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 2020 TO SEPTEMBER 2020

PROJECT No.

GT/GDED/092/2017

AUTHORS

V. Mvandaba, E. Kapangaziwiri, J. Shadung

DATE

30 October 2020

REPORT No.

CSIR/SPLA/WC/ER/2020/0035/A

PREPARED FOR	PREPARED BY
Management Authority Cradle of Humankind World Heritage Site Gauteng Department of Economic Development	Water Resources Competence Area Smart Places Council for Scientific and Industrial Research

SUMMARY

The Management Authority (MA) of the Cradle of Humankind World Heritage Site (COH WHS) appointed the CSIR to undertake the water resources monitoring programme of the property, as the preferred service provider, following the outcome of bid GT/GDED/092/2017. Thus, a continuation of project BIQ005/2008 commissioned to develop a water resources monitoring programme for the COH WHS property, the monitoring programme has since its inception in 2012 generated sixteen (16) bi-annual *status quo* reports. This document represents the sixteenth (17th) of such reports and covers the timeframe from April 2020 to September 2020.

An assessment of impacts on the water resources environment of the COH WHS 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 property, impacts are 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 summary of the current outcome is as follows;

- The total rainfall recorded for 2020 hydrological year at the HDS station and Sterkfontein station are respectively 827 mm and 2264 mm, with the total wet season rainfall measuring at 827 mm for the HDS station and 864 mm for the Sterkfontein station. The HDS station apparently received no dry season rainfall. Based on available historical data spanning an11-year period from 2009 to 2020, the 2015 and 2019 hydrological years have been the driest on record, while the 2017 and 2020 hydrological years are seemingly the wettest.

- As a consequence of the South African national lockdown restrictions, the DWS team was not able to collect rainwater samples in time for the results to be included in the April 2020 to September 2020 *status quo* report. Therefore, the only chemical analyses of rainwater in the south-western portion of the property are as of March 2020, before the lockdown restrictions. These results represent the late wet season/early dry season rainfall. 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.

- Against the background of large gaps, including a period of missing data from December 2019 to January 2020, the annual discharge indicates that the 2020 hydrological year recorded a discharge of ~21.6 Mm^3, which would make it *considerably greater* than the ~7.1 Mm^3 reported for 2019 hydrological year. The 7.1 Mm^3 discharge remains the *apparently* lowest recorded at station A2H049 over the historical total observed data period from 1973 to 2020, which has an *average* and *median* discharge of 26.3 Mm^3/a and 24.5 Mm^3/a, respectively. The period of no collection of data collection resulting in a large gap of missing data is certainly responsible for this anomaly.

- For the 2020 hydrological year, based on the available records, the **highest mean monthly instantaneous discharge** was approximately 1.34 m^3/s which is ~63% greater than the 0.82 m^3/s recorded for the 2019 hydrological year but lower than the 2.15 m^3/s and 1.46 m^3/s recorded for the 2017 and 2018 hydrological years respectively. The available discharge record for the 2020 hydrological year however has gaps, indicating missing information, for December 2019, January

2020 and September 2020. Given a median of 1.21 m^3/s, the **instantaneous discharge** for the 2020 hydrological year respectively falls within the 3rd quartile.

- 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. Additionally, the efficacy is reflected in the statistical analysis of the chemistry of the Tweelopies Spruit where median and 95%ile values in period E– that in most cases show the lowest values across the five periods of analysis and is similar to the period C-D which marks the commissioning of the AMD intervention measure.
-
- The updated records for July 2020 and September 2020 indicate flow losses between F11S12 and MRd of 11.7 ML/d and 21.9 ML/d respectively, which are significantly less than the losses of 62.9 ML/d and 57.4 ML/d reported for December 2019 and March 2020. This is to be expected given that the flows recorded in December 2019 and March 2020 were respectively captured during and after a period of intense, heavy rainfall in the Krugersdorp region which increased the flow levels in the river and also, possibly, the height of the subterranean water table and also subsequent reduction in the any abstractions between the two stations.

- The most recent data on groundwater elevation provided for the south-western portion of the property are as at October 2020. The groundwater elevation in the south-western portion of the property (the Zwartkrans Basin), where the allogenic recharge component is greatest, reflects minimal change in the groundwater rest level elevation in the southern segment, indicating very stable groundwater conditions in the region during the reporting period. A slight increase is, however, evident in groundwater level elevations in the central and the northern segments of the property.

- The recent September 2020 groundwater elevation of 1438.17 m amsl at the Sterkfontein Cave lake illustrates an approximate 0.5m increase in the groundwater level since September 2019, which represents the lowest groundwater elevation recorded during the 10-year period between February 2010 and March 2020.

- The highest discharges were measured for the Zwartkrans, Nouklip and Nash springs, respectively yielding 34.96 ML/d, 9.69 ML/d and 13.33 ML/d. However, it should be noted that the Zwartkrans spring discharge is regarded as highly uncertain. It remains evident that significant variability exists in the discharge measurements. No direct quantification has been conducted regarding the response of the individual springs to changes in rainfall and discharge across the COH WHS property; this exercise would require quantification of all the processes impacting channel transmission losses including water uses and rates of evapotranspiration.

- As a consequence of the South African national lockdown restrictions, the DWS team was not able to collect groundwater samples in time for the results to be included in the April 2020 to September 2020 *status quo* report. Subsequently, the most chemical analyses of groundwater provided for the south-western portion of the property are as at March 2020. 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 March 2020 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. Decreasing sulphate concentrations are observed in the central segment at the gauging stations A2N0600, GP00309, GP00312 and GP00313 e.g. the sulphate concentrations at A2N0600 and GP00312 respectively decreased from 770 SO_4/L to 721 SO_4/L and 1300 SO_4/L to 1220 SO_4/L.

- 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. Several accounts of obnoxious odours, murky water and foam seen in the Blougat Spruit and Bloubank Spruit rivers have been received from local residents of the COH WHS property and reported to the MA, however the source of water pollution has not been verified. It can be argued that the municipal wastewater poses a dire threat to the quality of water and subsequently fitness for use of receiving surface water resources as does mine water. This effect and impact extend into the Crocodile River - the main stem of the Bloubank Spruit.

- With the exception of the July 2020 pH level of 4.7, none of the variables reported for the Sterkfontein Cave fall outside their SANS (2015) 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. Since March 2020, the quantity of total coliform bacteria decreased from 547.5 MPN/100ml to 32.3 MPN/100ml and the *E. coli* decreased from 3.1 MPN/100ml to <1.0 MPN/100ml.

- The water from the major dolomitic springs is of excellent quality for all the parameters (i.e. pH, SEC, Ca, Mg, Na, K, Cl, SO_4, HCO_3, NO_3+NO_2, Si, Fe, Mn and Al) reported for both the March 2020 and September 2020 sampling results, with the exception of the Zwartkrans, Aquamine, Tweefontein and Cradle springs. The chemical results from the Zwartkrans Spring show probable mine water impact as evidenced by the high sulphate content and the Aquamine, Tweefontein and Cradle springs show pronounced concentrations of manganese, iron and aluminium. 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 limit of <10 MPN/100ml. 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 *E. coli* levels across all the sample results have, however, decreased since March 2020.

- A comparison with the previous results from the macroinvertebrate monitoring survey reveals a significant deterioration in the general ecological health of both the generally natural / moderately modified Skeerpoort River and the severely impacted Bloubank Spruit systems. This is best evidenced by the E/F ecological categories obtained for the Skeerpoort River and Bloubank Spruit sites. Effluent pollution at the BB@M and BB@NOE sites has clearly deteriorated with the health of both sites with ASTP being at lowest compared to all sampling periods. For S@HTL and S@NSP, the destruction of riparian ecosystem and aquatic habitat particularly aquatic vegetation has also further influenced the River Health Category relative to the previous sampling periods.

- No acute hazard was observed in all the tests with the exception of BB@M and BB@NOE (*S. Capricornatum* test). Samples at BB@M due **were classified as toxic** because of the growth inhibition of 20% or more being detected which indicated the slight acute hazard, while BB@NOE remains an eutrophication potential. To give a clear indication of the toxicity of the water from four sites a chronic assessment test might be required.

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 WHS property in the situation assessment report (Hobbs, 2011). The inclusion of macroinvertebrate monitoring results adds to the improved rigour and substance of the water resources monitoring programme.

CONTENTS

Page

FIGURES

TABLES

ANNEXURES

SYMBOLS, ACRONYMS & ABBREVIATIONS

~	approximately
>	greater than
<	less than
%	per cent (parts per hundred)
%ile	percentile
°C	degree(s) Celsius
Δh	change in head
a_h	hydrological year
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	milli Siemens 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 as service provider for 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 sixteen (16) 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, Mvandaba *et al.* 2019, Mvandaba *et al.*, 2020). This document represents the sixteenth (17th) such report and covers the period from March 2020 to September 2020.

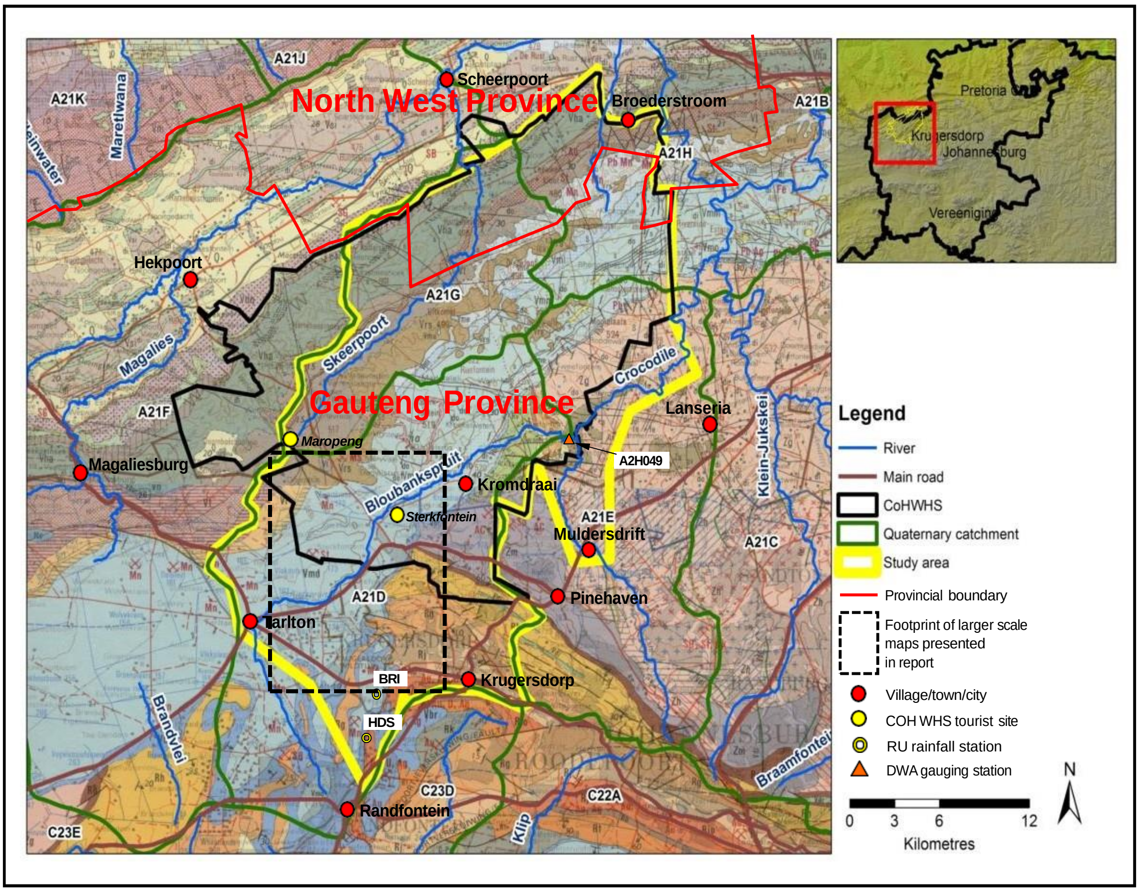


Figure 1 A map of the study area showing the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation.

2 TIMELINE OF KEY EVENTS

An updated timeline of key events since the start of mine water decanting 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 third State of Conservation (SOC) report (DEA, 2018) that was submitted to UNESCO's World Heritage Centre (WHC) for consideration by the World Heritage Committee. That SOC report was accepted by the Committee in July 2019. The outcome of this consideration sets out the concerns of the WHC for the property, 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.

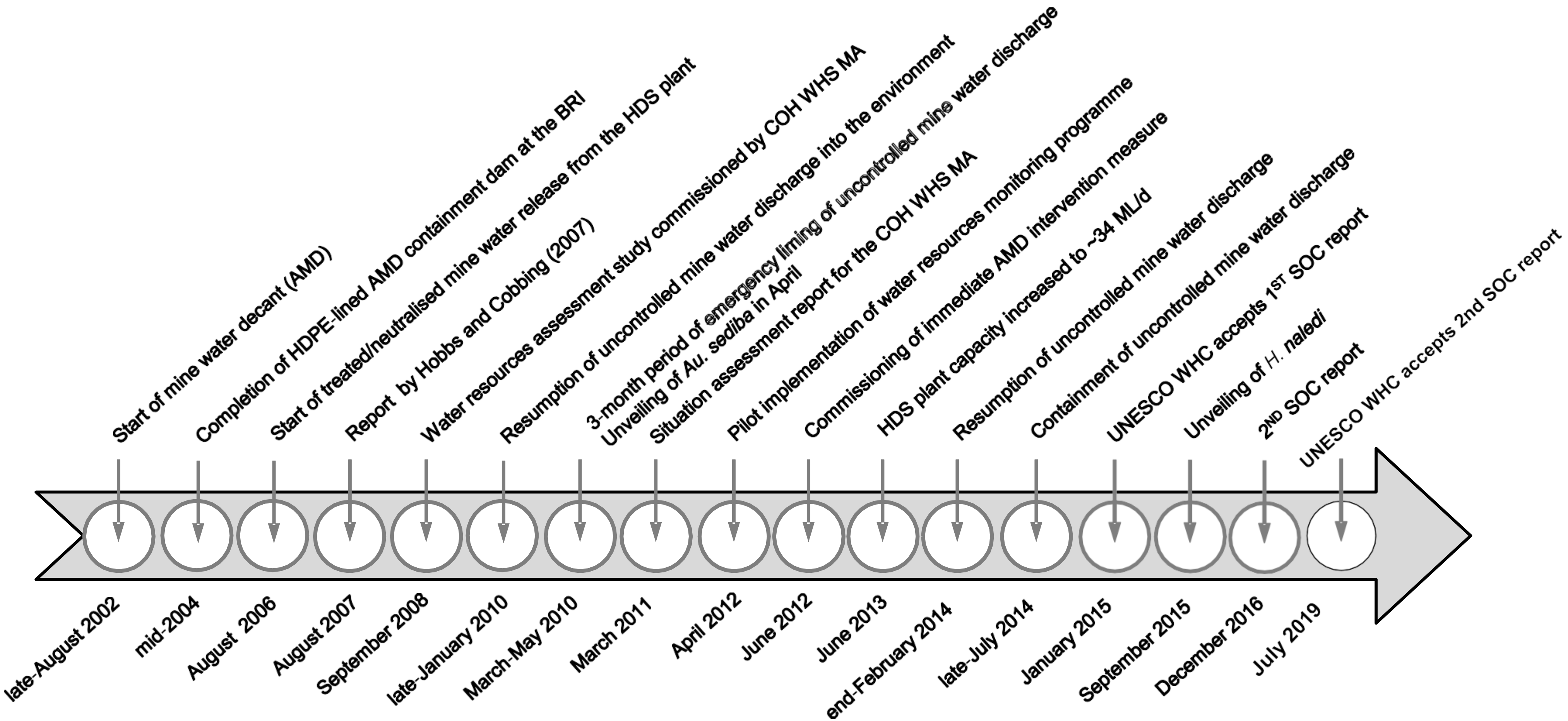


Figure 2 Timeline of key events relevant to the project and this report

3 RAINFALL

3.1 Quantity

The monthly precipitation record for the period October 2008 to September 2020 at the Sibanye-Stillwater (SS) [formerly Sibanye Gold (SG)] rainfall station HDS on the basin divide of North and South flowing rivers (i.e. the Limpopo and Vaal systems, respectively) 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**. Recent heavy rains and flash flood events in December 2019, February 2020 and March 2020 (SAWS, 2019; Nkanjeni, 2019; Head, 2020) have resulted in the 2020 hydrological year wet season rainfall (October 2019 to March 2020) for station HDS increase to 827 mm, with updated data at the Sterkfontein station illustrating an increase to an 864 mm. Previously, Mvandaba *et al.* 2020 reported wet season rainfall of 496 mm for the Sterkfontein station and indicated that the data available for the period October 2019 to March 2020 had gaps indicating missing values for some of the months in the reporting period. The DWS had indicated that the dataset could not be updated before the South African national lockdown began in March 2020. With the updated data, a comparison of the wet (summer) season precipitation record in the mine area to that at Sterkfontein Cave is given in **Figure 4**, with the following highlights:

- The total wet season rainfall of the 2019 and 2020 hydrological years (October to March) at the HDS station was 450 mm and 827 mm respectively, indicating an *apparent* ~84% increase;
- The total wet season rainfall of the 2019 and 2020 hydrological years (October to March) at the Sterkfontein Cave station was 489 mm and 864 mm respectively, indicating an *apparent* ~76% increase; The italics indicate that the data record had gaps that influenced the figures reported. Such changes would be near impossible unless a drastic climate shift were observed in the area.
- The wet season rainfall (450 mm) calculated for the 2019 hydrological year at the HDS station is the lowest quantity recorded for the station during the 9-year period from 2011 to 2020, while the lowest wet season rainfall (446 mm) recorded at the Sterkfontein station was measured in 2015;
- Zero rainfall has been recorded for the 2020 hydrological year dry season rainfall at the HDS station;
- The total rainfall recorded for the 2020 hydrological year at the HDS and Sterkfontein stations are, respectively, 827 mm and 2264 mm.
- During the 11-year period from 2009 to 2020, the 2015 and 2019 hydrological years have been the driest on record, while the 2017 and 2020 hydrological years are the wettest.

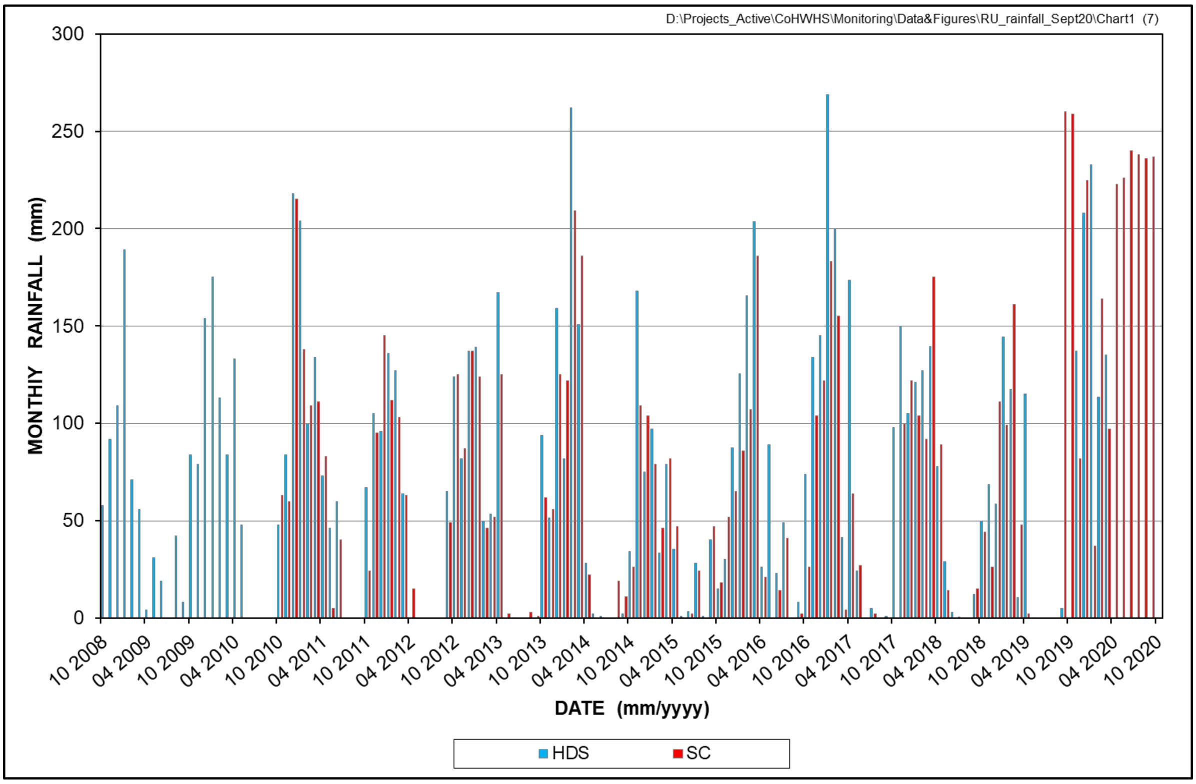


Figure 3 Monthly precipitation in the mine area (station HDS) from October 2008 to August 2020, and the contemporaneous record for the Sterkfontein Cave station from June 2010 to September 2020.

