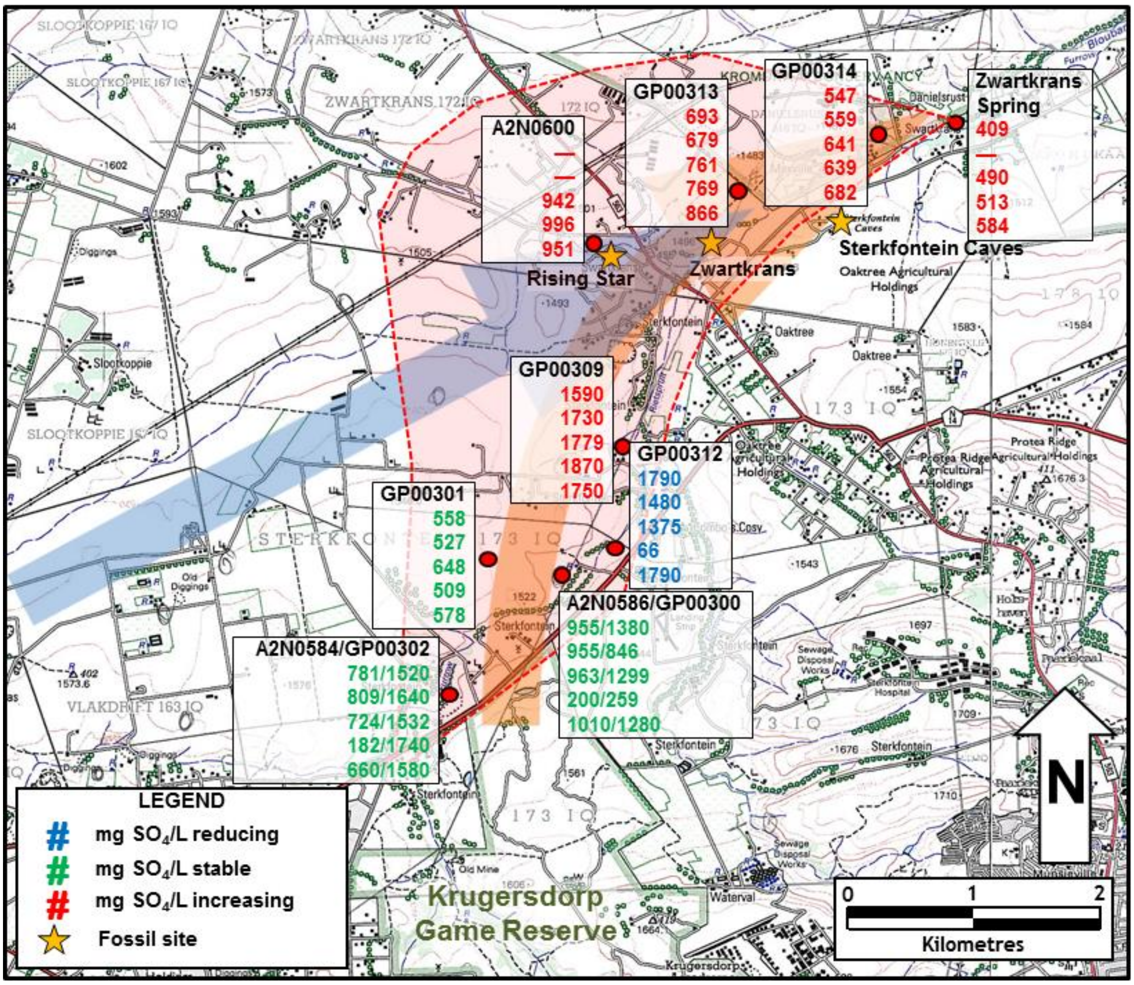

Figure 26 Distribution of sulfate levels in groundwater of the Zwartkrans Basin in July 2016 (1st value), February 2017 (2nd value), November 2017 (3rd value), March 2018 (4th value) and June 2018 (5th value), also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (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)

