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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 2019 TO SEPTEMBER 2019

PROJECT No.

GT/GDED/092/2017

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GAUTENG PROVINCE
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REPUBLIC OF SOUTH AFRICA

cradle of humankind
world heritage site

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 thirteen (14) bi-annual status quo reports. This document represents the fifteenth (15th) such report. It covers the timeframe April 2019 to September 2019.

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.

- Rainfall data from both the HDS and Sterkfontein Cave stations has been updated up to September 2019. The total rainfall recorded at the HDS station during the 2019 hydrological year was 570 mm, which is below the 863 mm recorded for the 2018 hydrological year and the 11-year average of 798 mm. The total rainfall recorded at the Sterkfontein Cave station during the 2019 hydrological year was 751 mm, which is greater than the 711 mm recorded for the 2018 hydrological year and the 8 year average of 695 mm. Both the HDS and Sterkfontein Cave stations experienced a period of 'no rainfall' between May and August for the 2019 hydrological year. The total 'wet season' rainfall (October 2018 to March 2019) recorded at the HDS station was 450 mm (the 11-year average is 655 mm) while at the Sterkfontein Cave, 489 mm was recorded. The wet season rainfall decreased at both the HDS and Sterkfontein Cave stations by 39% and 17%, respectively and represents the lowest wet season rainfall on record for the HDS station.

- The most recent chemical analyses of rainwater in the south-western portion of the property from May 2019 are provided. These results represent the late wet season/early dry season rainfall and while there is some variation from the early wet season results reported by Hobbs et al. (2018) and Bugan et al. (2019), these results continue to confirm the very low salinity and generally acidic nature of rainwater in the region. Inter-station differences in sulphate, total alkalinity and nitrate levels are not readily explained on the basis of the current understanding of temporal rainwater quality and distribution in the region.

- The 2019 hydrological year recorded a meagre discharge of 6.6 Mm^3, which is *significantly* lower than the 40.6 Mm^3 and 26.6 Mm^3 total annual discharge reported, respectively, for the 2017 and 2018 hydrological years. This is to be expected, given the missing discharge data record from May 2018 to May 2019, making it very difficult to make any sensible conclusions about the flow scenario for this period and, subsequently, the hydrological year. The available limited record of 6.6 Mm^3 discharge thus makes this the lowest recorded at station A2H049 over the total data historical period from 1973 to 2019, which has an average and median discharge of 26.4 Mm^3/a and 24.6 Mm^3/a, respectively. A decreasing trend is further observed when comparing the fourth quarter total discharge of the 2017 hydrological year (8.7 Mm^3) to the 2019 hydrological year (5.7

Mm^3). The trend correlates to the decreasing wet season rainfall. For the 2019 hydrological year, based on the currently available records from October 2018 to September 2019, the highest mean monthly instantaneous discharge was 0.82 m^3/s which is lower than the 2.15 m^3/s and 1.46 m^3/s reported, respectively, for the 2017 and 2018 hydrological years. Compared to the total historical data record from 1978 to 2019, the 0.82 m^3/s mean monthly instantaneous discharge is marginally greater than the median mean monthly instantaneous of 0.77 m^3/s calculated for the same period.

- 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 has 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 from early 2017 up to September 2019. However, when comparing SEC values between December 2018 and September 2019, an apparent marginal increase is observed.

- The groundwater elevation in the south-western portion of the property (the Zwartkrans Basin), where the allogenic recharge component is greatest, 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. The lake water level recorded in September 2018, December 2018 and March 2019 represents the lowest elevations recorded since end-2010. The recent September 2019 groundwater elevation of 1437.7 m above mean sea level (amsl) correlates to the trendline observed since November 2017 and illustrates an approximate 0.7 m decrease in the groundwater level since September 2018. The lowered groundwater level corresponds to the observed lower discharge in the Bloubank Spruit, which has partly been attributed to the temporary closure of the wastewater treatment plant.

- Similar to March 2019, flow was measured at eight of the ten identified springs in the study area during September 2019. In most cases, the spring discharge measured in September 2019 was below that reported by Bugan et al. (2018, 2019) and Hobbs (2011). Similar to Bugan et al. (2019), the highest discharges were realised for the Nouklip and Nash springs, respectively yielding 11.37 ML/d and 18.59 ML/d. It is evident that significant variability exists in the discharge measurements. There is therefore uncertainty associated with the data and currently no distinct pattern has been established regarding the response of the individual springs to changes in rainfall and discharge in the river systems across the CoHWHS property. It is however possible that the lack of rated cross-sections for discharge measurements, as well as a generally drier hydrological year, may be the cause of this variation and decreased discharge observed for most of the springs.

- Groundwater in the south-western portion of the property continues to experience a compromised quality reflected in sulphate levels of up to ~2000 mg/L. A comparison of sulphate levels over the period June 2016 to September 2019 indicates that sulphate levels in ambient groundwater have increased marginally 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 the main stem of the Bloubank Spruit.

- With the exception of the Zwartkrans Spring and the Kromdraai Spring, the water from the major dolomitic springs is of excellent quality for the parameters reported for both the March 2019 and September 2019 sampling results. The chemical analytical results from the Zwartkrans Spring and Kromdraai Spring do however show probable mine water impact as evidenced by the high sulphate content. Across all the spring sample results, the microbiological quality of the water is compromised by the total coliform bacteria which far exceeds the standard health-related limits. The most impacted sites include the Zwartkrans, Kromdraai, Danielsrust, Aquamine, Tweefontein and the Cradle Spring, which exhibit high levels of total coliform bacteria and E.coli.

- The macroinvertebrate monitoring survey reveals the substantial difference in biotic condition between the largely natural / moderately modified Skeerpoort River and the severely impacted Bloubank Spruit system. This is best evidenced by the C and 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. The Bloubank Spruit results are also similar to the September 2018 results. A comparison with previous results indicates 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 continue 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
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 thirteen (13) bi-annual status quo reports (i.e. Hobbs, 2012; 2013a; 2013b; 2014a; 2014b; 2015a; 2015b; 2016a; 2016b; 2017a; 2017b; Hobbs et al., 2018; Bugan et al., 2018 and Bugan et al., 2019). This document represents the fifteenth (15th) such report. It covers the period from April 2019 to September 2019.

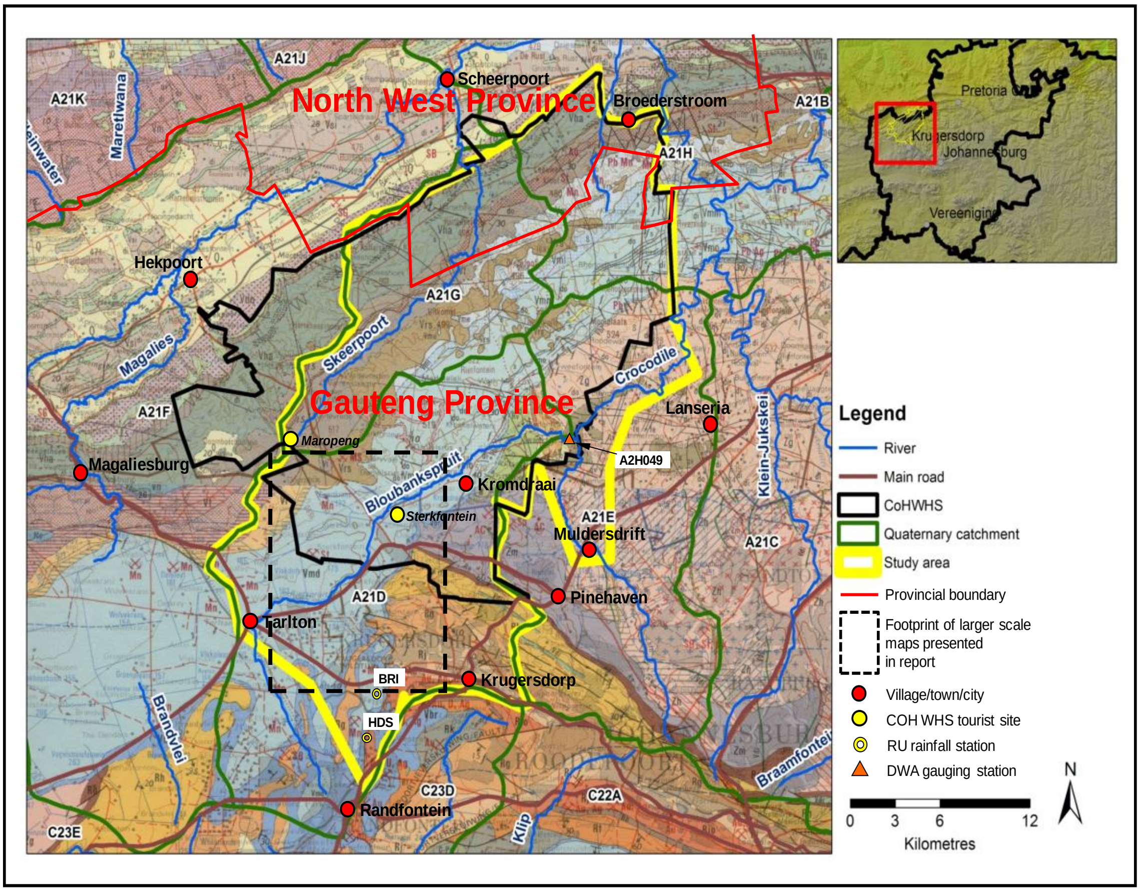


Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

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, 2018) submitted to UNESCO's World Heritage Centre (WHC) for examination by the World Heritage Committee. The outcome of this examination will set out the concerns of the WHC for the property, and which need to be addressed and responded to in the monitoring programme going forward. Progress with the resolution of the WHC's specific concerns will be documented in forthcoming State of Conservation reports.

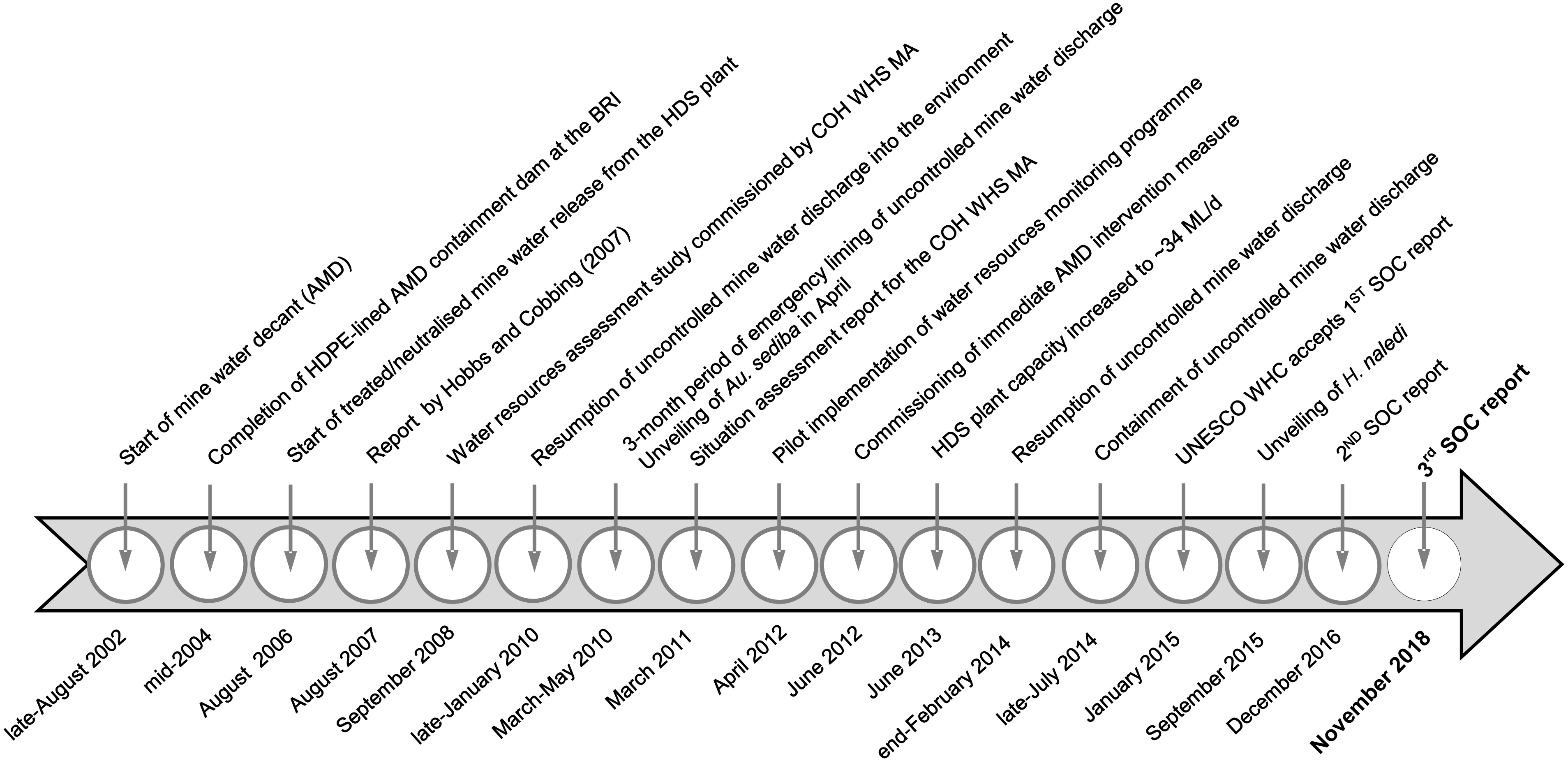


Figure 2 Timeline of key events relevant to the project and this report

3 RAINFALL

3.1 Quantity

The monthly precipitation record for the period October 2008 to September 2019 at the Sibanye-Stillwater (SS) [formerly Sibanye Gold (SG)] rainfall station HDS on the basin divide of North (i.e. Limpopo system) and South (i.e. the Vaal system) flowing rivers 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 2019 hydrological year was 570 mm, which is about 34% less than the total annual rainfall for the 2018 hydrological year (863 mm) and also below the 11-year average of 789 mm. The total rainfall recorded at the Sterkfontein Cave station during the 2019 hydrological year was 751 mm, which is approximately 6% greater than the 711 mm total rainfall recorded for the 2018 hydrological year. The 8 year average, from 2011 to 2019, of the observed historical record at the Sterkfontein Cave station is 695 mm. The total rainfall recorded during the period from October 2018 to March 2019 at the HDS station was approximately 450 mm (the 11-year average is 655 mm), with the Sterkfontein Cave station experiencing a slightly greater wet season rainfall of 489 mm. Based on available historical data, this represents the lowest wet season rainfall on record for the HDS station. A comparison of the wet (summer) season precipitation record in the mine area to that at Sterkfontein Cave is given in **Figure 4**. This comparison reveals the following:

- the total wet season rainfall of the 2018 and 2019 hydrological years (October to March) at the HDS station was 741 mm and 450 mm respectively;
- the total wet season rainfall of the 2018 and 2019 hydrological years (October to March) at the Sterkfontein Cave station was 593 mm and 489 mm respectively;
- during 2019 hydrological year, the wet season rainfall decreased at both the HDS and Sterkfontein Cave stations by 39% and 17%, respectively.
- Both the HDS and Sterkfontein Cave stations experienced a period of ‘no rainfall’ between May and August for the 2019 hydrological year.

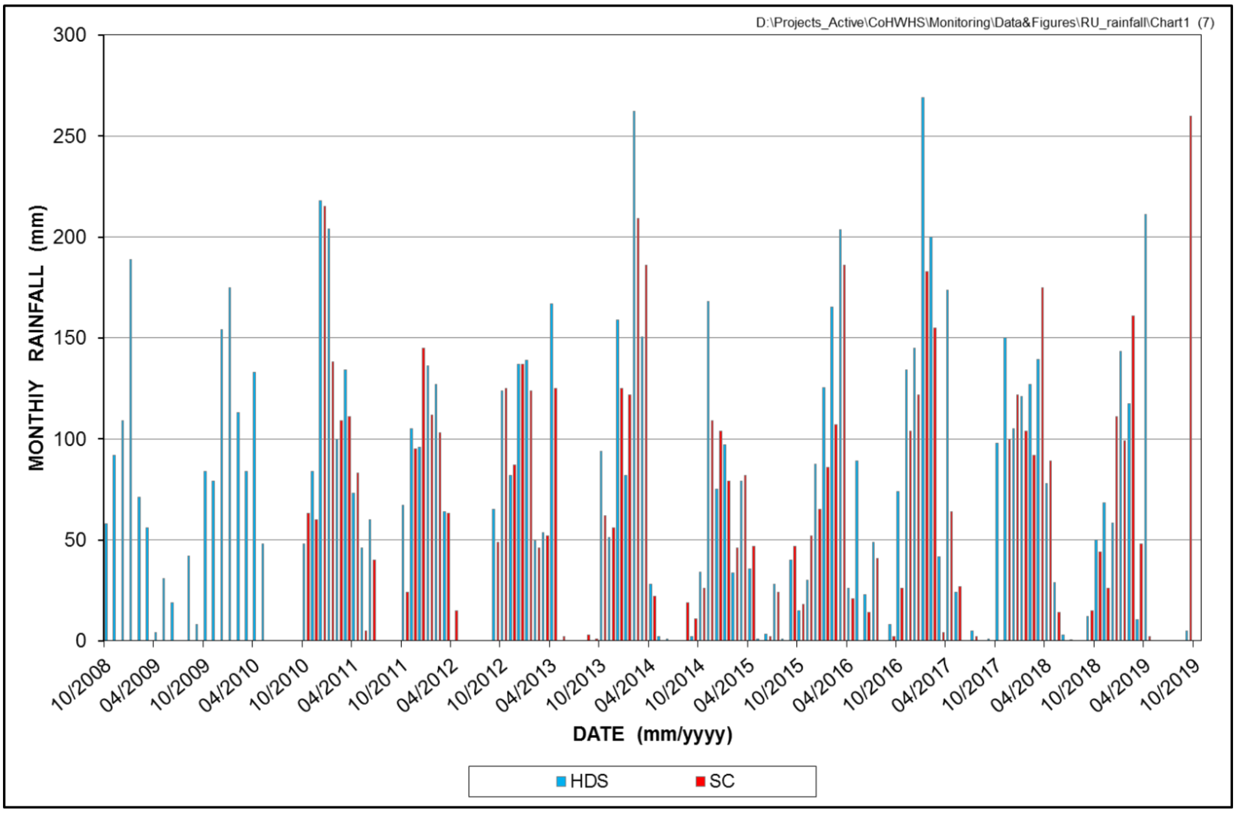


Figure 3 Monthly precipitation in the mine area (station HDS) from October 2008 to March 2019, and the contemporaneous record for the Sterkfontein Cave station from June 2010 to December 2018.