The correlation of monthly total rainfall records for the HDS and Sterkfontein Cave stations is presented in **Figure 5**. The data set (n = 96) excludes months of no rainfall (equal to 22) at both stations in order to remove the false correlation created by 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 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 for the 2019 hydrological year (October 2018 to March 2019) at the Sterkfontein Cave station should be approximately 350 mm whereas the observed wet season rainfall was 489 mm.

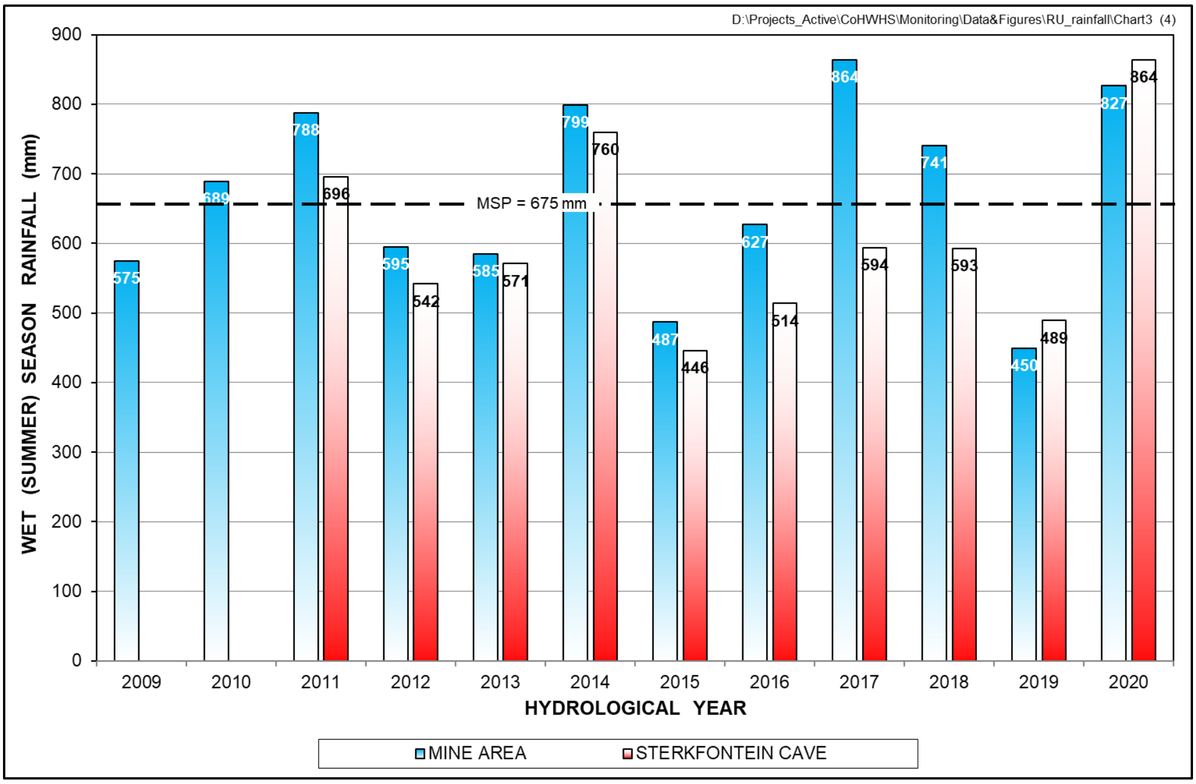


Figure 4 Total wet season (summer) rainfall in the mine area (HDS station) in the past eleven hydrological years, also showing the comparison with that for the available contemporaneous Sterkfontein Cave record; MSP denotes mean summer precipitation

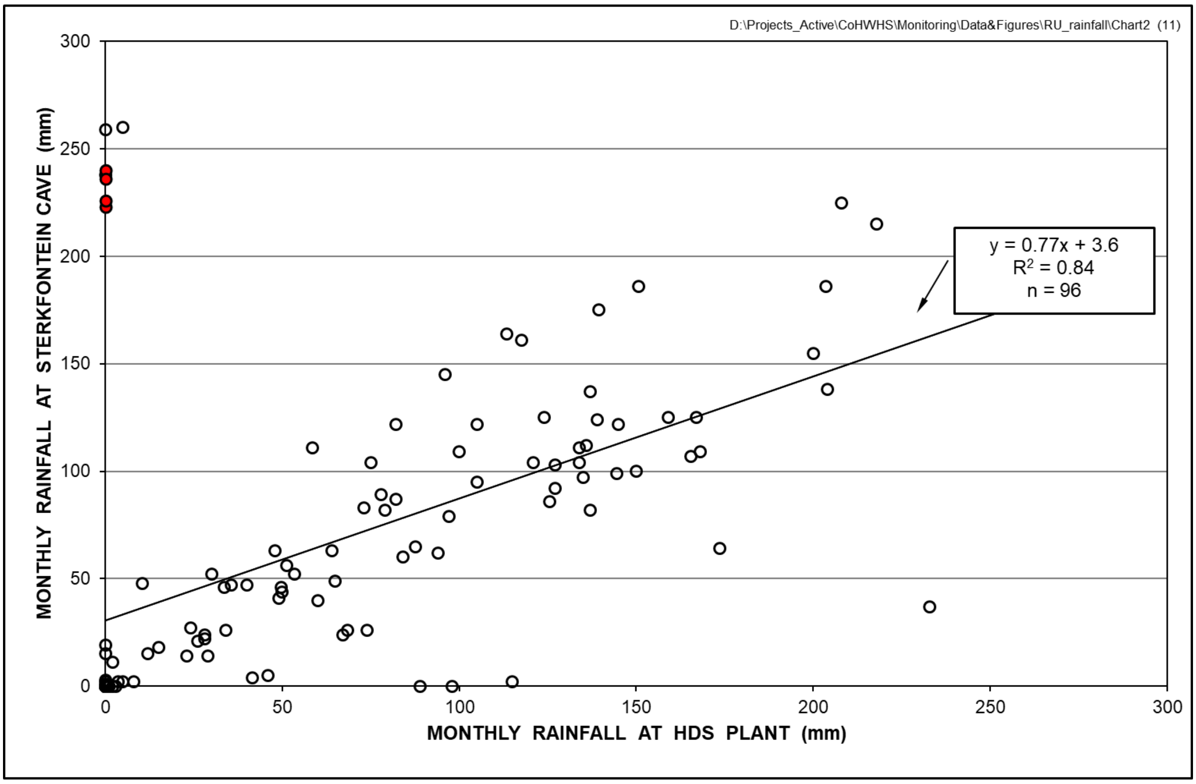


Figure 5 Correlation of total monthly rainfall at Sterkfontein Cave with that at the HDS mine water treatment plant in the mine area for the period of common record June 2010 to March 2020;

the red dots represent the rainfall for April 2020 to September 2020 and clearly illustrate the ‘zero rainfall’ dry season experienced at the HDS station.

3.2 Quality

The chemical composition of the rainwater in the south-western portion of the COH WHS 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 the 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 March 2020 are presented in **Table 1**, except for station HDS which shows data from the late dry season/early wet season as reported by Bugan *et al.* (2019). The results from the other three stations represent the late wet season/early dry season rainfall. The results presented are therefore the same as indicated in Mvandaba *et al.*, 2020. The main variation noted from the early wet season results reported by Hobbs *et al.* (2018) and Bugan *et al.* (2019) is the lower sulphate concentrations. The 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 2019 to early-March 2020

Variable/analyte	Unit	Rainfall Station			
		HDS[1]	GP00303[2]	GP00301[3]	SC[4]
Specific electrical conductance*	mS/m @ 25°C	18	3	3	3
pH*	$-\log_{10}\alpha_{H+}$	5.4	6.3	6.3	5.2
Calcium	mg Ca/L	6.7	0.5	<0.5	<0.5
Magnesium	mg Mg/L	1.4	<0.3	<0.3	<0.3
Sodium	mg Na/L	1.7	<0.6	<0.6	<0.6
Potassium	mg K/L	3.8	<0.6	<0.6	<0.6
Chloride	mg Cl/L	<2.0	<2.0	<2.0	<2.0
Sulphate	mg SO_4/L	32	5.3	5.7	11
Total alkalinity	mg $CaCO_3$/L	2.6	3.6	3.5	1.8
Nitrate + nitrite	mg N/L	11	0.9	0.5	0.5

* 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

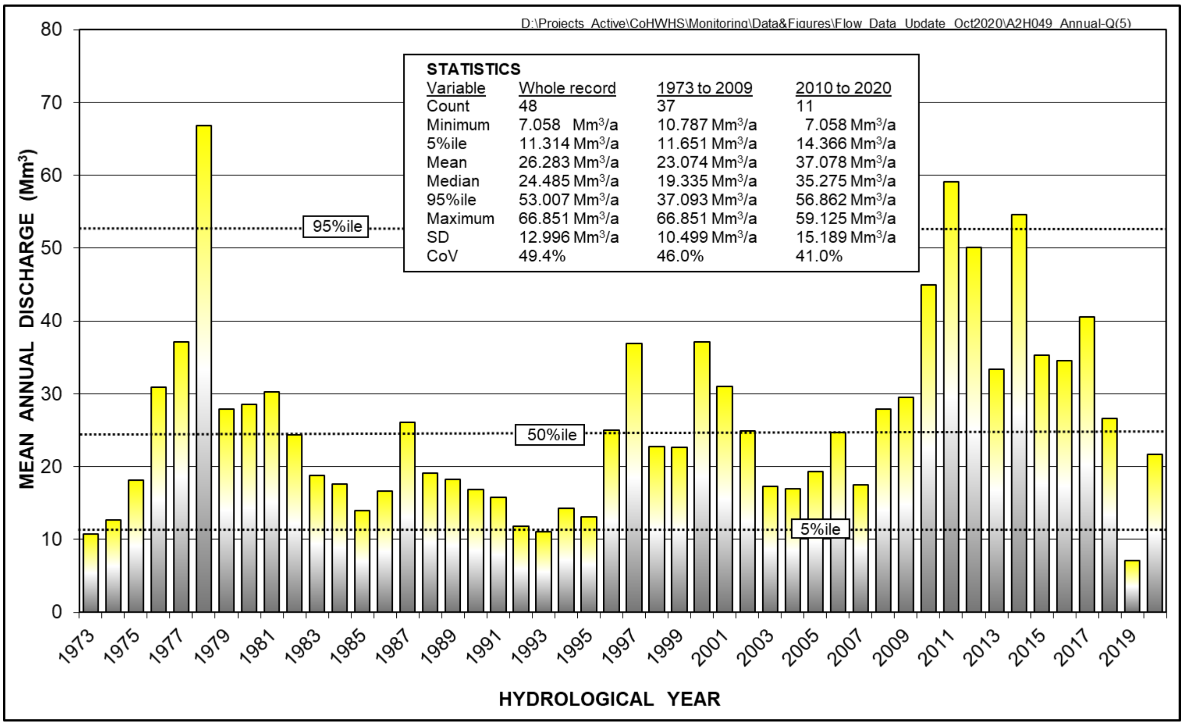
The DWS gauging station A2H049 measures the discharge from the Bloubank Spruit system, and is located about 700 m upstream of the system's confluence with the Crocodile River (**Figure 1**). The 47-year observed discharge record from 1972 to 2020 for this catchment (Quaternary A21D) provides the historical 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 and December 2019 to January 2020. The DWS attributed the period of 'no data' from June 2018 to May 2019 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. Following the lifting of the South African national lockdown restrictions, the DWS has been able to update the data record for the gauging station A2H049. The data record is updated from February 2020 to August 2020.

Table 2 Statistical analysis of Bloubank Spruit monthly discharge data gauged at station A2H049 in the period October 1972 to August 2020 (latest data as at September 2020)

Variable	Month											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	45	45	45	45	47	47	47	46	48	47	46	45
Minimum	0.682	0.269	0.711	0.721	0.706	0.828	0.886	0.847	0.521	0.939	0.890	0.770
5%ile	0.794	0.837	1.044	1.097	0.903	1.084	1.193	1.009	0.896	0.965	0.928	0.805
Mean	1.899	1.872	2.305	2.749	2.681	3.050	2.481	2.328	2.060	2.109	1.984	1.826
Median	1.691	1.896	2.092	2.513	2.222	2.566	2.132	1.993	1.772	1.879	1.804	1.587
95%ile	3.775	1.921	4.488	5.320	6.232	7.595	5.263	4.852	4.026	4.013	3.656	3.507
Maximum	4.211	1.941	5.900	12.079	10.619	11.351	6.081	5.373	5.166	4.754	4.055	4.342
SD	0.920	2.989	1.099	1.909	1.897	2.163	1.290	1.181	0.996	0.934	0.867	0.872
CoV (%)	48.45	2.95	47.68	69.47	70.75	70.91	52.02	50.72	48.33	44.28	43.71	47.78

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

Figure 6 shows the historical total annual discharge, in Mm^3, for complete hydrological years up to 2020. The annual discharge shown in **Figure 6** indicates that the 2020 hydrological year recorded a discharge of ~21.6 Mm^3, which would make it considerably greater than the ~7.1 Mm^3 annual discharge reported for the 2019 hydrological years. As stated by Mvandaba *et al.* (2020) the total annual discharge reported for the 2019 hydrological year did not represent the total annual record as some daily and monthly volumes are permanently missing from the data record. Additionally, the permanently missing data record from June 2018 to May 2019 has made it impossible to make logical conclusions with respect to the discharge situation in the COH WHS property. The 7.1 Mm^3 discharge remains the *apparently* lowest recorded at station A2H049 over the historical total observed data period from 1973 to 2020, which has an *average* and *median* discharge of 26.3 Mm^3/a and 24.5 Mm^3/a, respectively.



STATISTICS

Variable	Whole record	1973 to 2009	2010 to 2020
Count	48	37	11
Minimum	7.058 Mm^3/a	10.787 Mm^3/a	7.058 Mm^3/a
5%ile	11.314 Mm^3/a	11.651 Mm^3/a	14.366 Mm^3/a
Mean	26.283 Mm^3/a	23.074 Mm^3/a	37.078 Mm^3/a
Median	24.485 Mm^3/a	19.335 Mm^3/a	35.275 Mm^3/a
95%ile	53.007 Mm^3/a	37.093 Mm^3/a	56.862 Mm^3/a
Maximum	66.851 Mm^3/a	66.851 Mm^3/a	59.125 Mm^3/a
SD	12.996 Mm^3/a	10.499 Mm^3/a	15.189 Mm^3/a
CoV	49.4%	46.0%	41.0%

Figure 6 Graph of Bloubank Spruit annual discharge gauged at station A2H049 for the period October 1972 (a_h 1973) to August 2020 (a_h 2020)

The instantaneous observed monthly flow pattern at station A2H049 for the historical available record period October 1972 to August 2020 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 before dropping to a base discharge of 0.6 m^3/s to 0.8 m^3/s between June 2019 and October 2019. Following the recent heavy rains in December 2019, February 2020 and March 2020, the base discharge is seen to rise back up to ~1.0 m^3/s for the 2020 hydrological year wet season. Hobbs *et al.* (2018) attributed the consistent instantaneous low flow 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. The decrease in the instantaneous monthly flow pattern could therefore be postulated to be linked to the temporary closure of the treatment works facility and the general drier 2019 hydrological year.

For the 2020 hydrological year, based on the available records, the highest mean monthly instantaneous discharge was approximately 1.34 m^3/s which is ~ 63% greater than the 0.82 m^3/s recorded for the 2019 hydrological year but 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. Additionally, the 2020 hydrological year has data gaps for December 2019, January 2020 and September 2020. Although 2017 and 2020 appear to be the wettest hydrological years in the last ten years (**Figure 4**), they respectively produced **instantaneous discharge** of 2.15 m^3/s and 1.34 m^3/s (**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). Given a median of 1.21 m^3/s, the instantaneous discharge for the 2017 and 2020 hydrological years respectively falls within the 3rd and 4th quartiles.

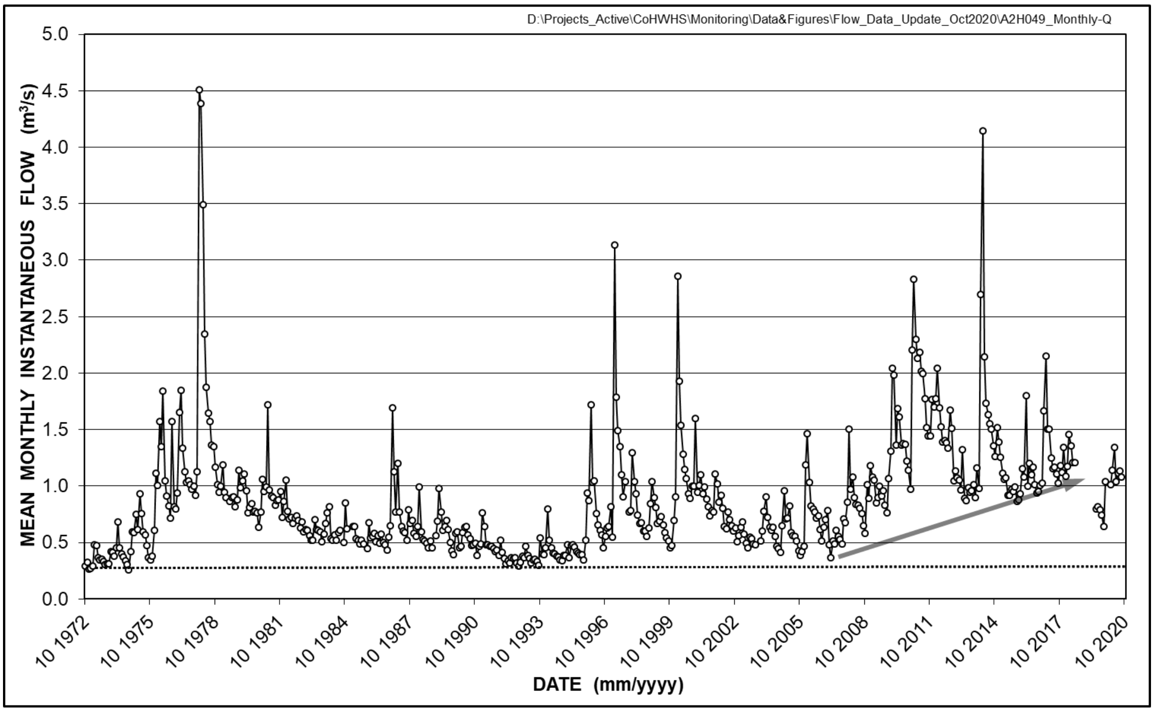


Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to August 2020 (latest data as at September 2020).

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 further occurrences 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 for 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 could 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 July 2020 and September 2020 indicate flow losses between F11S12 and MRd of 11.7 ML/d and 21.9 ML/d (**Figure 8**) respectively, which are significantly less than the losses of 62.9 ML/d and 57.4 ML/d reported for December 2019 and March 2020 (Mvandaba *et al.*, 2019; Mvandaba *et al.*, 2020). This is to be expected given that both the flows recorded in December 2019 and March 2020 were respectively captured during and after a period of intense, heavy rainfall in the Krugersdorp region, which implied general higher flows in the river and presumably a substantial rise in the subterranean water table in the area resulting in a weaker moisture gradient between the river and the subsurface. Such a scenario would also imply a reduction in whatever possible abstractions that would usually take place between the two measurement points. Flooding was reported in several localities in the Gauteng and North West provinces (SAWS, 2019; Nkanjeni, 2019; Head, 2020). Furthermore, the observed flow during July and September 2020 was gauged at the original gauging site for F11S12 where the rate of flow was noted to be impeded by the growth of vegetation (reeds) in the lake ahead of the gauging site. Compared to the losses reported in the 11-year period from September 2009 to March 2020, the loss of 62.9 ML/d remains the greatest surface flux reported and it is closely followed by the loss of 57.4 ML/d recorded in March 2020. The average and median losses recorded for the same 11-year period are 18.6 ML/d and 15.5 ML/d, respectively. The September 2020 streamflow records indicate some correlation to the Period 2 data set whereas the July 2020 has better correlation with 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 patterns revealed in **Figure 11** to **Figure 16** reflect a 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. Respectively, the values range between 7.3 to 8.5 for pH units and 272.0 mS/m to 408.0 mS/m for SEC between April 2019 and March 2020.

