

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 2023 TO SEPTEMBER 2023**

PROJECT No.

**GT/WHS/021/2022**

AUTHORS

**V. Mvandaba and J. Shadung**

DATE

**08 November 2023**

REPORT No.

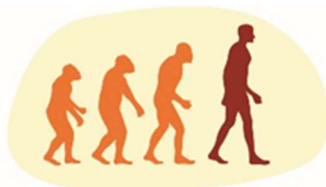
*TBC*

PREPARED FOR

Management Authority  
Cradle of Humankind World Heritage Site  
Gauteng Department of Economic Development

PREPARED BY

Water Centre  
Smart Places Cluster  
Council for Scientific and Industrial Research



**cradle of humankind**  
world heritage site

THIS PAGE HAS BEEN LEFT BLANK AND  
UNNUMBERED TO ACCOMMODATE  
DUPLEX (BACK-TO-BACK) PRINTING

PLEASE DISCARD WHEN PRINTING  
ON SINGLE PAGE SETTING

## SUMMARY

Following the conclusion of the bid GT/WHS/021/2022, the Management Authority (MA) of the Cradle of Humanity World Heritage Site (COHWHS) selected the CSIR as the preferred service provider to carry out the water resources monitoring programme of the site. The programme commenced in 2012 as a follow-up to project BIQ005/2008, which was commissioned to create a water resources monitoring programme for the COHWHS property. Since its commencement, eighteen (18) biannual *status quo* reports have been produced, including those compiled during the 2017 -2020 phase of the monitoring programme under the project GT/GDED/092/2017. This report, which spans the months of April 2023 to September 2023, is the nineteenth (19<sup>th</sup>) of its kind. Notably, there exists a 2-year gap in the monitoring programme between the finalization and closure of project GT/GDED/092/2017 in September 2020 and the commencement of the monitoring programme under project GT/WHS/021/2022 in September 2022. Although efforts have been made to 'close the gap' by way of data collection from relevant stakeholders who continued their respective monitoring activities during this period, there remain gaps of permanently missing data which may compromise the holistic understanding of the COHWHS hydro(geo)logical environment and the various linkages between its surface water and groundwater systems.

Nonetheless, the assessment of impacts on the water resources environment of the COHWHS property takes on a comprehensive approach noting the conceptual hydrophysical and hydrochemical model developed for the COHWHS property in the Situation Assessment Report (Hobbs, 2011) and pays particular attention to those resources that are conceptually understood to be most at risk. In the context of the COHWHS, focus is placed on wastewater sources of which mine water (*aka* acid mine/rock drainage) rising in the Western Basin, and local 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 which remains a primary concern of UNESCO's World Heritage Centre as it informs the Outstanding Universal Value (OUV) of the COHWHS.

A summary of the current *status quo* of the water resources environment of the COHWHS is as follows:

- During the 13 years spanning from 2009 to 2022, the wettest hydrological years were 2020 and 2023. Specifically, the wet season rainfall measured 718 mm and 1028 mm for the HDS station and 864 mm and 414 mm for the SC station during these respective years.
- No rainfall records are available for the SC station between January 2023 and September 2023 due to instrument and software failure.
- The rainwater chemistry continues to confirm the low salinity and generally acidic nature of rainwater in the region. However, no records have been available for the HDS station since 2019.
- The 2023 hydrological year recorded a discharge of ~77.5 Mm<sup>3</sup> for the Bloubankspruit, which is the maximum discharge recorded during the period of October 1972 to September 2023.
- Statistics confirm that the frequency of heavy rainfall events in the COHWHS region has increased since 2010.
- The pattern of the pH values recorded at the Hippo Dam and F11S12 stations (on the course of the Tweelopiespruit) between October 2022 and September 2023 illustrates a gradually increasing trend for both stations, ranging from 3.5 to 8.8 and 4.3 to 6.8, respectively. However, a lower range of pH values (below 6) for the F11S12 station were recorded between December 2022 and June 2023, indicating acidic conditions caused by apparent discharge of mine water. A yellow precipitate was

noted on the rocks lining the riverbed at the Pinocchio' Farm and Malmani Road (Rietspruit) sites.

- Between the period of October 2022 and September 2023, the sulphate values have respectively oscillated between 1420 mg/L and 2910 mg/L at the Hippo Dam and between 1180 mg/L and 2270 mg/L at F11S12.
- The most recent microbiological analyses of surface water samples collected at BG@N14, BB@M, BB@NOE, MRd and Pinocchio's Farm confirm the faecal contamination of surface water along the Blougatspruit, Bloubankspruit, Rietspruit and Tweelopiespruit, respectively. The most severe pollution is noted at BG@N14 and BB@M where the MPN count for *E.coli* consistently exceeds 2419.6 per 100mL.
- Water samples collected upstream of Percy Stewart WWTW indicated significantly lower *E.coli* counts compared to those water samples collected downstream of the WWTW.
- Recorded groundwater level elevations illustrate a slight decrease in the groundwater level elevations in the northern and central segments between March 2023 and September 2023. Barring the marked decrease in the groundwater level for station GP00308, the groundwater elevations in the southern segment display relatively stable to minimally decreasing values.
- In September 2023, the groundwater elevation of the Sterkfontein Cave lake stood at 1439.70 m amsl, indicating a decrease of approximately 0.52 m compared to the elevation recorded in March 2023.
- The highest discharges were recorded at the Zwartkrans, Nash, and Nouklip springs, producing approximately 9.44 ML/d, 18.64 ML/d, and 10 ML/d, respectively, in September 2023.
- The trendlines from July 2016 to March 2023 indicate that sulphate levels in ambient groundwater have generally reduced at the southwestern (ingress) end of the impacted zone but are still increasing at the north-eastern (discharge) end. There is however variability at individual stations and typically the sulphate values at the north-eastern end of the study area are lower than at the sites closer to the mine locations.
- The Sterkfontein Cave has remained inaccessible since March 2023. The management personnel for the Sterkfontein Caves property indicated that the roof of the Cave collapsed following the heavy rainfall experienced between in the early months of the wet season, November 2022 to February 2023.
- 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<sub>4</sub>, HCO<sub>3</sub>, NO<sub>3</sub>+NO<sub>2</sub>, Si, Fe, Mn and Al) reported for September 2022 to March 2023 sampling results, with the exception of the Zwartkrans and Aquamine springs. The chemical results from the Zwartkrans Spring show probable mine water impact as evidenced by the high sulphate content and the Aquamine spring show pronounced concentrations of manganese, iron and aluminium, which may reflect the interaction with the surrounding geology.
- Across all the spring sample results, the microbiological quality of the water is compromised by the total coliform bacteria and *E.coli* which far exceeds the standard health-related limits.
- A comparative analysis with prior findings from the macroinvertebrate monitoring survey highlights a persistent decline in the overall ecological well-being of the heavily affected Bloubankspruit

systems. This degradation is particularly evident in the ecological categories of E/F obtained for the BB@M site in both June and September 2023. In contrast, a noteworthy enhancement in the overall river health and ecological classification has been observed at both Skeerpoort River sites, namely S@NSp and S@HTL.

The findings presented in this report affirm and strengthen the conceptual hydrophysical and hydrochemical model previously developed for the Cradle of Humanity World Heritage Site (COHWHS) property, as outlined by Hobbs in 2011. The water resources monitoring results documented herein provide valuable empirical support, reinforcing the existing theoretical framework and contributing to a more comprehensive understanding of the hydrological dynamics within the COHWHS property.