5.2.3 Sterkfontein Cave

As part of Project GT/GDED/092/2017 the CSIR is responsible for the quarterly water quality monitoring of the groundwater in Sterkfontein Cave. The water chemistry results of samples collected in December 2017 and June 2018 are presented in **Table 6**. None of the variables reported for exceed the respective SANS (2015a) health-related limits for potable water. The chemistry of the Sterkfontein Cave Lake however does reflect the impact of poorer quality surface water on the karst groundwater. The alkaline pH value reflects the continuing neutralising capacity of the carbonate strata. Sterkfontein Cave is located on the periphery of the main groundwater flow vector towards Zwartkrans Spring and therefore the Lake water chemistry experiences a lesser mine water impact.

Table 6 Water chemistry results of samples collected at Sterkfontein Cave during December 2017 and June 2018

Variable	**December 2017**	**June 2018**	**SANS (2015a)[(1)]**
pH ($-\log_{10}\alpha_{H+}$)	7.9	8.0	5.0–9.7
SEC (mS/m)	88	90	<170
Ca (mg/L)	77	82	n.s.
Mg (mg/L)	46	50	n.s.
Na (mg/L)	33	36	<200
K (mg/L)	2.3	2.1	n.s.
Cl (mg/L)	37	37	<300
SO_4 (mg/L)	214	247	<500
HCO_3 (mg/L)	147	150	n.s.
NO_3+NO_2 (mg N/L)	6.8	6.9	<11
Si (mg/L)	5.9	5.5	n.s.
Fe (mg/L)	0.04	0.03	<2
Mn (mg/L)	0.02	0.07	<0.5
Al (mg/L)	<0.01	<0.01	<0.3

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

5.2.4 Dolomitic Springs

The dolomitic springs in the COH WHS (**Figure 27**) represent important groundwater sources for which comparatively little water quality information are available. As part of Project GT/GDED/092/2017 the CSIR is responsible for the bi-annual water quality monitoring of the dolomitic springs in the study area. The dolomitic springs were sampled during September 2018. However, as of the date of completion of this report, the analytical results were not available. Historic and recent water quality results related to the Zwartkrans Spring is presented in **Section 5.2**. The pH and SEC recorded in the field are presented in **Table 7**.

Only considering the available pH and SEC values, it is apparent that the water quality at all the springs, except Zwartkrans Spring, is representative of natural dolomitic groundwater. The pH ranges between 7.7 to 8.2. The SEC, excluding also Kromdraai Spring, ranges between 26.0 to 68.0 mS/m. The SEC is elevated at Kromdraai Spring, i.e. 108 mS/m.