The difference between 1.5 and 2 units for pH values recorded at the Hippo Dam and F11S12 stations is particularly distinct since the 2017 summer, with the values being lower at the downstream F11S12 station. Hobbs *et al.* (2018) postulated this as 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 SEC pattern at the downstream F11S12 station showed a decreasing trend; however, beyond March 2019 the pH pattern increased to a level similar to that at the Hippo Dam site before decreasing to a value of 167 mS/m during August 2019. Bugan *et al.* (2019) noted an increase in the sulphate concentration (**Figure 13**), and also the SEC values (**Figure 12**) from the upstream Hippo Dam station; however, between June and August 2019 there is a decrease in both variables at both the Hippo Dam and F11S12 stations. It can be reasonably assumed that the marked decrease corresponds to the temporary closure of the treatment works facility which directly discharges into the stream upstream of the gauging site. Beyond May 2019, manganese concentrations (**Figure 15**) are observed to increase at Hippo Dam, while a steady decline is noted at the downstream F11S12 site. Concentrations at both these sites are distinctly low between April 2019 and March 2020 with a single peak observed in January 2020. Uranium (**Figure 16**) remains the only other of the graphed variables that generally maintains a consistent concentration of ~0.01 mg/l between December 2016 and July 2019, although a marked increase in the concentration is noted beyond August 2019. At the Hippo Dam, concentrations range from 0.02 mg/L to 0.04 mg/L between April 2020 and August 2020.

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.

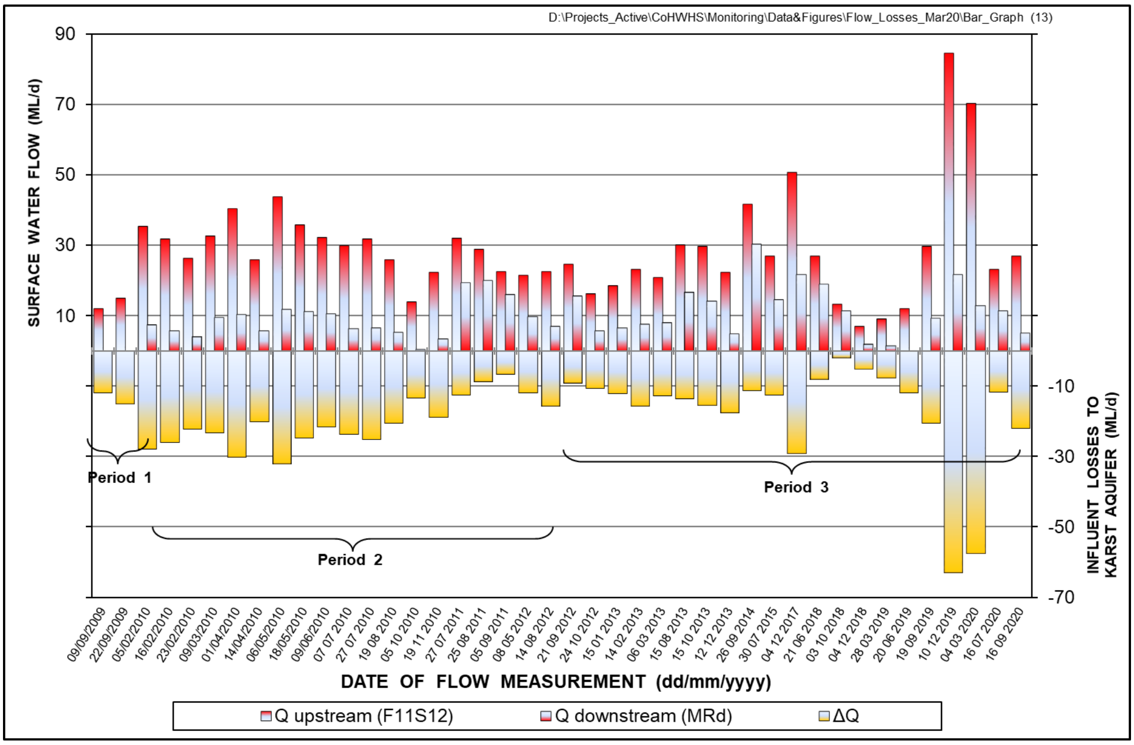


Figure 8 Graph of streamflow and influent losses to the karst aquifer in the lower Riet Spruit valley

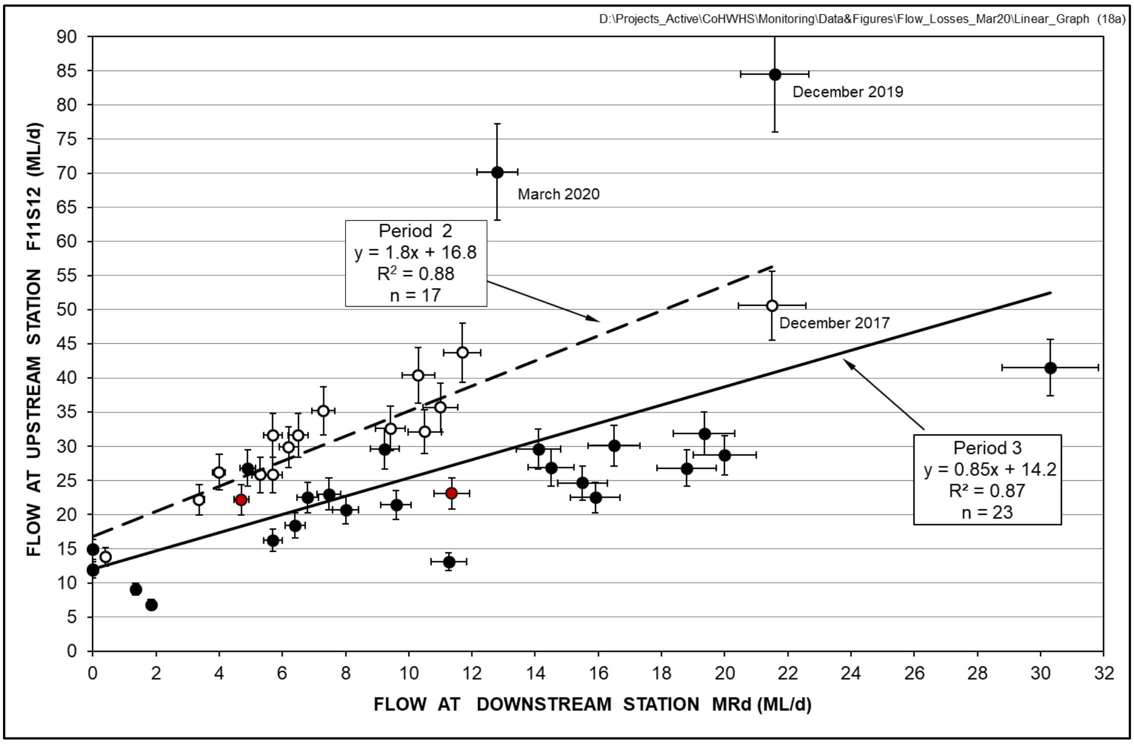


Figure 9 Correlation of streamflow at stations F11S12 and MRd in the lower Riet Spruit valley, with vertical error bars denoting ±10% at F11S12 and horizontal bars ±5% at MRd. The right-sided and left-sided red dots respectively illustrates the results of September and July streamflow.

4.3 4.3 Chemical Hydrology

4.3.1 Mine Water Impact

4.3.1.1 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 render 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 pH and SEC values at the Hippo Dam respectively range between 7.3 to 8.3 pH units and 374.0 mS/m to 410.0 mS/m between April 2020 and

August 2020, whereas at the Brickworks Dam the respective range is between 4.6 to 8.0 pH units and 167.0 mS/m to 334.0 mS/m.

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 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 SEC pattern at the downstream F11S12 station showed a decreasing trend however beyond March 2019 the SEC pattern increased to a level similar to that at the Hippo Dam site before decreasing to a value of 167 mS/m during August 2019. It is assumed that the marked decrease corresponds to the temporary closure of the treatment works facility. 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 between June and August 2019 there is a decrease in both variables at both the Hippo Dam and F11S12 stations. Between April 2020 and August 2020, the SEC and sulphate values have respectively oscillated between 296 mS/m and 376 mS/m, and 1707 mg/L and 2290 mg/L. 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. Concentrations at both these sites are distinctly low between April 2019 and March 2020, however a singular peak is noted in January 2020. Uranium (**Figure 16**) remains the only other of the graphed variables that generally maintains a consistent concentration of ~0.01 mg/l between December 2016 and July 2019, although a marked increase in the concentration is noted beyond August 2019. At the Hippo Dam, concentrations range 0.01 mg/L to 0.07 mg/L between August 2019 and March 2020.

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. Hobbs *et al.* (2018) notes that 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 and is similar to the period C-D which marks the commissioning of the immediate AMD intervention measure.

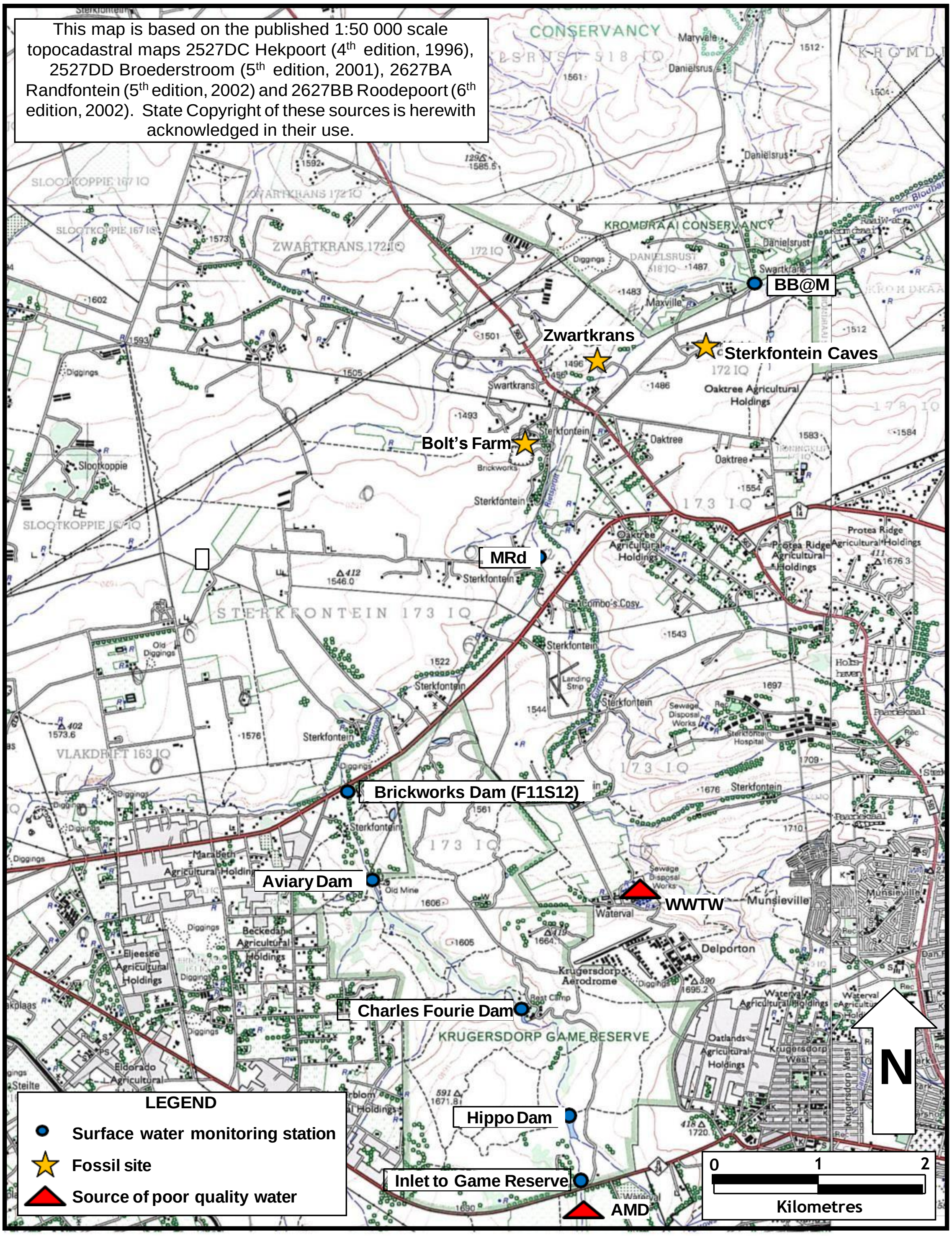

This map is based on the published 1:50 000 scale topocadastral maps 2527DC Hekpoort (4th edition, 1996), 2527DD Broederstroom (5th edition, 2001), 2627BA Randfontein (5th edition, 2002) and 2627BB Roodepoort (6th edition, 2002). State Copyright of these sources is herewith acknowledged in their use.

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

4.3.1.2 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 (Mvandaba *et al.*, 2019). 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 22**.

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.

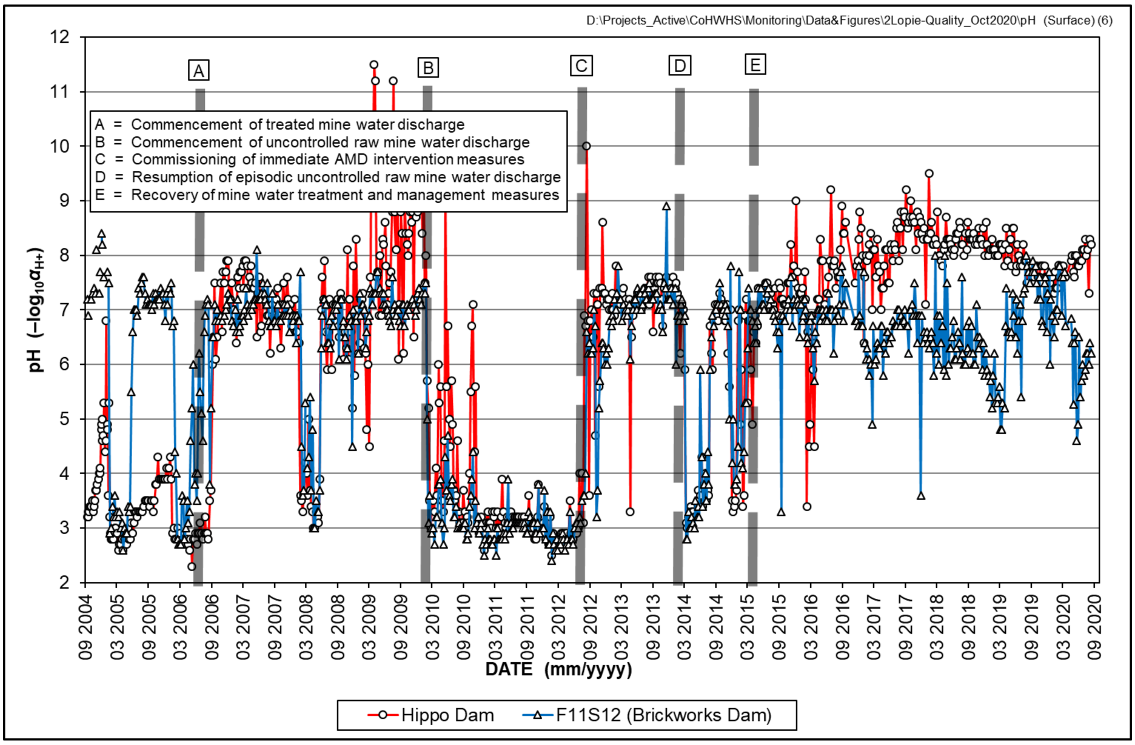


Figure 11 pH pattern of Tweelopie Spruit surface water in the period September 2004 to August 2020

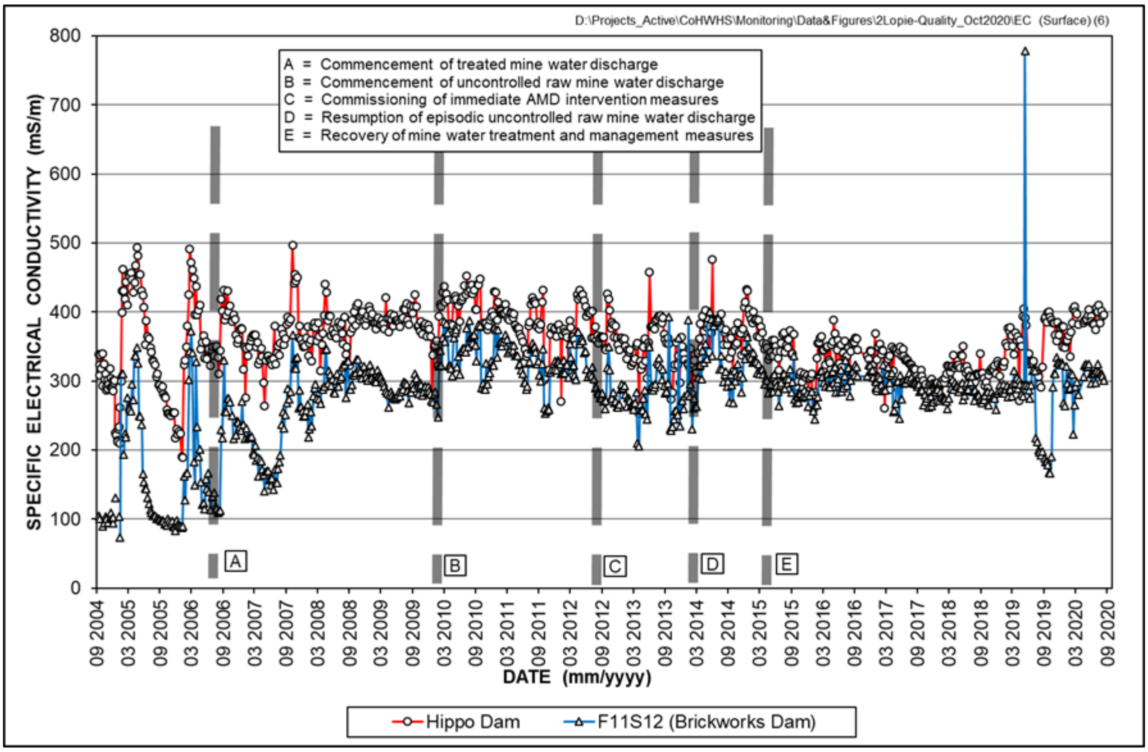


Figure 12 Specific electrical conductivity pattern of Tweelopie Spruit surface water in the period September 2004 to August 2020

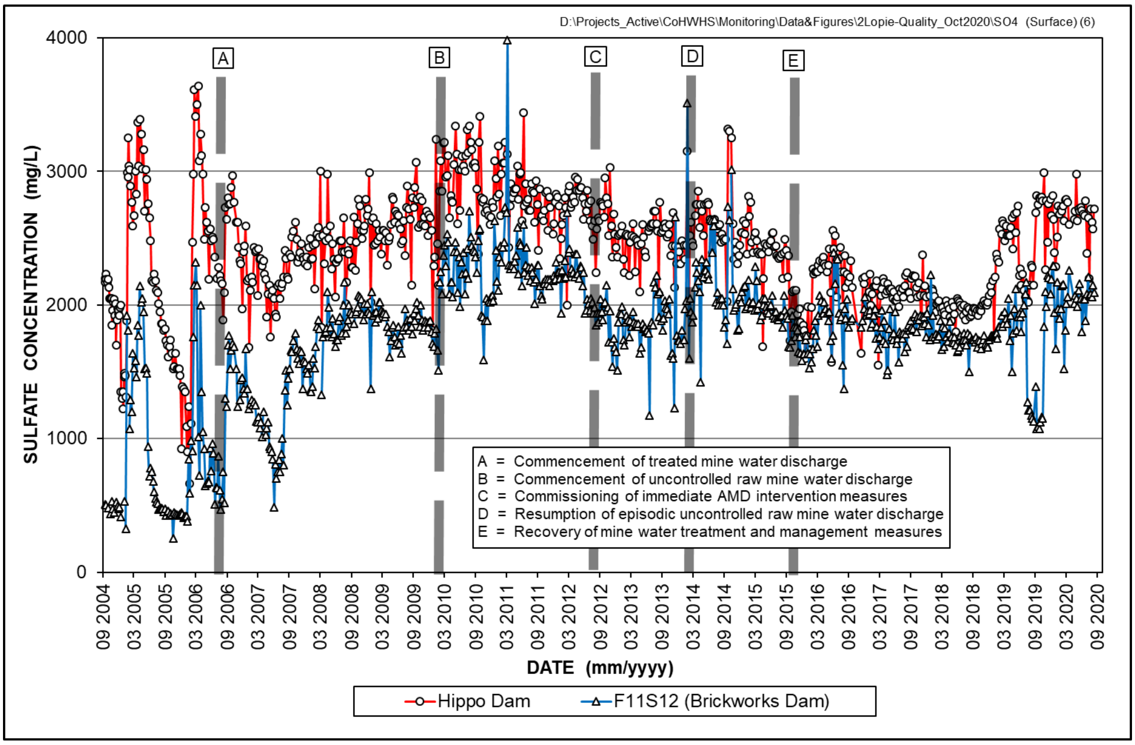


Figure 13 Sulphate pattern of Tweelopie Spruit surface water in the period September 2004 to August 2020