The correlation of monthly total rainfall records for the HDS and Sterkfontein Cave stations is presented in **Figure 5**. The data set (n = 111) excludes months of no rainfall (n = 22) 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) though with a fair bit of scatter from the linear graph. Consequently, the Sterkfontein Cave station would be expected to experience ~21% less rainfall on a monthly basis than station HDS (Hobbs et al., 2018) however for the 2019 hydrological year, the Sterkfontein Cave station has experienced a greater (by 32%) total annual rainfall than the HDS station. Using the linear regression equation (Hobbs et al., 2018) presented in **Figure 5** the wet season rainfall (October 2018 to March 2019) at the Sterkfontein Cave station should be approximately 350 mm whereas the observed wet season rainfall was 489 mm.

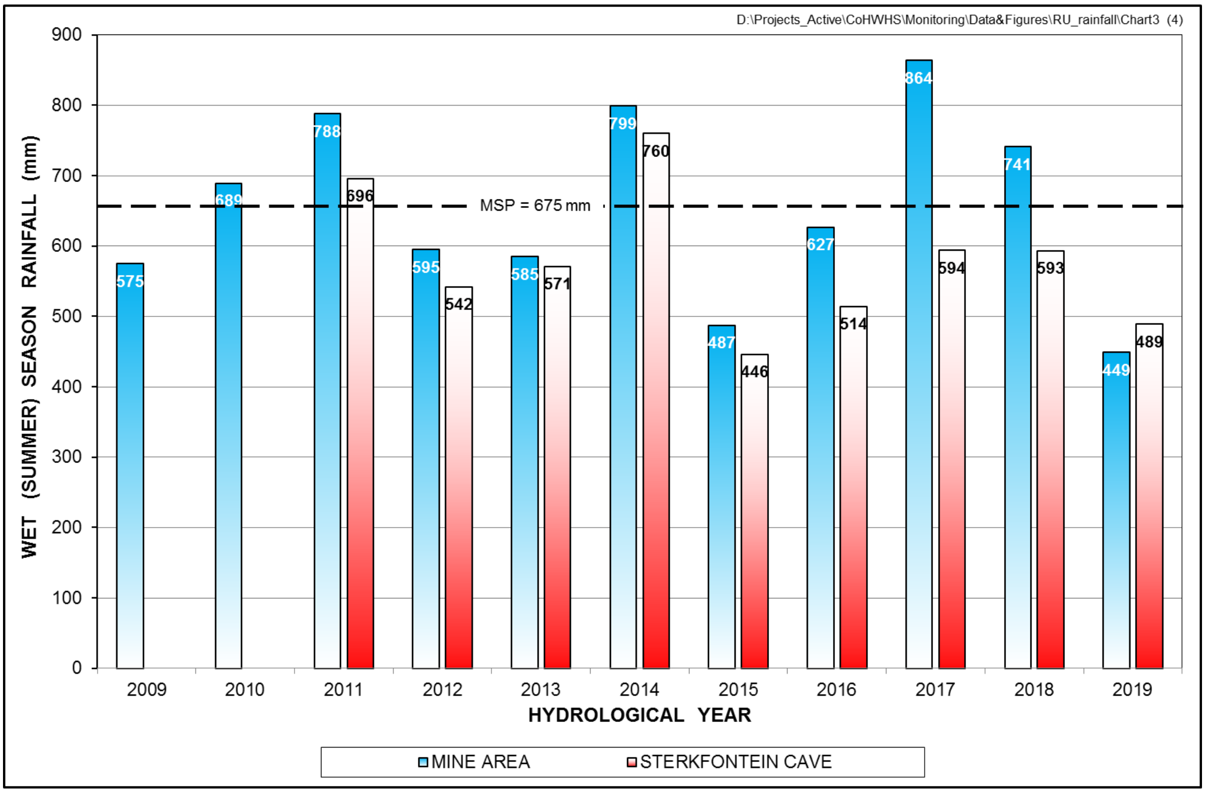


Figure 4 Total wet season (summer) rainfall in the mine area (HDS station) in the past eleven hydrological years, also showing the comparison with that for the available contemporaneous Sterkfontein Cave record; MSP denotes mean summer precipitation

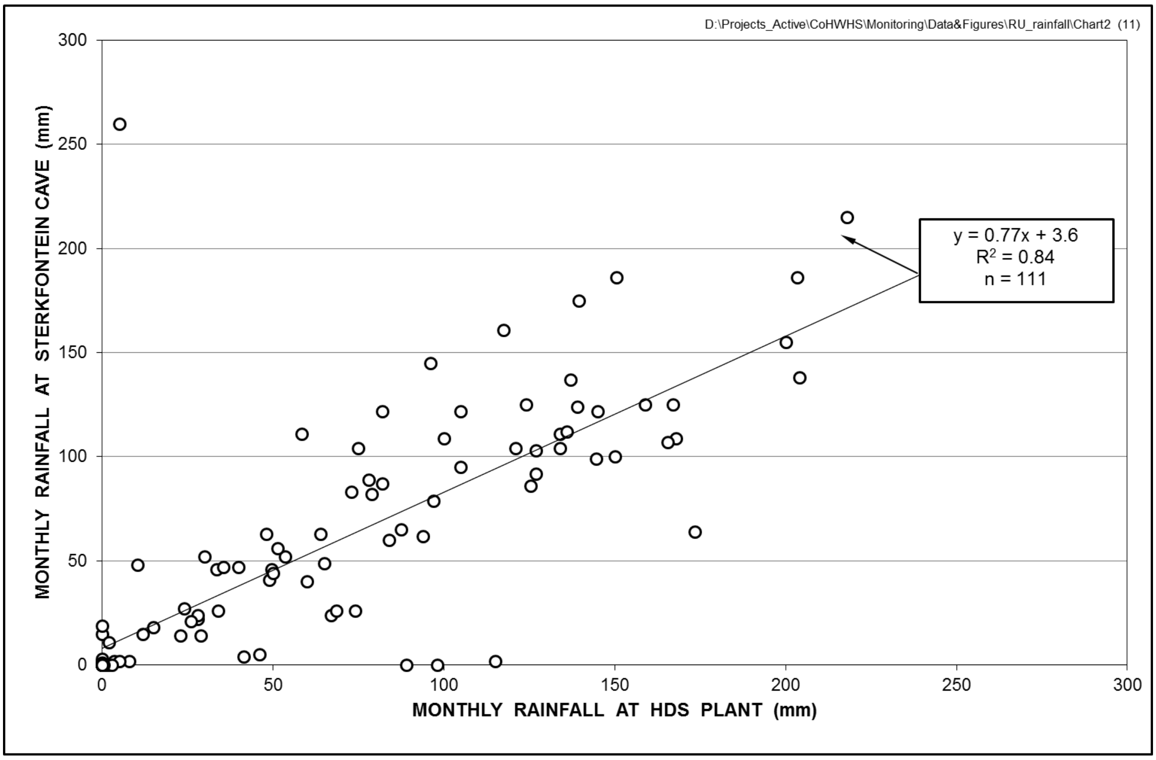


Figure 5 Correlation of total monthly rainfall at Sterkfontein Cave with that at the HDS mine water treatment plant in the mine area for the period of common record June 2010 to September 2019

3.2 Quality

The chemical composition of the rainwater in the south-western portion of the COH property is reflected in the samples obtained from 4 rainfall stations. These stations are operated and maintained by the Department of Water and Sanitation (DWS). The stations 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 from May 2019 are presented in **Table 1**, except for station HDS which shows data reported by Bugan et al., 2019. These results from the other three stations represent the late wet season/early dry season rainfall and while there is some variation from the early wet season results reported by Hobbs et al. (2018) and Bugan et al. (2019),these results continue to confirm the very low salinity and generally acidic nature of rainwater in the region. Inter-station differences in sulphate, total alkalinity and nitrate 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-May 2019

Variable/analyte	**Unit**	**Rainfall Station**			
		HDS[1]	**GP00303**[2]	**GP00301**[3]	**SC**[4]
Specific electrical conductance*	mS/m @ 25°C	18	4	4	3
pH*	$-\log_{10}\alpha_{H+}$	5.4	5.6	5.9	5.4
Calcium	mg Ca/L	6.7	0.9	0.9	5
Magnesium	mg Mg/L	1.4	0.3	0.2	0.8
Sodium	mg Na/L	1.7	0.2	0.4	1.2
Potassium	mg K/L	3.8	0.3	0.2	0.4
Chloride	mg Cl/L	<2.0	<2.0	<2.0	<2.0
Sulphate	mg SO_4/L	32	7	8.3	21
Total alkalinity	mg $CaCO_3$/L	2.6	<2.5	2.6	<2.5
Nitrate + nitrite	mg N/L	11	1.7	1.9	1.4

* Laboratory values
[1] At the high density sludge plant in the mine area (Bugan et al., 2019)
[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 A2H049 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 47-year observed discharge record from 1972 to 2019 for this catchment (Quaternary A21D) provides the historical monthly statistics reported in

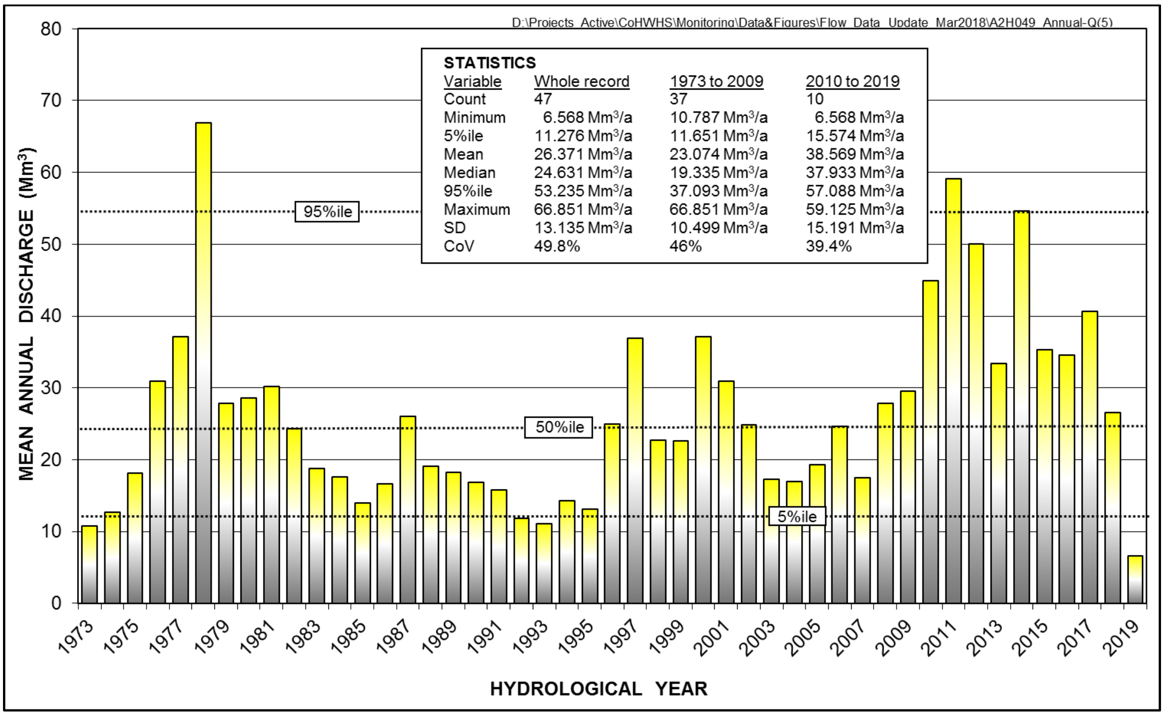
Table 2. The record is extended and updated as frequently as possibly when data are obtained from the station and processed by the DWS. However, no data were collected at the station for the period from June 2018 to May 2019. The DWS attributed this to financial challenges which made it difficult for them to perform regular data collections and updates, and the requisite maintenance of the data collection platforms.

Figure 6 shows the historical total annual discharge, in Mm^3, for complete hydrological years up to 2019. Against the background of large gaps, indicating an extensive period of missing data for the 2019 hydrological year, the annual discharge shown in **Figure 6** indicates that the 2019 hydrological year thus recorded a meagre discharge of 6.6 Mm^3, which would make it *significantly* lower than the 40.6 Mm^3 and 26.6 Mm^3 total annual discharge reported, respectively, for the 2017 and 2018 hydrological years. This permanently missing data record from June 2018 to May 2019 makes it impossible to make logical conclusions with respect to the discharge situation in the COH property. The 6.6 Mm^3 discharge makes this *apparently* the lowest recorded at station A2H049 over the historical total observed data period from 1973 to 2019, which has an *average* and *median* discharge of 26.4 Mm^3/a and 24.6 Mm^3/a, respectively. However, a comparison of the fourth quarter total discharge of the 2017 hydrological year (8.7 Mm^3) to the 2019 hydrological year (5.7 Mm^3) shows a decreasing trend. The trend apparently correlates well with the decreasing wet season rainfall trend observed and discussed in Section 3.1.

Table 2 Statistical analysis of Bloubank Spruit monthly discharge data gauged at station A2H049 in the period October 1972 to September 2019 (latest data as at September 2019)

Variable	**Month**											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	44	44	45	45	46	46	46	45	47	46	45	45
Minimum	0.682	0.815	0.711	0.721	0.706	0.828	0.886	0.847	0.521	0.939	0.890	0.770
5%ile	0.792	0.867	1.044	1.097	0.902	1.075	1.190	1.003	0.896	0.963	0.924	0.805
Mean	1.903	1.909	2.305	2.749	2.705	3.050	2.459	2.318	2.043	2.088	1.964	1.815
Median	1.684	1.745	2.092	2.513	2.296	2.550	2.060	1.961	1.746	1.787	1.743	1.561
95%ile	3.799	2.952	4.488	5.320	6.280	7.729	5.309	4.867	4.056	4.036	3.657	3.507
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	1.192	0.999	0.934	0.866	0.874
CoV (%)	48.9	43.7	47.7	69.5	70.6	71.7	52.7	51.4	48.9	44.7	44.1	48.2

- *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*



STATISTICS

Variable	Whole record	1973 to 2009	2010 to 2019
Count	47	37	10
Minimum	6.568 Mm^3/a	10.787 Mm^3/a	6.568 Mm^3/a
5%ile	11.276 Mm^3/a	11.651 Mm^3/a	15.574 Mm^3/a
Mean	26.371 Mm^3/a	23.074 Mm^3/a	38.569 Mm^3/a
Median	24.631 Mm^3/a	19.335 Mm^3/a	37.933 Mm^3/a
95%ile	53.235 Mm^3/a	37.093 Mm^3/a	57.088 Mm^3/a
Maximum	66.851 Mm^3/a	66.851 Mm^3/a	59.125 Mm^3/a
SD	13.135 Mm^3/a	10.499 Mm^3/a	15.191 Mm^3/a
CoV	49.8%	46%	39.4%

Figure 6 Graph of Bloubank Spruit annual discharge gauged at station A2H049 for the period October 1972 (a_h 1973) to September 2019 (a_h 2019)

The instantaneous observed monthly flow pattern at station A2H049 for the historical available record period October 1972 to September 2019 is shown in **Figure 7**. Hobbs et al. (2018) noted that the record reveals a consistent instantaneous low flow, or base discharge, in the order of 0.8 to 1 m^3/s since 2010. However, beyond 2017 the trend increased to the order of 1 to 1.2 m^3/s. Hobbs et al. (2018) attributed this to the contribution of 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 secondary contribution of municipal wastewater effluent from the Percy Stewart Wastewater Treatment Works of Mogale City.

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 spread out over the hydrological year rather than concentrated in a few months, to significantly impact on the observed discharge (Hobbs et al., 2018).

For the 2019 hydrological year, based on the currently available records, the highest mean monthly instantaneous discharge was about 0.82 m^3/s which is lower than the 2.15 m^3/s and 1.46 m^3/s recorded, respectively, for the 2017 and 2018 hydrological years. It is, however, prudent at this juncture to note that the 2019 hydrological year has gaps, indicating missing data for the period June 2018 to May 2019 (apparently a full year's record) when the DWS were unable to collect data from the station as a result of financial challenges.

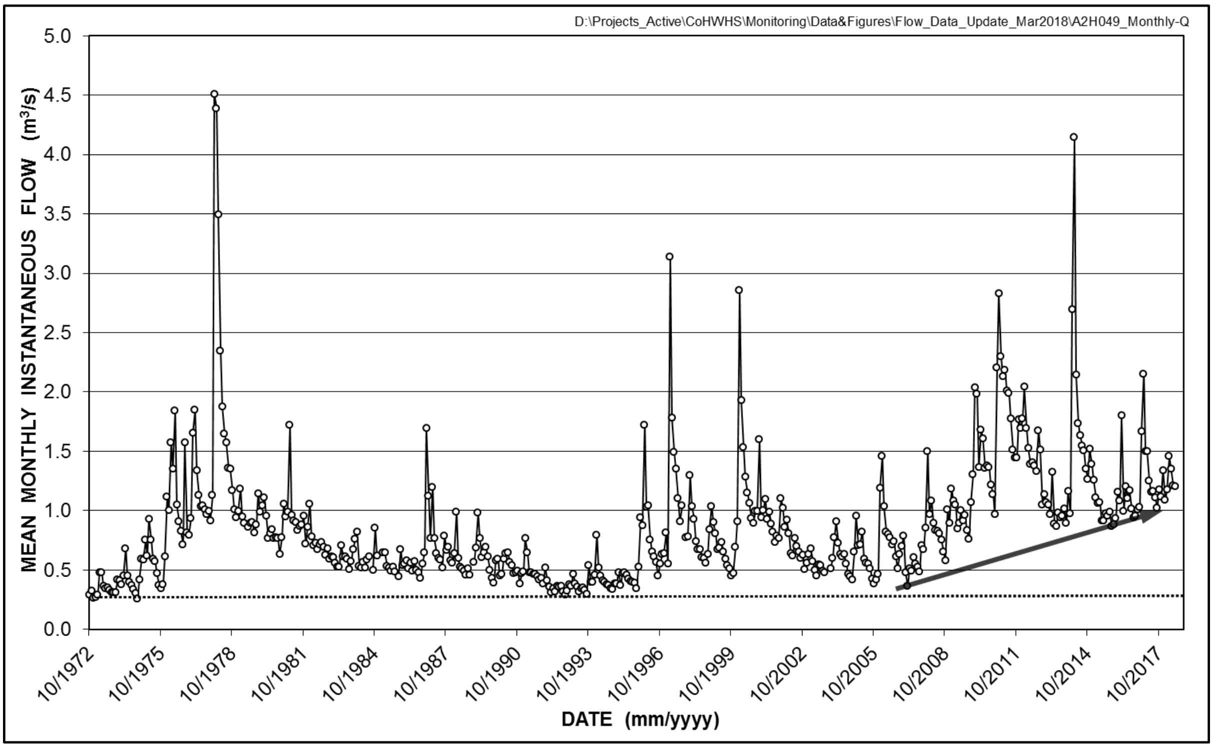


Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to September 2019 (latest data as at September 2019).