# CONTENTS

Page

SUMMARY .....	i
SYMBOLS, ACRONYMS & ABBREVIATIONS .....	vi

# **WATER RESOURCES STATUS REPORT FOR THE PERIOD APRIL 2023 TO SEPTEMBER 2023**

<b>1</b>	<b>INTRODUCTION, BACKGROUND &amp; CONTEXT .....</b>	<b>1</b>
<b>2</b>	<b>TIMELINE OF KEY EVENTS .....</b>	<b>2</b>
<b>3</b>	<b>RAINFALL .....</b>	<b>4</b>
<b>3.1</b>	<i>Quantity .....</i>	<i>4</i>
<b>3.2</b>	<i>Quality .....</i>	<i>5</i>
<b>4</b>	<b>SURFACE WATER HYDROLOGY.....</b>	<b>7</b>
<b>4.1</b>	<i>Physical Hydrology .....</i>	<i>7</i>
<b>4.2</b>	<i>Chemical Hydrology.....</i>	<i>10</i>
<b>4.4</b>	<i>Salt Load.....</i>	<i>21</i>
<b>5</b>	<b>GROUNDWATER HYDROLOGY.....</b>	<b>24</b>
<b>5.1</b>	<i>Physical Hydrogeology.....</i>	<i>24</i>
<b>5.2</b>	<i>Chemical Hydrogeology .....</i>	<i>33</i>
<b>6</b>	<b>RIVER HEALTH ASSESSMENT .....</b>	<b>41</b>
<b>6.1</b>	<i>Assessment &amp; Data Analysis .....</i>	<i>44</i>
<b>6.2</b>	<i>Macroinvertebrate Biomonitoring Results.....</i>	<i>45</i>
<b>6.3</b>	<i>Toxicity Testing Results .....</i>	<i>50</i>
<b>6.2.3</b>	<i>Hazard classification for natural waters .....</i>	<i>51</i>
<b>6.2.4</b>	<i>Discussion on River Health.....</i>	<i>53</i>
<b>7</b>	<b>DISCUSSION &amp; CONCLUSIONS.....</b>	<b>53</b>
<b>8</b>	<b>ACKNOWLEDGEMENTS .....</b>	<b>54</b>
<b>9</b>	<b>REFERENCES.....</b>	<b>55</b>
	<b>ANNEXURE A.....</b>	<b>60</b>
	<b>ANNEXURE B .....</b>	<b>67</b>
	<i>Toxicity assays .....</i>	<i>67</i>
	<i>Phytotoxicity test.....</i>	<i>69</i>
	<i>Ostracod test exposure .....</i>	<i>69</i>
	<i>Hazard classification for natural waters .....</i>	<i>69</i>

**FIGURES**

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

**Figure 2** Timeline of key events relevant to the project and this report.....3

**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. ....5

**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 .....6

**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..... 6

**Figure 6** Graph of Bloubankspruit annual discharge gauged at station A2H049 for the period October 1972 (a<sub>h</sub> 1973) to August 2020 (a<sub>h</sub> 2020) .....9

**Figure 7** Long-term monthly hydrograph of the Bloubankspruit at station A2H049 for the period October 1972 to August 2020 (latest data as at September 2020). ....10

**Figure 8** Graph of streamflow and influent losses to the karst aquifer in the lower Riet Spruit valley ..... 12

**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 ..... 13

**Figure 10** Locality map of surface water quantity and quality monitoring stations..... 15

**Figure 11** pH pattern of Tweelopiespruit surface water in the period September 2004 to August 2020..... 16

**Figure 12** Specific electrical conductivity pattern of Tweelopiespruit surface water in the period September 2004 to August 2020 ..... 17

**Figure 13** Sulphate pattern of Tweelopiespruit surface water in the period September 2004 to August 2020 ..... 17

**Figure 14** Iron pattern of Tweelopiespruit surface water in the period June 2009 to August 2020..... 18

**Figure 15** Manganese pattern in Tweelopiespruit surface water in the period June 2009 to August 2020..... 18

**Figure 16** Uranium pattern in Tweelopiespruit surface water in the period June 2009 to August 2020..... 19

**Figure 17** Murky water with foam was observed along the causeway of the Bloubankspruit in December 2019 (left) and downstream at Bloubankspruit in March 2020 (right) .....22

**Figure 18** Long-term (June 1979 to March 2018) monthly TDS load pattern and trend in the Bloubankspruit at station A2H049.....23

**Figure 19** Long-term (June 1979 to April 2018) monthly SO<sub>4</sub> load pattern and trend in the Bloubank Spruit at station A2H049.....24

**Figure 20** Long-term (June 1979 to March 2018) trend in the SO<sub>4</sub>: TDS ratio at station A2H049 ...24

**Figure 21** Pattern and trend of the SO<sub>4</sub>: TDS ratio at station A2H049 since the start of mine water decant in the Western Basin in mid-2002.....25

Figure 22	Monthly SO <sub>4</sub> concentration and load pattern and trend in the Bloubankspruit at station A2H049 since mid-2002.....	25
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 .....	27
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.....	28
Figure 25	A significant difference in the groundwater level of the Sterkfontein cave lake in September 2018 (left) and September 2019 (right) was observed. ....	28
Figure 26	The concrete furrow where water from the Broederstroom spring collects as it flows downstream .....	31
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 .....	34
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 .....	35
Figure 29	Distribution of sulphate levels in groundwater of the Zwartkrans Basin in July 2016 (1 <sup>st</sup> value), February 2017 (2 <sup>nd</sup> value), November 2017 (3 <sup>rd</sup> value), March 2018 (4 <sup>th</sup> value), June 2018 (5 <sup>th</sup> value), September 2018 (6 <sup>th</sup> value), December 2018 (7 <sup>th</sup> value), March 2019 (8 <sup>th</sup> value), June 2019 (9 <sup>th</sup> value), September 2019 (10 <sup>th</sup> value), December 2019 (11 <sup>th</sup> value) and March 2020 (12 <sup>th</sup> 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) .....	36
Figure 30	Map showing the regional geology of the study area, dolomitic compartment boundaries, groundwater flow vectors and the major dolomitic springs .....	38
Figure 31	Map showing sites of relevance to the river health assessment .....	41
Figure 32	Percentage growth rate of <i>S. capricornutum</i> in test samples (undiluted), relative to the control. ....	48

## TABLES

Table 1	Composite rainwater chemistry in the south-western portion of the property in the period late-March 2019 to early-March 2020 .....	7
Table 2	Statistical analysis of Bloubankspruit monthly discharge data gauged at station A2H049 in the period October 1972 to August 2020 (latest data as at September 2020) .....	8
Table 3	Summary statistics of period-related surface water chemistry variability in the Tweelopiespruit.....	20
Table 4	Synoptic overview of Bloubankspruit 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) .....	21
Table 5	Dolomitic spring discharge measured in March 2020 and September 2020.....	32

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.....	37
Table 7	Water chemistry results of samples collected at the major dolomitic springs during March 2020 and September 2020 .....	39
Table 8	River Health Classification (Dallas, 2007) .....	42
Table 9	Synoptic river health assessment outcome for September 2020 .....	42
Table 10	Comparison of present biomonitoring results for site S@NSp with previous results ....	43
Table 11	Comparison of present biomonitoring results for site S@HTL with those of the Fourie <i>et al.</i> (2014) “site B” results .....	44
Table 12	Comparison of present biomonitoring results for site BB@M with those of the Hill <i>et al.</i> (2014) study .....	45
Table 13	Comparison of present biomonitoring results for site BB@NOE with those of the Hill <i>et al.</i> (2014) study.....	46
Table 14	Results of the <i>D. Magna</i> screening assays expressed as percentage mortality after 24 and 48 hours. ....	48
Table 15	Hazard classification system for screening tests (Persoone <i>et al.</i> , 2003). ....	49
Table 16 B.2a	Results of the <i>D. Magna</i> screening assays expressed as percentage mortality after 24 and 48 hours (September 2019) .....	69
Table 17 B.3b	Physicochemical parameters per sample measured at the start and end of the tests (September 2019) .....	70

## ANNEXURES

- A Description of the aquatic biomonitoring sites
- B Toxicity testing results

## SYMBOLS, ACRONYMS & ABBREVIATIONS

~	approximately
>	greater than
<	less than
%	per cent (parts per hundred)
%ile	percentile
°C	degree(s) Celsius
$\Delta h$	change in head
$a_h$	hydrological year
<i>aka</i>	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.	<i>Circa</i> (about)
COHWHS	Cradle of Humankind World Heritage Site ( <i>aka</i> '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)