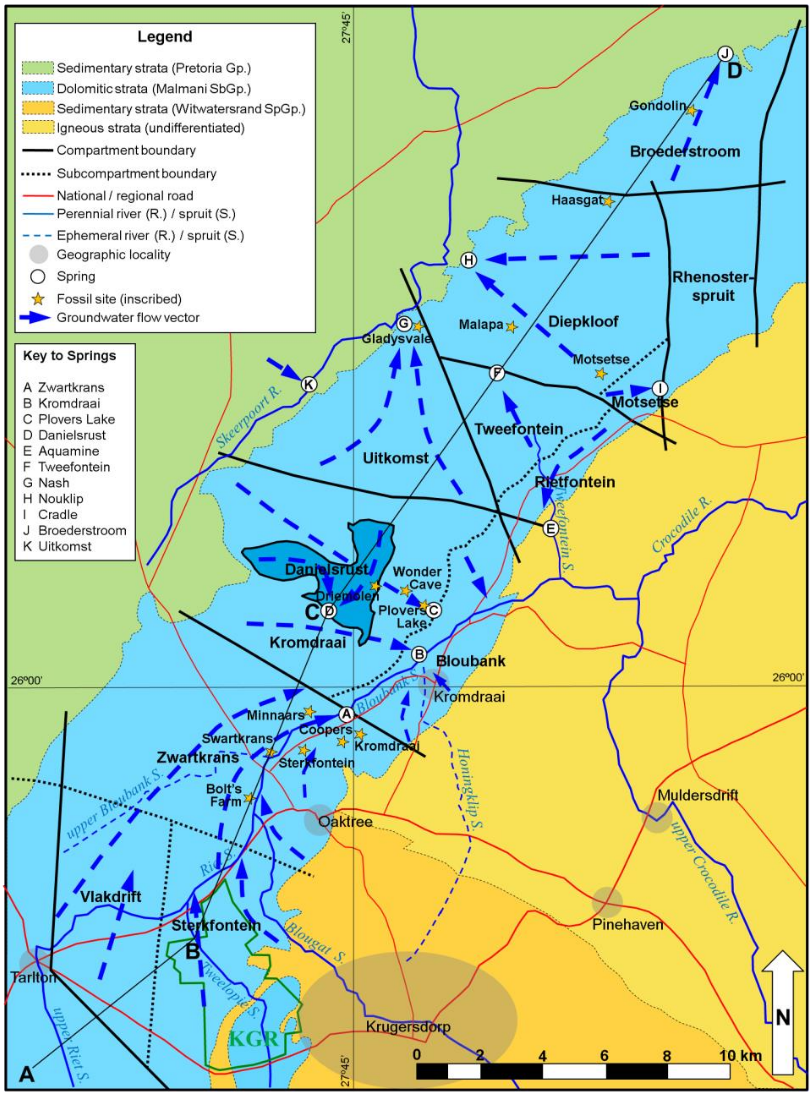

Figure 27 Map showing the regional geology of the study area, dolomitic compartment boundaries, groundwater flow vectors and the major dolomitic springs

Table 7 Field measured water quality indicators recorded at the dolomitic springs during September 2018

Dolomitic Spring	**Variable**	
	pH ($-\log_{10}\alpha_{H+}$)	**Specific electrical conductance (mS/m)**
SANS (2015a) (1)	**5.0 – 9.7**	**<170**
Zwartkrans Spring	8.00	140.0
Danielsrust Spring	8.10	26.0
Nouklip Spring	8.00	38.0
Nash Spring	8.10	26.0
Tweefontein Spring	8.20	35.0
Cradle Spring	7.70	68.0
Aquamine Spring	7.90	56.0
Plover's Lake Spring	8.20	35.0
Kromdraai Spring	7.70	108.0
Broederstroom Spring	8.00	52.0

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

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 largely natural Skeerpoort River and two sites on the impacted Bloubank Spruit (**Figure 28)**.

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.

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 largely undisturbed, natural conditions for reference purposes, although 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.