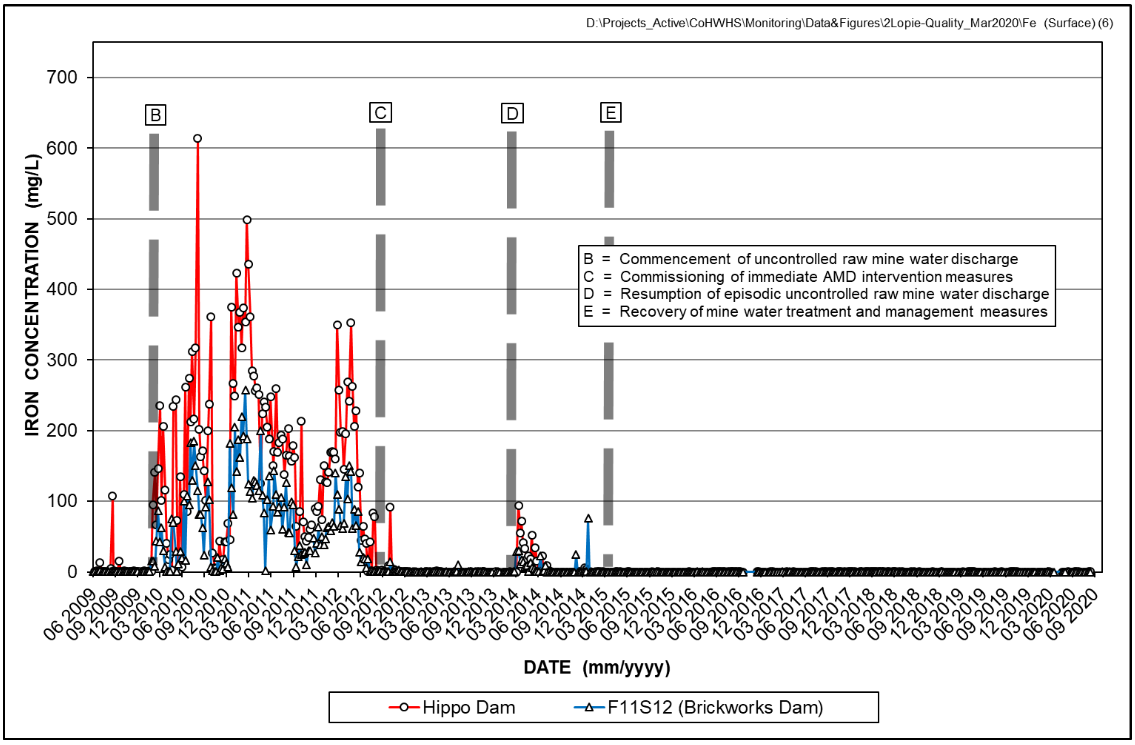


Figure 14 Iron pattern of Tweelopie Spruit surface water in the period June 2009 to August 2020

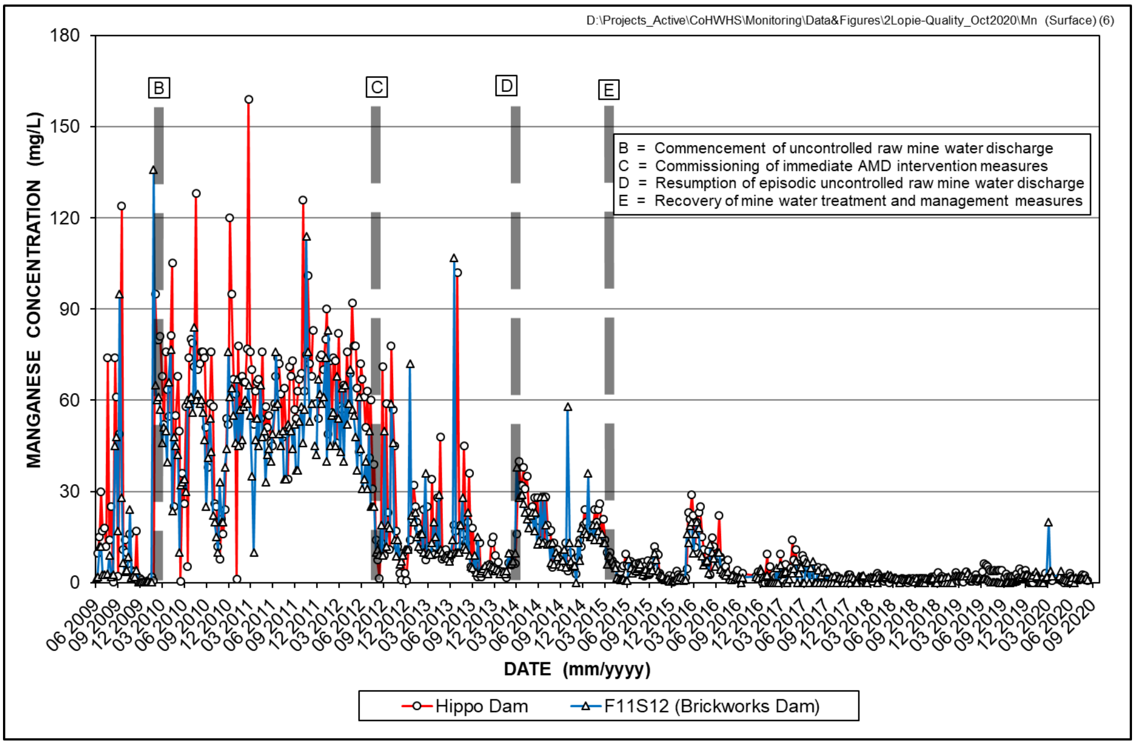


Figure 15 Manganese pattern in Tweelopie Spruit surface water in the period June 2009 to August 2020

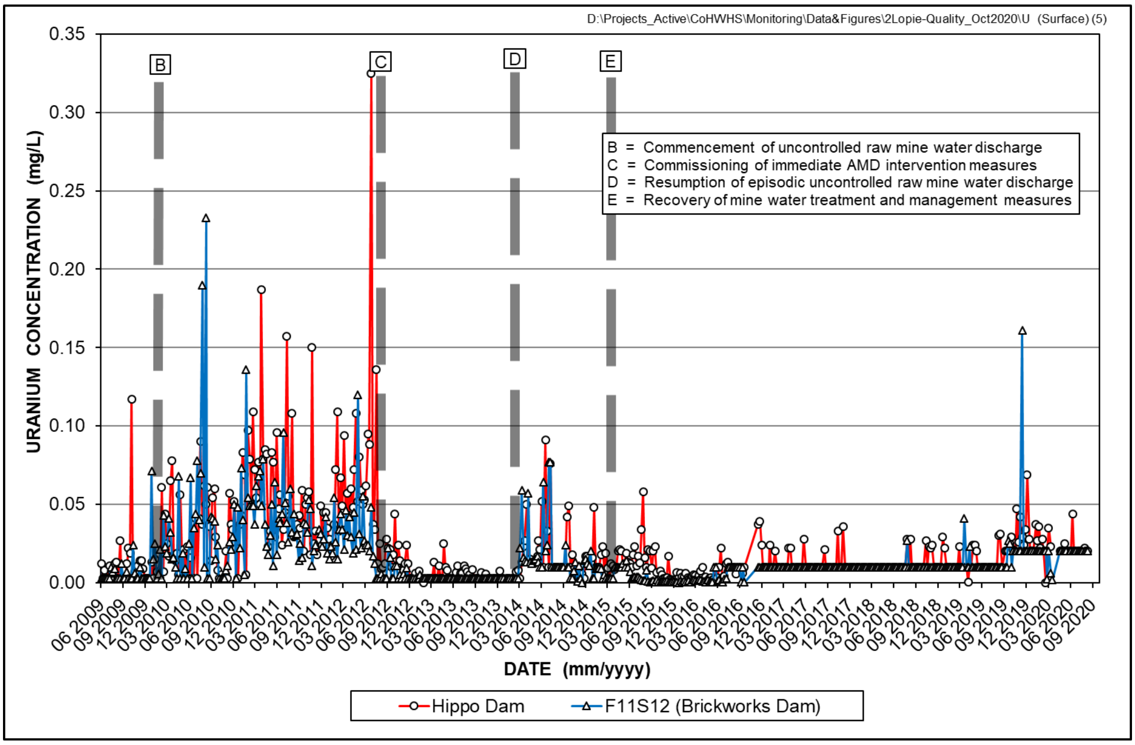


Figure 16 Uranium pattern in Tweelopie Spruit surface water in the period June 2009 to August 2020

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	269	173	128	83	57	276
	5%ile	3.6	2.8	5.9	3.2	6.8	3.9	2.7	5.3	3.0	5.4
	Mean	—	—	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	4.9	7.9	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	0.7	0.9	0.4	0.9	1.7	0.7
	CoV (%)	22.0	30	11	32	9.0	14	14	13	32	10
SEC (mS/m)	n	175	129	83	57	269	172	128	83	57	276
	Mean	374	391	350	376	337	268	332	281	329	291
	Median	379	393	354	377	336	283	330	276	323	293
	95%ile	426	438	395	417	395	329	378	350	391	323
	SD	32	33	34	28	33	48	29	34	34	41
	CoV (%)	9	8	10	7	10	18	9	12	10	14
SO_4 (mg/L)	n	176	128	82	56	269	171	128	83	56	276
	Mean	2448	2846	2520	2585	2238	1636	2264	1879	2137	1832
	Median	2460	2815	2525	2541	2180	1760	2240	1870	2075	1840
	95%ile	2828	3220	2770	2950	2766	2015	2593	2148	2640	2160
	SD	262	226	193	231	295	349	245	268	274	222
	CoV (%)	11	8	8	9	13	21	11	14	13	12
Fe (mg/L)	n	33	129	83	57	242	33	128	82	57	230
	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	0.1	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	187	94	79	407	2518	115
Mn (mg/L)	n	34	129	83	57	249	33	128	83	57	231
	Mean	18.1	62.7	16.5	17.3	3.8	10.3	50.3	14.4	16.1	3.0
	Median	9.8	65.0	11.0	16.0	2.2	2.7	50.0	10.0	14.0	1.8
	95%ile	74.0	95.0	56.1	32.6	11.9	46.2	76.0	45.0	30.4	9.8
	SD	27.6	23.5	18.0	9.1	4.6	19.4	17.6	15.8	9.9	3.6
	CoV (%)	153	38	109	53	120	188	35	110	61	117

(1) 09/2006 – 01/2010 (2) 02/2010 – 07/2012 (3) 08/2012 – 02/2014 (4) 03/2014 – 03/2015 (5) 04/2015 – 09/2020

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

4.3.2 Municipal Wastewater Impact

The Blougat Spruit is the conduit for municipal wastewater effluent into the COH WHS 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. Additionally, several accounts of obnoxious odours, murky water and foam seen in the Blougat Spruit and Bloubank Spruit rivers (**Figure** 17) have been received from local residents of the COH WHS property and reported to the MA, however the source of water pollution has not been verified. It can thus be argued that the municipal wastewater poses an equally dire threat to the quality and subsequent 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.

Figure 17 Murky water with foam was observed along the causeway of the Bloubank Spruit in December 2019 (left) and downstream at Bloubank Spruit in March 2020 (right).

4.4 Salt Load

The combination of flow and hydrochemical data allows for a re-assessment of the total dissolved solids (TDS) (**Figure 18**) and SO_4 (**Figure 19**) 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 attributed this suspension of scheduled updates to financial challenges which made it difficult for them to perform regular data collections, and conduct the requisite maintenance of the data collection platforms

(Mvandaba *et al.*, 2019). No additional sampling was conducted for the April 2020 to September 2020 reporting period 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 18**) indicates an increasing salt load since early-2007. The text box in **Figure 18** 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 18** (text box). An evaluation of the sub-regional 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 19**) mimics the TDS load pattern (**Figure 18**) 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 20** and **Figure 21**, which reflect more recent SO_4**:** TDS ratio values in the range 45 to 50%.

The closer inspection in **Figure 22** of the SO_4 data recorded at station A2H049 indicates a trebling of the SO_4 concentration (from ~120 mg/L to ~380 mg/L) between mid-2010 and mid-2014, followed by a period of comparatively consistent rising concentrations from 360 to 415 mg/L to the end of the record. These circumstances are confirmed by the load and concentration statistics presented in the text boxes.

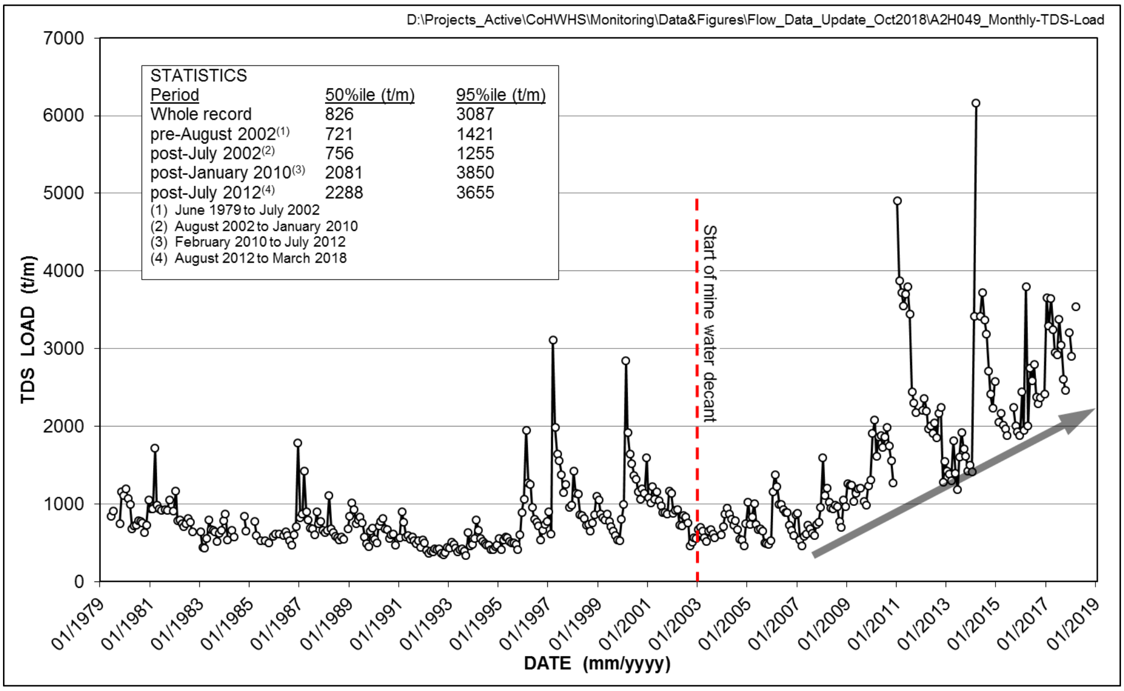
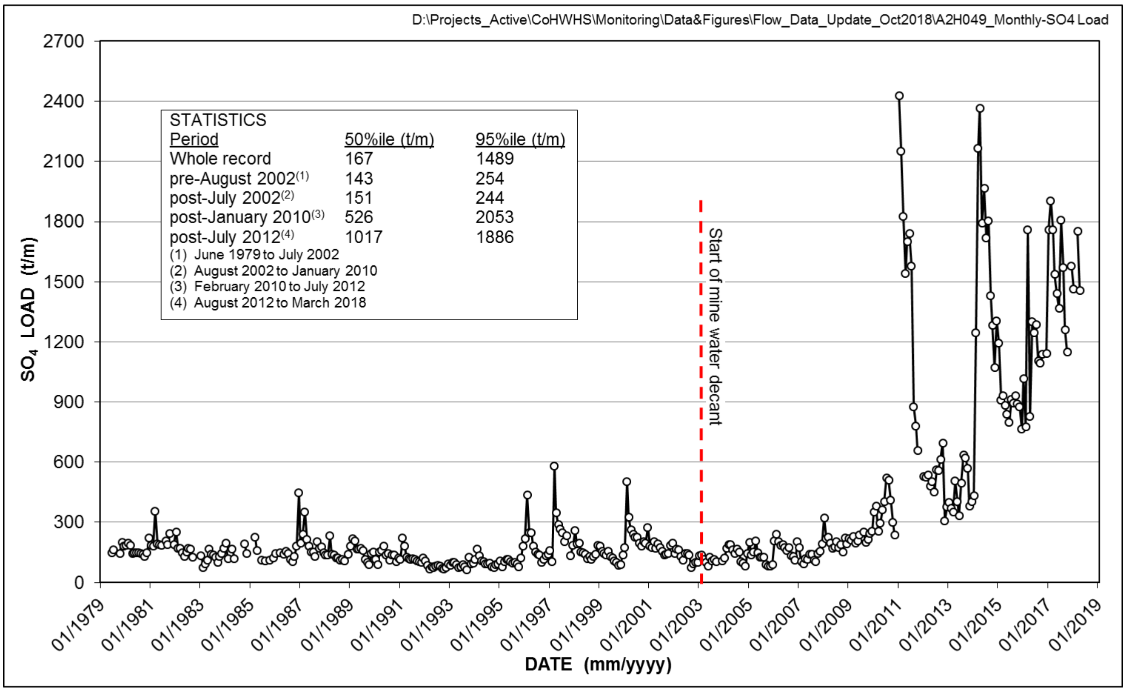


Figure 18 Long-term (June 1979 to March 2018) monthly TDS load pattern and trend in the Bloubank Spruit at station A2H049



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

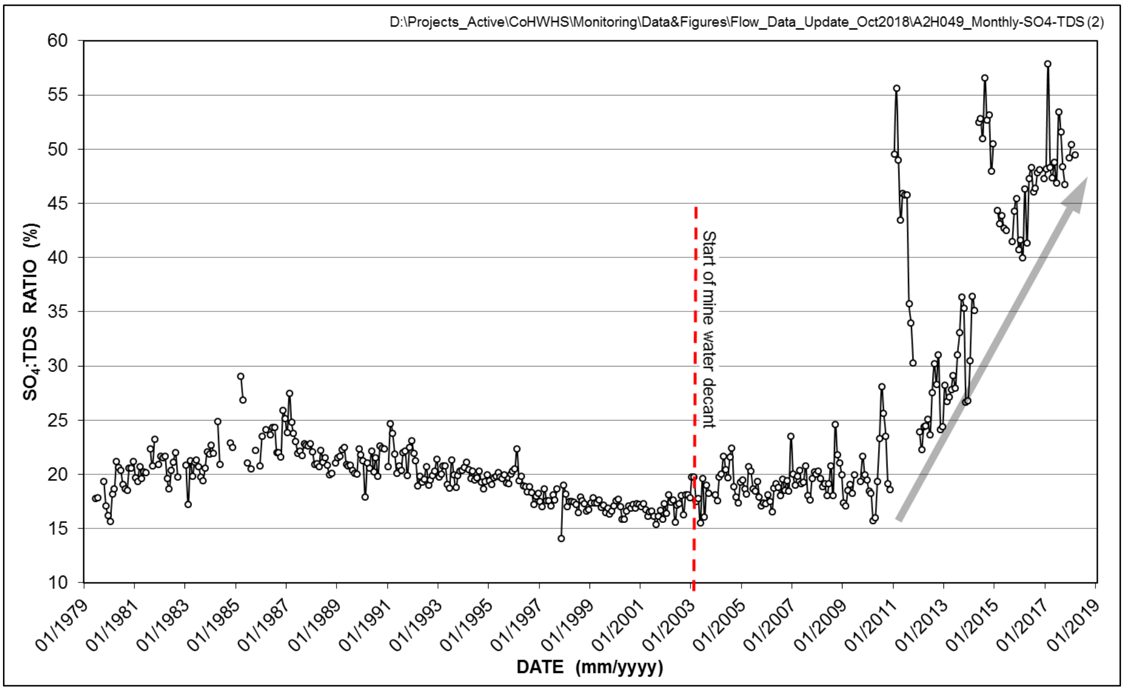


Figure 20 Long-term (June 1979 to March 2018) trend in the SO_4: TDS ratio at station A2H049