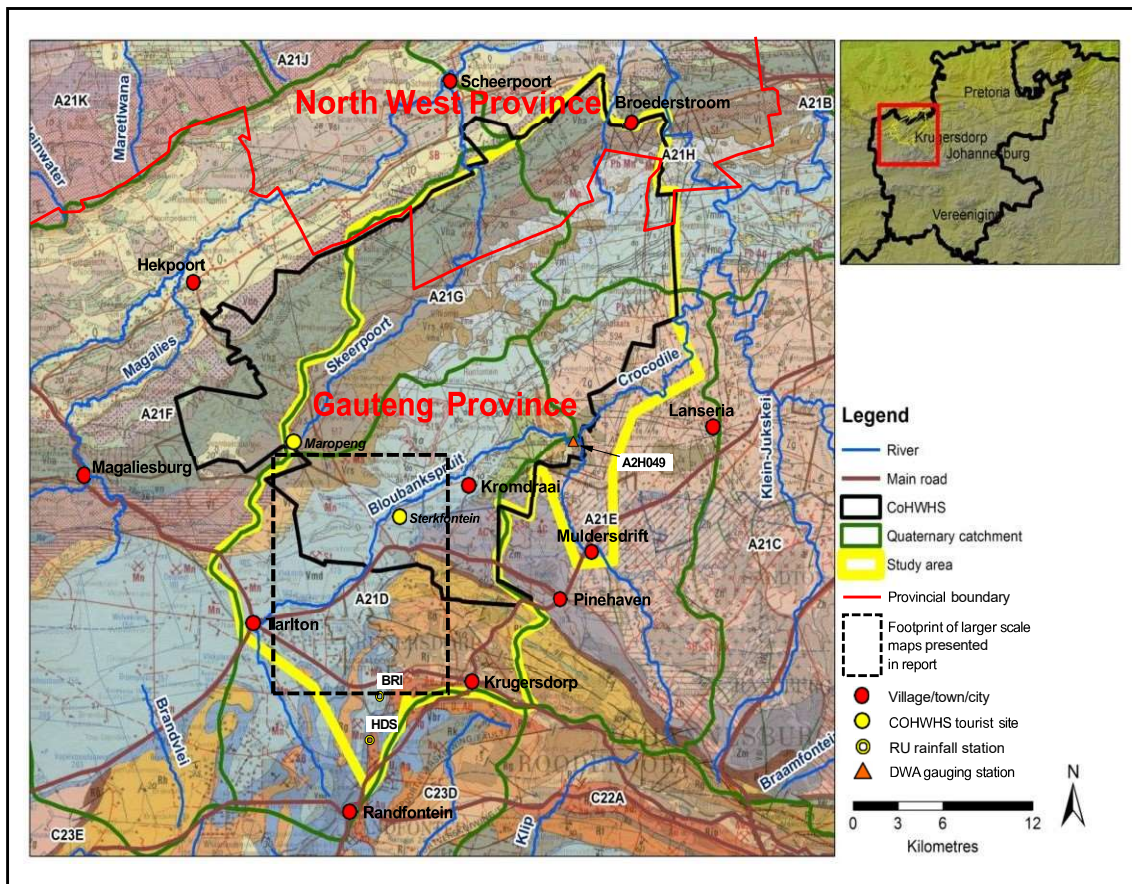
m <sup>3</sup> /s	cubic metre(s) per second
Mm <sup>3</sup>	million cubic metre(s)
Mm <sup>3</sup> /a	million cubic metres per annum
MPN	most probable number
mS/m	milli Siemens per metre
n	count
n.s.	not specified
pp	pages
Q <sub>50</sub>	discharge exceeded 50% of the time (50%ile or median)
REGM	Randfontein 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

THIS PAGE HAS BEEN LEFT BLANK AND  
UNNUMBERED TO ACCOMMODATE  
DUPLEX (BACK-TO-BACK) PRINTING

PLEASE DISCARD WHEN PRINTING  
ON SINGLE PAGE SETTING

# 1 INTRODUCTION, BACKGROUND & CONTEXT

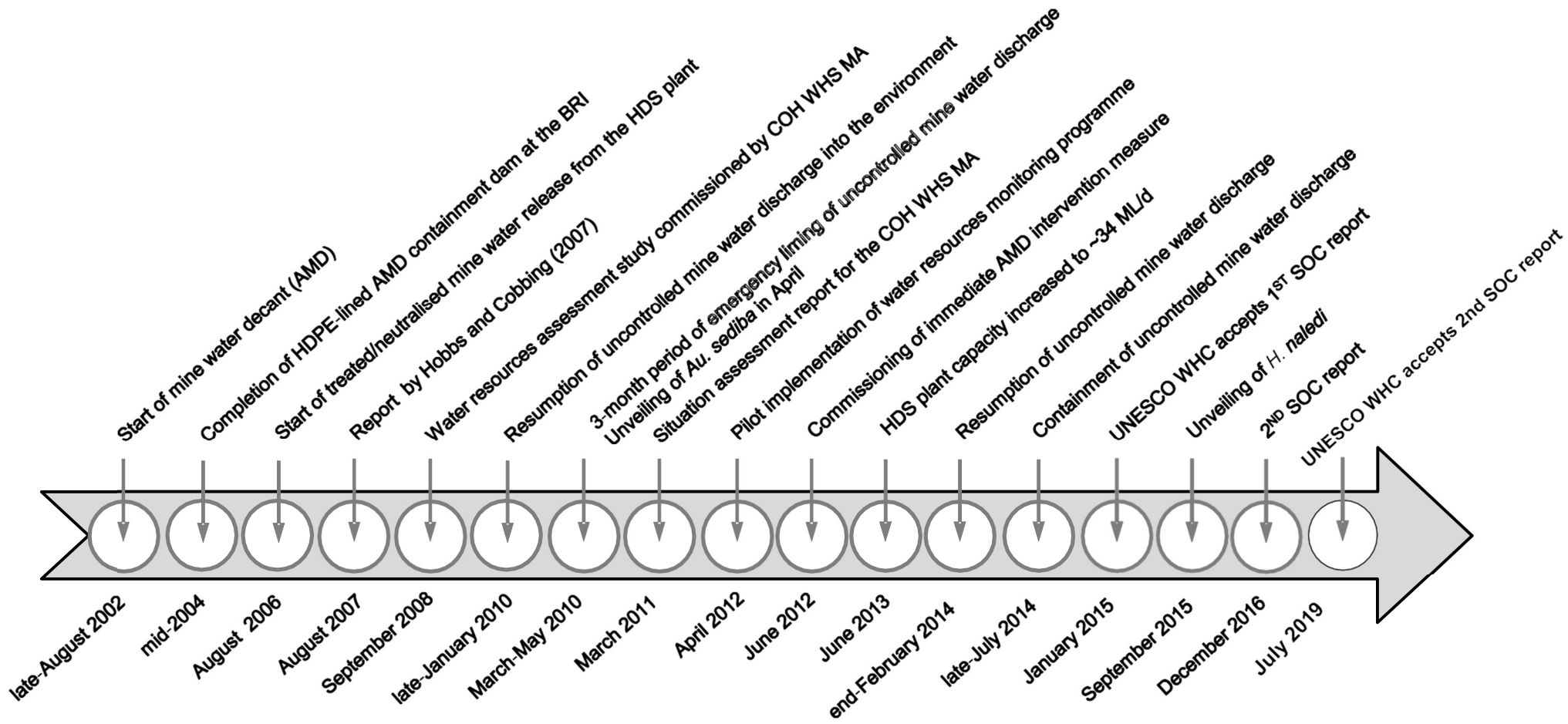
The Management Authority (MA) of the Cradle of Humankind World Heritage Site (COHWS) appointed the CSIR to serve as service provider for the water resources monitoring programme of the property (**Figure 1**) following the outcome of bid GT/WHS/021/2022. Since its inception in 2012, the monitoring programme has, to date, generated eighteen (18) 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.*, 2020a, Mvandaba *et al.*, 2020b, Mvandaba *et al.* 2023). This document represents the nineteenth (19<sup>th</sup>) such report and covers the period from April 2023 to September 2023.



**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 fourth State of Conservation (SOC) report (DEA, 2022) that was submitted to UNESCO's World Heritage Centre (WHC) for consideration by the World Heritage Committee. 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