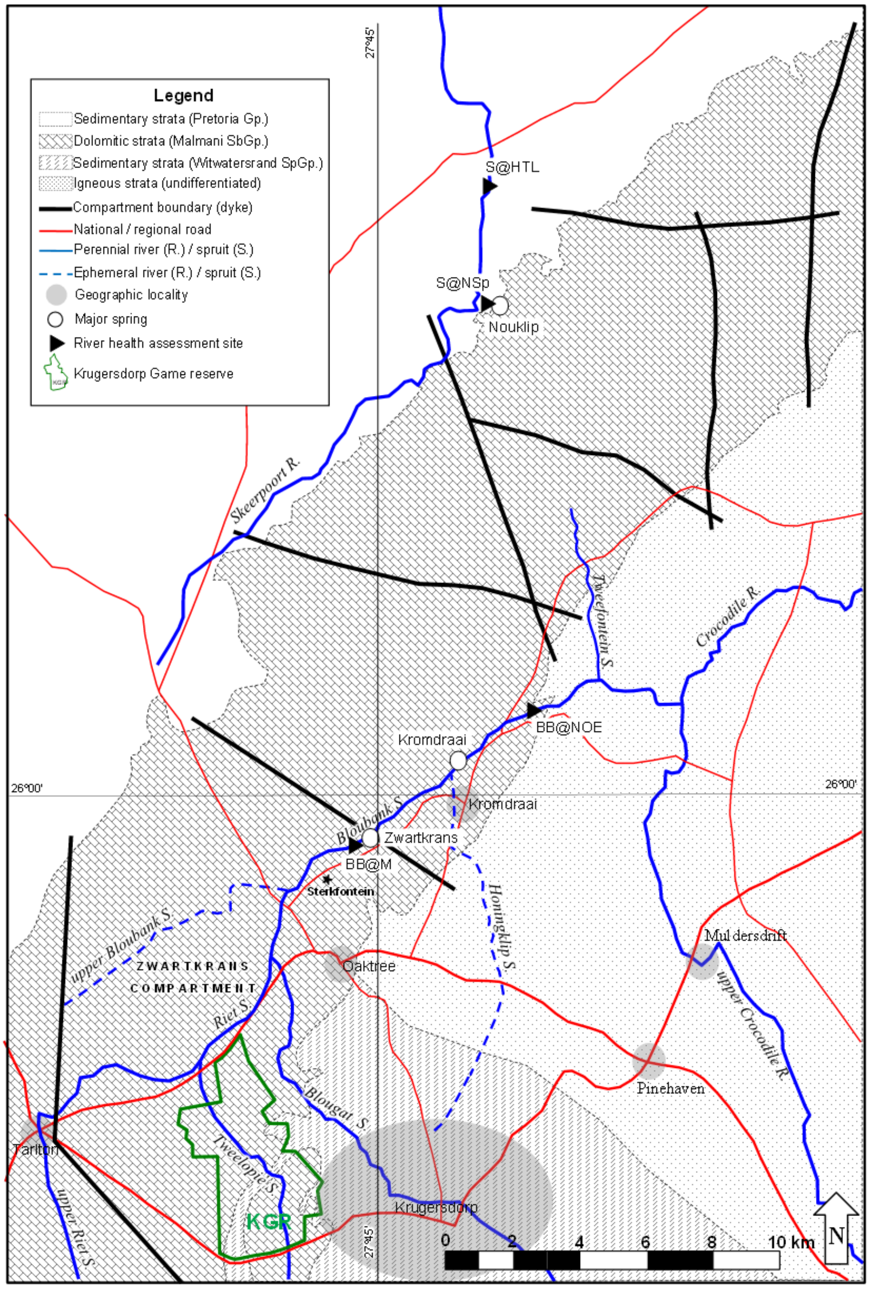

Figure 28 Map showing sites of relevance to the river health assessment

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. River health is classified according to the criteria set out in **Table 8** below. A description of the survey sites is given in **Annexure A**.

Table 8 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

6.2 Macroinvertebrate Biomonitoring Results

6.2.1 Current Assessment Outcome

A synthesis of the current results is presented as a synoptic assessment in **Table 9**, and the results discussed in **Section** Error! Reference source not found.**.**

The upstream Skeerpoort River has improved to a category B from a C previously and the downstream site scored a B opposed to an A category in February 2018. Both sites on the Bloubank Spruit scores as an E/F category with the upstream site remaining in a seriously modified state while the biological integrity of the downstream site degraded (from a category D previously).

The full set of results obtained during the February 2018 survey for each of the sites are presented in **Annexure B.**

Table 9 Synoptic river health assessment outcome for September 2018 (from **Annexure B**).

SITE	Date	Ecological category	Condition	Description
S@NSp	26/09/2018	B	Good	Largely natural with few modifications
S@HTL	17/10/18*	B	Good	Largely natural with few modifications
BB@M	26/09/2018	E/F	Seriously modified	Seriously modified
BB@NOE	26/09/2018	E/F	Seriously modified	Seriously modified

- Due to SASS accreditation by the Department of Water and Sanitation (DWS) that took place during September 2018, this site was sampled three weeks later than the other sampling sites.