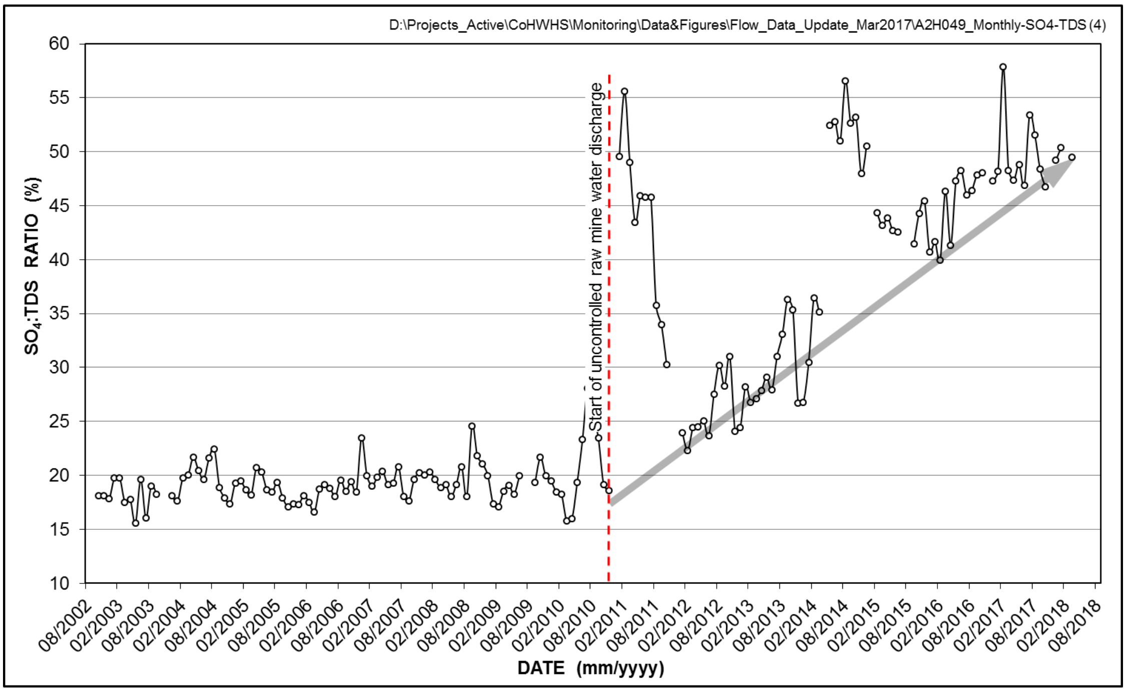
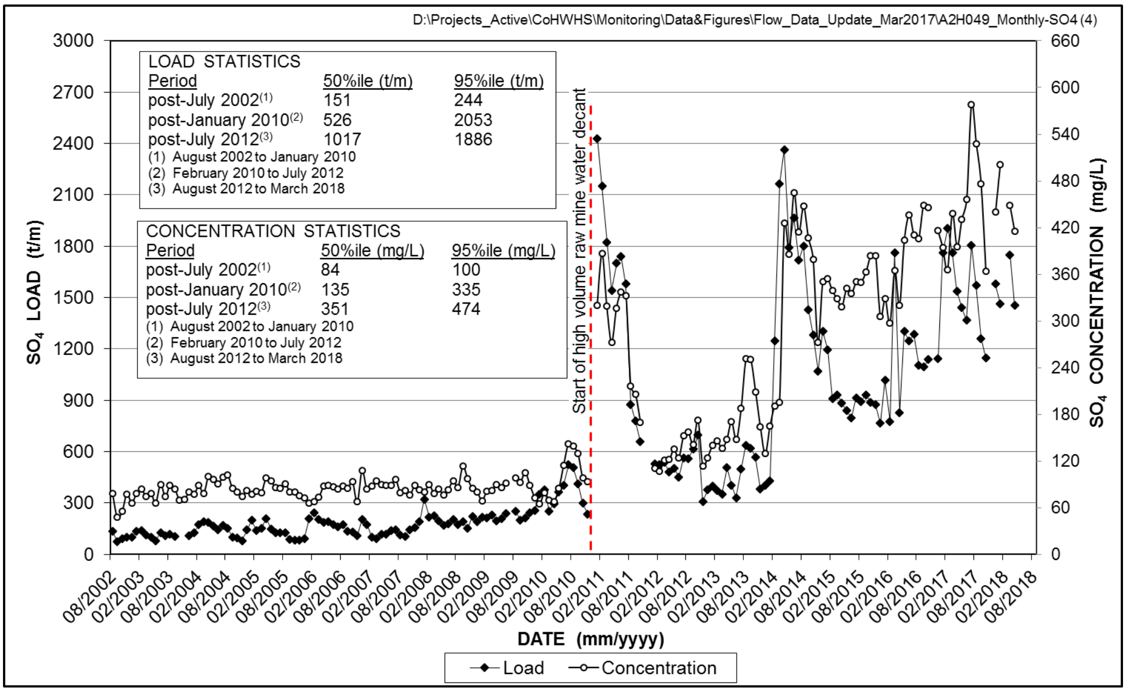


Figure 21 Pattern and trend of the SO4: TDS ratio at station A2H049 since the start of mine water decant in the Western Basin in mid-2002



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 22 Monthly SO4 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 23.** 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. As a consequence of the restrictions of the South African national lockdown period, monitoring of groundwater level was not conducted as per the usual quarterly frequency. Therefore, there exists a permanent data gap between April 2020 and September 2020. The latest results represented herein were captured in late October 2020.

5.1.2 Sub-regional Groundwater levels

The groundwater hydrographs presented in **Figure 23** reflect minimal change in the groundwater rest level elevation in the southern segment in the reporting period, indicating very stable groundwater conditions in the region. A slight increase is, however, evident in groundwater level elevations in the central and the northern segments. The lake water level in Sterkfontein Cave at the north-eastern discharge end of the Zwartkrans Basin most clearly reflects the general increase in groundwater levels, as shown in **Figure 24**.

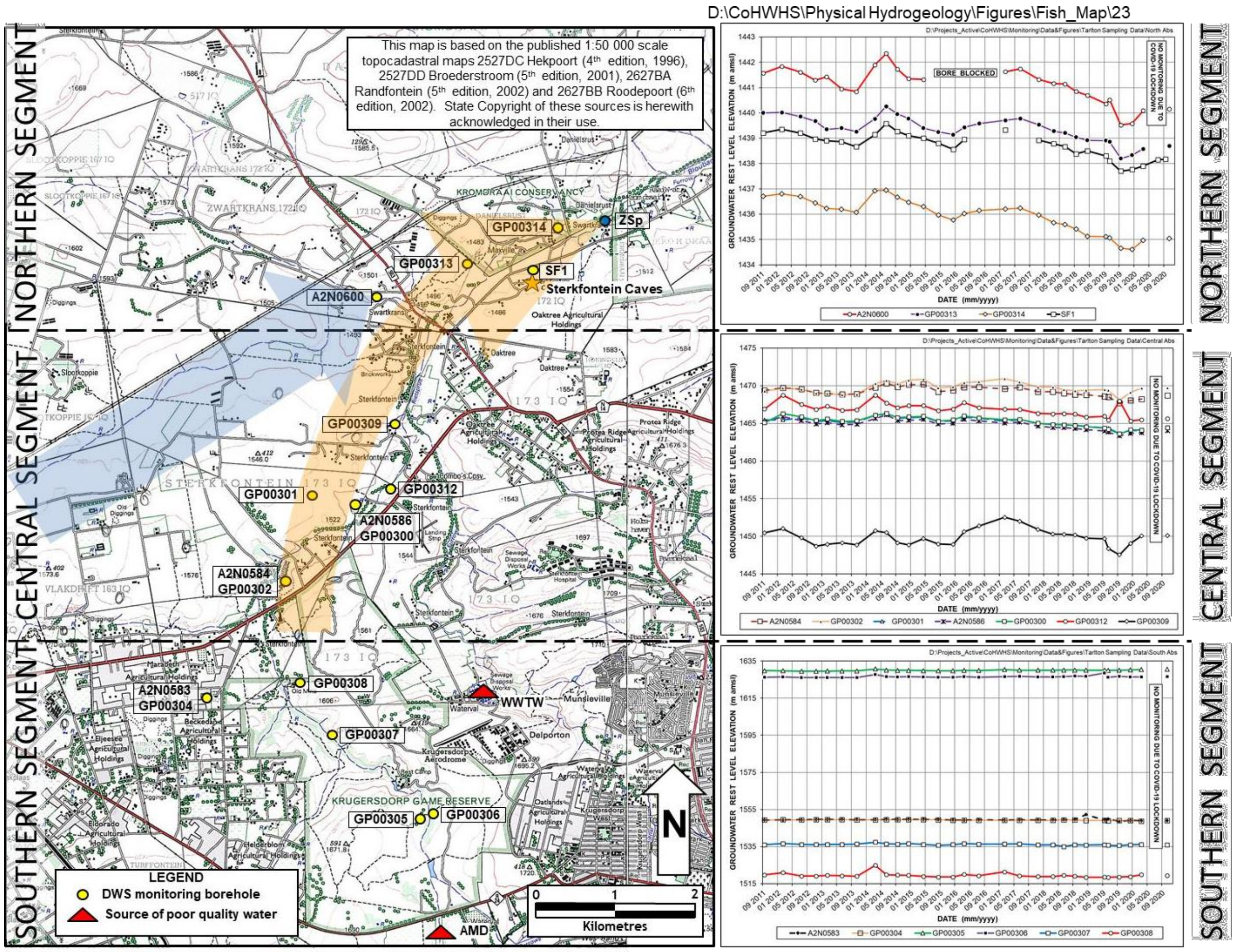


Figure 23 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

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 extensively and in detail by Hobbs and De Meillon (2017).

The cave water level response in the last 14 years is illustrated in **Figure 24**. 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 represented the lowest elevations recorded since end-2010. The recent September 2020 groundwater elevation of 1438.17 m amsl illustrate an approximate 0.5 m increase in the groundwater level since September 2019 which represents the lowest groundwater elevation recorded during the 10-year period between February

2010 and September 2020 (**Figure 25**). The increase in groundwater level corresponds to the observed increase in groundwater rest level elevation observed in the central and northern segments of the COH WHS property (**Figure 23**).

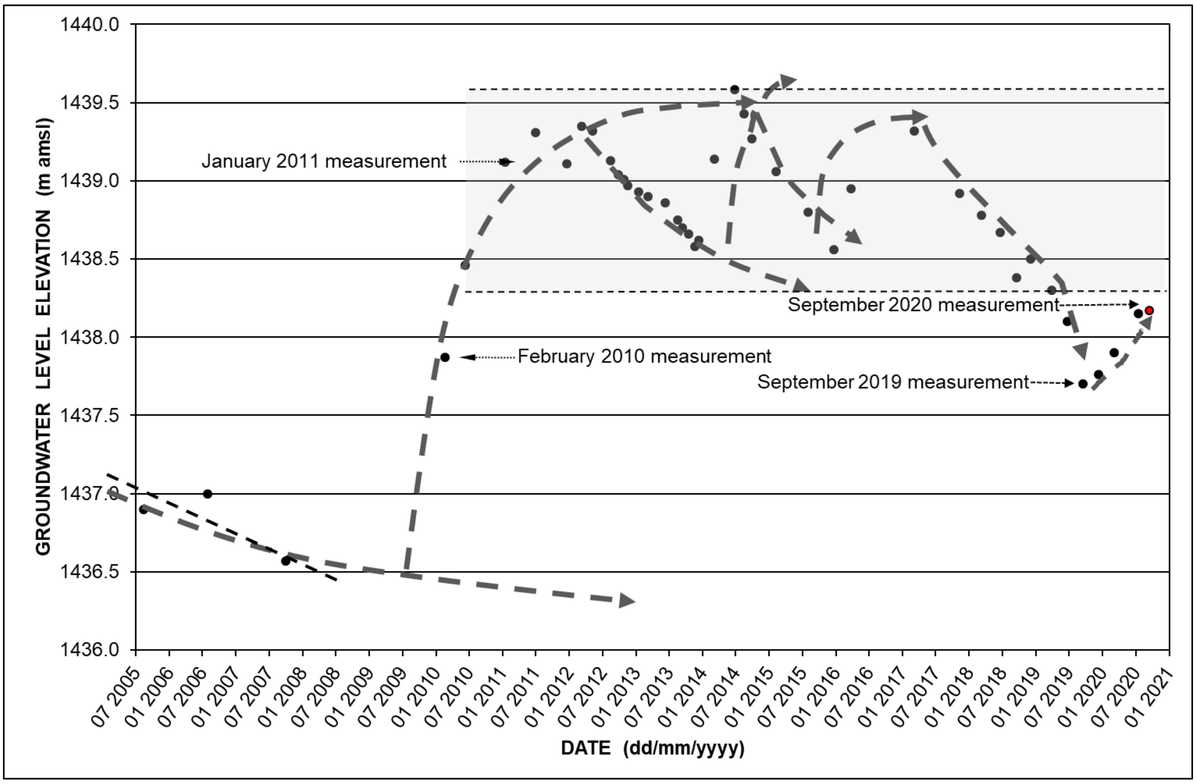


Figure 24 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the lake water level in Sterkfontein Cave; red dot represents March 2020 groundwater level and the shaded area denotes magnitude of fluctuation since mid-2010

Figure 25 A significant difference in the groundwater level of the Sterkfontein cave lake in September 2018 (left) and September 2019 (right) was observed.

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. Since March 2019, flow has been measured at eight (**Table 5**) of the ten identified springs at a biannual frequency. The 'measured discharge' (**Table 5**) is the discharge measured upstream and downstream of the eye of the spring therefore the 'spring discharge' represents the output of the spring which is calculated from the difference between the two measurements. At some sites no hydrologically suitable cross-sectional area for measurement could be identified in the vicinity of these springs; therefore, only a portion of the cross-section is gauged e.g. at the Tweefontein and Nash springs only a portion of the width of the stream generated by the discharge from the springs is gauged and an appropriate uncertainty factor often is added when required. These areas were identified as suitable 'temporary' sites due to observation of some laminar flow that can provide a rough estimate of the discharge from these springs. The following observations were made about the discharge measurements and results:

- During the September 2020 monitoring run, a discharge of 0.405 m^3/s (34.97 ML/d) was measured for the Zwartkrans Spring, which is significantly greater than the discharge of 0.056 m^3/s (i.e. 4.87 ML/d) that was measured during the March 2020 monitoring run. Bugan *et al.*, (2019) and Mvandaba *et al.* (2019) noted that there is continuous direct abstraction from a borehole next to the spring which implies that the actual contribution of the Zwartkrans spring to the river flow, and the consequent discharge determined, may have been compromised.

- The 5.06 ML/d discharge reported for September 2020 (**Table 5**) indicates the combined discharge from the two channels which provide the expected yield from the Plover's Lake and NIROX springs. It was measured at the downstream control site that was introduced to the Plover's Lake gauging sites in September 2019 (Mvandaba *et al.*, 2019). As previously discussed, the 'bucket and stopwatch' method is regarded as highly uncertain with respect to the determination of the true yield of the Plover's Lake springs on the NIROX property. A control site was, therefore, established upstream of the culvert (downstream of the multiple eyes of the spring) and through the use of a 'float' (used if the current meter propeller cannot rotate as a result of the water depth being too shallow), the discharge was found to be 2.17 ML/d (previously 2.19 ML/d in March 2020) which is greater than the 0.57 ML/d measured using the bucket method. Mvandaba *et al.* (2019) discussed that proper gauging is only feasible when flow is reasonably high to allow the flow meter propeller to be adequately immersed in the water and turn without hindrance. At the original gauging site, the total flow was 1.80 ML/d; however, measurements could not be taken at two of the 'culverts' as a result of a lack of flow in one culvert and shallow water depth which prevented the flow meter propeller from being suitably immersed for proper gauging.

- Due to the low velocity of the river, which is understood to be a result of the high sedimentation and pooling caused by fallen vegetation along the course of the Bloubank Spruit and the consequent inability of the flowmeter to acquire a reading of the discharge of the river, a 'float' mechanism was used to estimate the flow measurements at a site ~100m upstream of the Kromdraai Spring. The discharge measured in September 2020 amounted to 52.70 mL/d (0.61 m3/s), while downstream of the Kromdraai Spring the discharge was measured as 53.55 ML/d

(0.62 m3/s). The cross-sectional area of the Bloubank Spruit was used to determine the flow measurements at the downstream site. The apparent 0.85ML/d discharge of the Kromdraai Spring is significantly less than the 8.63 ML/d measured in March 2020. As discussed by Mvandaba *et al.* (2020), the flow measured in the Bloubank Spruit during the March 2020 monitoring run resulted from the heavy rains experienced in December 2019 and end-February/early-March 2020.

- The discharge at Danielsrust Spring was measured as 3.04 ML/d, which included a +/-20% uncertainty to account for flow diversions near the gauging site. The discharge measured during the September 2020 monitoring run was ~28% greater than the discharge recorded for March 2020 (Mvandaba *et al.*, 2020).

- A suitable gauging site could not be established for the Tweefontein Spring because the water level in the channel created by the discharge of the spring was too low. The discharge at the Nouklip Spring decreased by 1.17 ML/d while the Nash discharge increased by ~9.28 ML/d. Hobbs *et al.* (2011) contents that the Tweefontein spring contributes autogenic recharge to the Diepkloof Compartment, therefore it also contributes to the discharge of the Nouklip spring. The gauging sites used for the Tweefontein and Nash spring discharge measurements, however, provide a partial account of the flow in the respective systems. As explained in Section 5.1.4, if a hydrologically suitable cross-sectional area for measurement cannot be established in the vicinity of these springs, only a portion of the stream generated by the spring is gauged, ideally where some laminar flow is observed. Although the groundwater flow paths in each karst compartment in the COH WHS property have been described and illustrated (Hobbs, 2011; **Figure 27**), the direct hydraulic relationship between the springs has not been established nor quantified under the scope of this study.
- 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). The measurement site is a concrete furrow where water from the Broederstroom spring collects as it flows downstream (**Figure 26**). Using the hand-held flowmeter, a discharge of 2.01 ML/d was measured during the September 2020 monitoring run. This flow is ~40% less the 3.33 ML/d flow recorded in March 2020 and ~17% more than the 1.72 ML/d discharge measured in September 2019. However, given the direct abstraction from the spring as well as multiple occurrences of pooling found along the length of the channel fed by the spring, it remains uncertain whether this measurement provides a true reflection of the yield of the spring. To account for the indeterminate measurement, an appropriate uncertainty factor (of say 10-15%) could be added to the measured spring discharge, in future sampling exercises.

It remains evident that significant variability exists in the discharge measurements. The highest discharges were measured for the Zwartkrans, Nouklip and Nash springs, respectively yielding 34.96 ML/d, 9.69 ML/d and 13.33 ML/d; however it should be noted that the Zwartkrans spring discharge is regarded as highly uncertain. No direct quantification has been conducted regarding the response of the individual springs to changes in rainfall and discharge across the COH WHS property; this exercise would require quantification of all the processes impacting channel transmission losses including water uses and rate of evapotranspiration.

Figure 26 The concrete furrow where water from the Broederstroom spring collects as it flows downstream

Table 5 Dolomitic spring discharge measured in March 2020 and September 2020

Spring	Compartment	Measured Discharge (Mar 20)		Spring Discharge (Mar 20)		Measured Discharge (Sep 20)		Spring Discharge (Sep 20)		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	0.734	63.41	0.056	4.87	0.47	40.64	0.405	34.97	~0.1	~8.6
Zwartkrans (downstream)		0.79	68.28			0.875	75.61				
Plover’s Lake	Krombank	0.06(2)	6.08(2)	0.065	6.55	0.043	4.49	0.05	5.06	~0.06	~5.2
Plover’s Lake (culvert)		0.005	0.47			0.007	0.57				
Kromdraai (upstream)	Krombank	0.998	86.25	0.138	8.63	0.61	52.70	0.01	0.85	~0.28	~24.1
Kromdraai (downstream)		0.86	94.89			0.62	53.55				
Danielsrust	Danielsrust	0.03	2.37	0.03	2.37	0.035	3.04	0.035	3.04	~0.03	~2.4
Nouklip	Diepkloof	0.126	10.86	0.126	10.86	0.112	9.69	0.112	9.69	~0.14	~12.4
Tweefontein	Tweefontein	0.003	0.275	0.003	0.275	n/a	n/a	n/a	n/a		
Nash	Uitkomst	0.262	22.61	0.262	22.61	0.154	13.33	0.154	13.33		
Broederstroom	Broederstroom	0.039	3.33	0.039	3.33	0.023	2.01	0.023	2.01	~0.02	~1.8

(1) After Hobbs (2011)

(2) Measured at Plover’s Lake ‘control site’

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 27** and **Figure 28**. Whereas the older stations support a quasi-continuous monitoring record dating back to 2003, the record of the newer stations commences in March 2011. The outcome of this DWS groundwater monitoring programme (hereinafter referred to as simply 'the monitoring programme') forms the basis for evaluating the hydrochemical impact of mine water on the receiving karst environment (**Section 5.2.2**). As a consequence of the South African national lockdown restrictions, the DWS team was not able to collect groundwater samples in time for the results to be included in the April 2020 to September 2020 *status quo* report. Subsequently, the most chemical analyses of groundwater provided for the south-western portion of the property are as at March 2020.

5.2.2 Mine Water Impact

The pH and SEC values measured during the monitoring programme in the Zwartkrans Basin during March 2018 and December 2019 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; Mvandaba and Kapangaziwiri, 2019). The caution pertains to the known element of vertical chemical stratification that exists in a 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 27** and **Figure 28** with the aid of bar graphs for the chemical variables pH and SEC respectively.

The bar graphs in **Figure 27** 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 5.0 to 8.4, 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 6.4 to 8.5.

The bar graphs in **Figure 28** 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 September 2019 and March 2020, the salinity is constrained to the range 124 to 295 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 (September 2019 to March 2020) salinity is constrained to the range 148 to 180 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 29**.

The extent of the mine water impact on the karst aquifer of the Zwartkrans Basin is shown in **Figure 29**, 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, September 2019, December 2019 and March 2020 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.