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. During the June 2019 quarterly monitoring run, the gauging site for F11S12 was moved to a location 20 m downstream from the weir where the water collects into a narrow outlet and flows before crossing the bridge under the N14 road. The decision was taken upon noticing that the growth of dense vegetation within the dam at the original site impeded the rate of flow by inducing pooling of the flow, which affected measurement accuracy. During the same monitoring run, no flow was observed at the MRd site. The event of the disappearing discharge was reportedly due to the temporary closure of the Mintek short-term treatment plant which, along with the Percy Stewart Wastewater Treatment Works, feeds treated effluent into the Blougat Spruit. However, this does not make hydrologic sense given that substantial flow had been observed and recorded at F11S12, just about 4 km upstream of this monitoring site. While it is possible that some flow diversion was occurring along the intervening stretch of the river, this could not be ascertained. Flow at MRd was observed during the subsequent September monitoring run. Figure 8 does however illustrate two other occurences of ‘no flow’ at MRd in the year 2009. During this period, flow at F11S12 is less than 15 ML/d. Similarly, in June 2019, flow at F11S12 measured approximately 12 ML/d.There is currently no clear explanation which gives details to the lack of flow observed at MRd in June 2019; however Hobbs (unpublished PhD research, 2018) put forward the suggestion of a threshold flow value which needs to be met before flow at the downstream MRd site can occur. The observation put forward by Hobbs (2018) still needs to be interrogated and further investigation into the water use activities in the vicinity of the site and computation of the various factors contributing to physical surface water fluxes (channel transmission losses), including the capacity of the karst aquifer, may provide an acceptable answer.

The updated records for June 2019 and September 2019 indicate losses (between F11S12 and MRd) of 11.9 ML/d and 20.4 ML/d (**Figure 8**) respectively, which are more than the losses of 5.0 ML/d and 7.8 ML/d reported for December 2018 and March 2019 (Bugan et al., 2019). Compared to the losses reported in the 10-year period from September 2009 to September 2019, the loss of 20.4 ML/d reported in June 2019 is approximately more than average and median losses of 16.5 ML/d and 15.2 ML/d reported over the same 10-year period. The increased streamflow is attributed to the high flow observed at F11S12 (29.6 ML/d) which is considered to be a result of the relocation of the gauging site and the release of treated effluent into the Tweelopies Spruit, although the volume of effluent released following the temporary closure of the treatment plant is currently unknown.

The recent streamflow records indicate better correlation to the Period 3 data set (**Figure 9**).

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 sulphate (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.

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 (period E - present in the figures). 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 up to end 2018, 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 since the 2017 summer. The difference amounts to approximately between 1.5 and 2 pH units, being lower at the downstream F11S12 station. Hobbs et al. (2018) postulated this as 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**). Since late 2018, the pH pattern at the downstream F11S12 station showed a decreasing trend (Bugan et al., 2019), however beyond March 2019 the pH pattern increased to a level similar to that at the Hippo Dam site. Bugan et al. (2019) noted an increase in the sulphate concentration (Figure 13), and resultantly also the SEC values (Figure 12), from the upstream Hippo Dam station however beyond May 2019 there is a decrease in both variables at both the Hippo Dam and F11S12 stations. Beyond May 2019, manganese concentrations (**Figure 15**) are observed to increase at Hippo Dam, while a steady decline pattern is noted at the downstream F11S12 site. Uranium (**Figure 16**) remains the only other of the graphed variables that generally maintains a consistent concentration, although a few peaks in concentration are noted in August 2019.

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. As noted by Hobbs et al. (2018), 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 in most cases show the lowest values across the five periods of analysis.

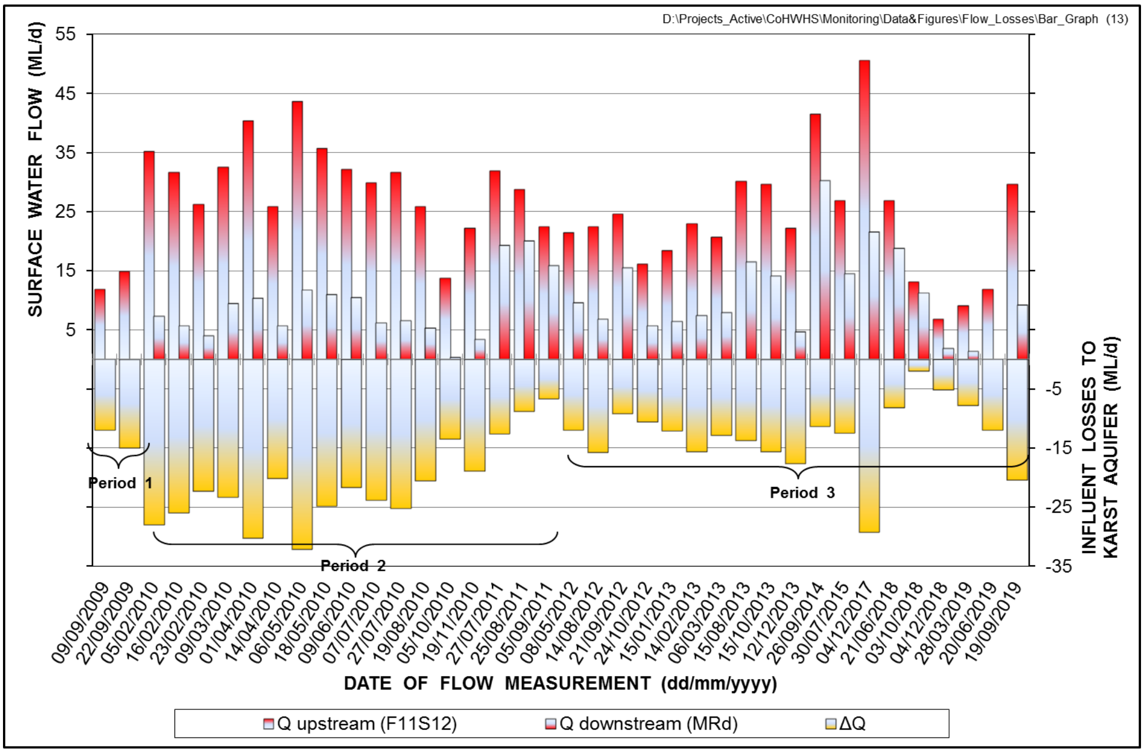


Figure 8 Graph of streamflow and influent losses to the karst aquifer in the lower Riet Spruit valley

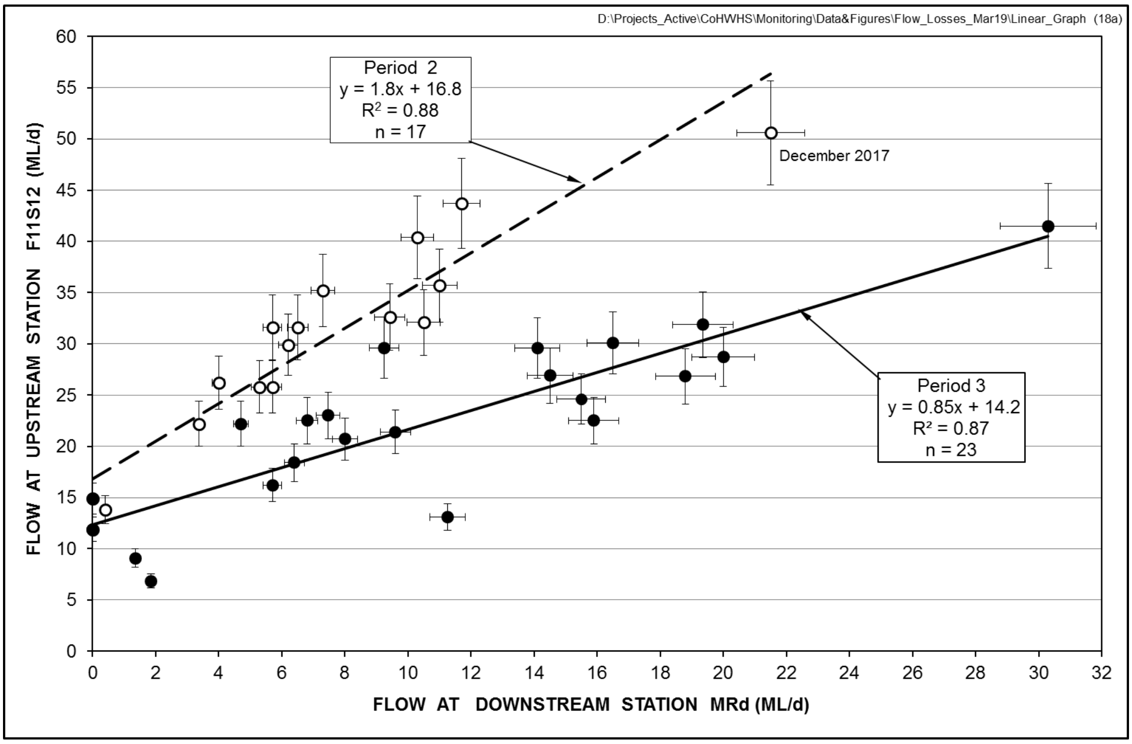
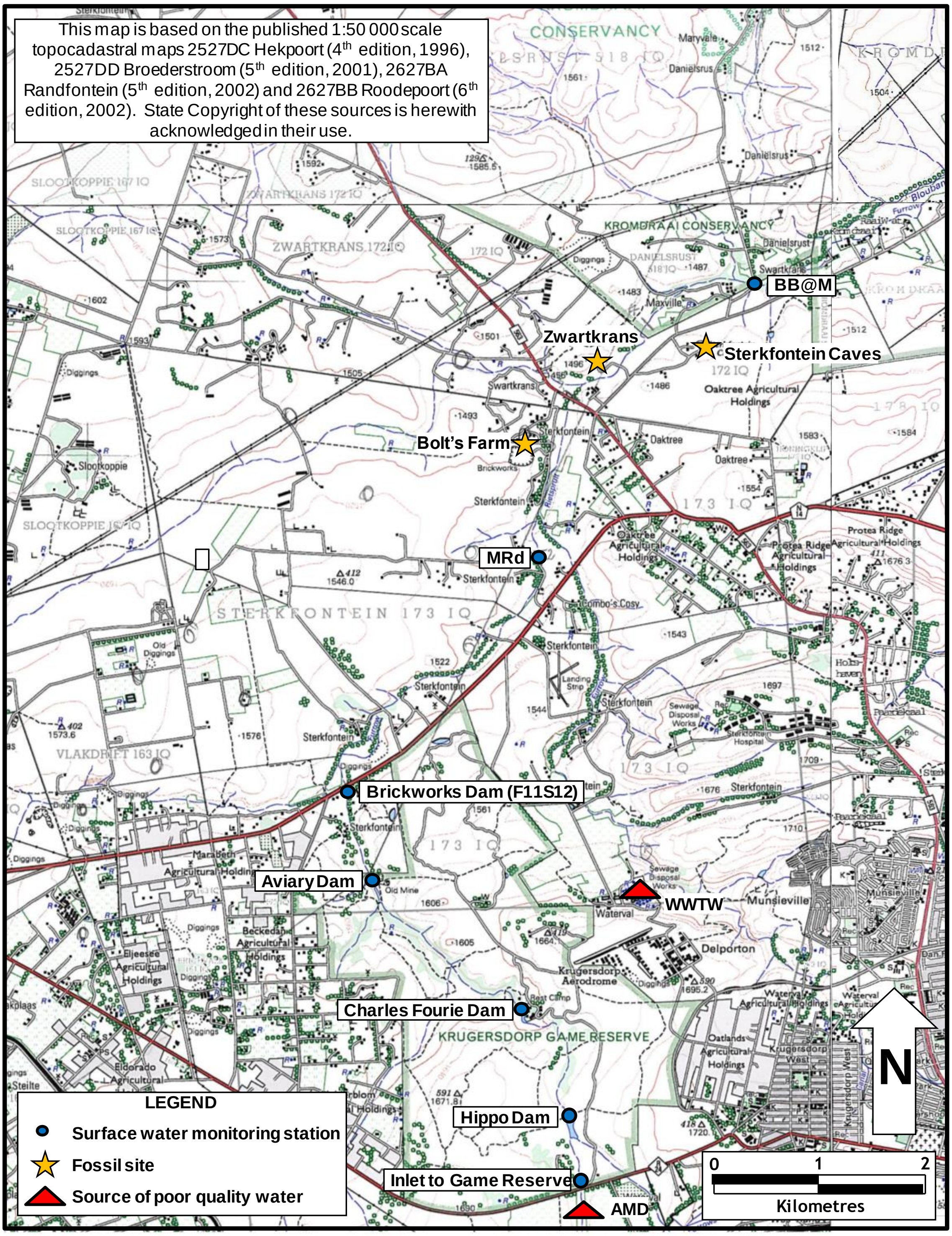


Figure 9 Correlation of streamflow at stations F11S12 and MRd in the lower Riet Spruit valley, with vertical error bars denoting ±10% at F11S12 and horizontal bars ±5% at MRd



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

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

4.2.1.2 Bloubank Spruit

The statistical overview of synoptic surface water chemistry data for DWS flow gauging station A2H049 (**Table 4**) at the lower end of the Bloubank Spruit system presented in previous reports, has been amended to bring out substantial temporal changes in variable-specific values. The available dataset has not been updated by the DWS since May 2018, owing to financial challenges expressed by the DWS. Therefore, the statistical analysis and narrative presented are the same as reported by Bugan et al. (2019). 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 May 2018). 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.

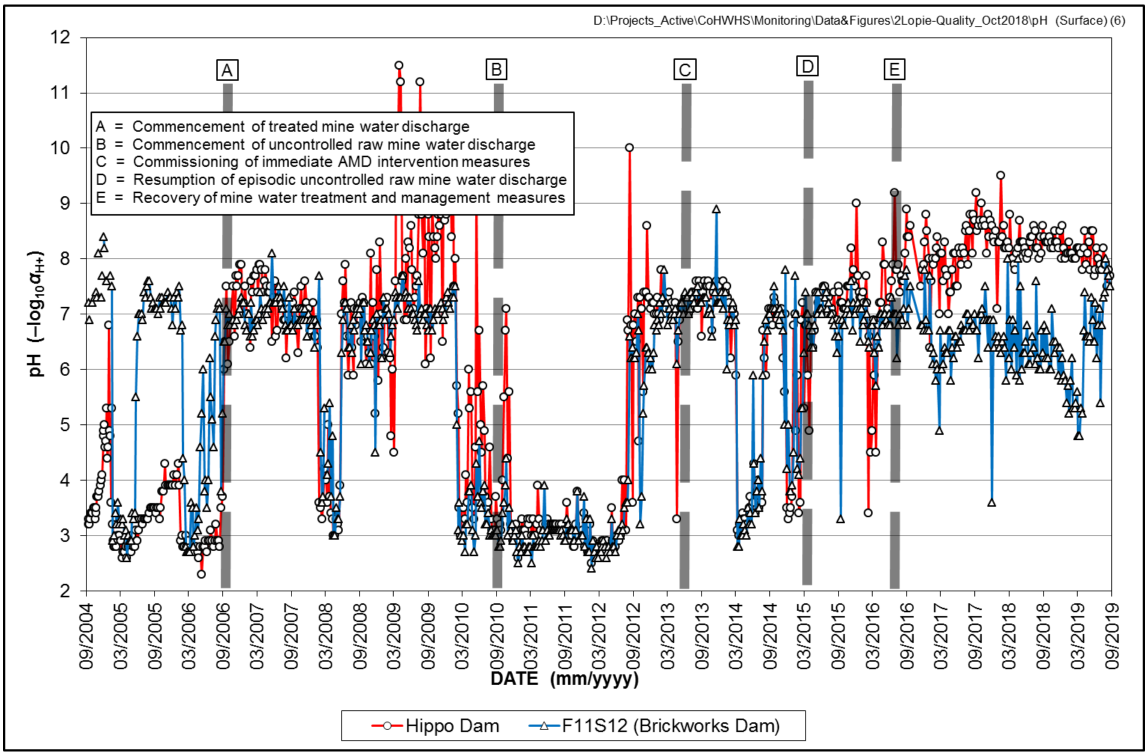


Figure 11 pH pattern of Tweelopie Spruit surface water in the period September 2004 to August 2019

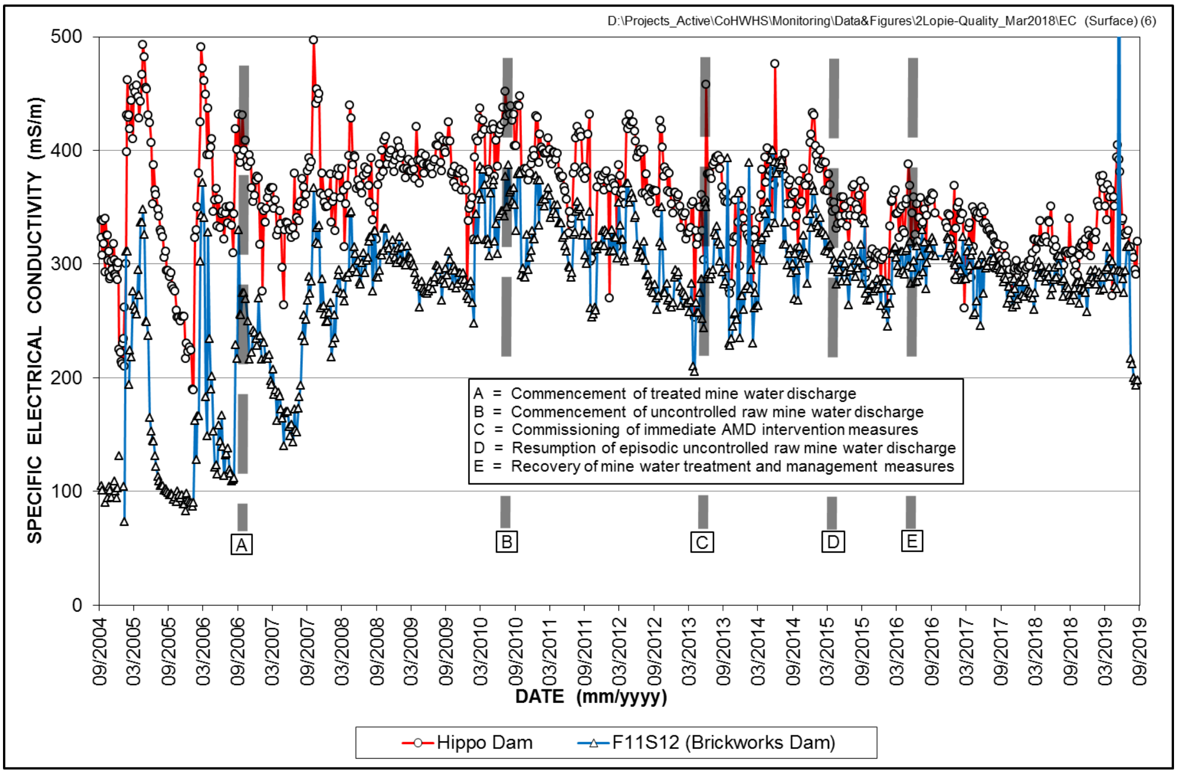


Figure 12 Specific electrical conductivity pattern of Tweelopie Spruit surface water in the period September 2004 to August 2019