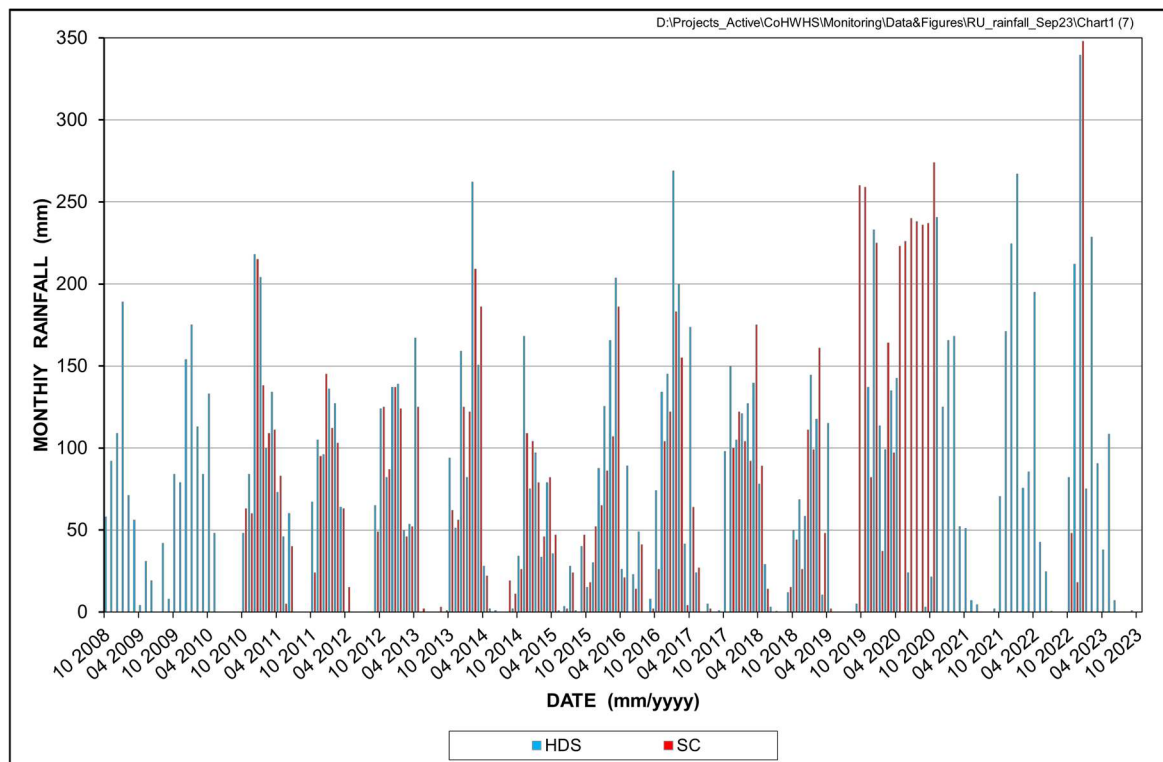
### 3 RAINFALL

#### 3.1 Quantity

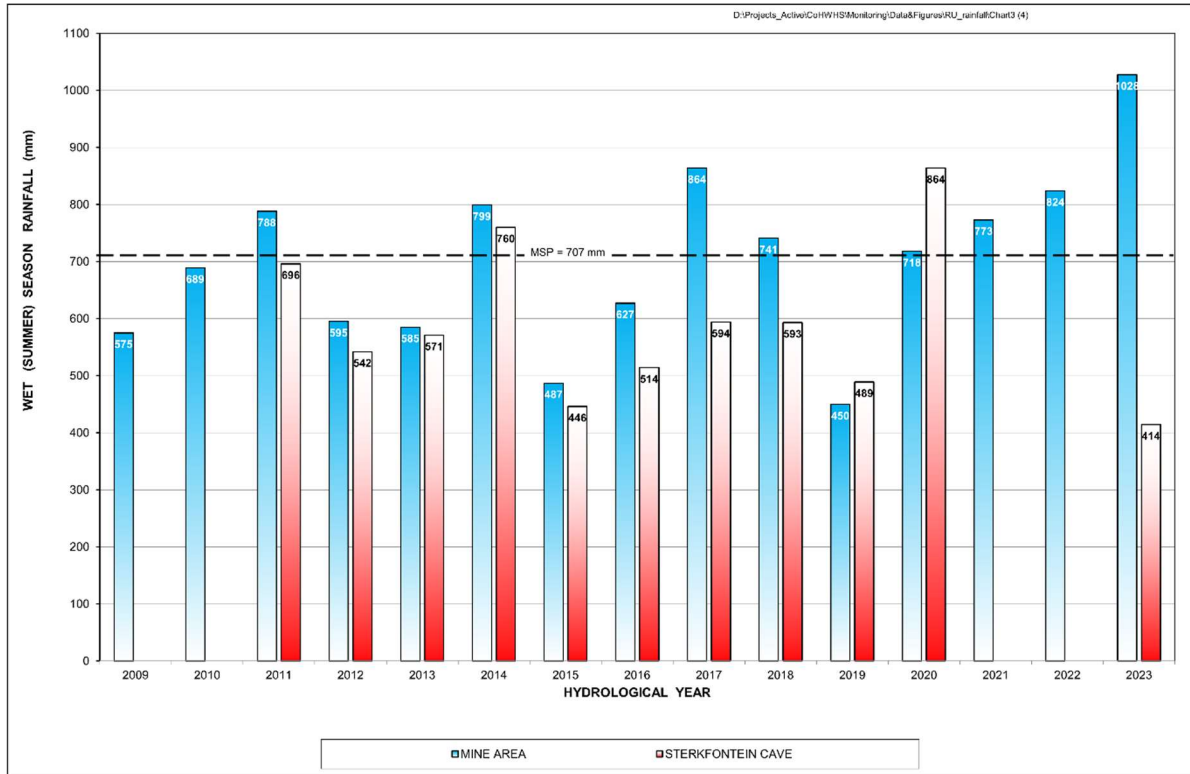
The monthly precipitation data covering the period from October 2008 to September 2023, observed at the Sibanye-Stillwater (SS) rainfall station HDS within the mine vicinity, and station SC positioned approximately 13 km northward at the Sterkfontein Cave (**Figure 1**) is presented in **Figure 3**. Available data records from November 2020 to December 2022, indicate an apparent gap of missing rainfall data for the SC station from November 2020 to September 2023. Analysis of the available data records between November 2020 and December 2022 reveals an apparent gap of missing rainfall data for the SC station, spanning from November 2020 to September 2023. The Department of Water and Sanitation (DWS) has ascribed this data gap to instrument and software malfunction, as reported by De Meillon in January 2023 and October 2023. The almost two-year data gap therefore renders it impossible to make a logical comparison of the rainfall record in the mine area to that the Sterkfontein Cave. However, given the fifteen-year data record illustrated in **Figure 4**, some statistics can be considered for the region:

During the 13-year period spanning from 2009 to 2022, the hydrological years 2015 and 2019 marked the driest periods on record. The wet season rainfall was recorded at 487 mm and 450 mm for the HDS station and 446 mm and 489 mm for the SC station during these years, respectively. In contrast, the wettest hydrological years were 2020 and 2023, witnessing substantial rainfall. Specifically, the wet season rainfall measured 718 mm and 1028 mm for the HDS station and 864 mm and 414 mm for the SC station during these respective years.

Notably, the summer rainfall in 2023 experienced a significant increase of 15% at station HDS, reaching 1028 mm compared to the 894 mm recorded in the preceding rainy season of 2022. The mean summer precipitation (MSP) at this location was measured at 707 mm. Moreover, the total rainfall, encompassing both wet and dry seasons, recorded at station HDS in 2023 amounted to 1182 mm, marking the highest precipitation level observed since 2009.



**Figure 3** Monthly precipitation in the mine area (station HDS) from October 2008 to September 2023, and the contemporaneous record for the Sterkfontein Cave station from June 2010 to September 2020.



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

### 3.2 Quality

The chemical composition of the rainwater in the southwest region of the COHWS property is reflected in the samples collected from the four rainfall stations run 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. Due to these factors, the chemistry of the collected rainwater must be a composite of the contributions made by the numerous precipitation events that occurred throughout the collecting period. 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 April 2023 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). Attempts by the CSIR Project Team to acquire data for this site from either Sibanye-Stillwater and/or the DWS have been unsuccessful. The results from the GP00303, GP00301 and SC stations represent the late wet season/early dry season rainfall. The rainwater chemistry observed at these monitoring stations consistently reaffirms the region's characteristic of exceptionally low salinity and predominantly acidic properties. While it is apparent that the rainwater chemistry at the high density sludge (HDS) station is relatively more saline than the other three rainfall stations, the current knowledge of the temporal rainwater quality and distribution in the area cannot readily explain inter-station variances in sulphate, total alkalinity, and nitrate levels as there is insufficient data for the comparison.