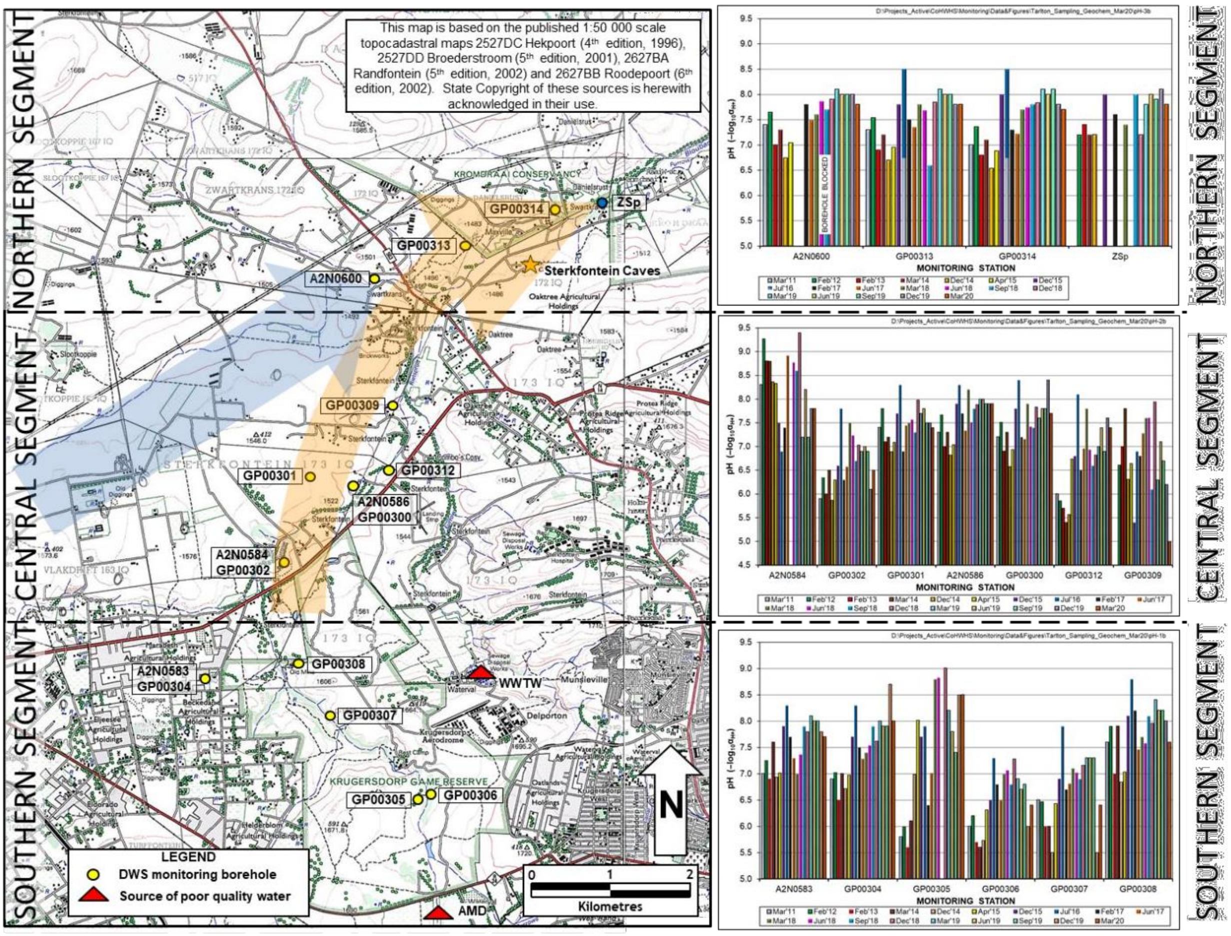


Figure 27 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

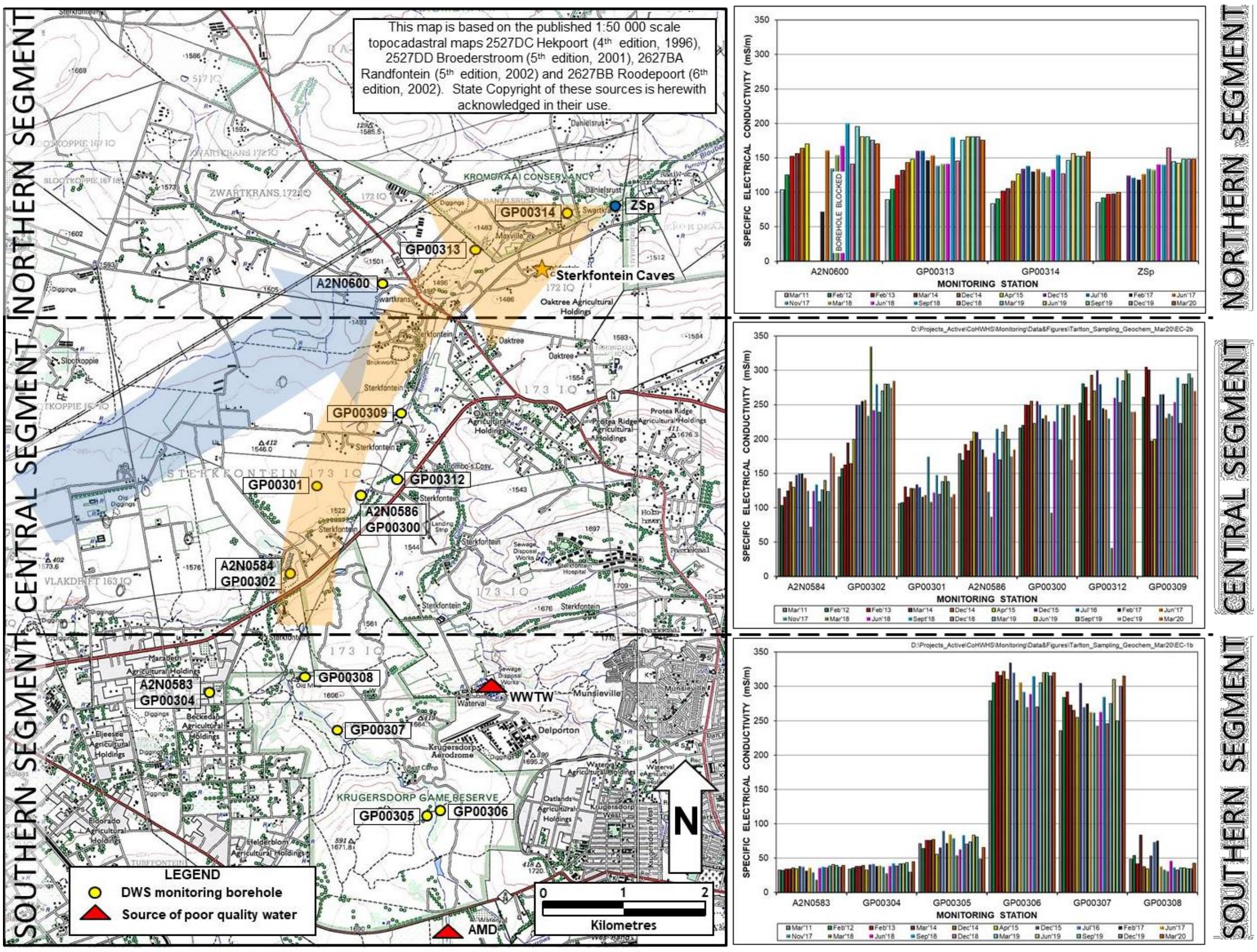


Figure 28 Distribution of DWS monitoring boreholes with SEC pattern and trend as bar graphs; brown arrow denotes principal direction of impacted groundwater flow, and blue arrow direction of natural karst groundwater flow

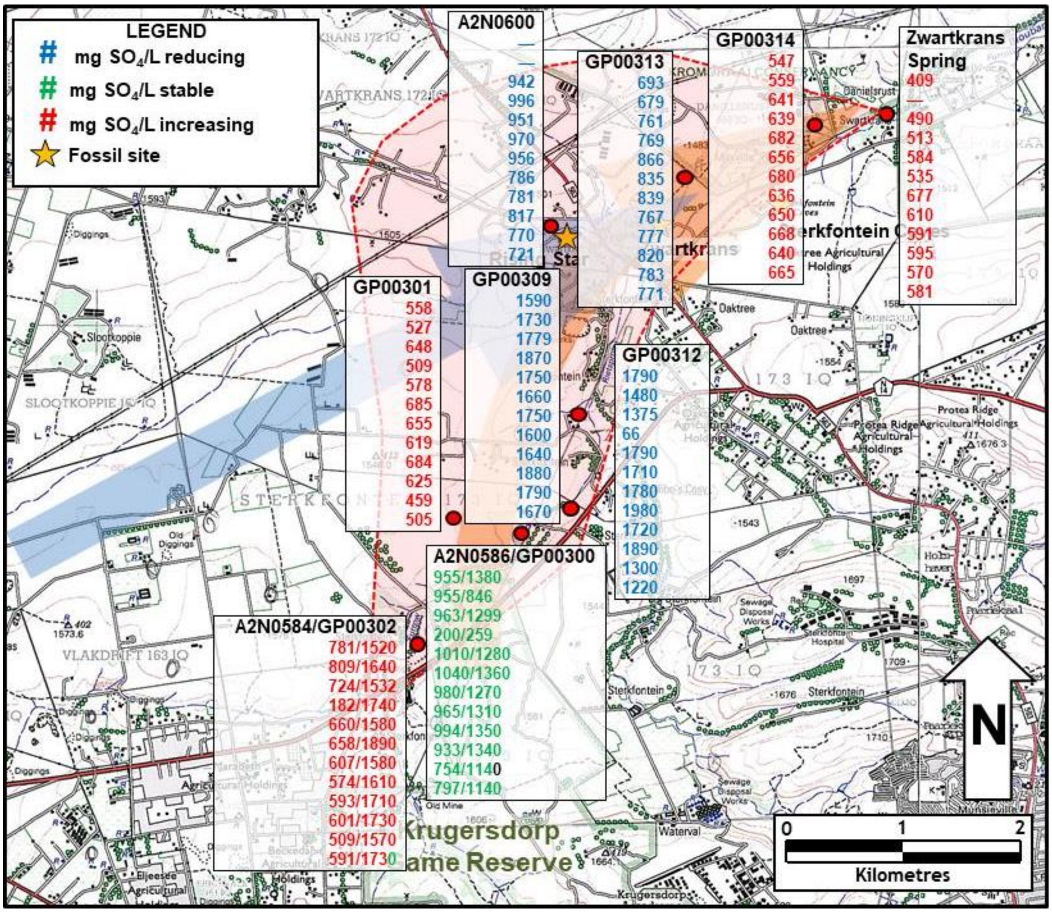


Figure 29 Distribution of sulphate levels in groundwater of the Zwartkrans Basin in July 2016 (1st value), February 2017 (2nd value), November 2017 (3rd value), March 2018 (4th value), June 2018 (5th value), September 2018 (6th value), December 2018 (7th value), March 2019 (8th value), June 2019 (9th value), September 2019 (10th value), December 2019 (11th value) and March 2020 (12th 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 March 2019, June 2019, September 2019, December 2019, March 2020 and September 2020 are presented in **Table 6**. With the exception of the July 2020 pH level of 4.7, none of the variables reported for fall outside of 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. Since March 2020, the quantity of total coliform bacteria decreased from 547.5 MPN/100ml to 32.3 MPN/100ml and the *E. coli* decreased from 3.1 MPN/100ml to <1.0 MPN/100ml. The moderately 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, September 2019, December 2019, March 2020, July 2020 and September 2020

Variable	Mar 19	Jun 19	Sep 19	Dec 19	Mar 20	Jul 20	Sep 20	SANS (2015a)[(1)]
pH ($-\log_{10}\alpha_{H+}$)	8	8.1	8.1	8.2	7.9	4.7	7.9	5.0–9.7
SEC (mS/m)	92	92	95	94	100	90	100	<170
Ca (mg/L)	90	89	88	89	91	95	88	n.s.
Mg (mg/L)	53	54	54	53	50	58	51	n.s.
Na (mg/L)	35	37	33	34	35	38	33	<200
K (mg/L)	1.5	1.6	1.5	1.5	2	1.5	1.3	n.s.
Cl (mg/L)	37	37	36	37	38	37	37	<300
SO_4 (mg/L)	273	271	259	262	298	286	267	<500
HCO_3 (mg/L)	148	146	148	142	146	160	145	n.s.
NO_3+NO_2 (mg N/L)	7.1	7	6.6	7	7.4	7.6	7	<11
Si (mg/L)	5.9	7	5.8	6	5.8	5.6	6	n.s.
Fe (mg/L)	0.02	0.31	0.02	0.17	0.04	<0.01	0.03	<2
Mn (mg/L)	<0.01	0.32	<0.01	0.03	0.02	0.02	0.01	<0.5
Al (mg/L)	0.03	0.14	0.02	0.05	0.03	0.02	0.02	<0.3
Total coliform bacteria (MPN/100 ml)	1046.2	125.9	35.5	248.1	547.5	78	32.3	<10
E. coli (MPN/100 ml)	<9.8	4.1	<1.0	3.1	3.1	<1	<1	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 30**) 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 2020 and September 2020. 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**.

The waters from the major dolomitic springs are of excellent quality for the parameters reported for both the March 2020 and September 2020 sampling results, with the exception of the Zwartkrans, Aquamine, Tweefontein and Cradle springs. The chemical analytical results from the Zwartkrans Spring show probable mine water impact as evidenced by the high sulphate content which exceeds the standard health-related limits. The chemistry results reported for both March 2020 and September 2020 at the Zwartkrans and Kromdraai springs 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. The Aquamine, Tweefontein and Cradle springs show pronounced concentrations of manganese, iron and aluminium. These minerals occur naturally in karst sediments, therefore the recent fluctuation in concentrations of these minerals at the locality of the springs may be linked to the resuspension of minerals due to movement of sediments during the periods of heavy rainfall (Diković and Koželj, 2015).

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, Nash and the Cradle Spring, which exhibit high levels of total coliform bacteria and *E. coli*. The *E. coli* levels across all the sample results have, however, decreased since March 2020. It should 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.

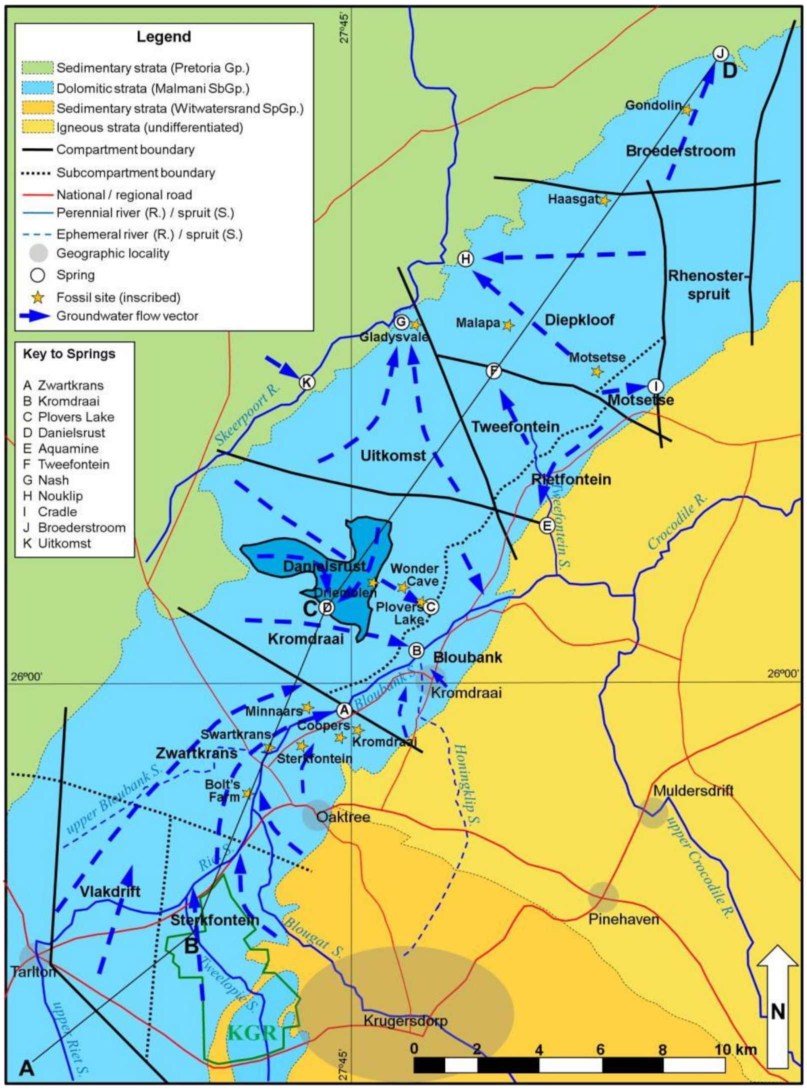


Figure 30 Map showing the regional geology of the study area, dolomitic compartment boundaries, groundwater flow vectors and the major dolomitic springs

Table 7 Water chemistry results of samples collected at the major dolomitic springs during March 2020 and September 2020

Variable	Zwartkrans Spring		Kromdraai Spring		Plovers Lake Spring		Danielsrust Spring		Aquamine Spring		Tweefontein Spring		Nash Spring		Nouklip Spring		Cradle Spring		Broederstroom Spring		SANS
	Mar 20	Sep 20	Mar 20	Sep 20	Mar 20	Sep 20	Mar 20	Sep 20	Mar 20	Sep 20	Mar 20	Sep 20	Mar 20	Sep 20	Mar 20	Sep 20	Mar 20	Sep 20	Mar 20	Sep 20	(2015a)(1)
pH ($-\log_{10}\alpha_{H+}$)	7.8	8.1	7.8	8.1	8.1	8.4	7.9	7.9	7.8	7.6	8	8	8.2	8	8	8.2	7.7	8	7.8	7.9	5.0–9.7
SEC (mS/m)	148	150	70	76	35	35	26	27	60	66	36	37	25	36	37	39	74	74	54	50	<170
Ca (mg/L)	160	172	68	72	39	39	28	30	71	66	40	42	27	26	43	44	86	72	59	60	n.s.
Mg (mg/L)	79	82	37	40	23	22	16	17	42	38	23	24	16	16	24	25	52	52	37	36	n.s.
Na (mg/L)	56	56	22	22	1.6	1.6	0.9	1	3.8	3.3	1	1.2	1.3	1.3	1.1	1.1	3.4	3.3	1.3	1.2	<200
K (mg/L)	2.1	2	1.1	1.1	<0.6	<0.6	<0.6	<0.6	<0.6	0.8	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	n.s.
Cl (mg/L)	42	44	25	27	<2.0	<2.0	<2.0	2.1	4.5	3.4	<2.0	2	<2.0	<2.0	<2.0	<2.0	3.5	3.6	<2.0	<2.0	<300
SO_4 (mg/L)	581	632	156	169	3.8	5.3	3.1	3.9	14	9.5	5.5	6.3	1.6	2.2	4.8	5.6	23	22	20	20	<500
HCO_3 (mg/L)	142	141	156	160	184	184	132	130	315	304	178	184	133	133	196	196	385	386	271	267	n.s.
NO_3+NO_2 (mg N/L)	7.7	6.9	4.4	4.6	0.5	0.33	0.5	0.5	0.3	0.08	0.5	0.39	0.2	0.16	0.3	0.24	0.2	0.06	0.6	0.41	<11
Si (mg/L)	6.4	6.5	5.7	5.7	5.9	6.1	5.4	5.3	14	13	4.6	4.9	4.5	5.3	4.4	4.9	19	9.6	4.4	4.8	n.s.
Fe (mg/L)	<0.01	<0.01	0.05	0.04	0.06	0.05	0.33	0.02	17	24	0.5	0.17	<0.01	<0.01	0.02	0.05	9.8	2.4	0.02	0.02	<2
Mn (mg/L)	<0.01	<0.01	0.03	0.03	0.08	<0.01	0.09	<0.01	2.6	8.8	0.98	0.2	<0.01	<0.01	0.03	<0.01	2.5	0.36	<0.01	<0.01	<0.5
Al (mg/L)	0.01	<0.01	0.03	0.03	0.04	<0.01	0.24	<0.01	5.6	3.1	0.33	0.07	<0.01	<0.01	0.02	<0.01	7.2	1.3	0.02	0.02	<0.3
Total coliform bacteria (MPN/100 ml)	1553.1	185	>2419.6	>2419.6	46.5	18.5	461.1	111.2	>2419.6	>2419.6	>2419.6	1299.7	178.9	133.4	178.9	5.2	>2419.6	2419.6	193.5	30.5	<10
E.coli (MPN/100 ml)	7.3	<1	290.9	38.8	<1.0	<1	18.9	11	104.6	18.5	1203.3	29.8	5.2	<1	<1.0	<1	161.6	52.9	14.8	<1	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

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 31)**.

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 spring water-driven headwater stream in a karst landscape as can be found in the COH WHS.

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.