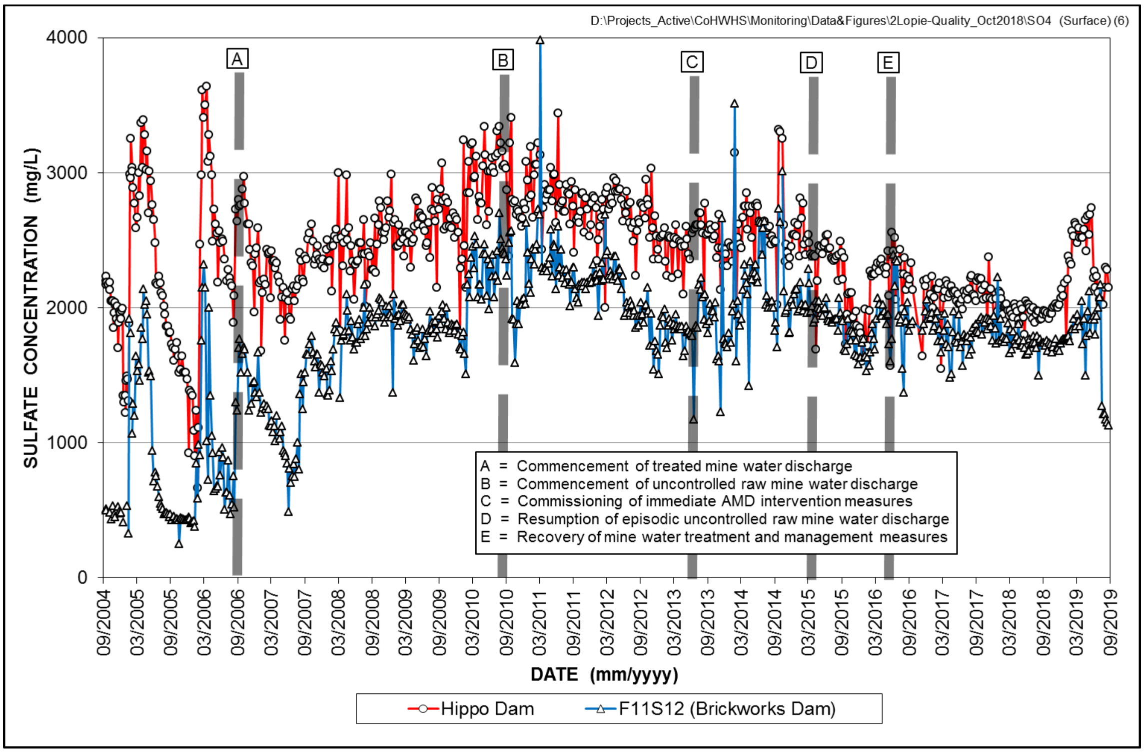


Figure 13 Sulphate pattern of Tweelopie Spruit surface water in the period September 2004 to August 2019

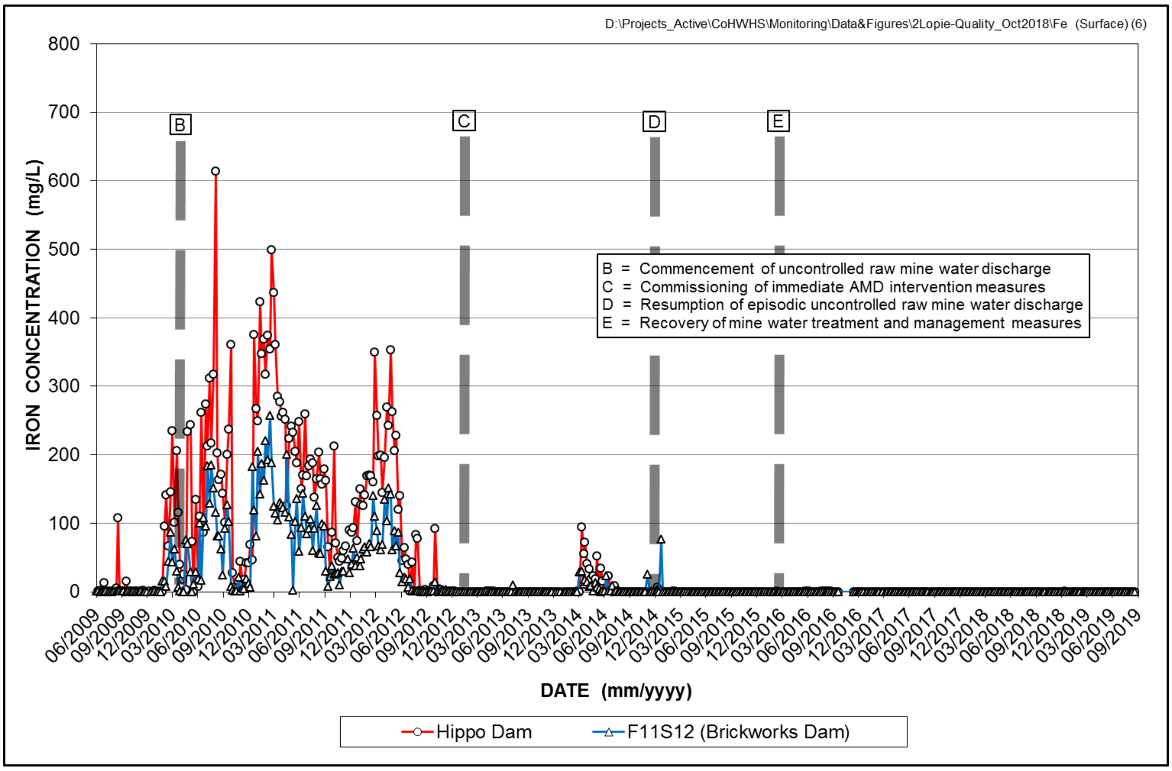


Figure 14 Iron pattern of Tweelopie Spruit surface water in the period June 2009 to August 2019

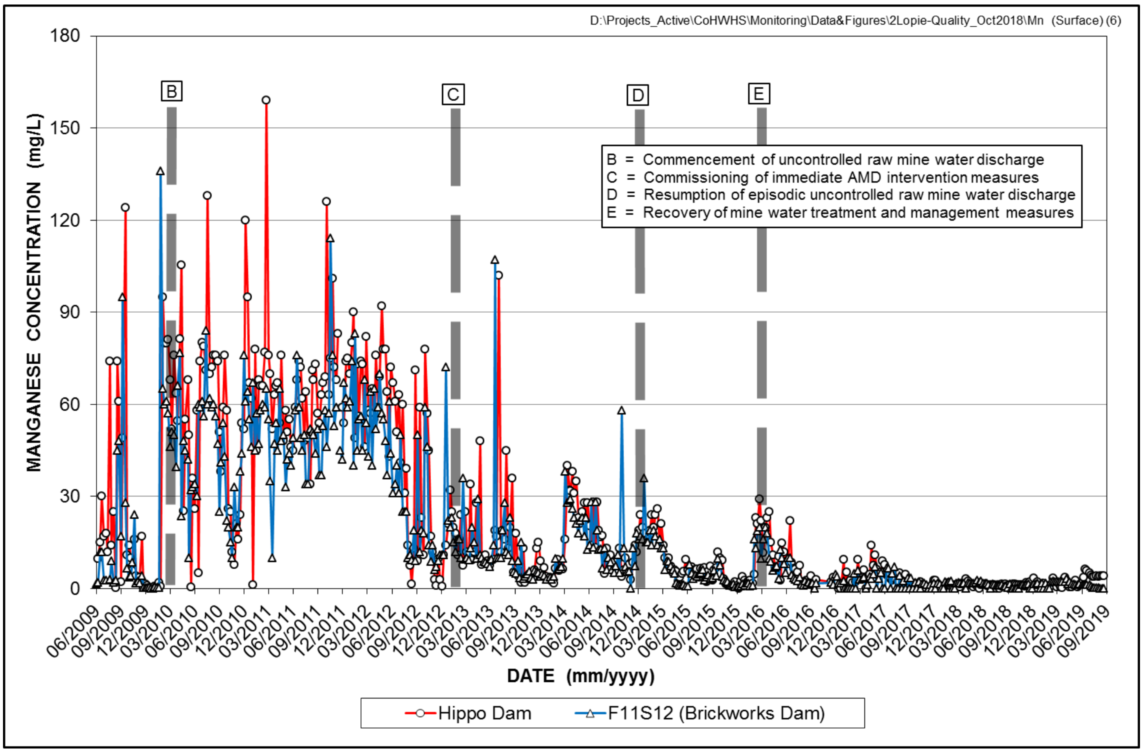


Figure 15 Manganese pattern in Tweelopie Spruit surface water in the period June 2009 to August 2019

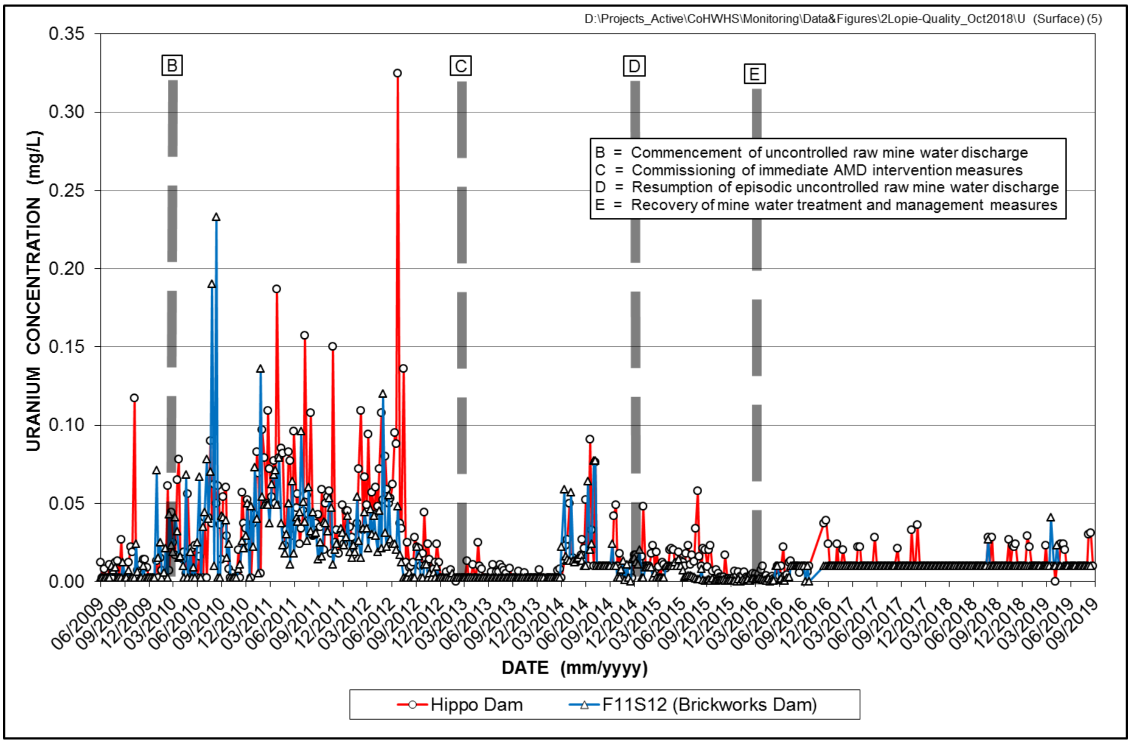


Figure 16 Uranium pattern in Tweelopie Spruit surface water in the period June 2009 to August 2019

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	213	173	128	83	57	229.0
	5%ile	3.6	2.8	5.9	3.2	6.9	3.9	2.7	5.3	3.0	5.4
	Mean	—	—	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	4.9	8.1	6.9	3.0	7.0	5.0	6.7
	95%ile	9.3	5.7	7.6	7.1	8.7	7.4	3.9	7.4	7.4	7.7
	SD	1.5	1.0	0.8	1.6	0.8	0.9	0.4	0.9	1.7	0.7
	CoV (%)	22.0	30	11	32	9.5	14	14	13	32	10.1
SEC (mS/m)	n	175	129	83	57	213	172	128	83	57	229.0
	Mean	374	391	350	376	326.6	268	332	281	329	287.4
	Median	379	393	354	377	324.0	283	330	276	323	289.0
	95%ile	426	438	395	417	369.4	329	378	350	391	317.0
	SD	32	33	34	28	26.4	48	29	34	34	43.2
	CoV (%)	9	8	10	7	8.1	18	9	12	10	15.0
SO_4 (mg/L)	n	176	128	82	56	213	171	128	83	56	229.0
	Mean	2448	2846	2520	2585	2137.2	1636	2264	1879	2137	1792.5
	Median	2460	2815	2525	2541	2110.0	1760	2240	1870	2075	1800.0
	95%ile	2828	3220	2770	2950	2540.0	2015	2593	2148	2640	2056.0
	SD	262	226	193	231	220.9	349	245	268	274	211.5
	CoV (%)	11	8	8	9	10.3	21	11	14	13	11.8
Fe (mg/L)	n	33	129	83	57	196	33	128	82	57	189.0
	Mean	4.7	168.4	2.5	8.9	0.1	0.3	72.9	0.47	4.9	0.0
	Median	0.4	163.0	0.03	0.10	0.0	0.2	64.0	0.08	0.04	0.0
	95%ile	13.8	365.2	3.1	52.6	0.3	0.8	186.3	1.00	25.7	0.1
	SD	18.8	116.2	13.10	19.5	0.1	0.3	57.7	1.9	12.2	0.0
	CoV (%)	399	69	528	220	189.9	94	79	407	2518	116.0
Mn (mg/L)	n	34	129	83	57	199	33	128	83	57	189.0
	Mean	18.1	62.7	16.5	17.3	4.1	10.3	50.3	14.4	16.1	3.2
	Median	9.8	65.0	11.0	16.0	2.3	2.7	50.0	10.0	14.0	1.9
	95%ile	74.0	95.0	56.1	32.6	14.1	46.2	76.0	45.0	30.4	10.0
	SD	27.6	23.5	18.0	9.1	5.0	19.4	17.6	15.8	9.9	3.7
	CoV (%)	153	38	109	53	120.0	188	35	110	61	113.1

(1) 09/2006 – 01/2010 (2) 02/2010 – 07/2012 (3) 08/2012 – 02/2014 (4) 03/2014 – 03/2015 (5) 04/2015 – 05/2019

Table 4 Synoptic overview of Bloubank Spruit water chemistry at station A2H049 in the periods August 2002 to January 2010 and February 2010 to May 2018 (latest data as at 25 October 2019)

Variable	Statistical Parameter														SANS (2015a)(1)
	Period August 2002 to January 2010							Period February 2010 to May 2018							
	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	202	7.5	8.2	8.2	8.5	0.3	3.7	5.0–9.7
SEC (mS/m)	232	51.1	61.2	62.3	66.8	5.0	8	199	61.5	93.4	90.1	126.0	23.2	24.8	<170
TDS (mg/L)	137	347.6	438.5	448.9	479.3	41.5	9	134	474.7	695.8	674.9	980.1	171.9	24.7	<1200
Ca (mg/L)	172	40.1	51.3	52.1	57.7	5.31	10	191	54.3	96.3	90.7	153.7	33.0	34.3	n.s.
Mg (mg/L)	171	23.3	30.2	30.4	34.9	4.8	16	192	28.4	44.2	42.8	59.7	10.6	24.0	n.s.
Na (mg/L)	185	19.1	27.5	27.7	34.0	4.7	17	166	28.3	41.7	40.5	58.4	10.1	24.3	<200
K (mg/L)	173	1.4	2.4	2.4	3.4	0.7	27	169	2.9	4.1	4.0	5.7	1.0	24.4	n.s.
Cl (mg/L)	175	29.2	36.2	36.3	43.5	4.8	13	198	31.3	38.8	38.5	45.3	5.3	13.6	<300
SO_4 (mg/L)	191	63.4	85.8	83.9	110.0	15.1	18	189	96.8	284.0	247.8	475.0	132.7	46.7	<500
HCO_3 (mg/L)	185	146.1	188.1	190.2	216.1	21.1	11	189	242.4	422.2	404.4	621.6	121.6	28.8	n.s.
NO_3+NO_2 (mg N/L)	214	3.294	4.740	4.414	7.085	1.190	25	193	3.5	5.6	5.4	8.3	1.6	27.7	<11
PO_4 (mg P/L)	247	0.043	0.189	0.158	0.451	0.131	69	197	0.005	0.097	0.048	0.261	0.124	127.8	n.s.
Si (mg/L)	247	4.93	5.84	5.83	6.69	0.60	10	198	4.95	5.64	5.60	6.59	0.61	10.86	n.s.
Fe (mg/L)	69	0.006	0.035	0.014	0.120	0.056	163	61	0.004	0.019	0.012	0.072	0.024	126.3	<2
Mn (mg/L)	69	0.001	0.049	0.002	0.146	0.226	459	61	0.001	0.162	0.003	0.05	0.855	527.8	<0.5
Al (mg/L)	65	0.001	0.060	0.014	0.091	0.262	437	60	0.003	0.019	0.009	0.057	0.026	136.8	<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.