**Table 1** Composite rainwater chemistry in the south-western portion of the property

Variables	Unit	Rainfall Station			
		HDS <sup>1</sup>	GP00303 <sup>2</sup>	GP00301 <sup>3</sup>	SC <sup>4</sup>
Specific electrical conductance*	mS/m @ 25°C	18	3	3	3
pH*	$-\log_{10} a_{H^+}$	5.4	5.7	5.9	5.5
Calcium	mg Ca/L	6.7	0.8	0.5	0.6
Magnesium	mg Mg/L	1.4	0.4	<0.3	<0.3
Sodium	mg Na/L	1.7	<0.6	<0.6	<0.6
Potassium	mg K/L	3.8	0.7	<0.6	<0.6
Chloride	mg Cl/L	<2.0	<2.0	<2.0	<2.0
Sulphate	mg SO <sub>4</sub> /L	32	6.5	6.2	5.9
Total alkalinity	mg CaCO <sub>3</sub> /L	2.6	2.6	2.8	2.1
Nitrate + nitrite	mg N/L	11	1.0	0.57	0.23

\* Laboratory values

<sup>1</sup> At the high-density sludge plant in the mine area (Bugan *et al.*, 2019)

<sup>2</sup> At monitoring borehole GP00303, Vlakplaats 160IQ, Tarlton (sampled 18 April 2023)

<sup>3</sup> At monitoring borehole GP00301, Sterkfontein 173IQ (sampled 18 April 2023)

<sup>4</sup> At Sterkfontein Cave (sampled 18 April 2023)

## 4 SURFACE WATER HYDROLOGY

### 4.1 Physical Hydrology

#### 4.1.1 Surface Water Discharge

The discharge of the Bloubankspruit system is monitored at the DWS gauging station A2H049, strategically located approximately 700 meters upstream from the system's confluence with the Crocodile River (**Figure 1**). The comprehensive 51-year observed discharge record from 1972 to 2023 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. As previously reported by Mvandaba *et al.* (2020b), data collection at the station faced interruptions during specific periods. Notably, no data were collected from June 2018 to May 2019 and again from December 2019 to January 2020. The absence of data between June 2018 and May 2019 was attributed to financial constraints, impeding regular data collection, updates, and essential maintenance of the data collection platforms at that time. Following the alleviation of national lockdown restrictions in South Africa, the DWS resumed the data update process for gauging station A2H049. In a subsequent update reported by Mvandaba *et al.* (2023), the data record was extended from September 2020 to March 2023. However, it revealed additional gaps in the data, specifically from December 2021 to January 2022, June 2022 to July 2022, and February 2023 to March 2023. Instrumental failure was cited as the cause for the missing data between February 2023 and March 2023 (Serome, 2023). Nevertheless, the DWS has since managed to recover the data for this period. The current updated data record encompasses information from January 2023 through to September 2023, providing a more comprehensive and recent overview of the Bloubankspruit system's discharge patterns.

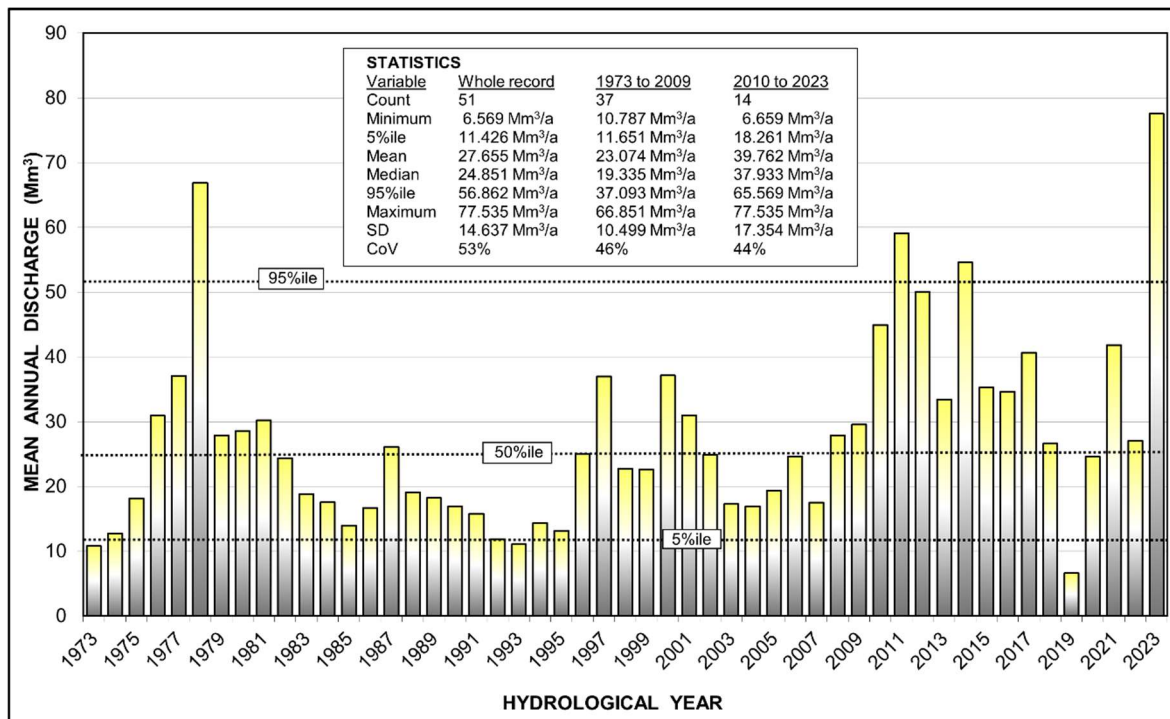
**Table 2** Statistical analysis of Bloubankspruit monthly discharge data gauged at station A2H049 in the period October 1972 (ah 1973) to September 2023 (ah 2023) (latest data as at September 2023).

Variable	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Count (n)	48	48	47	47	50	50	50	49	50	49	49	49
Minimum	0.682	0.268	0.711	0.721	0.706	0.828	0.886	0.847	0.521	0.939	0.890	0.770
5%ile	0.802	0.839	1.046	1.098	0.906	1.111	1.202	1.027	0.896	0.968	0.938	0.811
Mean	1.939	1.921	2.432	2.978	2.905	3.239	2.619	2.461	2.165	2.180	2.085	1.937
Median	1.712	1.773	2.127	2.526	2.385	2.624	2.169	2.024	1.825	1.919	1.969	1.628
95%ile	3.701	2.946	4.543	6.944	6.871	8.922	5.605	4.987	4.250	4.184	3.881	3.682
Maximum	4.211	4.577	7.199	13.007	10.619	11.351	7.007	5.708	6.427	5.031	4.897	4.773
SD	0.905	0.834	1.099	1.909	1.910	2.187	1.296	1.192	0.993	0.944	0.876	0.882
CoV (%)	47	43	45	64	66	68	49	48	46	43	42	46

- All units are Mm<sup>3</sup> unless otherwise indicated.

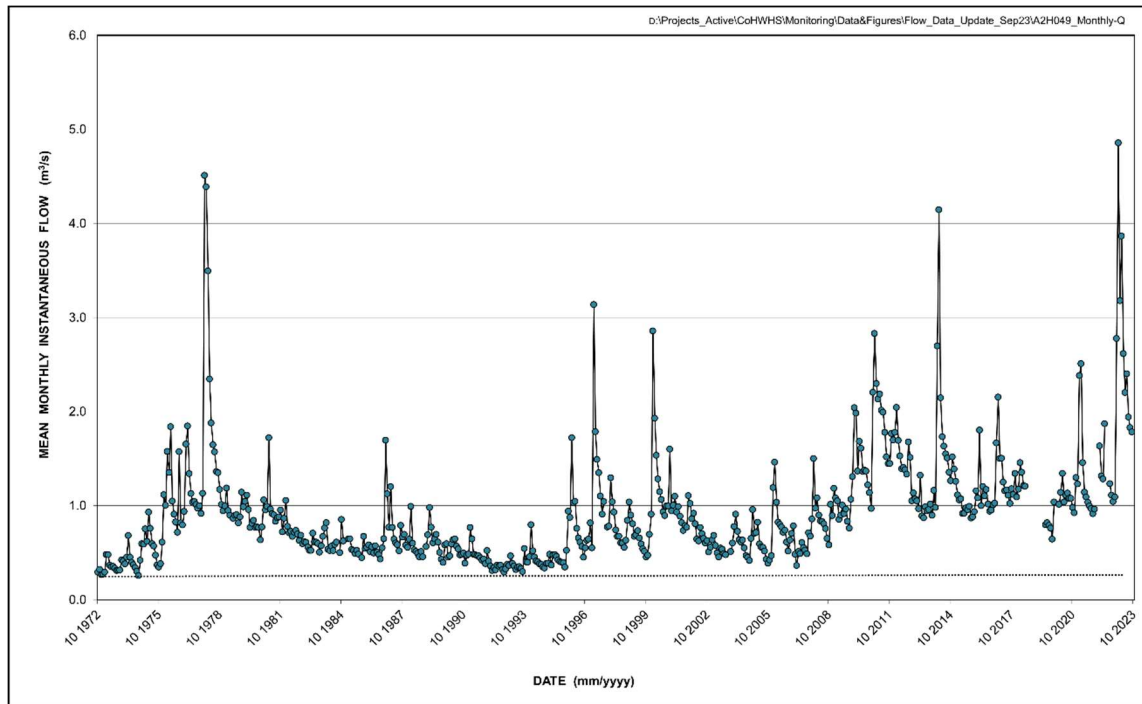
- Analysis excludes months with missing and station rating exceedance data, but includes unaudited (recent) and estimated data

**Figure 6** shows the historical total annual discharge, in Mm<sup>3</sup>, for complete hydrological years up to September 2023. Notably, the most recent complete hydrological year in the record is the 2023 hydrological year. The annual discharge illustrated in **Figure 6** indicates that the 2023 hydrological year recorded a discharge of ~77.5 Mm<sup>3</sup>, which is the maximum discharge recorded for the Bloubankspruit during the period of October 1972 to September 2023. The discharge of this magnitude aligns with the occurrence of flash floods in the region between November 2022 and March 2023, following intense rainfall events (Krugersdorp News, December 2022). The recorded annual discharge of 77.5 Mm<sup>3</sup> is approximately double the mean annual discharge of 39.8 Mm<sup>3</sup> and the median discharge of 37.9 Mm<sup>3</sup>, for the period 2010 to 2023. The statistics shown in **Figure 6** confirm that the frequency of heavy rainfall events in the region has increased since 2010.