6.2.2 Comparison with Historical Results and General Observations

6.2.2.1 Skeerpoort River

In **Table 10**, seasonal sampling (summer and spring) is compared for site S@NSp.

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.

The habitat and flow for both sampling dates was similar, with good flow and varied, adequate habitat availability. Habitat included a variety of stones-in-current (SIC), sandy areas, bedrock, and good leafy vegetation, with smaller areas of other habitats. The flow was mixed, with some riffles, some slow running water, and a pool of stiller water. The surrounding area is largely undisturbed, natural vegetation. A few hundred metres upstream there is evidence of heavy erosion from flooding, which could easily affect the invertebrate sampling scores.

The site has only been sampled twice, and some differences are noted. Overall, the habitats remained similar. *Baetidae* and other mayflies numbers remain similar in both samples (although more diverse in the September sample), but the *Corixidae* and other bugs and beetle numbers increased. This would be due to the fact that heavy rains and flooding had occurred prior to the February visit, and most free-swimming beetles and bugs would have been washed downstream. Although the overall SASS score is less, the Average Score Per Taxon (ASPT) is higher, indicating a greater proportion of more sensitive families.

The River Health Category rating for this site in September 2018 was B (Good). In February 2018 the classification was C (fair). As was reported previously, the ASPT of 5.8 – 5.9 is borderline (for Category B), and in February 2018 it fell just short. It is expected that this particular site will continue to oscillate between the two classifications. S@NSp is a headwater stream, and macroinvertebrate diversity in headwaters can tend to differ, but are generally lower than in the middle reaches of a river network (widely reported in numerous sources, and reviewed in Clarke et al., 2008). This would also account for higher scores in the downstream Skeerpoort River site (even though it is downstream of a trout farm).

Table 10 Comparison of present biomonitoring results for site S@NSp with February 2018 results.

Site: S@NSp		**River: Grootspruit (tributary of the Skeerpoor River)**							
Date	Ecological category	**SASS associated scores**						**Dominance ***	
		SASS5	Taxa	ASPT	IHAS	Highest Sensitivity	Total Invertebrates	Dominant Feeding Group	Dominant Taxa
27/02/2018	C	105	18	5.8	71%	12	130	Predators	*Baetidae*
26/09/2018	B	95	15	6.3	73%	10	238	Predators	*Corixidae*

The study by Fourie et al. (2014) provides a comparatively recent assessment against which to gauge the present river condition at site S@HTL. This is provided in **Table 11**, which shows similar results and suggests a slight temporal change in ecological category. This is likely because sampling at this site took place three weeks later than at the other study sites as the DWS SASS proficiency testing took place at the same time as the scheduled September 2018 sampling. Further to this, a large hail storm was reported to have occurred four days prior to the sampling taking place. The aforementioned factors most likely contributed to the lowering of the scores and subsequently the ecological category from an A to a B at this site.

Table 11 Comparison of present biomonitoring results for site S@HTL with those of the Fourie et al. (2014) "site B" results.

Site: S@HTL		**River: Skeerpoort River**							
Date	Ecological category	**SASS associated scores**						**Dominance ***	
		SASS5	Taxa	ASPT	IHAS	Highest Sensitivity	Total Invertebrates	Dominant Feeding Group	Dominant Taxa
##/01/2014[1]	A	~200[2]	~34[2]	~6.0[2]	-	-	-	-	-
13/02/2018	A	185	27	6.9	72%	13	653	Collector-Gatherers	*Tricorythidae*
17/10/2018	B	170	29	5.9	73%	12	524	Collector-Gatherers	*Baetidae*

[1] From Fourie et al. (2014)
[2] 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 12** (site BB@M) and **Table 13** (site BB@NOE).

Table 12 Comparison of present biomonitoring results for site BB@M with those of the Hill et al. (2014) study.