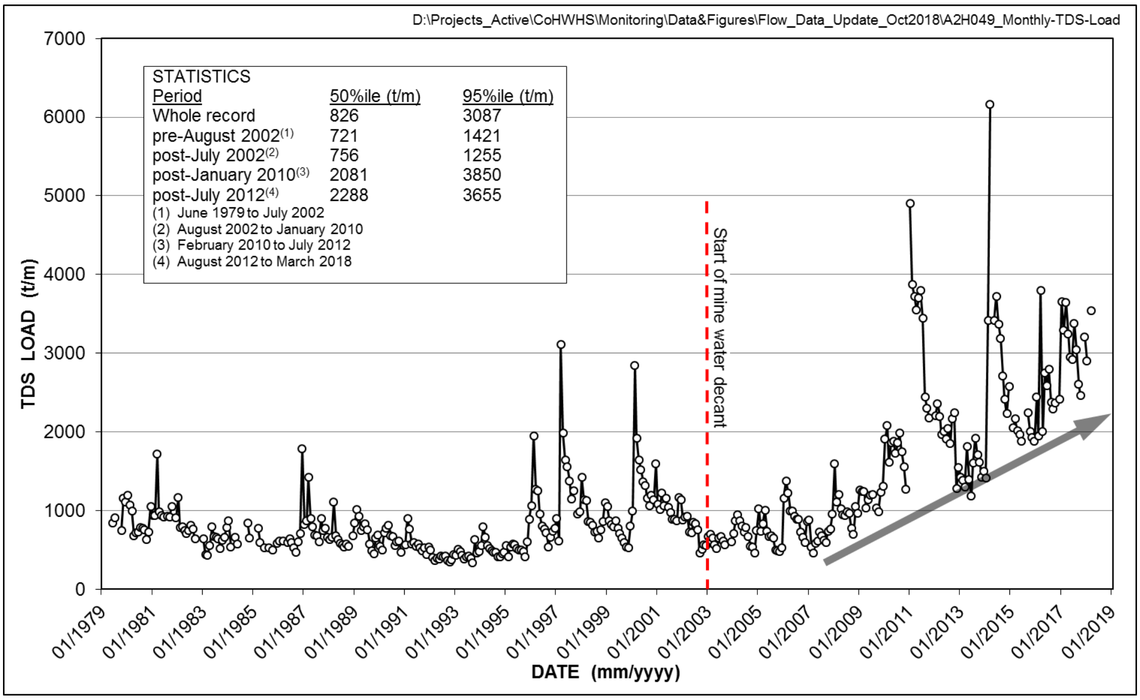
The severity of the bacteriological contamination is reflected in total coliform and *E. coli* values that routinely exceed a most probable number (MPN) count of 2419.6 per 100 mL at BG@N14 and other downstream sites. These counts on occasion reach values of 10's of thousand. It can be argued that the 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 hydrochemical data from station A2H049 has not been updated by DWS since May 2018 - the DWS has attributed this to financial challenges which made it difficult for them to perform regular data collections and updates, and conduct the requisite maintenance of the data collection platforms. Therefore, the data and analysis presented below is the same as that presented and discussed by Bugan et al. (2019). 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 a significant increase in the 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 sulphate 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

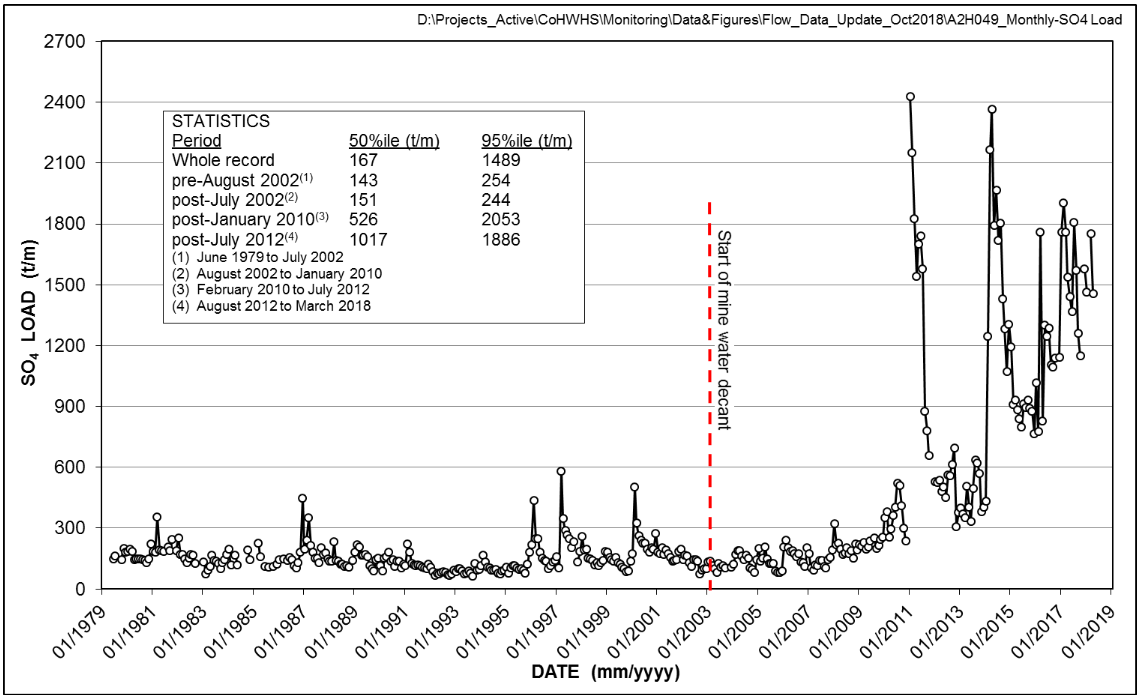


STATISTICS

Period	50%ile (t/m)	95%ile (t/m)
Whole record	826	3087
pre-August 2002$^{(1)}$	721	1421
post-July 2002$^{(2)}$	756	1255
post-January 2010$^{(3)}$	2081	3850
post-July 2012$^{(4)}$	2288	3655

(1) June 1979 to July 2002
(2) August 2002 to January 2010
(3) February 2010 to July 2012
(4) August 2012 to March 2018

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



STATISTICS

Period	50%ile (t/m)	95%ile (t/m)
Whole record	167	1489
pre-August 2002$^{(1)}$	143	254
post-July 2002$^{(2)}$	151	244
post-January 2010$^{(3)}$	526	2053
post-July 2012$^{(4)}$	1017	1886

(1) June 1979 to July 2002
(2) August 2002 to January 2010
(3) February 2010 to July 2012
(4) August 2012 to March 2018

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

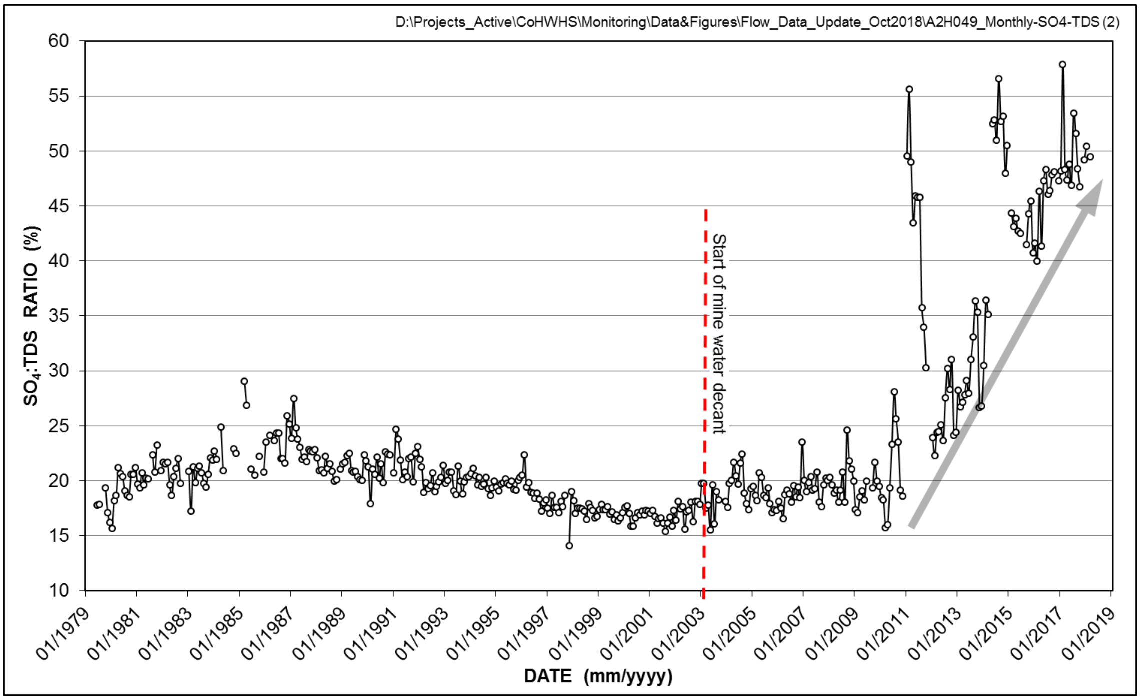


Figure 19 Long-term (June 1979 to March 2018) trend in the SO_4:TDS ratio at station A2H049

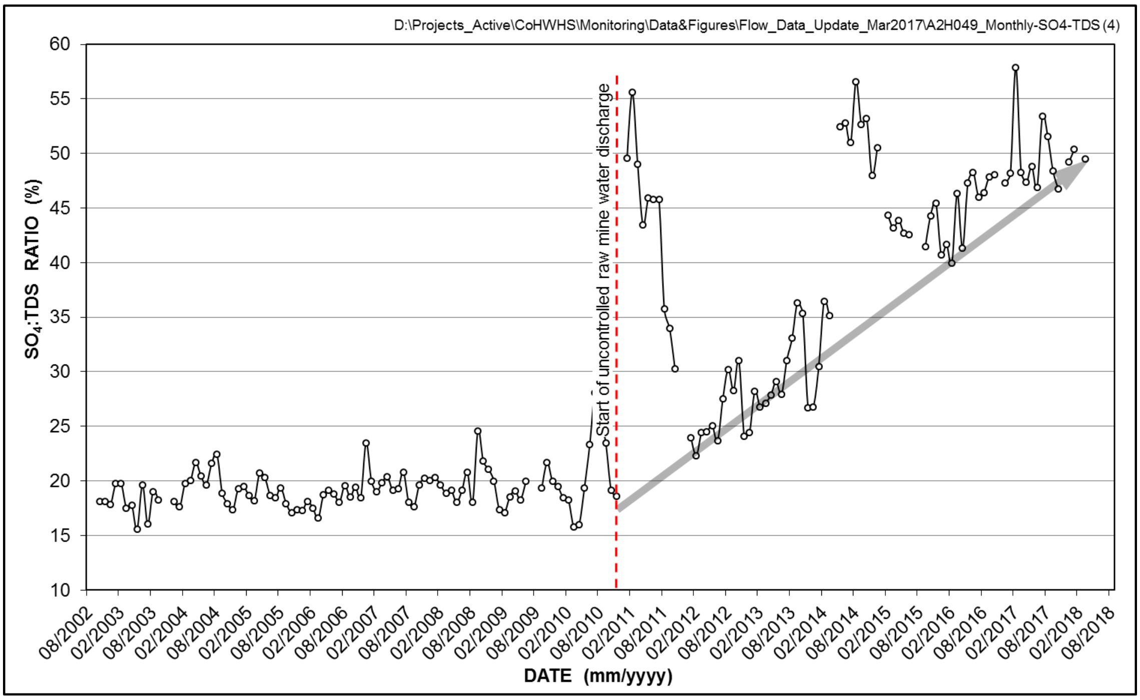
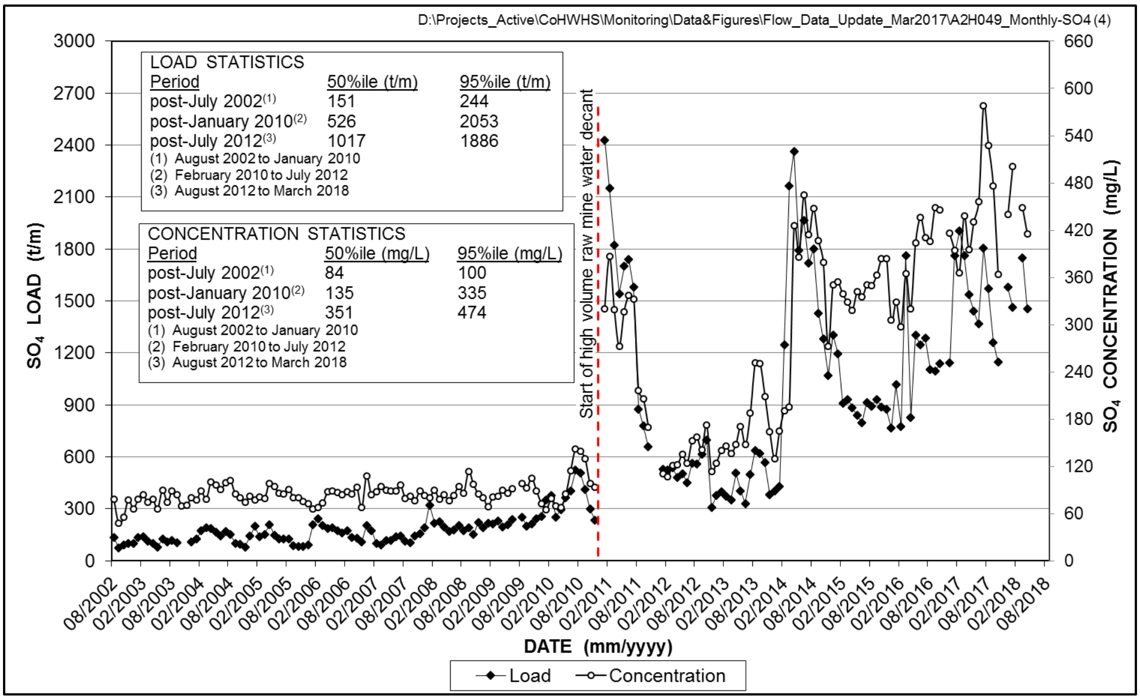


Figure 20 Pattern and trend of the SO_4:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin in mid-2002



LOAD STATISTICS

Period	50%ile (t/m)	95%ile (t/m)
post-July 2002(1)	151	244
post-January 2010(2)	526	2053
post-July 2012(3)	1017	1886

(1) August 2002 to January 2010
(2) February 2010 to July 2012
(3) August 2012 to March 2018

CONCENTRATION STATISTICS

Period	50%ile (mg/L)	95%ile (mg/L)
post-July 2002(1)	84	100
post-January 2010(2)	135	335
post-July 2012(3)	351	474

(1) August 2002 to January 2010
(2) February 2010 to July 2012
(3) August 2012 to March 2018

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 general decline in groundwater level elevations in the central and especially the northern segments is evident, with the exception of station GP00312 which exhibits an apparent increase in groundwater level. 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**.

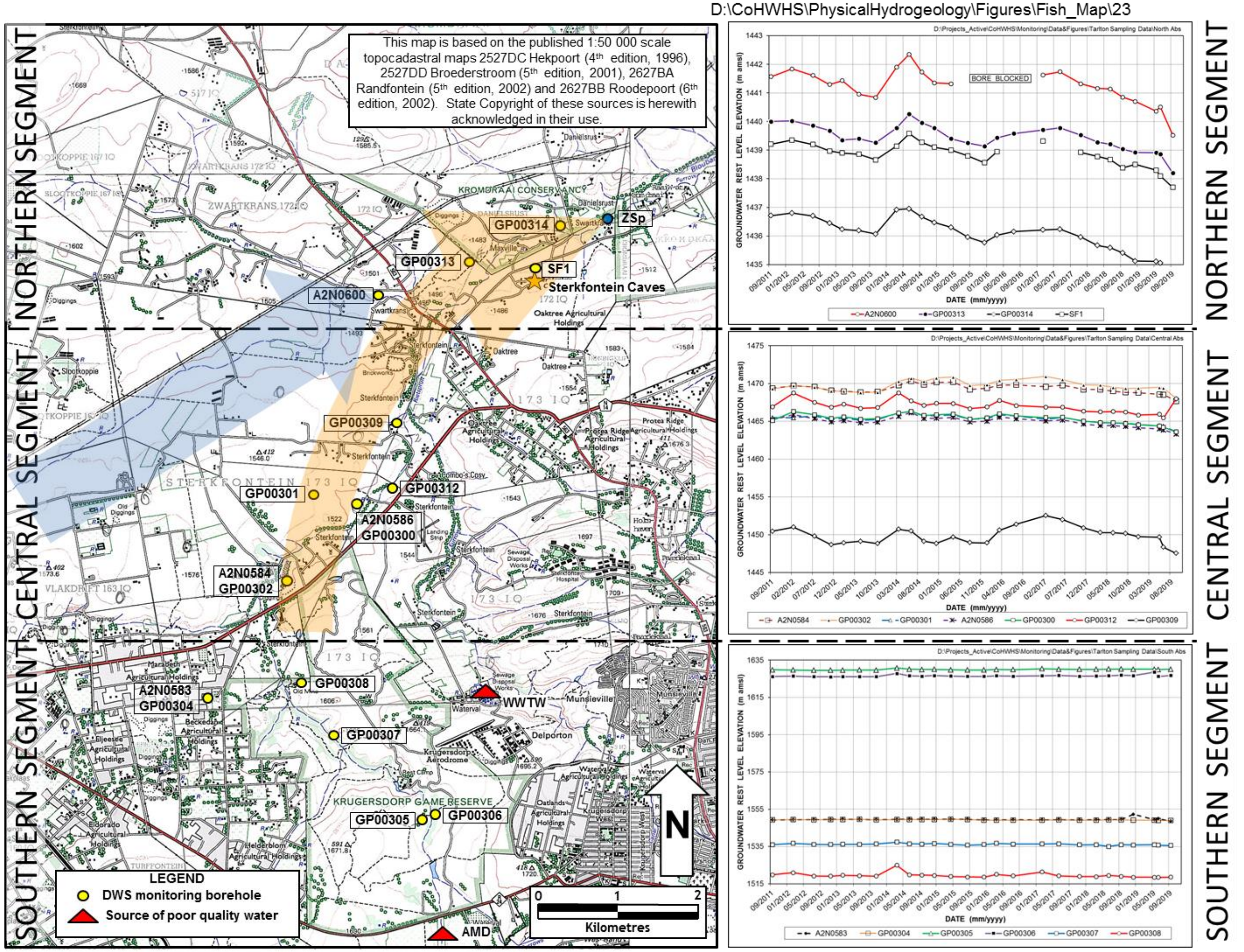


Figure 22 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

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 14 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 has been 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 (Hobbs et al., 2018). However, the groundwater level recorded in September 2018, December 2018 and March 2019 and September 2019 represents the lowest elevations recorded since end-2010. The recent September 2019 groundwater elevation of 1437.7 m amsl correlates to the trendline observed since November 2017 and illustrates an approximate 0.7 m decrease in the groundwater level since September 2018. The lowered groundwater level corresponds to the observed lower discharge in the Bloubank Spruit, which has partly been attributed to the reported temporary closure of the wastewater treatment plant.