**Figure 6** Graph of Bloubankspruit annual discharge gauged at station A2H049 for the period October 1972 (ah 1973) to September (ah 2023)

**Figure 7** illustrates the mean monthly instantaneous flow pattern at station A2H049 for the period October 1972 to September 2023. Based on the available data record, the maximum mean monthly instantaneous discharge for the period October 1972 (ah 1973) to September (ah 2023) is 4.9 m<sup>3</sup>/s, which is in fact the mean monthly discharge of the Bloubankspruit in January 2023. As mentioned in **Section 4.1.1**, several flash floods were reported in the Krugersdorp region during the months of November 2022 to March 2023. The discharge of 4.9 m<sup>3</sup>/s is approximately 6 times the median discharge of 0.79 m<sup>3</sup>/s and 5 times the average discharge of 0.92 m<sup>3</sup>/s for the period October 1972 (ah 1973) to September (ah 2023). According to Hobbs *et al.* (2018), the Bloubankspruit has experienced an instantaneous low flow, or base discharge, in the range of 0.8 to 1 m<sup>3</sup>/s since 2010. This figure appears to be consistent with the average baseflow that is observed for the ah 2023 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.

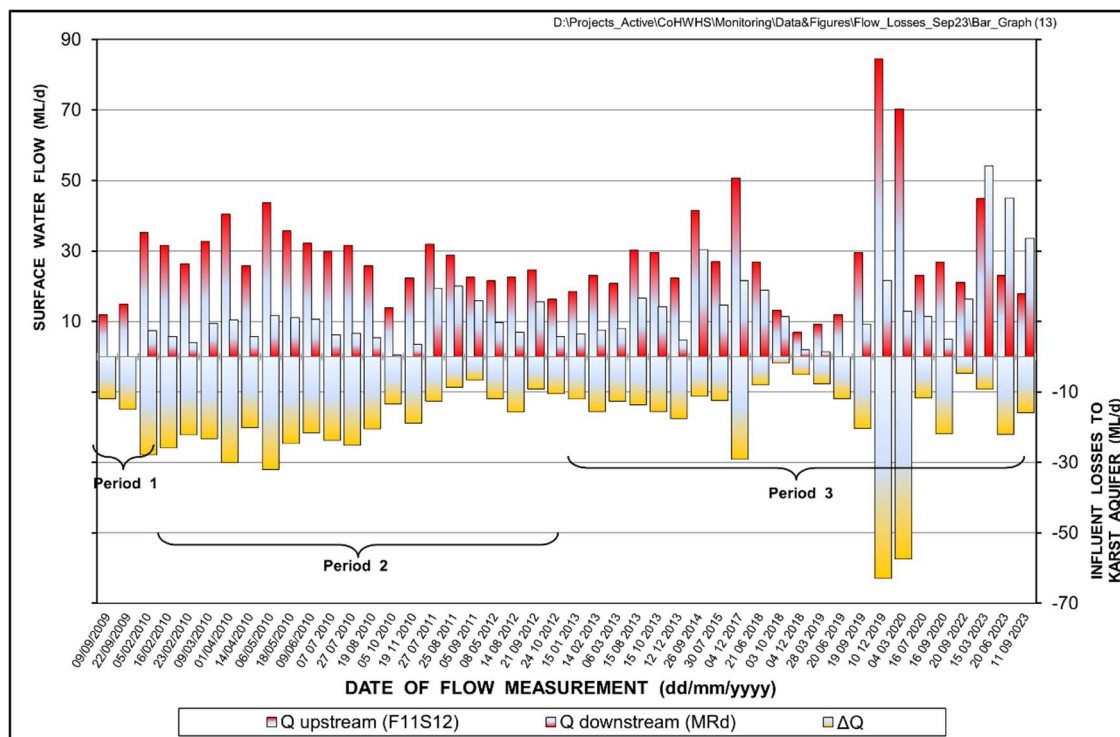


**Figure 7** Long-term monthly hydrograph of the Bloubankspruit at station A2H049 for the period October 1972 to September 2023 (latest data as of September 2023).

#### 4.1.2 Surface Water Fluxes

The extent of surface water loss, primarily to the karst aquifer, is determined by calculating the difference in measured streamflow discharge at two key stations: F11S12 (Brickworks Dam) situated at the lower end of the Tweelopiespruit, and MRd, located approximately 3.9 km downstream along the Rietspruit (**Figure 9**). As reported by Mvandaba *et al.* (2023), during the September 2022 monitoring run, the gauging site was found to be permanently closed off by the property owner, for citing security reasons. Consequently, a new gauging site was established ~250m downstream from the station F11S12, on the property Pinocchio's Farm. Streamflow measurements at this site are conducted at a culvert through which the Tweelopiespruit flows, ensuring the continuity of data collection.

The most recent data captured in June 2023 and September 2023 shows surface flow fluxes between the Pinocchio's Farm gauging site and MRd of magnitude 22.0 ML/d and 15.9 ML/d, respectively. These surface flow fluxes fall between the 50<sup>th</sup> and 95<sup>th</sup> percentile of the 15-year period from September 2009 to September 2023 (**Figure 8**) and are greater than the average and median losses recorded for the same 15-year period of 18.1 ML/d and 15.5 ML/d, respectively.



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

## 4.2 Chemical Hydrology

### 4.2.1 Mine Water Impact

#### 4.2.1.1 Tweelopiespruit / Riet Spruit

From the point 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 approximately 6.6 km, the chemistry of surface water in the Tweelopiespruit is still being monitored by Sibanye-Stillwater on a weekly basis at five localities (**Figure 10**). The monitoring of the variables pH, electrical conductivity (EC) and sulphate (SO<sub>4</sub>) dates 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<sub>4</sub>), **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 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 trend of each respective parameter has been discussed by Mvandaba *et al.* (2023) for the period August 2020 to September 2022, therefore for the discussion in this report, focus will be placed in the emerging trends from October 2022 to September 2023:

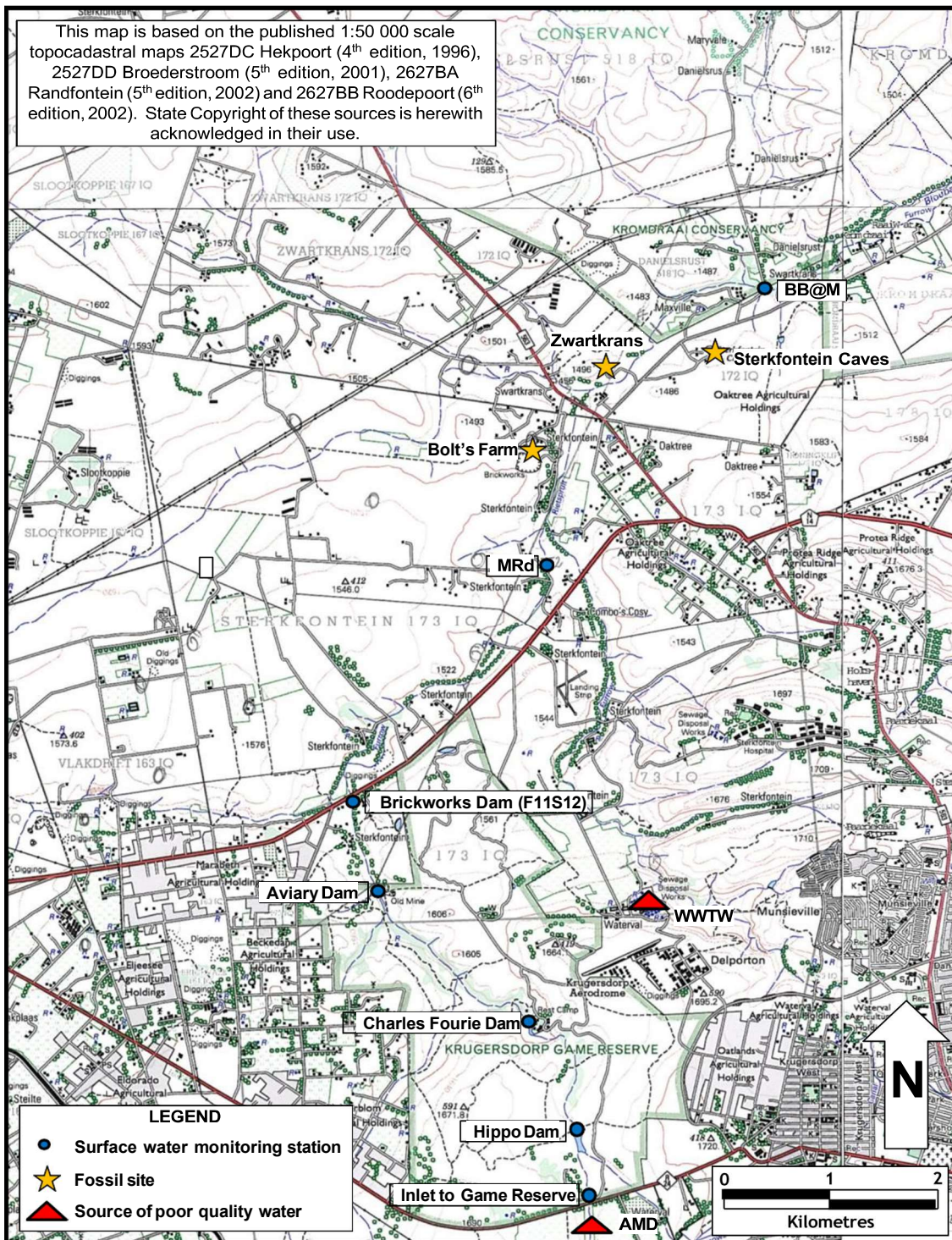
- The pattern of the pH values (**Figure 11**) recorded at the Hippo Dam and F11S12 stations between October 2022 and September 2023 illustrates a gradually increasing trend for both stations, ranging from 3.5 to 8.8 and 4.3 to 6.8, respectively. The lower range of pH values (below 6) for the F11S12

station were recorded between December 2022 and June 2023, indicating acidic conditions.

- The SEC values (**Figure 12**) at both stations indicate a gradual decreasing trend, however the concentrations have oscillated between 301 mS/m and 365 mS/m for the Hippo Dam station and 251 mS/m and 320 mS/m for the F11S12 station.
- Sulphate concentrations (**Figure 13**) appears to be stable at both stations, however a rapid increase was noted for the F11S12 station between June and July 2023. Between the period of October 2022 and September 2023, the sulphate values have respectively oscillated between 1420 mg/L and 2910 mg/L at the Hippo Dam and between 1180 mg/L and 2270 mg/L at F11S12.
- The iron concentration (**Figure 14**) at the Hippo Dam station indicates generally stable levels with a range of 0.003 mg/L to 3.3 mg/L. At the F11S12 station, a gradually decreasing trend is noted with values ranging from 0.0 mg/L to 0.2 mg/L.
- Manganese concentrations (**Figure 15**) at both the Hippo Dam and F11S12 stations display a marginal decline pattern, ranging from 0.1 mg/L to 5.9 mg/L. It is however noteworthy to report the elevated concentrations between December 2022 and February 2023.
- Uranium (**Figure 16**) has maintained a consistent concentration of 0.02 mg/l beyond 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–F defined by the divisions recognised in **Figure 11** to **Figure 16** is presented in **Table 3**. Period F in Table 3 provides a more recent look at the statistics between October 2020 and September 2023, but may be considered to generally show the continuation of the recovery of mine water treatment and management measures. The outcome of the statistical analysis offers a quantitative assessment of the specific differences in variables between different periods at each station and across various stations. Notably, the deviations indicating poorer quality discharge during the B–C and D–E periods are evident in the median values of all variables, except possibly iron, at both stations. Hobbs et al. (2018) observed that this finding implies that the exceptionally wet hydrological year of 2017 did not have a similarly adverse impact on the quality of mine water discharges to the environment, unlike the situations observed in the 2010, 2011, and 2014 hydrological years. The primary reason behind these observations can be attributed to the mine water control and management measures that have been implemented in the Western Basin.

The effectiveness of these measures is clearly reflected in the median and 95<sup>th</sup> percentile values during the E–F and F- periods, which, in most cases, exhibit the lowest values across the five periods of analysis. This trend is comparable to the C-D period, which corresponds to the implementation of immediate Acid Mine Drainage (AMD) intervention measures. These findings underline the positive impact of the recent interventions on the quality of mine water discharges, providing compelling evidence of the success of the implemented control and management strategies.



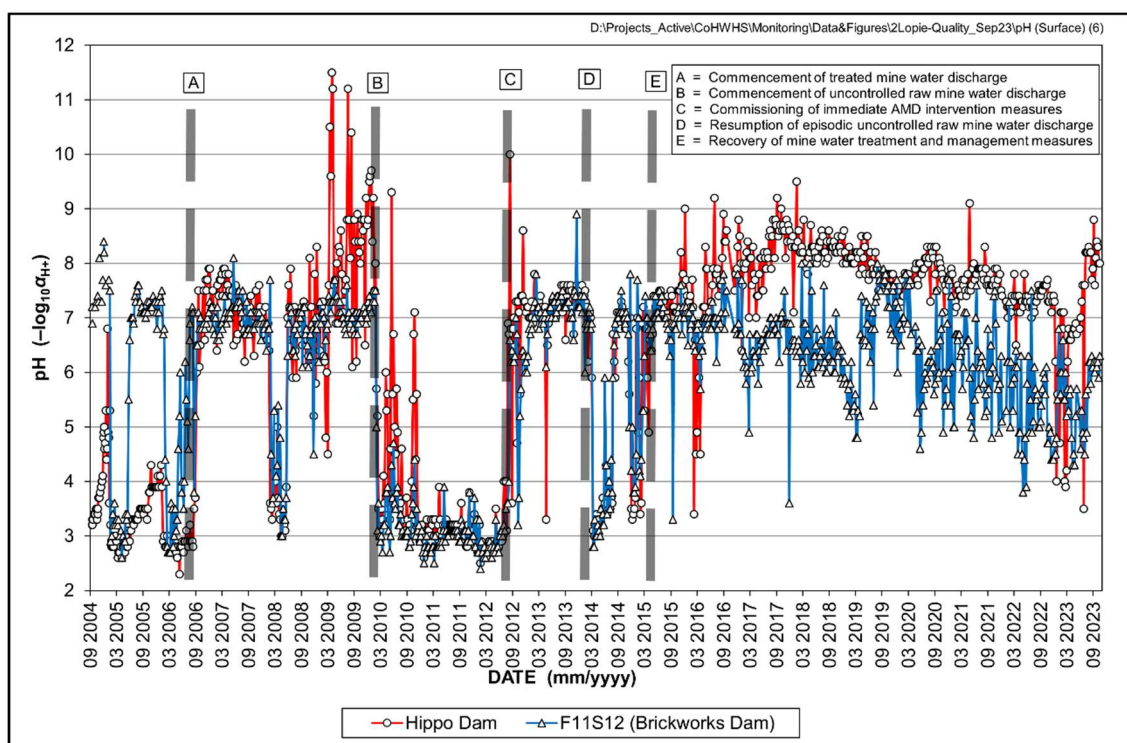
**Figure 10** Locality map of surface water quantity and quality monitoring stations