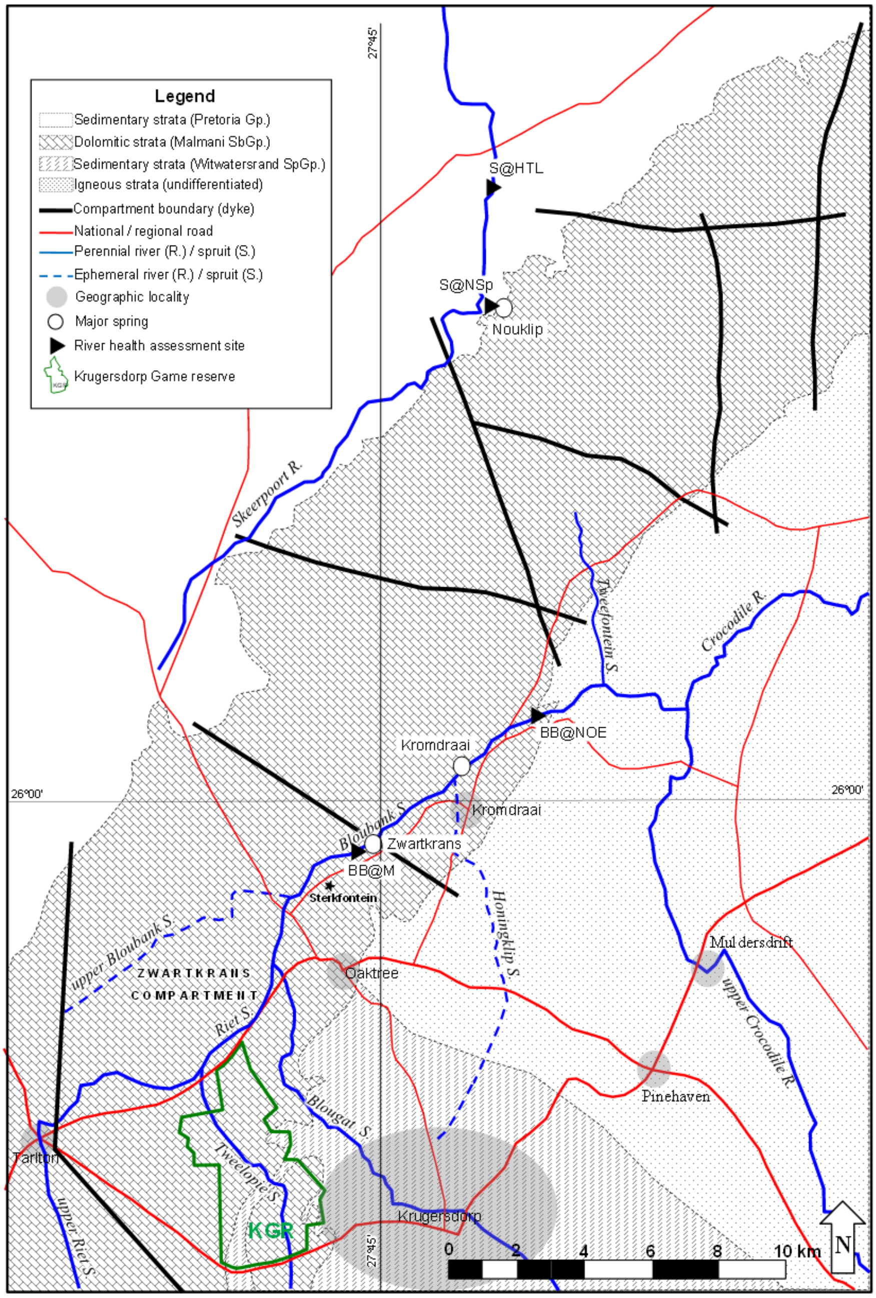


Figure 31 Map showing sites of relevance to the river health assessment

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 reach of the Skeerpoort River, marked by the site S@NSp, scored an E/F indicates that the status of the river health has deteriorated since the March 2020 assessment which scored in the B category (Mvandaba *et al.*, 2020). Downstream at the S@HTL site, the status of the river health scored an E/F signalling another deterioration on the A category scored during the March 2020 sampling. The status of the BB@M site on the Bloubank Spruit scored an E/F category which indicates that this reach of the river remains in a seriously modified state as previously scored. Due to highly turbulent flow at the BB@NOE was not assessed in March 2020 field trip assessment. However, BB@NOE was sampled during the current field trip and the score remained at E/F as it was in the preceding assessments. The full set of results obtained during the September 2020 survey for each of the sites are presented in **Section 6.2.2** below**.**

Table 9 Synoptic river health assessment outcome for September 2020.

SITE	Date	Ecological category	Condition	Description
S@HTL	14/09/2020	E/F	Seriously modified	Seriously modified
S@NSp	15/09/2020	E/F	Seriously modified	Seriously modified
BB@M	06/09/2020	E/F	Seriously modified	Seriously modified
BB@NOE	16/09/2020	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 WHS property even though it is located downstream of the karst area.

The habitat and flow for all five 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. However, in the September 2020 monitoring and sampling run some deterioration in habitat quality was observed. There is a huge bedrock with lack of stones-in-current habitat for sampling, while vegetation was inadequate compared to previous sampling period. Gravel, sand and mud (GSM) was relatively the same as the preceding sampling periods. 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.

With the exception of the September 2020 sampling run, the site has been sampled on five occasions, and all the SASS5 scores have been generally similar, with the River Health Category being between B (good) and C (fair).Overall, the habitats have remained similar. Four sampling trips (February 2018 and March 2019) and (September 2019 and March 2020) show similarities in the family presence with few noticeable variations on the last two trips (i.e. September 2019, *teloganodidae*, *notonectidae* and *psychimyiidae* have not been found in the three preceding field trips and the same goes for March 2020 with regards to 7 families (*atyidae*, *polamonidae*, *plecoptera*, *notonectidae*, *calopterygidae*, *ecnomidae* and *dixidae*). 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 March 2020 was B (good), while in September 2019 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 therefore it is expected that this particular site will continue to oscillate between a Category B and C. However, in the current sampling period (September 2020), the River Health Category fall under the category E/F which indicated a seriously modified sites. This could be attributed to local disturbances such as habitat quality changes. The low levels of habitat heterogeneity and diversity at this site during the current assessment are other likely contributors of the low macro-invertebrate diversity (Chakona *et al.*, 2008), this particularly affected the sensitive families compared to previous sampling periods.

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 Skeerpoort River)**							
		SASS associated scores						**Dominance ***	
Date	Ecological category	SASS 5	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*
02/03/2020	B	138	21	6.6	66	14	338	Predator	*Palaemonidae*
14/09/2020	E/F	53	14	4.5	59	12	229	Predator	*Simuliidae*

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 has been sampled on six occasions with the exception of the current monitoring period (i.e. September 2020), and the SASS5 scores are also generally similar. The River Health Category generally borders between A (Natural), and B (Good).

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 scored category B in the three sampling trips. While the SASS5 score and number of taxa was the lowest in the current fieldtrips compared to the three last sampling trips (i.e. October 2018, March 2019 and September 2019), however the ASPT score remained the highest. 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.

However, during the current sampling run, noticeable changes at the site were observed. The surrounding area showed that riparian trees and overhanging vegetation were cut off. Besides the sampling site having similar habitat characteristics (as previous sampling runs) such as stones in current and out of current and GSM, a lower vegetation diversity and quality was observed. During this current monitoring and sampling run, the River Health Category was the worst since the inception of this study, category E/F which indicates a seriously modified site. The local disturbances (i.e. riparian vegetation cutting and modification of aquatic vegetation) may have had an impact in lower composition and diversity of sensitive macroinvertebrates at this site. Lack of higher sensitive macroinvertebrates have a direct impact on the SASS score (Dickens and Graham, 2002), which also influences the River Health Category of the site. Karaouzas *et al.*, (2007) have indicated that disturbances retain tolerant and generalist species which dominate the aquatic community.

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**							
		SASS associated scores						**Dominance ***	
Date	Ecological category	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*
02/03/2020	A	90	13	6.9	77%	15	399	Predators	*Pleidae*
15/09/2020	E/F	70	16	4.3	69%	12	328	Predators	*Baetidae*

1 From Fourie *et al.* (2014)

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

6.2.2.2 Bloubank Spruit

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
23/02/12	E/F	32	9	3.6	57				
16/05/12	E/F	53	14	3.8	81	13	653	Collector-Gathers	*Tricorythidae*
24/10/12	E/F	35	10	3.5	72	12	524	Collector-Gathers	*Baetidae*
06/03/13	E/F	52	13	4	74	13	437	Predator	*Baetidae*
15/08/13	E/F	34	9	3.8	65	12	277	Predators	*Baetidae* and *Pleidae*
12/12/13	E/F	38	10	3.8	61				
13/02/18	E/F	27	8	3.4	67	13	653	Collector-Gathers	*Tricorythidae*
25/09/18	E/F	48	11	4.4	71	12	524	Collector-Gathers	*Baetidae*
28/03/19	E/F	46	12	3.8	66	13	437	Predator	*Baetidae*
16/09/19	E/F	36	10	3.6	65	12	277	Predators	*Baetidae* and *Pleidae*
04/03/20	E/F	27	8	3.9	56%	6	735	Predators	*Chironomidae, Ceratopogenidae* and *Culicidae*
16/09/20	E/F	13	4	3.2	75	5	382	Predators	*Chironomidae*

Site BB@M typically 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. However, during the current sampling run, the water was too turbid with high density of algae which indicates high wastewater effluent pollution. The River Health Category remains similar to the previous sampling campaign as it scored E/F. Furthermore, it was noticeable that the SASS score, number of taxa and ASTP was the worst compared to the previous sampling campaigns even though the habitat quality is relatively better.

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
23/02/12	E/F	52	12	4.3	52	6	206	Collector-Filterers	*Hydropsychidae*
16/05/12	E/F	41	10	4.1	59	6	269	Collector-Gatherers	*Baetidae*
24/10/12	C	59	11	5.4	61	12	230	Collector-Gatherers	*Baetidae*
06/03/13	B	60	10	6.0	55	12	225	Collector-Gatherers	*Baetidae*
12/12/13	D	32	6	5.3	53	12	329	Collector-Gatherers	*Baetidae*
13/02/18	D	57	12	4.8	58	12	234	Collector-Gatherers	*Baetidae*
25/09/18	E/F	30	8	3.8	55	6	275	Predators	*Corixidae*
25/03/19	E/F	33	8	4.1	54	6	178	Predators	*Simuliidae*
17/09/19	E/F	64	14	4.6	58	8	781	Predators	*Ceratopogenidae and Chironomidae*
04/03/20		Sampling could not be conducted							
16/09/20	E/F	38	11	3.4	50	6	320	Predators	*Chironomidae*

The instream water was very turbid, more or less the same as at upstream site BB@M. There is, however, a trout farm approximately 100 m upstream of the site that was discharging into the Bloubank Spruit at the time of sampling. This may have contributed 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. However, during the March 2020 biannual water resources monitoring run, the river health assessment could not be conducted at the BB@NOE site due to highly turbulent and unsafe flow that posed a danger to the operator. According to (Dickens and Grahams, 2002), it is the prerogative of the operator to desist from sample collection if she/he considers the conditions in the river or the surroundings to be unsafe. During the current monitoring run, the assessment was conducted at this site and the River Health category remains the same as three previous periods. Furthermore, the ASTP score is the worst compared to all previous assessment periods.

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: 6.45%; S@NSP test sample: 1.98%; BB@M test sample: 29.06% and B@NOE test sample: 21.44%. Inhibition of > 20% indicates toxicity and stimulation of > 20% indicates potential eutrophication. In all the sites, there was an indication of potential eutrophication in two sites namely; BB@M and B@NOE as stimulation exceeded 20%. 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 samples at BB@M and BB@NOE with 45% and 50% mortality after 48 hours, respectively. The sites S@HTL and S@NSp show no toxic effects while BB@NOE and BB@M show acute hazard effects.

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

Sample	Time (hrs)	Mortality (No. of organisms)	Mortality (%)
CONTROL	24	0	0
	48	0	0
S@NSp	24	1	5
	48	1	5
S@HTL	24	0	0
	48	1	5
BB@NOE	24	3	15
	48	9	45
BB@M	24	5	25
	48	10	50

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 (**Figure 32)**. 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 was toxic as growth inhibition of 20% or more was detected while BB@NOE remained an eutrophication potential with growth rate above control. Sites S@HTL and S@NSP remained nontoxic with growth rate less than 20% relative to control.

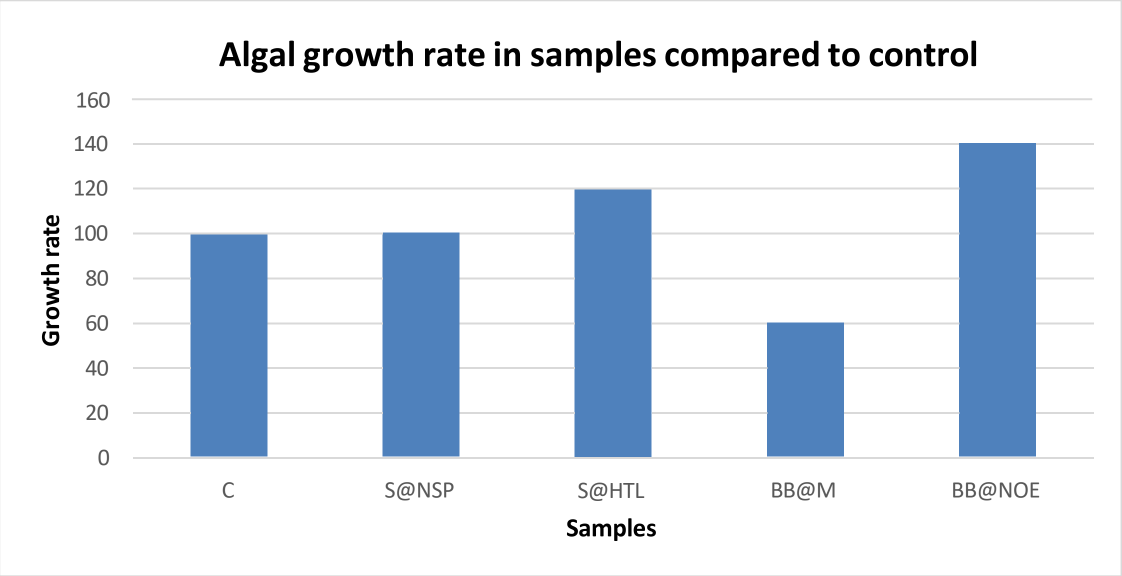


Figure 32 Percentage growth rate of *S. capricornutum* in test samples (undiluted), relative to the control.

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 15**), based on either screening or definitive testing protocols.

Table 15 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).

No acute hazard was observed in all the tests with the exception of BB@M and BB@NOE (*S. Capricornatum* test). Samples at BB@M were toxic as growth inhibition of 20% or more was detected which indicated the slight acute hazard while BB@NOE remains eutrophication potential.

Discussion on River Health

Poor water quality originating from WWTW influences water quality in the Bloubank Spruit River while local disturbances affects the ecological health of Skeerpoort River. The macroinvertebrates assessment indicates that the anthropogenic activities occurring in both rivers affect the ecosystem health leading to a decrease in taxa and total SASS5 scores. Effluent pollution in BB@M and BB@NOE has clearly led to the deterioration of the health of both sites with ASTP being at lowest compared to all sampling campaigns. At S@HTL and S@NSP, the destruction of riparian ecosystem and aquatic habitat particularly aquatic vegetation has also further influenced the River Health Category relative to the previous sampling periods.

Natural compounds and anthropogenic pollutants such as organic compounds, pesticides and heavy metals released into the environment accumulate in ecosystems, particularly freshwater bodies and pose a risk to endogenous organisms. The undesired effects range from alteration of natural microbial communities (Sheik *et al.*, 2012) to physiological disorders in higher organisms. Therefore, it is crucial to detect potential signs of toxicity throughout the year in all four seasons.

- The macroinvertebrate monitoring survey reveals a substantial change in biotic condition between the largely natural / moderately modified Skeerpoort River and the severely impacted Bloubank Spruit system. This is best evidenced by the previous sampling period findings (i.e. A and B ecological Categories) of the Skeerpoort River sites versus the E/F Category of the current results of the same river. While Bloubank River has consistently being on E/F, however the current results indicates that the ecological health is worsening as observed from ASPT, SASS score and number of taxa point of view. For instance, BB@M recorded the lowest SASS score, number of taxa and ASTP since the inception of assessment in this site. While BB@NOE had the lowest ASPT as compared to the previous assessment. A comparison with previous results indicates a greater deterioration on the general ecological health.

The toxicity results in indicates that Bloubank River poses toxic effects to water flea (*D. magna*), bacteria (*V. fischeri*) and algae (*S. capricornutum*). According to *V. fischeri* test results, BB@M and BB@NOE indicated toxicity to bacteria as they exceeded 20% inhibition compared to control. While S@HTL and

S@NSP showed no signs of toxicity. For algal test and water flea test, the toxic effects was found at BB@M and BB@NOE.

These toxicity tests and macroinvertebrates assessment clearly indicates that these sites are heavily affected by anthropogenic impacts occurring on the catchment. Proper rehabilitation of the current wastewater treatment activities is also essential to avoid or minimise effluent related impacts in the future. The results of this assessment study clearly indicates that improved management and maintenance of WWTWs is crucial. Furthermore, the results of this assessment further indicates the importance of macroinvertebrates monitoring and toxicity tests river health status, toxicity potential and also potential pollution hotspots.

7 DISCUSSION & CONCLUSIONS

An assessment of impacts on the water resources environment of the COH WHS 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 property, impacts are 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 summary of the current outcome is as follows:

- The total rainfall recorded for 2020 hydrological year at the HDS station and Sterkfontein station are respectively 827 mm and 2264 mm, with the total wet season rainfall measuring at 827 mm for the HDS station and 864 mm for the Sterkfontein station. The HDS station apparently received no dry season rainfall. Based on available historical data spanning an 11-year period from 2009 to 2020, the 2015 and 2019 hydrological years have been the driest on record, while the 2017 and 2020 hydrological years are seemingly the wettest.

- Due to the South African national lockdown restrictions, the DWS were unable to collect rainwater samples in time for the results to be included in the April 2020 to September 2020 *status quo* report, therefore the most recent chemical analyses of rainwater in the south-western portion of the property from March 2020 are provided. These results represent the late wet season/early dry season rainfall. 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.

- Against the background of large gaps, including a period of missing data from December 2019 to January 2020, the annual discharge indicates that the 2020 hydrological year recorded a discharge of ~21.6 Mm^3, which would make it *considerably greater* than the ~7.1 Mm^3 reported for 2019 hydrological year. The 7.1 Mm^3 discharge remains the *apparently* lowest recorded at station A2H049 over the historical total observed data period from 1973 to 2020, which has an *average* and *median* discharge of 26.3 Mm^3/a and 24.5 Mm^3/a, respectively. The large period of missing data is certainly responsible for this deviation.

- For the 2020 hydrological year, based on the available records, the highest mean monthly instantaneous discharge was approximately 1.34 m^3/s which is ~ 63% greater than the 0.82 m^3/s

recorded for the 2019 hydrological year but lower than the 2.15 m^3/s and 1.46 m^3/s recorded, respectively, for the 2017 and 2018 hydrological years. The data record for the 2020 hydrological year does however has gaps for December 2019, January 2020 and September 2020 discharge. Given a median of 1.21 m^3/s, the instantaneous discharge for the 2020 hydrological year respectively falls within the 3rd quartile.

- 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. Additionally, the efficacy is reflected in the statistical analysis of the chemistry of the Tweelopies Spruit where median and 95%ile values in period E– that in most cases show the lowest values across the five periods of analysis and is similar to the period C-D which marks the commissioning of the AMD intervention measure.

- The updated records for July 2020 and September 2020 indicate flow losses between F11S12 and MRd of 11.7 ML/d and 21.9 ML/d respectively, which are significantly less than the losses of 62.9 ML/d and 57.4 ML/d reported for December 2019 and March 2020. This is to be expected given that both the flows recorded in December 2019 and March 2020 were respectively captured during and after a period of intense, heavy rainfall in the Krugersdorp region which increased the flow levels in the river and also possibly the height of the subterranean water table and the subsequent reduction in the any abstractions between the two stations.

- The most recent data on groundwater elevation provided for the south-western portion of the property are as at October 2020. The groundwater elevation in the south-western portion of the property (the Zwartkrans Basin), where the allogenic recharge component is greatest, reflects minimal change in the groundwater rest level elevation in the southern segment, indicating very stable groundwater conditions in the region during the reporting period. A slight increase is, however, evident in groundwater level elevations in the central and the northern segments of the property.

- The recent September 2020 groundwater elevation of 1438.17 m amsl illustrate an approximate 0.5 m increase in the groundwater level since September 2019, which represents the lowest groundwater elevation recorded during the 10-year period between February 2010 and March 2020.

- The highest discharges were measured for the Zwartkrans, Nouklip and Nash springs, respectively yielding 34.96 ML/d, 9.69 ML/d and 13.33 ML/d, however it should be noted that the Zwartkrans spring discharge is regarded as highly uncertain. It remains evident that significant variability exists in the discharge measurements. No direct quantification has been conducted regarding the response of the individual springs to changes in rainfall and discharge across the COH WHS property; this exercise would require quantification of all the processes impacting channel transmission losses including water uses and rate of evapotranspiration.

- Due to the South African national lockdown restrictions, the DWS were unable to collect groundwater samples in time for the results to be included in the April 2020 to September 2020 *status quo* report, therefore the most recent chemical analyses of groundwater in the south-western portion of the property from March 2020 are provided. 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 March 2020 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. Decreasing sulphate concentrations are observed in the central segment at the gauging stations A2N0600, GP00309, GP00312 and GP00313 e.g. the sulphate concentrations at A2N0600 and GP00312 respectively decreased from 770 SO_4/L to 721 SO_4/L and 1300 SO_4/L to 1220 SO_4/L.