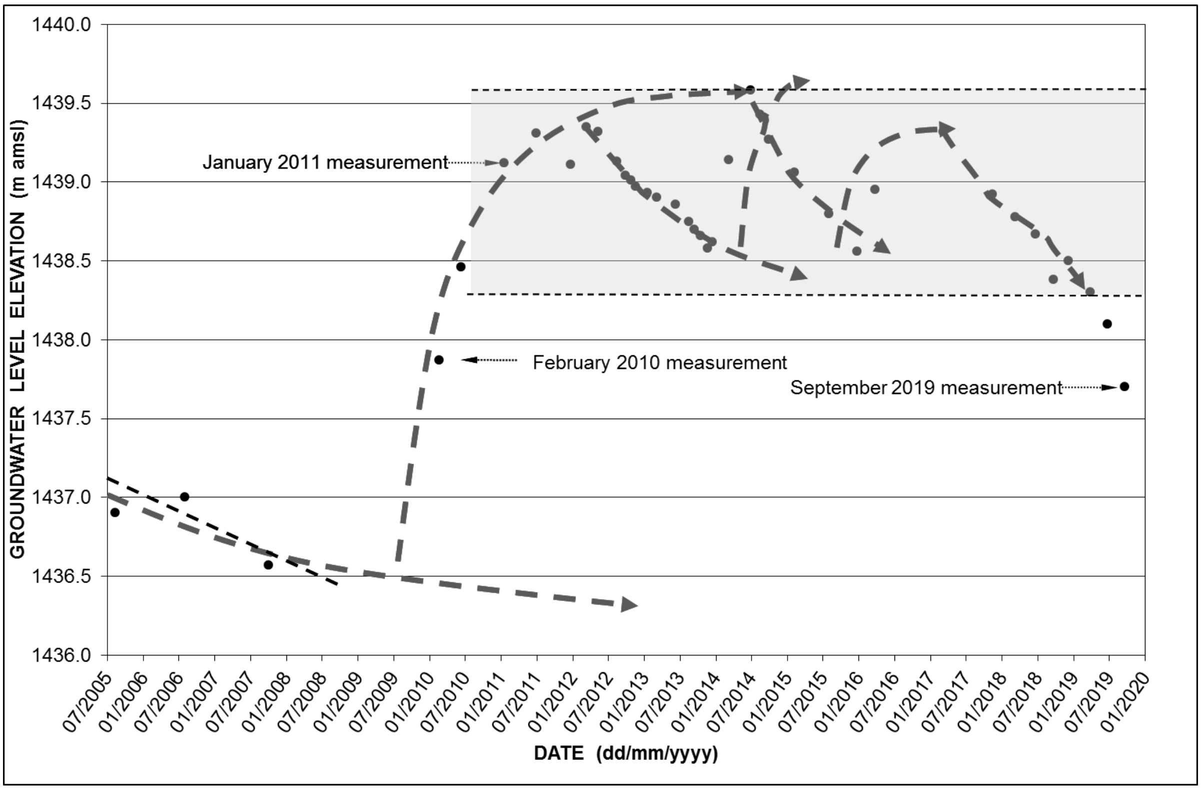


Figure 23 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the lake water level in Sterkfontein Cave; shaded area denotes magnitude of fluctuation since mid-2010

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. During March 2019, flow was measured at eight (**Table 5**) of the ten identified springs. During September 2019, flow was measured at eight (**Table 5**) of the ten identified springs. At some sites no suitable cross-sectional area for measurement could be identified in the vicinity of these springs. It should however be borne in mind that only a portion of the cross-section was gauged at the Tweefontein and Nash springs during March 2019, i.e. only a portion of the width of the stream generated by the discharge from the springs. These areas were identified as suitable 'temporary' sites that can provide a rough estimate of the discharge from these springs. The following observations were made about the discharge measurements and results:

- As per Bugan et al. (2019), continuous direct abstraction was noted during the September 2019 monitoring which 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 discharge measured in September 2019 was ~74% less than the discharge reported in March 2019 and ~39% less than the discharge reported in September 2018.
-
- The 2.99 ML/d discharge reported in Table 5 provides the combined discharge measured from the two channels which provide the expected yield from the Plover's Lake springs. The volumetric measurement acquired through use of the 'bucket and stopwatch' method as described in the monitoring manual (Hobbs, 2012) is uncertain with respect to the determination of the true yield of the Plover's Lake springs on the NIROX property. A control site was established upstream of the culvert (downstream of the multiple eyes of the spring) and the discharge was found to be 2.11 ML/d which is significantly greater than the 0.4 ML/d acquired using the bucket method. However, measurement at this control site is only feasible when flow is reasonably high to allow the propeller to be adequately immersed in the water and turn without hindrance. The combined flow of the NIROX control site and the Plover's Lake gauging site was calculated to be 4.7 ML/d. A measurement was also taken at the control site described by Bugan et al. (2019) as downstream from the gauging site on the Plover's Lake property. The flow measured at the control site amounted to 4.68 ML/d. Given that the flow measured at this site provides the estimated combined outflow of the springs located on both the NIROX and Plover's Lake property and is similar to the calculated 4.7 ML/d, it makes sense continue to use this new established control site on the NIROX property for future flow measurements.
- The cross-sectional area of the Bloubank Spruit was used to determine the flow measurements at both the upstream and downstream sites near the Kromdraai Spring. The 2.79 ML/d discharge measured in September 2019 is ~10% less than that measured in March 2019 and ~74% less than the flow measured in September 2018.
- The discharge at Danielsrust Spring was recorded as 1.53 ML/d. However, to account for outflows observed near the gauging site, an additional 20% uncertainty was added to the flow giving a discharge 1.84 ML/d.
- The discharge of the Broederstroom spring was gauged ~150 m downstream from the eye of the spring at the control site described by Bugan et al. (2019). Due to the shallow depth of the water

at the site, a float was used to determine the discharge of the spring. The 1.72 ML/d discharge measured is similar to the discharge reported by Hobbs (2011) however multiple occurrences of pooling in the channel fed by the spring, it is uncertain whether this measurement uncertain to give a true level of the discharge of the spring.

- In most cases, the spring discharge measured in September 2019 was below that reported by Bugan et al. (2018, 2019) and Hobbs (2011). As per Bugan et al. (2019), the highest discharges were realised for the Nouklip and Nash springs, respectively yielding 11.37 ML/d and 18.59 ML/d.

It is evident that significant variability exists in the discharge measurements. This produces uncertainty associated with the data and currently no distinct pattern has been established regarding the response of the individual springs to changes in rainfall and discharge across the CoHWHS property . It is however interpreted that the lack of rated cross-sections for discharge measurements, as well as a drier hydrological year as discussed in Section 3.1, may be the cause of this variation and decreased discharge observed for most of the springs.

Table 5 Dolomitic spring discharge measured in March 2019 and September 2019

Spring	Compartment	Measured Discharge (Mar 2019)		Spring Discharge (Mar 2019)		Measured Discharge (Sep 2019)		Spring Discharge (Sep 2019)		Previous Discharge Volume [1]	
		(m^3/s)	(ML/d)	(m^3/s)	(ML/d)	(m^3/s)	(ML/d)	(m^3/s)	(ML/d)	(m^3/s)	(ML/d)
Zwartkrans (upstream)	Zwartkrans	0.611	52.83	0.091	7.83	0.553	47.81	0.024	2.07	~0.1	~8.6
Zwartkrans (downstream)		0.702	60.66			0.577	49.88				
Plover's Lake	Krombank	0.02	1.44	0.03	2.00	0.03	2.59	0.035	2.99	~0.06	~5.2
Plover's Lake (culvert)		0.01	0.56			0.005	0.40				
Kromdraai (upstream)	Krombank	0.69	59.77 [2]	0.04	3.13	0.62	53.54	0.03	2.79	~0.28	~24.1
Kromdraai (downstream)		0.73	62.90			0.65	56.33				
Danielsrust	Danielsrust	0.02	1.52	0.02	1.52	0.02	1.84	0.02	1.84	~0.03	~2.4
Nouklip	Diepkloof	0.12	9.90	0.12	9.90	0.13	11.37	0.13	11.37	~0.14	~12.4
Tweefontein	Tweefontein	0.002	0.17	0.002	0.17	0.015	1.26	0.015	1.26		
Nash	Uitkomst	0.16	13.79	0.160	13.79	0.22	18.59	0.22	18.59		
Broederstroom	Broederstroom	0.02	1.49	0.02	1.49	0.42	1.72	0.42	1.72	~0.02	~1.8

[1] after Hobbs (2011)

[2] estimation based on the width and average depth of the river recorded in September 2018

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 (Hobbs et al., 2018). 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. 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. Recent pH values in the central segment bracket the range 6.3 to 8.2, and those in the northern segment range from 7.8 to 8.1. In the southern segment, the most recent pH values are in the range 6.7 to 8.4. 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 increasing 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. Between March 2019 and September 2019, the salinity is constrained to the range 124 to 300 mS/m. In the northern segment, the spatial salinity trend along the flow path is a declining one, however at each of the stations, with the exception of the Zwartkrans Spring, an increasing trend in salinity is apparent. The recent (March 2019 to September 2019) salinity is constrained to the range 142 to 195 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 sulphate 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, June 2018, September 2018,December 2018, March 2019, June 2019 and September 2019 values. The comparison indicates that during the 2019 hydrological year, sulphate levels in ambient groundwater have slightly increased 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 sulphate concentrations was observed during March 2018 at some of the monitoring points located at the south-western end of the impacted zone, however these values have increased. The reason for this is not currently discernible.

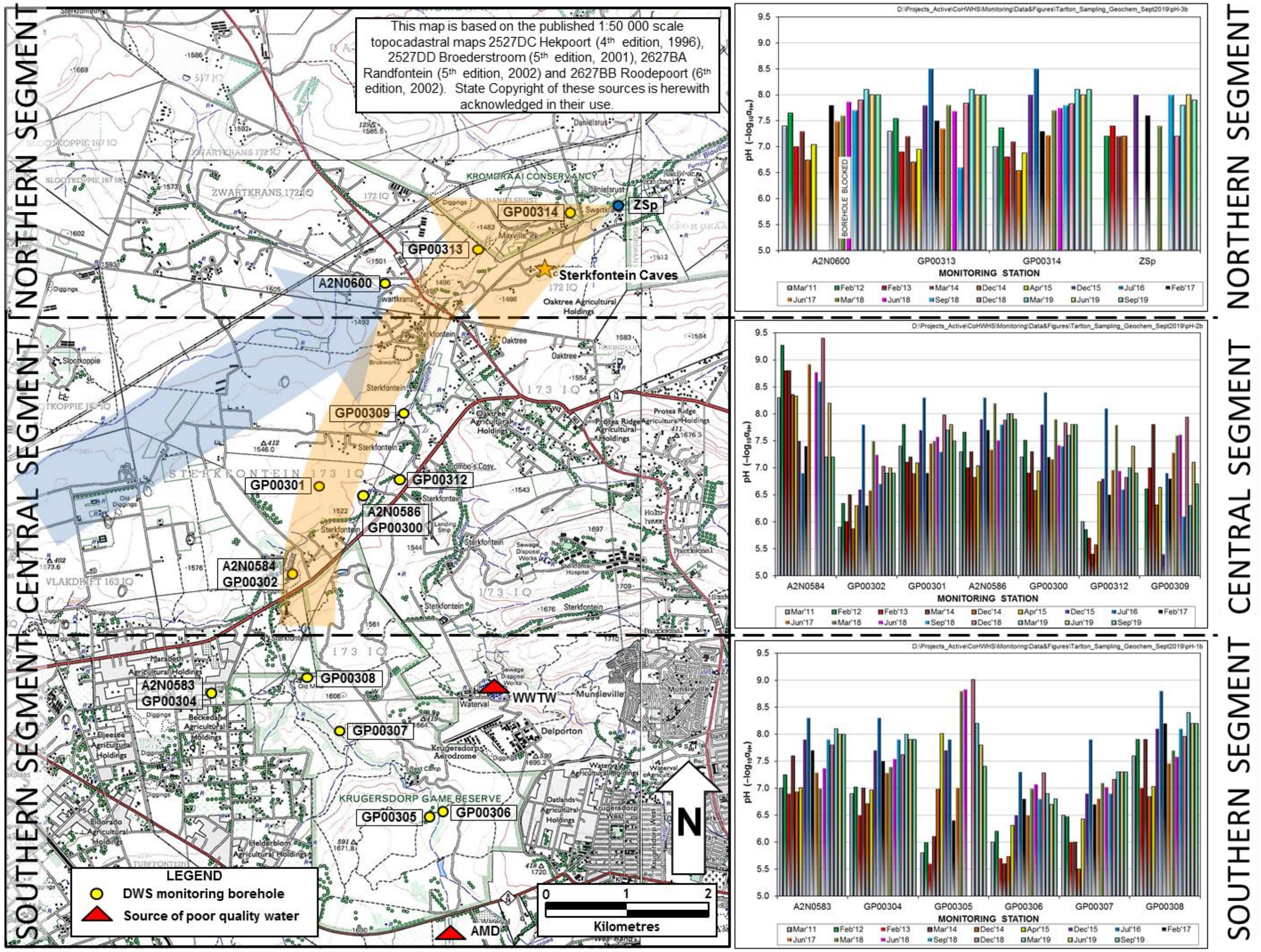


Figure 24 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

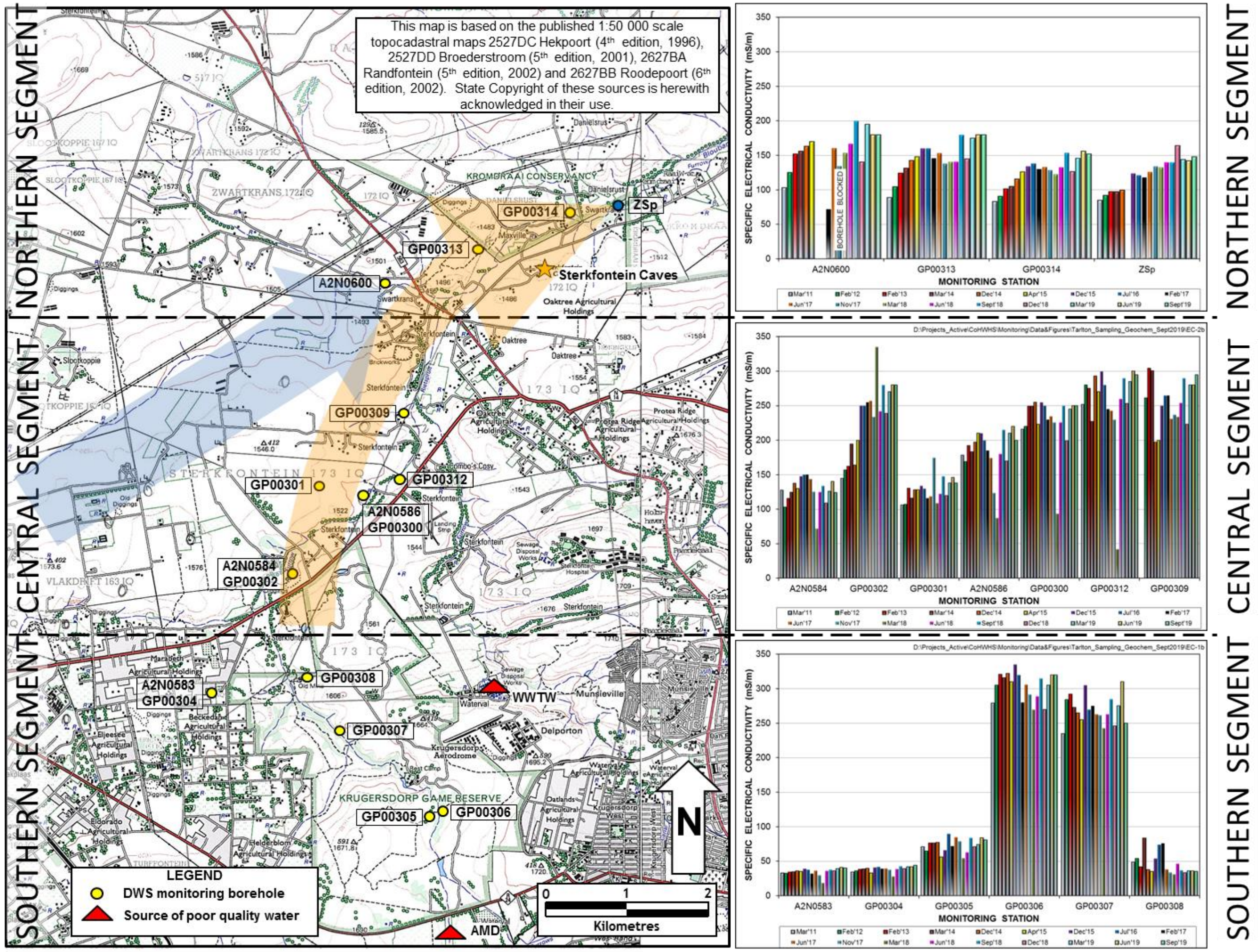


Figure 25 Distribution of DWS monitoring boreholes with SEC pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

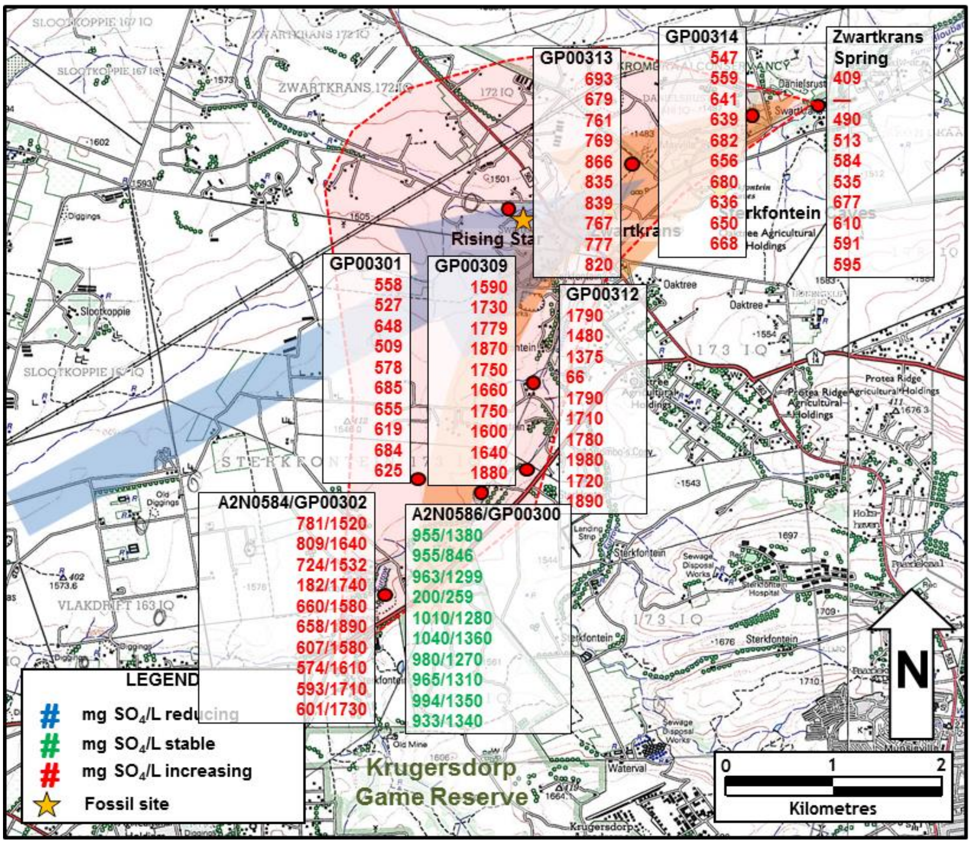


Figure 26 Distribution of sulphate levels in groundwater of the Zwartkrans Basin in July 2016 (1st value), February 2017 (2nd value), November 2017 (3rd value), March 2018 (4th value), June 2018 (5th value), September 2018 (6th value), December 2018 (7th value), March 2019 (8th value), June 2019 (9th value), September 2019 (10th 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 2018, March 2019, June 2019 and September 2019 are presented in **Table 6**. None of the variables reported for, exceed the respective SANS (2015a) health-related limits for potable water. The microbiological quality of the water is however compromised by the total coliform bacteria which exceeds the standard health-related limits across all sample results and thus reflects 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 2018, March 2019, June 2019 and September 2019

Variable	**December 2018**	**March 2019**	**June 2019**	**September 2019**	**SANS (2015a)**[1]
pH ($–\log_{10}\alpha_{H+}$)	8.3	8.0	8.1	8.1	5.0–9.7
SEC (mS/m)	90	92	92	95	<170
Ca (mg/L)	88	90	89	88	n.s.
Mg (mg/L)	54	53	54	54	n.s.
Na (mg/L)	34	35	37	33	<200
K (mg/L)	1.6	1.5	1.6	1.5	n.s.
Cl (mg/L)	36	37	37	36	<300
SO_4 (mg/L)	259	273	271	259	<500
HCO_3 (mg/L)	145	148	146	148	n.s.
NO_3+NO_2 (mg N/L)	6.1	7.1	7.0	6.6	<11
Si (mg/L)	5.9	5.9	7.0	5.8	n.s.
Fe (mg/L)	0.03	0.02	0.31	0.02	<2
Mn (mg/L)	0.02	<0.01	0.32	<0.01	<0.5
Al (mg/L)	0.04	0.03	0.14	0.02	<0.3
Total coliform bacteria (MPN/100 ml)	82	1046.2	125.9	35.5	<10
E.coli (MPN/100 ml)	<1	<9.8	4.1	<1.0	n.d.