Site: BB@M		**River: Bloubank Spruit**							
Date	Ecological category	**SASS associated scores**						**Dominance ***	
		SASS5	Taxa	ASPT	IHAS	Highest Sensitivity	Total Invertebrates	Dominant Feeding Group	Dominant Taxa
23/02/2012	E/F1	32	9	3.6	57%	6	239	Collector-Gatherers	*Chironomidae*
16/05/2012	E/F1	53	14	3.8	81%	6	129	Collector-Gatherers	*Baetidae*
24/10/2012	E/F1	35	10	3.5	72%	6	926	Collector-Filterers	*Simuliidae*
06/03/2013	E/F1	52	13	4.0	74%	7	843	Collector-Filterers	*Simuliidae*
15/08/2013	E/F1	34	9	3.8	65%	6	667	Collector-Filterers	*Simuliidae*
12/12/2013	E/F1	38	10	3.8	61%	7	611	Collector-Filterers	*Simuliidae*
13/02/2018	E/F	27	8	3.4	67%	6	219	Collector-Filterers	*Simuliidae*
25/09/2018	E/F	48	11	4.4	71%	8	405	Collector-Filterers	*Simuliidae*

Site BB@M has an excellent habitat abundance and diversity, with large areas of sand, stones in current, and leafy vegetation. There is also some flow variability, with slow and faster moving areas, and a few small pools downstream of the bridge.

The site has been fairly consistent throughout its sampling history, and results generally fall within boundaries previously recorded, with the exception that the ASPT is a little higher. This indicates that some more sensitive families are present than previously observed. Even though this is only one sample, it is encouraging, and it will be interesting to see if this situation repeats itself in future sampling, although peaks like this have happened before; e.g. 16/05/2012 and 06/03/2103. The dominant feeding group and taxa have been consistent since late 2012.

Site BB@NOE has been sampled numerous times since 2012 and data from those investigations are shown in **Table 13** below.

Table 13 Comparison of present biomonitoring results for site BB@NOE with those of the Hill et al. (2014) study.

Site: BB@NOE		**River: Bloubank Spruit**							
Date	Ecological category	**SASS associated scores**						**Dominance ***	
		SASS5	Taxa	ASPT	IHAS	Highest Sensitivity	Total Invertebrates	Dominant Feeding Group	Dominant Taxa
23/02/2012	E/F	52	12	4.3	52%	6	206	Collector-Filterers	*Hydropsychidae*
16/05/2012	E/F	41	10	4.1	59%	6	269	Collector-Gatherers	*Baetidae*
24/10/2012	C	59	11	5.4	61%	12	230	Collector-Gatherers	*Baetidae*
06/03/2013	B	60	10	6.0	55%	12	225	Collector-Gatherers	*Baetidae*
12/12/2013	D	32	6	5.3	53%	12	329	Collector-Gatherers	*Baetidae*
13/02/2018	D	57	12	4.8	58%	12	234	Collector-Gatherers	*Baetidae*
25/09/2018	E/F	30	8	3.8	55%	6	275	Predators	*Corixidae*

This site appears to be turbid, even when the upstream sites BB@M has clear water. There is however a trout farm approximately 100 metres upstream of the site that had been discharging into the Bloubank Spruit at the time of sampling. This may contribute to the turbidity and ecological condition at the site although there may be another cause from elsewhere.

The variability of this site, in terms of its ecological condition has been mentioned in previous reports (Hill *et al*, 2014). The habitat at this site is inferior to the upstream site in that it is mostly bedrock and large stones. There is a little sand, and the overhanging vegetation is often limited. All macroinvertebrate families found on this occasion were present in the February 2018 sampling set.

6.3 Toxicity Testing Results

Freshwater toxicity screening tests with *Daphnia magna* were performed on surface water samples collected at the Skeerpoort River sites (S@NSp and 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 DC.1** of **Annexure C**.