- 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. Several accounts of obnoxious odours, murky water and foam seen in the Blougat Spruit and Bloubank Spruit rivers have been received from local residents of the COH WHS property and reported to the MA, however the source of water pollution has not been verified. It can be argued that the municipal wastewater poses a dire threat to the quality of water and subsequently fitness for use of receiving surface water resources as does mine water. This effect and impact extend into the Crocodile River - the main stem of the Bloubank Spruit.

- With the exception of the July 2020 pH level of 4.7, none of the variables reported for the Sterkfontein Cave fall outside of the respective SANS (2015) 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. Since March 2020, the quantity of total coliform bacteria decreased from 547.5 MPN/100ml to 32.3 MPN/100ml and the *E. coli* decreased from 3.1 MPN/100ml to <1.0 MPN/100ml.

- The water from the major dolomitic springs is of excellent quality for all the parameters (i.e. pH, SEC, Ca, Mg, Na, K, Cl, SO_4, HCO_3, NO_3+NO_2, Si, Fe, Mn and Al) reported for both the March 2020 and September 2020 sampling results, with the exception of the Zwartkrans, Aquamine, Tweefontein and Cradle springs. The chemical results from the Zwartkrans Spring show probable mine water impact as evidenced by the high sulphate content and the Aquamine, Tweefontein and Cradle springs show pronounced concentrations of manganese, iron and aluminium. 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 limit of <10 MPN/100ml. 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 *E. coli* levels across all the sample results have, however, decreased since March 2020.

- A comparison with the previous results from the macroinvertebrate monitoring survey reveals a significant deterioration in the general ecological health of both the generally natural / moderately modified Skeerpoort River and the severely impacted Bloubank Spruit system. This is best evidenced by the E/F ecological categories obtained for both the Skeerpoort River sites Bloubank Spruit sites. Effluent pollution at the BB@M and BB@NOE sites has clearly deteriorated the health of both sites with ASTP being at lowest compared to all sampling periods. While for S@HTL and S@NSP, the destruction of riparian ecosystem and aquatic habitat particularly aquatic vegetation has also further influenced the River Health Category relative to the previous sampling periods.

- No acute hazard was observed in all the tests with the exception of BB@M and BB@NOE (*S. Capricornatum* test). Samples at BB@M were classified as toxic due to growth inhibition of 20% or more being detected which indicated the slight acute hazard, while BB@NOE remains a eutrophication potential.To give a clear indication of the toxicity of the water from four sites a chronic assessment test might be required.

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. However, one of the major issues encountered during the April 2019 to September 2020 reporting period, was the inconsistency in data records from the DWS. Personnel from the DWS attributed the suspension of scheduled data updates to financial challenges and the restrictions of the South African national lockdown which made it difficult for relevant directorates to perform regular data collections, and conduct the requisite maintenance of the data collection platforms.

8 ACKNOWLEDGEMENTS

The compilation of this report has been made possible in part by the continued assistance of DWS staff Messrs Theo Moolman and Nico de Meillon in the collection of field data. The services of the DWS staff Mr Divan van Niekerk (Mine Water Quality Management), Mr Frans Le Roux (Hydrometry: A2H049) Ms's Marica Erasmus and Elna Vermaak (Resource Quality Information Services), Ms Busisiwe Sekgomane (PDA Requests) and Ms Edeline Mashabela (Hydstra Support) in the provision of water resources monitoring data is also recognised and appreciated. Gratitude is extended to Ms Karen du Plessis of Sibanye-Stillwater for the provision of mine water and rainfall data associated with the mine area. Finally, the goodwill and cooperation of numerous landowners (too many to list individually) in granting permission to access their properties for the purpose of collecting water resource data, is gratefully acknowledged.

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

9 REFERENCES

Bredenkamp, D.B., van der Westhuizen, C., Wiegmans, F.E. and Kuhn, C.M. 1986. *Ground-water supply potential of dolomite compartments west of Krugersdorp.* Report GH3440. Vols. 1 & 2. Department of Water Affairs & Forestry. Pretoria. 81 pp.

Bugan, R.D.H., Mvandaba, V., Kapangaziwiri, E.; Hill, L. and McMillan, P.H. 2018. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2018.* Report no. CSIR/NRE/WR/IR/2018/0084/C. Council for Scientific & Industrial Research. Pretoria. 40 pp.

Bugan, R.D.H., Mvandaba, V., Kapangaziwiri, E.; Hill, L. and McMillan, P.H. 2019. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to March 2019.* Report no. CSIR/NRE/WR/ER/2019/0022/B. Council for Scientific & Industrial Research. Pretoria. 40 pp.

Chakona, A. Phiri, C.C. Magadza, C.H.D. Brendonck, L. 2008. The Influence of habitat structure and flow permanence on macroinvertebrate assemblages in temporary rivers in north western Zimbabwe. *Hydrobiologia,* 607:199-209.

Clarke, A., MacNally, R., Bond, N. and Lake, P.S. 2008. Macroinvertebrate Diversity in Headwater Streams: A Review. *Freshwater Biology*, 53 (9): 1707-1721.

Cummins, K.W., Merritt, R.W. and Andrade, P.C.N. 2005. *The use of invertebrate functional groups to characterise ecosystem attributes in selected streams and rivers in south Brazil.* Studies on Neotropical Fauna and Environment. Vol. 40. No. 1. pp. 69-89.

Dallas, H.F. 2007. *River Health Programme: South African Scoring System (SASS) data interpretation guidelines (Draft report).* Prepared for the Institute of Natural Resources and the Resource Quality Services River Health, Department of Water Affairs and Forestry. Pretoria/Cape Town.

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

DEA 2018. *State of Conservation report to UNESCO on Decision 41 Com 7b.72 in regard to the Fossil Hominid Sites of South Africa World Heritage Site (The Sterkfontein, Swartkrans, Kromdraai and Environs Component) (C 915 BIS).* Department of Environmental Affairs. 37 pp.

Dickens, C.W.S. and Graham, P.M. 2002. *The South African Scoring System (SASS) Version 5 rapid bio assessment method for rivers.* African Journal of Aquatic Science. Vol. 27. No. 1. pp. 1-10.

Diković, S. and Koželj, A. 2015. Groundwater quality in changing hydrological conditions and comparison with the results of long-term monitoring. In Hajna, N.Z, Ravbar, N., Rubinić, J. and Petrič, M. (Eds.), *Life and Water on Karst: Monitoring of transboundary water resources of Northern Istria*. pp 105-122. Ljubljana, Slovenia: Založba ZRC.

DWA 2011. *Mine water management in the Witwatersrand gold fields with special emphasis on acid mine drainage.* Report to the Inter-Ministerial Committee on Acid Mine Drainage. 128 pp.

Fourie, H.E., Thirion, C. and Weldon, C.W. 2014. *Do SASS5 scores vary with season in the South African Highveld? A case study on the Skeerpoort River, North West Province, South Africa.* African Journal of Aquatic Science. Vol. 39. No. 4. pp. 369-376.

Head, T., 2020. Watch: Gauteng floods – Johannesburg plunged underwater on Friday. *The South African*, 28 February 2020. Available: https://www.thesouthafrican.com/news/weather/gauteng-floods-johannesburg-weather-friday-28-february-traffic-latest/ (Accessed 13 May 2020)

Hill, L., McMillan, P. and Cheng, P. 2014. *An assessment of the biotic response in streams of the Western Basin that receive neutralised acid mine drainage.* Report no. CSIR/NRE/WR/IR/2014/0021/B. Pretoria. 26 pp.

Hobbs, P.J. (Ed.) 2011. *Situation assessment of the surface water and groundwater resource environments in the Cradle of Humankind World Heritage Site.* Report prepared for the Management Authority. Department of Economic Development. Gauteng Province. South Africa. 424 pp.

Hobbs, P.J. 2012. *Pilot implementation of a surface water and groundwater resources monitoring programme for the Cradle of Humankind World Heritage Site: Status report for the period April to September 2012.* Report no. CSIR/NRE/WR/ER/2012/0088/B. Council for Scientific & Industrial Research. Pretoria. 39 pp.

Hobbs, P.J. 2013a. *Pilot implementation of a surface water and groundwater resources monitoring programme for the Cradle of Humankind World Heritage Site: Situation assessment and status report for the period April 2012 to March 2013.* Report no. CSIR/NRE/WR/ER/2013/0023/B. Council for Scientific & Industrial Research. Pretoria. 48 pp.

Hobbs, P.J. 2013b. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2013.* Report no. CSIR/NRE/WR/ER/2013/0083/A. Council for Scientific & Industrial Research. Pretoria. 47 pp.

Hobbs, P.J. 2014a. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2013 to March 2014.* Report no. CSIR/NRE/WR/IR/2014/0049/A. Council for Scientific & Industrial Research. Pretoria. 42 pp.

Hobbs, P.J. 2014b. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April* *to September 2014.* Report no. CSIR/NRE/WR/ER/2014/0063/A. Council for Scientific & Industrial Research. Pretoria. 55 pp.

Hobbs, P.J. 2015a. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2014 to March 2015.* Report no. CSIR/NRE/WR/ER/2015/0026/A. Council for Scientific & Industrial Research. Pretoria. 53 pp.

Hobbs, P.J. 2015b. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2015.* Report no. CSIR/NRE/WR/ER/2015/0067/A. Council for Scientific & Industrial Research. Pretoria. 57 pp.

Hobbs, P.J. 2016a. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2015 to March 2016.* Report no. CSIR/NRE/WR/ER/2016/0058/A. Council for Scientific & Industrial Research. Pretoria. 42 pp.

Hobbs, P.J. 2016b. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2016.* Report no. CSIR/NRE/WR/ER/2016/0073/A. Council for Scientific & Industrial Research. Pretoria. 37 pp.

Hobbs, P.J. 2017a. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2016 to March 2017.* Report no. CSIR/NRE/WR/ER/2017/0008/A. Council for Scientific & Industrial Research. Pretoria. 28 pp.

Hobbs, P.J. 2017b. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2017.* Report no. CSIR/NRE/WR/ER/2017/0072/A. Council for Scientific & Industrial Research. Pretoria. 26 pp.

Hobbs, P.J. 2017c. *TDS load contribution from acid mine drainage to Hartbeespoort Dam, South Africa.* Water SA. Vol 43. No. 4. 12 pp.

Hobbs, P.J. and de Meillon, N. 2017. *Hydrogeology of the Sterkfontein Cave System, Cradle of Humankind, South Africa.* South African Journal of Geology. Vol 120. No. 3. pp. 403-420.

Hobbs, P.J., Hill, L. and McMillan, P.H. 2018. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2018.* Report no. CSIR/NRE/WR/ER/2018/0010/A. Council for Scientific & Industrial Research. Pretoria. 40 pp.

Karaouzas, I. Gritzalis, K. Skoulikidis, N. 2007. Land use effects on macroinvertebrates assemblages and stream quality along an agricultural river basin. *Environmental Bulletin* **16**(6):645-653.

McMillan, P.H. 1998. *An integrated habitat assessment system for the rapid biological assessment of rivers and streams*. Internal STEP report no. ENV-P-I 98088. CSIR. 37 pp.

Mvandaba, V. and Kapangaziwiri, E. 2019. *Surface Water and Groundwater Resources Monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa.* Progress Report No.27, GT/GDED/092/2017. CSIR, Pretoria.

Mvandaba, V., Kapangaziwiri, E. and Shadung, J. 2019. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April to September 2019.* Council for Scientific & Industrial Research. Pretoria. 77 pp.

Mvandaba, V., Kapangaziwiri, E. and Shadung, J. 2020. *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2019 to March 2020.* Council for Scientific & Industrial Research. Pretoria. 77 pp.

Nkanjeni, U. 2019. 'Dramatic scenes of chaos in parts of Gauteng after flooding', *Times Live*, 10 December. Available at: https://www.timeslive.co.za/news/south-africa/2019-12-10-dramatic-scenes-of-chaos-in-parts-of-gauteng-after-flooding/. (Accessed 13 May 2020).

Ramaphosa, C. 2020. *Update on the Coronavirus COVID-19 lockdown* (Transcript). Available: https://www.gov.za/speeches/president-cyril-ramaphosa-update-coronavirus-covid-19-lockdown-30-mar-2020-0000 (Accessed 27 May 2020).

SANS 2015a. *South African National Standard (SANS) 241-1. Drinking water*. *Part 1: Microbiological, physical, aesthetic and chemical determinands*. Edition 2. Standards South Africa. Pretoria. 14 pp.

SANS 2015b. *South African National Standard (SANS) 241-2. Drinking water*. *Part 2: Application of SANS 241-1*. Edition 2. Standards South Africa. Pretoria. 14 pp.

SAWS (South African Weather Services), 2019. *Heavy downpours expected over eastern, northern and central parts in South Africa from tonight until Thursday, 5 December 2019*. Media Release, 3 December 2019. Available at: https://www.weathersa.co.za/Documents/Corporate/Medrel3Dec2019%20.pdf (Accessed 13 May 2020).

Sheik, C.S. Mitchell, T.W. Rizvi, F.Z. Rehman, Y. Faisal, M. Hasnain, S. McInerney, M.J. Krumholtz, L.R. 2012. Exposure of soil microbial communities to chromium and arsenic alters their diversity and structure. Available: https://doi.org/10.1371/journal.pone.0040059 (Accessed 10 October 2020).

Slabbert, L. 2004. *Methods for direct estimation of ecological effect potential (DEEEP).* Report no.: 1313/1/04. Water Research Commission, Pretoria. 100 pp.

Stumpf, S., Valentine-Darby, P. and Gwilliam, E. 2009. *NPS inventory and monitoring program.* Aquatic Macroinvertebrates – Ecological role. US National Park Service.

USEPA 2002. *Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms.* Fifth Edition. Report no.: EPA-821-R-02-012. U.S. Environmental Protection Agency. USA.

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. Although much of the surrounding area is natural and undisturbed, several riparian trees were observed to be chopped and cut down. 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	02/03/2020	15/09/2020
Turbellaria	40	3	1			
Oligochaeta		1	2			
Potamonautidae	3	3	12	11	3	7
Hydracarina	40	1	4			
Baetidae	80	240	80	109	88	120
Caenidae	30	20	6	3		11
Prosopistomatidae					8	
Teloganodidae	2		2	12		
Heptageniidae	10	40	30			
Leptophlebiidae	240	100	60			
Tricorythidae	1		4			
Chlorocyphidae	20	20	15			
Coenagrionidae		2		4	4	4
Lestidae	3	1	6			
Aeshnidae	2	15	20		1	5
Gomphidae	1	2	2			
Libellulidae	1		1	3		1
Pyralidae			1			
Belostomatidae	30	2	60			
Corixidae	40	4	2			1
Gerriae	2				10	
Naucoridae			1			
Nepidae	2	6				
Notonectidae			30		9	120
Pleidae	20	15	30	101	180	
Veliidae	40	1	2			
Hydropsychidae	6	2	1	80	10	
Philopotamidae		2	30			
Dytiscidae		3				6
Psychomyiidae					7	
Elmidae	20	8	10	4		
Gyrinidae	2	1				
Libellulidae	40	20	10	4		
Ceratopogogonidae		2		3	7	4
Athericidae	5	6				
Chironomidae			3	20	44	4
Dixidae	2	2				
Simuliidae	1	1	12		28	4
Tabanidae		1				4
Tipulidae						20
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	02/03/2020	14/09/2020
Oligochaeta	1		1		45	
Potamonautidae	8		8		5	1
Atyidae					8	
Palaemonidae					120	
Hydracarina	1	4		3		
Plecoptera					1	
Baetidae	40	30	6	5	10	29
Notonemouridae					1	
Caenidae	6	4	30	3		20
Teloganodidae				5	1	
Leptophlebiidae		10				
Tricorythidae		6				
Chlorocyphidae		1	1			
Calopterygidae					1	
Coenagrionidae	12		3		1	
Aeshnidae	1			12	12	
Gomphidae	16	20	50			14
Pyralidae	1		1			
Libellulidae					1	
Corixidae	5	100	20			1
Gerridae	5			4	1	1
Hydrometridae					1	14
Naucoridae			12			
Notonectidae				3	1	
Pleidae	1	2	6	107		
Veliidae	10	15	10	6	88	11
Ecnomidae					7	
Hydropsychidae		30	3		9	
Psychmyiidae				3		3
Gyrinidae	12					
Psephenidae	6	1	2			
Ceratopogonidae			2			
Chironomidae	3			6	8	4
Dixidae					8	9
Simuliidae		12		12	9	
Tabanidae	1		3			9
Tipulidae		2				110
Ancylidae	1		2			
Planorbinae*		1				

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	02/03/2020	16/09/2020
Turbellaria		1	8	4	15	44
Leeches	1		1			
Oligochaeta		1		6	2	
Crustacea	3	1	2	6		
Potamonautidae	40	40		8		
Baetidae		40	10	12	19	
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	38	
Psychomiidae			3	15		
Gyrinidae			1			
Ceratopogonidae				161	120	1
Chironomidae				33	219	330
Culicidae					180	
Simuliidae				29	5	
Physidae					7	7
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	16/09/2020
Turbellaria		1		4	33
Annelida					4
Leeches		1			
Oligochaeta	2			6	6
Crustacea	2	1	3	6	
Potamonautidae	80	40	4	8	3
Baetidae	10	40	30	12	24
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	6
Psychomiidae	40	100	40	15	
Gyrinidae	1				6
Ceratopogonidae	50	200	60	161	3
Chironomidae				33	220
Culicidae					
Simuliidae				29	
Syrphidae					17
Ancylidae				4	1

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).

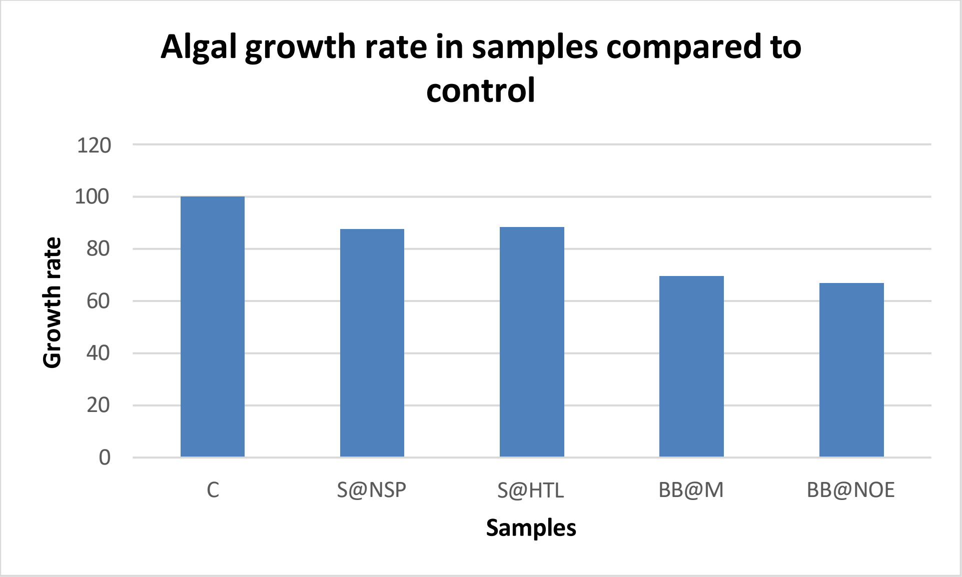
Sites	Time	Temperature	pH	EC	Oxygen
Control	0	22.9	8.01	298	7.88
	48	22.4	8.15	277	6.45
S@HTL	0	22.9	7.55	401	7.93
	48	22.0	7.18	445	7.81
S@HTC	0	22.3	7.58	333	7.90
	48	22.4	7.77	385	7.25
BB@M	0	22.6	7.20	1389	7.45
	48	22.0	7.39	1402	7.25
BB@NOE	0	22.8	7.54	1258	7.39
	48	22.9	7.78	1316	7.49

PREVIOUS TOXICITY TESTING RESULTS

V. fischeri test (March 2020)

15-minutes for the V. fischeri luminescence inhibition (-) / stimulation (+) test after a 15-minute exposure period were as follows: S@HTL test sample: 4.36%; S@NSP test sample: 0.98%; BB@M test sample: 24.06% and B@NOE test sample: 20.18%. Inhibition of > 20% indicates toxicity and stimulation of > 20% indicates potential eutrophication. In all the sites, there was an indication of potential eutrophication in two sites namely; BB@M and B@NOE as stimulation exceeded 20%. Tests were accepted as the% CV was > 3%.

S. Capricornatum test (March 2020)



D. magna test

Table 16 B.2a Results of the *D. Magna* screening assays expressed as percentage mortality after 24 and 48 hours (September 2019).

Sample	Time (hrs)	Mortality (No. of organisms)	Mortality (%)
CONTROL	24	0	0
	48	0	0
S@NSp	24	0	0
	48	5	25
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 (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.2c 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.2d 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 17 B.3b. Physicochemical parameters per sample measured at the start and end of the tests (September 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.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).

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