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

n.s no standard

n.d not detected

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 March 2019 and September 2019. The results are presented in **Table 7**. Historic and recent water quality results related to the Zwartkrans Spring is also presented in **Section 5.2**.

With the exception of the Zwartkrans Spring and the Kromdraai Spring, the water from the major dolomitic springs is of excellent quality for the parameters reported for both the March 2019 and September 2019 sampling results. The chemical analytical results from the Zwartkrans Spring and Kromdraai Spring do however show probable mine water impact as evidenced by the high sulphate content. Unlike the results reported in December 2018 (Bugan et al., 2019) the March 2019 and September 2019 are understood to show better representation of the quality of the springs. Water samples were taken directly at the point of 'bubbling' which is understood to be the locality of the eye for each spring system. Due to the position of the Kromdraai spring being within the channel of the Bloubank Spruit, some intermixing may occur between groundwater emerging from the spring and surface water within the Bloubank Spruit, impacting on the observed results

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Across all the spring sample results, the microbiological quality of the water is compromised by the total coliform bacteria which far exceeds the standard health-related limits. The most impacted sites include the Zwartkrans, Kromdraai, Danielsrust, Aquamine, Tweefontein and the Cradle Spring, which exhibit high levels of total coliform bacteria and E.coli. It should however be considered that these springs are open and easily accessible to animals, and may therefore be directly impacted by surface runoff, animal droppings, etc., therefore if these sources are considered for human drinking water supply purposes, it is advisable to re-test these parameters.

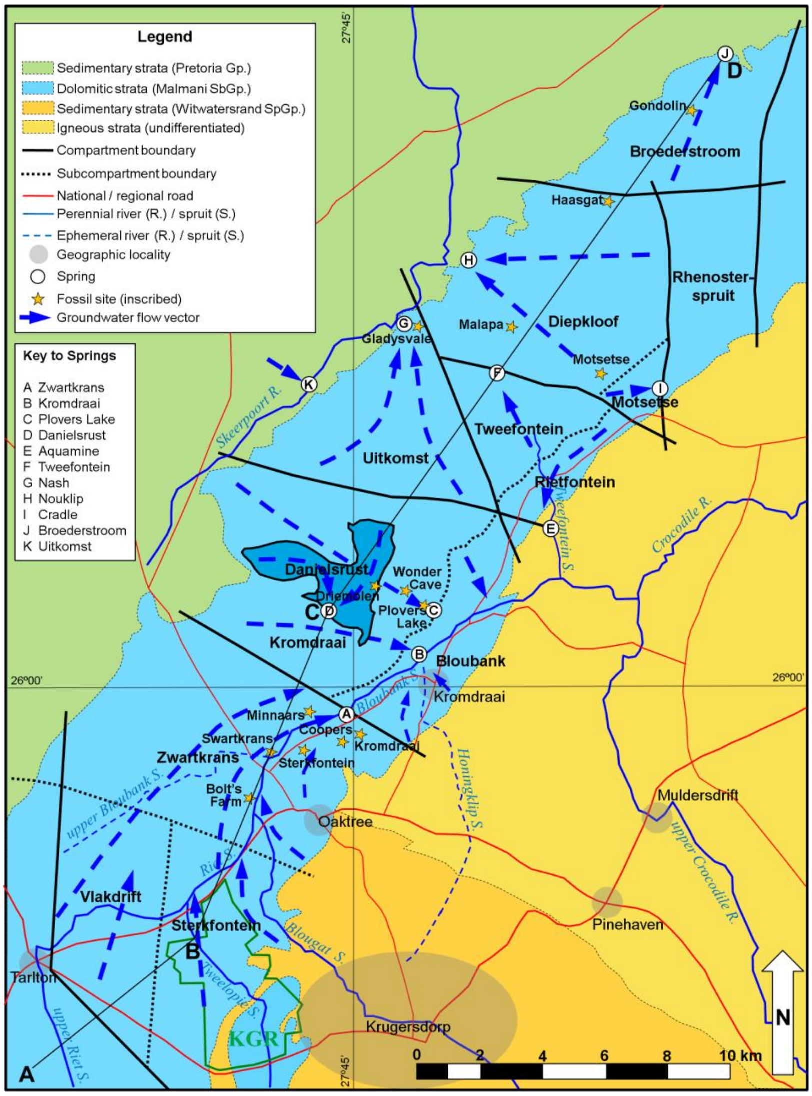

Figure 27 Map showing the regional geology of the study area, dolomitic compartment boundaries, groundwater flow vectors and the major dolomitic springs

Table 7 Water chemistry results of samples collected at the major dolomitic springs during March 2019 and September 2019

Variable	**Zwartkrans Spring**		**Kromdraai Spring**		**Plovers Lake Spring**		**Danielsrust Spring**		**Aquamine Spring**		**Tweefontein Spring**		**Nash Spring**		**Nouklip Spring**		**Cradle Spring**		**Broederstroom Spring**		**SANS**
	Mar-19	**Sep-19**	**Mar-19**	**Sep-19** (2)	**Mar-19**	**Sep-19**	**Mar-19**	**Sep-19**	**Mar-19**	**Sep-19**	**Mar-19**	**Sep-19**	**Mar-19**	**Sep-19**	**Mar-19**	**Sep-19**	**Mar-19**	**Sep-19**	**Mar-19**	**Sep-19**	**(2015a)**(1)
pH ($-\log_{10}\alpha_{H^+}$)	7.8	7.9	7.9	8.2	8.4	8.2	8.2	8.2	7.8	8.2	7.9	8.3	8.0	8.3	8.1	8.3	8.3	8.2	7.6	8.2	5.0–9.7
SEC (mS/m)	144	148	66	68	35	35	25	25	62	55	36	35	26	25	37	36	60	71	52	50	<170
Ca (mg/L)	159	162	62	63	39	39	27	28	70	61	42	42	27	28	41	42	56	58	70	56	n.s.
Mg (mg/L)	85	80	39	38	25	24	18	16	43	38	25	22	19	16	26	24	52	53	43	36	n.s.
Na (mg/L)	59	55	22	20	1.4	1.7	1.0	1.0	4.5	3.5	1.6	1.8	1.4	1.3	1.3	1.1	3.6	3.4	1.2	1.5	<200
K (mg/L)	2.5	2.2	12	0.9	0.3	0.3	0.2	0.2	0.6	0.9	0.2	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2	n.s.
Cl (mg/L)	46	47	25	27	< 2.0	<2.0	<2.0	<2.0	6.4	4.4	2.2	2.3	<2.0	<2.0	<2.0	<2.0	3.9	4.5	<2.0	2.6	<300
SO_4 (mg/L)	610	595	132	140	4.5	4.6	3.4	3.1	24	13	8.1	16	2.0	1.7	5.8	5.0	18	20	17	17	<500
HCO_3 (mg/L)	144	144	163	160	136	183	129	131	319	289	188	184	136	135	197	198	314	323	266	264	n.s.
NO_3+NO_2 (mg N/L)	7.8	7.5	4.5	4.8	0.2	0.5	0.5	0.5	0.3	0.9	0.6	0.7	0.2	0.2	0.3	0.3	<0.1	<0.1	0.4	0.4	<11
Si (mg/L)	6.7	6.1	5.7	5.5	6.0	5.7	5.4	5.1	7.4	12	4.9	4.8	5.1	4.8	5.1	4.7	7.7	11	5.0	4.4	n.s.
Fe (mg/L)	0.02	0.04	<0.01	0.02	0.03	0.03	0.05	0.04	1.7	41	0.04	0.33	0.05	<0.01	0.03	0.03	0.14	4.0	0.05	0.02	<2
Mn (mg/L)	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.37	15	0.04	0.53	<0.01	<0.01	<0.01	<0.01	0.01	0.94	0.13	<0.01	<0.5
Al (mg/L)	0.04	0.02	0.01	0.01	0.02	<0.01	0.01	0.03	0.47	16	0.03	0.18	0.01	0.01	<0.01	0.01	0.03	2.5	0.02	<0.01	<0.3
Total coliform bacteria (MPN/100 ml)	1732.9	178.9	>2419.6	>2419.6	161.6	83.3	325.5	307.6	>2419.6	>2419.6	>2419.6	686.7	129.6	101.2	33.2	44.1	68.4	>2419.6	186.0	75.4	<10
E.coli (MPN/100 ml)	3.1	<1.0	1732.9	25.6	<1.0	<1.0	18.7	4.1	35.9	2.0	1732.9	15.6	<1.0	3.1	<1.0	<1.0	<1.0	9.7	<1.0	<1.0	n.d.

(1)- Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person; n.s. – no standard; n.d. – not detected

(2)-September 2019 sample taken directly at one of the localities of the 'multiple-eye' spring

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.

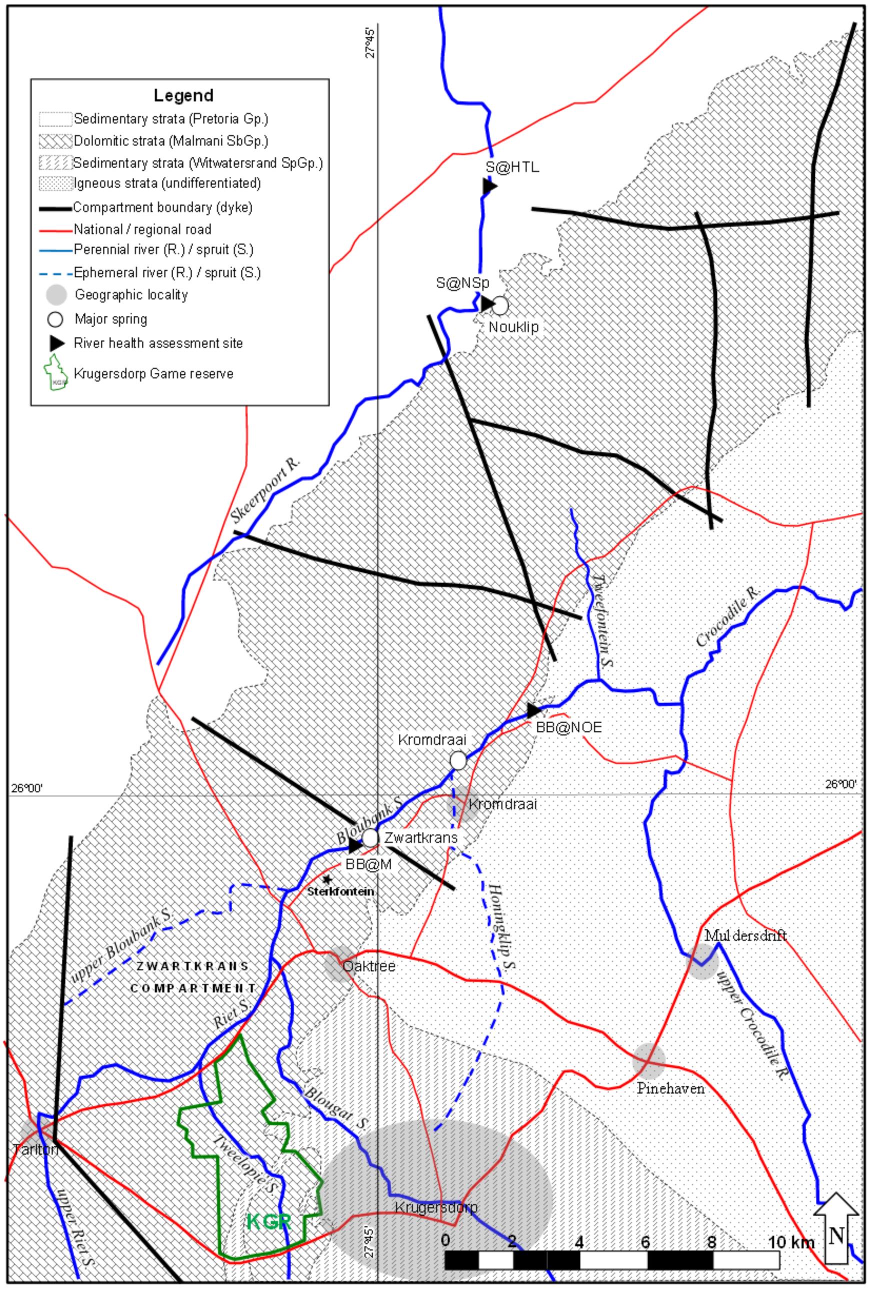

Figure 28 Map showing sites of relevance to the river health assessment

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 6.2.2.**

The upstream Skeerpoort River currently scored a C as previously scored in March 2019 and the downstream site scored a B as similarly scored during the March 2019 sampling. The status of both sites on the Bloubank Spruit scored an E/F category, remaining in a seriously modified state as previously. The full set of results obtained during the September 2019 survey for each of the sites are presented in **Section 6.2.2** below**.**

Table 9 Synoptic river health assessment outcome for September 2019.

SITE	Date	Ecological category	Condition	Description
S@NSp	16/09/2019	**C**	Fair	Moderately modified
S@HTL	16/09/2019	**B**	Good	Largely natural with few modifications
BB@M	17/09/2017	**E/F**	Seriously modified	Seriously modified
BB@NOE	17/09/2019	**E/F**	Seriously modified	Seriously modified

6.2.2 Comparison with Historical Results and General Observations

6.2.2.1 Skeerpoort River

In Table 10, seasonal sampling (summer, spring and summer) is compared for site S@NSp. 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 all three 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 is evidence of heavy erosion from flooding, which could easily affect the invertebrate sampling scores.

The site has been sampled on three occasions, and the SASS5 scores are generally similar. The River Health Category borders between a B (good), and C (fair). Overall, the habitats remained similar. The two end-of-summer sampling trips (February 2018 and March 2019) show similarities in the family presence, and also have the same River Health Category (due to the slightly lower average score (ASPT)). The dominant feeding group throughout are predators, and all samples have a number of sensitive species.

The River Health Category rating for this site in September 2018 was B (good), while in February 2018 and March 2019, the classification was C (fair). As was noted previously, the ASPT of 5.8 – 5.9 is borderline (of a Category B), and in February 2018 and March 2019 it fell just short of a Category B. It is expected that this particular site will continue to oscillate between a Category B and C. In the current monitoring, the site still scored category C as the last sampling in September 2019.

S@NSp is a headwater stream, and macroinvertebrate diversity in headwaters do 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 previous results

Site: S@NSp		**River: Grootspruit (tributary of the Skeerpoor River)**							
		SASS associated scores						**Dominance ***	
Date	Ecological category	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*
26/03/2019	C	99	17	5.8	75%	12	160	Predators	*Gomphidae*
16/09/2019	C	70	12	5.8	70%	12	169	Predator	*Pleidae*

S@HTL

In **Table 11** seasonal sampling for site S@HTL is compared and includes results of the study by Fourie et al. (2014) which provides a comparatively recent assessment against which to gauge the present river condition at the site. The site remains in a B Category as before, namely October 2018 and March 2019.

The sampling area has a pool of slow-moving/still water, leading to a narrower region of faster-flowing riffles. Most habitats were well represented. Although most scores and habitat were similar, the ASPT has dropped one point since February 2018, (indicating a lower proportion of the scarcer sensitive families), which is the cause of the River Health Category change from A to B. However, a good diversity of invertebrate families and most Functional Feeding Groups were represented. The site currently scored category B as the last two sampling trips. The Skeerpoort River at this site is more in the middle reaches of the river system, and as such is expected to have a larger diversity of macroinvertebrates.

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*
25/03/2019	B	170	28	6.1	76%	13	437	Predators	*Baetidae*
17/09/2019	B	99	16	6.2	70	12	354	Predators	*Baetidae and Pleidae*

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

6.2.2.2 Bloubank Spruit

BB@M

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

		SASS associated scores						**Dominance**	
Date	Ecological category	SASS 5	Taxa	ASPT	IHAS	Highest Sensitivity	Total Invertebrates	Dominant feeding group	Dominant Taxa
23/02/2012	E/F	32	9	3.6	57%				
16/05/2012	E/F	53	14	3.8	81%	13	653	Collector-Gathers	*Tricorythidae*
24/10/2012	E/F	35	10	3.5	72%	12	524	Collector-Gathers	*Baetidae*
06/03/2013	E/F	52	13	4	74%	13	437	Predator	*Baetidae*
15/08/2013	E/F	34	9	3.8	65%	12	277	Predators	*Baetidae* and *Pleidae*
12/12/2013	E/F	38	10	3.8	61%				
13/02/2018	E/F	27	8	3.4	67%	13	653	Collector-Gathers	*Tricorythidae*
25/09/2018	E/F	48	11	4.4	71%	12	524	Collector-Gathers	*Baetidae*
28/03/2019	E/F	46	12	3.8	66%	13	437	Predator	*Baetidae*
16/09/2019	E/F	36	10	3.6	65%	12	277	Predators	*Baetidae* and *Pleidae*

Site BB@M has a variety of good habitat 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. The dominant feeding group and taxa have been consistent since late 2012.