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 C.2** (**Annexure C**). The results for the *D. magna* toxicity tests are summarised in **Table C.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@NSp, S@HTL and BB@M. This corresponds with the results of the summer sampling at these sites in February.

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 recent monitoring 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 amounted to 741 mm in the mine area and 593 mm at Sterkfontein Cave. These values are 7% and 0.5% higher, respectively, than the means of the last 8 years of record common to both stations. Total rainfall recorded at the HDS station during the 2018 hydrological year was 863 mm, which is above the 10 year average of 811 mm. The total rainfall recorded at the Sterkfontein Cave station during the period October 2017 to July 2018 was 696 mm.

- Chemical analyses of rainwater in the south-western portion of the property confirm the very low salinity (specific electrical conductance or SEC ≤10 mS/m) of this water. The results represent a mixture of precipitation events over a period of ~3 months ending late-June 2018, and therefore are not representative of specific events. This influences especially the veracity of the pH values, which range from 5.1 to 6.6.

- 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 in the last 18 months, and in SEC values which show a decline in this period.

- The groundwater elevation in the south-western portion of the property (the Zwartkrans Basin) where the allogenic recharge component is greatest and reflects little change. 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.

- During September 2018, the discharge was measured at 6 out of the ten dolomitic springs in the study area. When compared to previous the discharge volumes previously measured by Hobbs (2011), the September 2018 readings were generally below these estimates. It should however be borne in mind that the discharge volumes exhibit seasonal variations and that the September 2018 measurements were taken at the end of the dry season.

- 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 period June 2016 to June 2018 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.

- 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 largely natural Skeerpoort River and the severely impacted Bloubank Spruit system. This is best evidenced by the B ecological category of the Skeerpoort River sites versus the 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 show that the river is in a seriously modified ecological state (E/F) and further reveal a decline in category from D at the lower site to E/F. A comparison with previous results however indicate a greater deterioration at the upstream site versus the marginal deterioration at the downstream site. The river health survey and monitoring add 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 Mr Divan van Niekerk (Mine Water Quality Management), 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.

The significant contribution of the late Mr Phil Hobbs (CSIR, Senior Research Hydrogeologist) to the hydrophysical and hydrochemical understanding of COH WHS, as well as to the development of the monitoring programme is greatly acknowledged. Mr Hobbs was also instrumental in laying the foundation for the bi-annual status quo assessment which are required as part of this project.

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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.

Figure A.1: Downstream site S@HTL on the Skeerpoort River

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.

Figure A.2: Upstream site S@NSp on the Skeerpoort River

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.

Figure A.3: Site BB@M on the Bloubank Spruit

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.

Figure A.4: Site BB@NOE on the Bloubank Spruit

ANNEXURE B

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 9** 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 C

TOXICITY TESTING RESULTS

Table C.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 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, de-chlorinated tap 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 C.2a Results of the *D. magna* screening assays expressed as per cent mortality after 24 and 48 hours (September 2018).

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

Table C.2b Results of the *D. magna* screening assays expressed as per cent mortality after 24 and 48 hours (February 2018).

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 C.3a. Physicochemical parameters per sample measured at the start and end of the tests (September 2018).

Sample	**Time (hrs)**	**Temperature (°C)**	**pH**	**SEC (mS/m)**	**Dissolved oxygen (mg/L)**
CONTROL	0	20.0	8.21	25.5	7.52
	48	20.0	7.78	36.7.7	7.47
N@NSP	0	20.0	7.99	36.4	8.31
	48	20.1	8.41	45.4	7.43
HTC (S@HTL)	0	20.0	7.63	35.0	7.62
	48	20.0	8.08	33.6	7.31
BB@NOE	0	20.0	7.93	136.4	8.73
	48	20.0	7.96	148.2	7.45
BB@M	0	20.0	6.67	184.4	7.61
	48	20.0	6.96	209.4	7.33

Table C.3b. Physicochemical parameters per sample measured at the start and end of the tests (February 2018).

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