BB@NOE

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*
25/03/2019	E/F	33	8	4.1	54%	6	178	Predators	*Simuliidae*
17/09/2019	E/F	64	14	4.6	58%	8	781	Predators	*Ceratopogenidae and Chironomidae*

The instream water was very turbid, even though the upstream site BB@M has clear water. There is however a trout farm approximately 100 m 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 a previous report (Hill *et al*, 2014). The instream habitat at this site is less diverse than the upstream site and consist mostly bedrock and large stones. There is a little sand, and the overhanging vegetation is often limited. As can be seen in **Table 13**, scores remain low. For the first time though, the blackfly (*Simuliidae*), (FFG – collector-gatherer) was the dominant species, although more individuals were sampled on the previous trip.

Results indicate marginally lower scores than those of the upstream site, as was the case in March 2019, although the ASPT is slightly higher. This is of some concern, as it appears that upstream discharges may have an (intermittent) impact.

6.3 Toxicity Testing Results

The results are reported per bioassay. Freshwater toxicity screening tests with *Vibrio fischeri*, *Daphnia magna* and algae *(Selenastrum capricornutum)* 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, 15 minutes *vibrio fischeri*, acute 48 hour *D. magna* tests and 72-hours *S. capricornutum* were conducted under static conditions to assess the short-term toxicity potential of water samples from the selected sites using organisms on three different level on trophic level. The test conditions and test acceptability criteria are summarised in **Table B.1, B.2 and B.3** of **Annexure B**.

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 for the three tests are summarised below.

15-minute *Vibrio fischeri* test

Physical parameters measured at the start and end of each test with a hand-held Hach HQ 40D multi parameter meter, are summarised in **ANNEXURE B**.

15-minutes for the V. fischeri luminescence inhibition (-) / stimulation (+) test after a 15 minute exposure period were as follows: S@HTL test sample: 4.67%; S@NSP test sample: 8.96%; BB@M test sample: 1.35% and B@NOE test sample: -2.05%. Inhibition of > 20% indicates toxicity and stimulation of > 20% indicates potential eutrophication. In all the sites smapled, there was no indication of toxicity and potential eutrophication. Tests were accepted as the% CV was > 3%.

48-hour *Daphnia magna* test

Table 14 summarises the results of D. magna exposed to the undiluted test samples S@HTL, S@NSP, BB@M and B@NOE. The tests were accepted as no mortality (≤ 10%) was observed in the Control. At the end of the exposure period (48 hours), the highest mortality was found in sample S@NSP (25% mortality after 48 hours) and in other samples there was no acute hazard.

Table 14 Results of the D. Magna screening assays expressed as percentage mortality after 24 and 48 hours.

Sites	Time (hours)	% Mortality
C	24	0
	48	0
S@HTL	24	0
	48	0
S@NSP	24	0
	48	25
BB@M	24	0
	48	0
BB@NOE	24	5
	48	5

72-hour *Selenstarum capricornutum* test

The percentage algal growth rate in the undiluted test samples was compared to the algal growth rate in the Control. Samples with a growth rate less than 80% (> 20% growth inhibition) compared to the Control, are regarded as samples with a toxicity potential According to the results, samples at BB@M and BB@NOE were toxic as growth inhibition of 20% or more was detected.

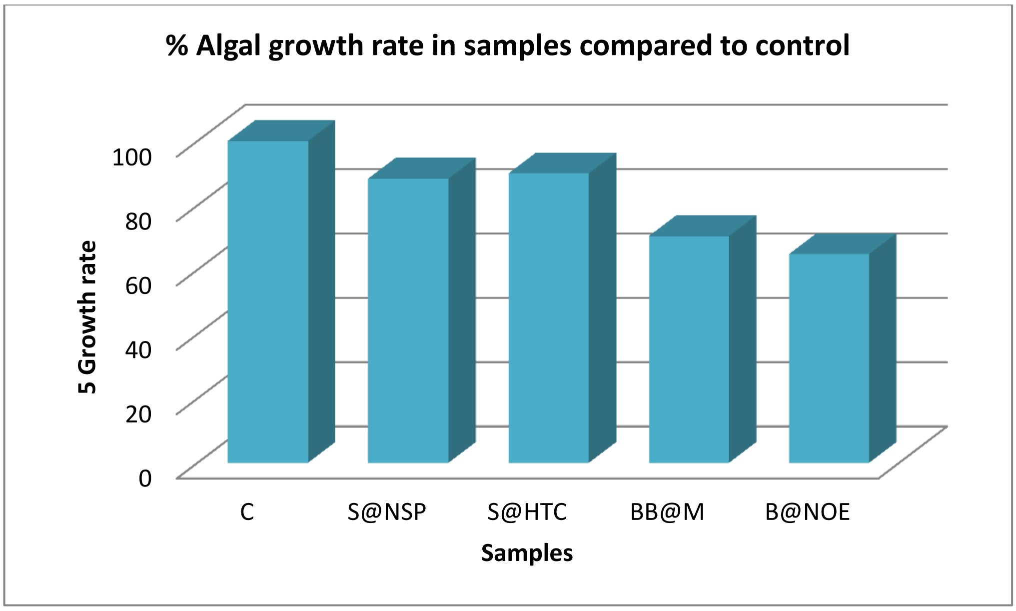

Figure 29 Percentage growth rate of *S. capricornutum* in test samples (undiluted), relative to the control.

7 DISCUSSION & CONCLUSIONS

The karst environment of a portion of the Zwartkrans Basin in the south-western quadrant of the property reflects an apparent marginal increase in SO_4 levels in the ‘upstream’ reaches and a continued increase in the ‘downstream’ reaches in the recent monitoring results. At present the reason for the changes in SO4 levels recorded remains inconclusive, however further investigation into the reported temporary closure of the WWTW may provide some clarification. Further observations are listed as follows:

- The total rainfall recorded at the HDS station during the 2019 hydrological year was 570 mm, which is below the 863 mm recorded for the 2018 hydrological year and the 11 year average of 798 mm. The total rainfall recorded at the Sterkfontein Cave station during the 2019 hydrological year was 751 mm, which is greater than the 711 mm recorded for the 2018 hydrological year and the 8 year average of 695 mm. Both the HDS and Sterkfontein Cave stations experienced a period of ‘no rainfall’ between May and August for the 2019 hydrological year. The total ‘wet season’ rainfall (October 2018 to March 2019) recorded at the HDS station was 450 mm (the 11 year average is 655 mm) while at the Sterkfontein Cave, 489 mm was recorded. The wet season rainfall decreased at both the HDS and Sterkfontein Cave stations by 39% and 17%, respectively and represents the lowest wet season rainfall on record for the HDS station.

- The 2019 hydrological year recorded a meagre discharge of 6.6 Mm3, which is significantly lower than the 40.6 Mm3 and 26.6 Mm3 total annual discharge reported, respectively, for the 2017 and 2018 hydrological years. This is to be expected, given the missing discharge data record from May 2018 to May 2019, making it very difficult to make any sensible conclusions about the flow scenario for this period and, subsequently, the hydrological year. The available limited record of 6.6 Mm3 discharge thus makes this the lowest recorded at station A2H049 over the total data historical period from 1973 to 2019, which has an average and median discharge of 26.4 Mm3/a and 24.6 Mm3/a, respectively.

- The success of the mine water control and management measures has 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 from early 2017 up to September 2019, however an apparent marginal increase in SEC has been observed between December 2018 and September 2019.

- The groundwater elevation in the south-western portion of the property (the Zwartkrans Basin), where the allogenic recharge component is greatest, 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. The lake water level recorded in September 2018, December 2018 and March 2019 represent the lowest elevations recorded since end-2010.

- In most cases, the spring discharge measured in September 2019 was below that reported by Bugan et al. (2018, 2019) and Hobbs (2011). Similar to Bugan et al. (2019), the highest discharges were realised for the Nouklip and Nash springs, respectively yielding 11.37 ML/d and 18.59 ML/d. It is evident that significant variability exists in the discharge measurements. There is, therefore, uncertainty associated with the data and currently, no distinct pattern has been established regarding the response of the individual springs to changes in rainfall and discharge in the river systems across the CoHWHS property. It is, however, possible that the lack of rated cross-sections for discharge measurements, as well as a generally drier hydrological year, may be the cause of this variation and decreased discharge observed for most of the springs.

- Groundwater in the south-western portion of the property continues to experience a compromised quality reflected in sulphate levels of up to ~2000 mg/L. A comparison of sulphate levels over the period June 2016 to September 2019 indicates that sulphate levels in ambient groundwater have increased 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 the main stem of the Bloubank Spruit.

- The macroinvertebrate monitoring survey reveals the substantial difference in biotic condition between the largely natural / moderately modified Skeerpoort River and the severely impacted Bloubank Spruit system. This is best evidenced by the C and 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. The Bloubank Spruit results are also similar to the September 2018 results. A comparison with previous results indicates 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 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.

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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 Site 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.

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

The macroinvertebrate family diversity for this site is summarised in **Table A.1** below.

Table A.1: Macroinvertebrate families present at site S@HTL

Macroinvertebrate families	**13/02/2018**	**17/10/2018**	**25/03/2019**	**16/09/2019**
Turbellaria	40	3	1	
Oligochaeta		1	2	
Potamonautidae	3	3	12	11
Hydracarina	40	1	4	
Baetidae	80	240	80	109
Caenidae	30	20	6	3
Teloganodidae	2		2	12
Heptageniidae	10	40	30	
Leptophlebiidae	240	100	60	
Tricorythidae	1		4	
Chlorocyphidae	20	20	15	
Coenagrionidae		2		4
Lestidae	3	1	6	
Aeshnidae	2	15	20	
Gomphidae	1	2	2	
Libellulidae	1		1	3
Pyralidae			1	
Belostomatidae	30	2	60	
Corixidae	40	4	2	
Gerriae	2			
Naucoridae			1	
Nepidae	2	6		
Notonectidae			30	
Pleidae	20	15	30	101
Veliidae	40	1	2	
Hydropsychidae	6	2	1	80
Philopotamidae		2	30	
Dytiscidae		3		
Elmidae	20	8	10	4
Gyrinidae	2	1		
Libellulidae	40	20	10	4
Ceratopogogonidae		2		3
Athericidae	5	6		
Chironomidae			3	20
Dixidae	2	2		
Simuliidae	1	1	12	
Tabanidae		1		
Tipulidae				
Ancylidae				
Planorbinae*				

A.3 Site 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. The habitat is varied and adequate, and large areas of the riverbed are sandy. The surrounding area is largely undisturbed, natural vegetation. The macroinvertebrate family diversity for this site is summarised in **Table A.2**.

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

Table A.2: Macroinvertebrate families present at site S@NSp

Macroinvertebrate families	27/02/2018	26/09/2018	26/03/2019	16/09/2019
Oligochaeta	1		1	
Potamonautidae	8		8	
Hydracarina	1	4		3
Baetidae	40	30	6	5
Caenidae	6	4	30	3
Teloganodidae		10		5
Leptophlebiidae		6		
Tricorythidae		1	1	
Chlorocyphidae	12		3	
Coenagrionidae	1			
Aeshnidae	16	20	50	12
Gomphidae	1		1	
Pyralidae	5	100	20	
Corixidae	5			
Gerridae			12	4
Naucoridae	1	2	6	
Notonectidae	10	15	10	3
Pleidae		30	3	107
Veliidae	12			6
Hydropsychidae	6	1	2	
Psychmyiidae			2	3
Gyrinidae	3			
Psephenidae		12		
Ceratopogonidae	1		3	
Chironomidae		2		6
Simuliidae	1		2	12
Tabanidae		1		
Tipulidae				
Ancylidae				
Planorbinae*				

A.4 Site 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.

The macroinvertebrate family diversity for this site is summarised in **Table A.3** below.

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

Table A.3: Macroinvertebrate families present at site BB@M

BB@M	13/02/2018	25/09/2018	25/03/2019	17/09/2019
Turbellaria		1	8	4
Leeches	1		1	
Oligochaeta		1		6
Crustacea	3	1	2	6
Potamonautidae	40	40		8
Baetidae		40	10	12
Coenagrionidae		10		3
Aeshnidae		8	3	
Gomphidae		1	6	
Corixidae	30			
Gerriade	4	3	12	
Pleidae			1	7
Ecnomidae	40	100	20	18
Veliidae	1			
Hydropsychidae	100	200	300	55
Psychomiidae			3	15
Gyrinidae			1	
Ceratopogonidae				161
Chironomidae				33
Culicidae				
Simuliidae				29
Ancylidae				4

A.5 Site 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 diversity at the site is far less compared to the upstream site and is mostly bedrock and large stones. There is little sand, and the overhanging vegetation is often limited. The macroinvertebrate family diversity for this site is summarised in **Table A.4**.

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

Table A.4: Macroinvertebrate families present at site BB@NOE

BB@NOE	13/02/2018	25/09/2018	25/03/2019	17/09/2019
Turbellaria		1		4
Leeches		1		
Oligochaeta	2			6
Crustacea	2	1	3	6
Potamonautidae	80	40	4	8
Baetidae	10	40	30	12
Coenagrionidae		10		3
Aeshnidae		8	25	
Gomphidae		1		
Corixidae	2			
Gerriade	2			
Pleidae			15	7
Ecnomidae	40		1	18
Veliidae	3	3		
Hydropsychidae	2			55
Psychomiidae	40	100	40	15
Gyrinidae	1			
Ceratopogonidae	50	200	60	161
Chironomidae				33
Culicidae				
Simuliidae				29
Ancylidae				4

ANNEXURE B

MATERIALS AND METHODS

Toxicity assays

A battery of four screening toxicity assays was conducted on each sample according to standard procedures, under laboratory conditions (**Table B.1, B.2, B.3 and B.4**):

- 15-minute *Vibrio fischeri* (bacterium)
- 72-hour *Selenastrum capricornutum* (algae)
- 48-hour *Daphnia magna* (water flea)

The assays were performed to assess the toxicity potential of the test samples by assessing the response of the exposed test organisms. The test organisms were applied directly to the test samples (screening assays), except in the case of the algal assay and bacterium assay where samples were filtered through a 45 µm filter prior to testing. When a 50% or more toxicity effect was detected, definitive tests were conducted.

15-minute *Vibrio fischeri* screening assay

Table B.1 Summary of test conditions and test acceptability criteria for the bacterium *Vibrio fischeri* growth tests (ISO, 1998).

Parameter	Condition maintained during test
Test type	Static non-renewal
Volume of test sample	0.5 mℓ
Exposure period	15 and /or 30 minutes
Number of replicate chambers	2
Measurement equipment	Luminoskan Sirius Luminometer
Adjustment	20% salinity adjustment
Effects measured and interpretation	Screening test - % Luminescence inhibition (-) / stimulation (+) relative to the Control; Inhibition / Stimulation of ≥20% over control indicates toxic activity; Definitive test - EC20 and EC50 –values

72 / 96-hour Selenastrum capricornutum screening assay

Table B.2: Summary of test conditions and test acceptability criteria for the *Selenastrum capricornutum* growth inhibition tests – microplate assay for effluents and receiving waters (Slabbert, 2004).

Parameter	Condition maintained during test
Test type	Static non-renewal
Temperature	24± 2° C
Light quality	“Cool white” fluorescent lighting
Light intensity	4306 lux
Photoperiod	Continues
Volume of test sample	180 µl (plus 20 µl algal inoculum and medium)
Age of algal culture	4 to 6 days

Inoculum size	200 000 cells/ml
Number of replicate chambers	5
Shaking rate:	100 cpm continuous
Aeration	None
Dilution water	Algal stock culture media
Test duration	72 to 96 hours
Effects measured	Percentage inhibition or stimulation of growth compared to Control
Interpretation	Inhibition of ≥20% over Control indicates toxic activity, while growth of ≥20% over controls indicates stimulation

48-hour *Daphnia magna* screening assay

Table B.3 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%

Hazard classification for natural waters

A risk/hazard class was determined by application of the DEEEP (Direct Estimation of Ecological Effect Potential) (DWAF, 2003; Slabbert, 2004) recommended protocols and the hazard classification system for natural waters (Persoone *et al*., 2003). This hazard class equates to the level of acute or chronic risk posed by the water sample tested. A percentage effect (PE)[1] is determined for each of the tests in the battery of screening bioassays by measuring either immobility/mortality or inhibition/stimulation, depending on the type of test. The sample is then ranked into one of five classes (Table 5), based on either screening or definitive testing protocols.

Table B.4 Hazard classification system for screening tests (Persoone *et al*., 2003)

Class	Description
CLASS I	No acute hazard – none of the tests shows toxic effect.
CLASS II	Slight acute hazard – a statistically significant percentage effect is reached in at least one test, but the effect level is below 50%.
CLASS III	Acute hazard – the 50 % effect level is reached or exceeded in at least one test, but the effect level is below 100%.
CLASS IV	High acute hazard – the 100% effect is reached in at least one test.
CLASS V	Very high acute hazard – the 100%percentage effect is reached in all the tests.

[1] Percentage effect: 10% effect = slight toxicity for daphnia and fish; 20% effect = slight toxicity for algae and bacteria; 50% and > effect = toxicity for all test organisms (bacteria, algae, daphnia, fish).

Table B.5 Physicochemical parameters per sample measured at the start and end of the tests (September 2019).

Sites	Time	Temperature	pH	EC	Oxygen
Control	0	22.6	8.23	259	7.1
	48	22.5	8.15	266	6.99
S@HTL	0	22.5	7.65	373	7.96
	48	22.4	7.54	388	7.88
S@HTC	0	22.5	7.79	308	7.92
	48	22.6	7.82	302	7.88
BB@M	0	22.3	7.27	1483	7.53
	48	22.4	7.37	1477	7.52
BB@NOE	0	22.8	7.64	1150	7.56
	48	22.4	7.33	1136	7.5

PREVIOUS TOXICITY TESTING RESULTS

Table B.2a Results of the *D. magna* screening assays expressed as per cent mortality after 24 and 48 hours (March 2019).

Sample	Time (hrs)	Mortality (No. of organisms)	Mortality (%)
CONTROL	24	0	0
	48	0	0
S@NSp	24	0	0
	48	0	0
S@HTL	24	0	0
	48	0	0
BB@NOE	24	0	0
	48	0	0
BB@M	24	0	0
	48	0	0

Table B.2b 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 B.2c 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 B.3a Physicochemical parameters per sample measured at the start and end of the tests (March 2019).

Sample	Time (hrs)	Temperature (°C)	pH	SEC (mS/m)	Dissolved oxygen (mg/L)
CONTROL	0	19.3	7.04	254	7.71
	48	20.0	7.48	349	7.37
S@NSP	0	19.6	7.48	405	7.79
	48	20.0	7.78	438	7.28
S@HTL	0	19.5	7.40	340	8.30
	48	20.1	7.64	426	7.12
BB@NOE	0	19.6	7.10	1204	7.31
	48	20.2	7.40	1464	6.94
BB@M	0	19.7	6.93	1795	6.87
	48	20.1	7.01	2092	6.73

Table B.3b. 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.3c. 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