#### 4.2.1.2 Bloubankspruit

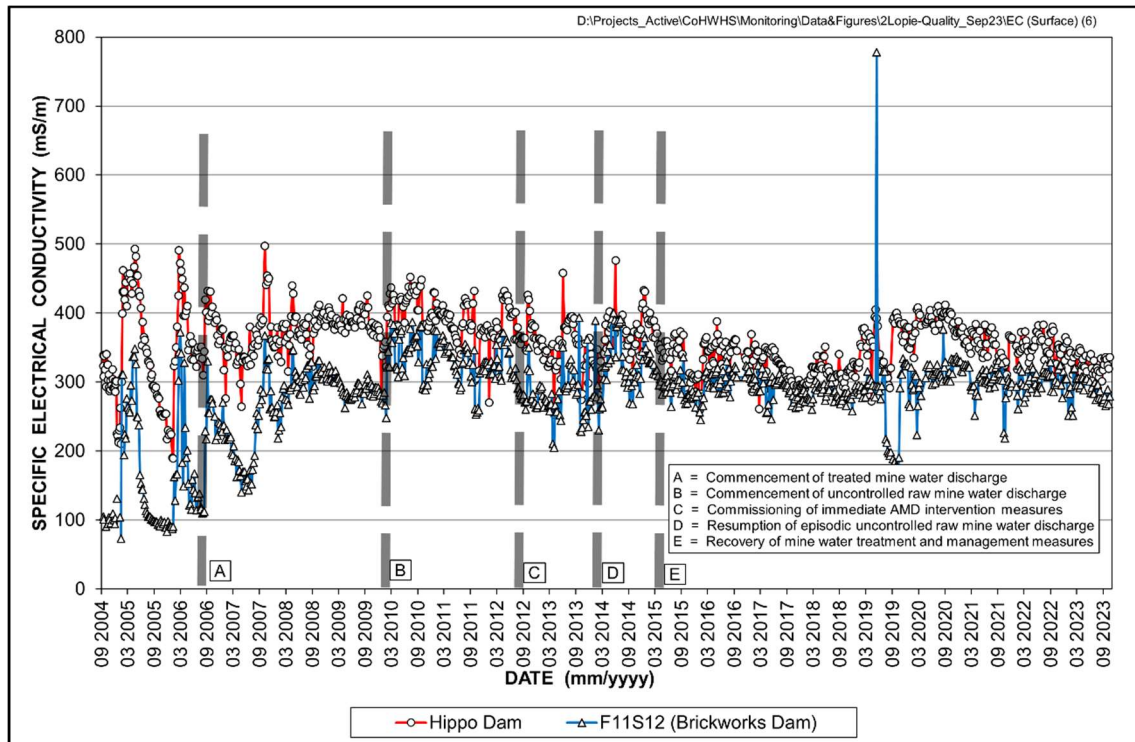
The comprehensive analysis of synoptic surface water chemistry data for the DWS flow gauging station A2H049 (**Table 4**) at the lower reach of the Bloubankspruit system, as detailed in earlier reports, has been revised to highlight significant temporal variations in specific variable values. Noteworthy gaps existed in the dataset between May 2018 and July 2022 due to the absence of data collection activities at the site. The DWS attributed this hiatus to financial constraints and instrument failures.

The recent data update, encompassing the timeframe from July 2022 to November 2022, provides a more current perspective, filling the gaps in the dataset. This update ensures a more recent portrayal of the surface water chemistry dynamics, allowing for a nuanced understanding of the current variable-specific changes.

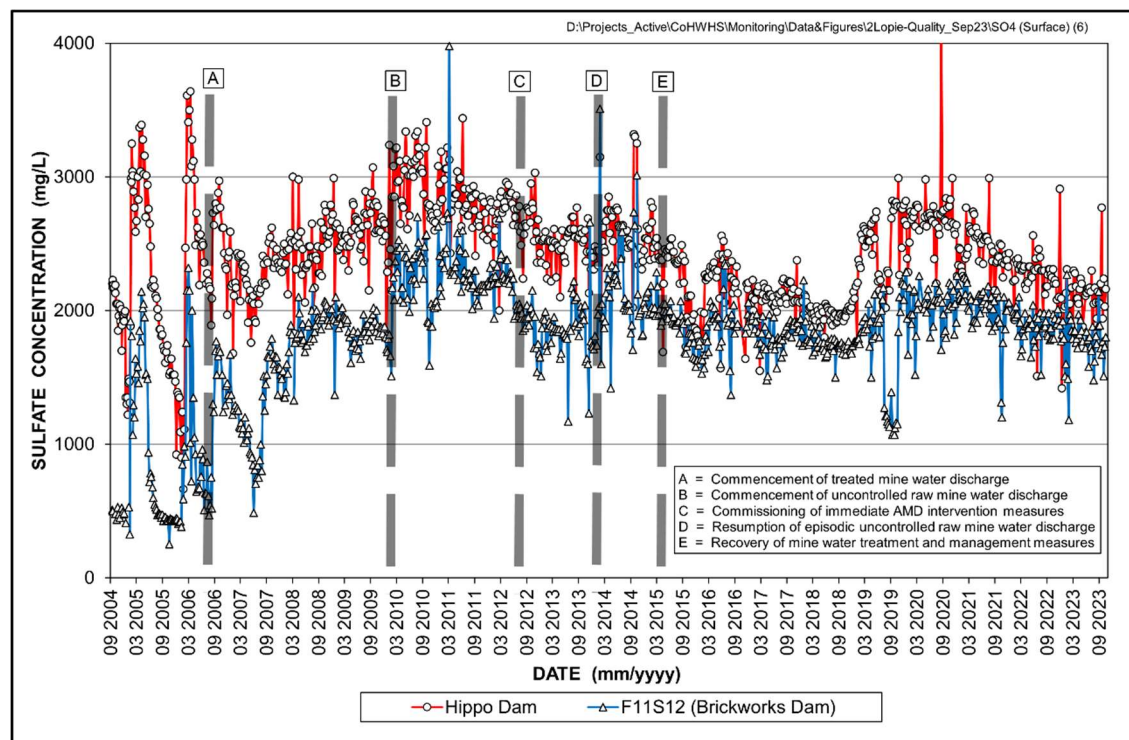
**Table 4** reflects statistics for a ‘pre-impact’ period, August 2002 to January 2010, and a ‘post-impact’ period February 2010 to May 2018, and July 2022 to November 2022. Barring sulphate concentrations at the 95<sup>th</sup> percentile (during the July 2022 to November 2022 period), none of the variables 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 C5 (95<sup>th</sup>ile) level and, in the case of pH, also at the C95 (5<sup>th</sup>ile) level.



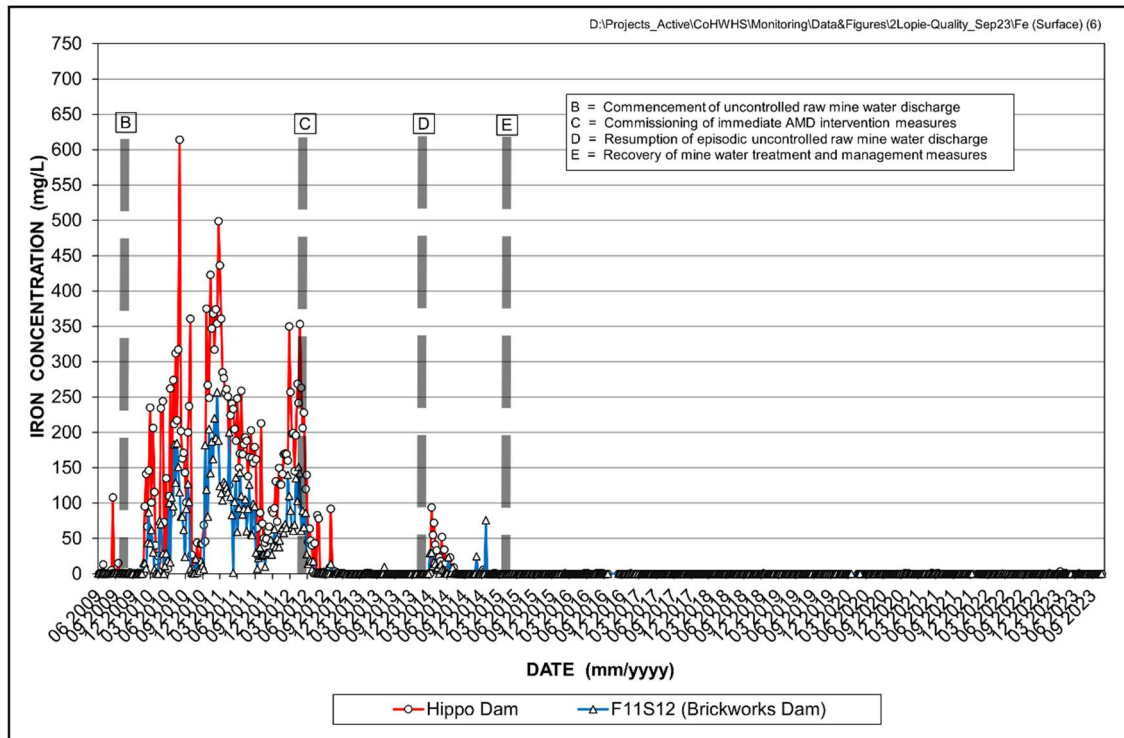
**Figure 11** pH pattern of Tweelopiespruit surface water in the period September 2004 to September 2023



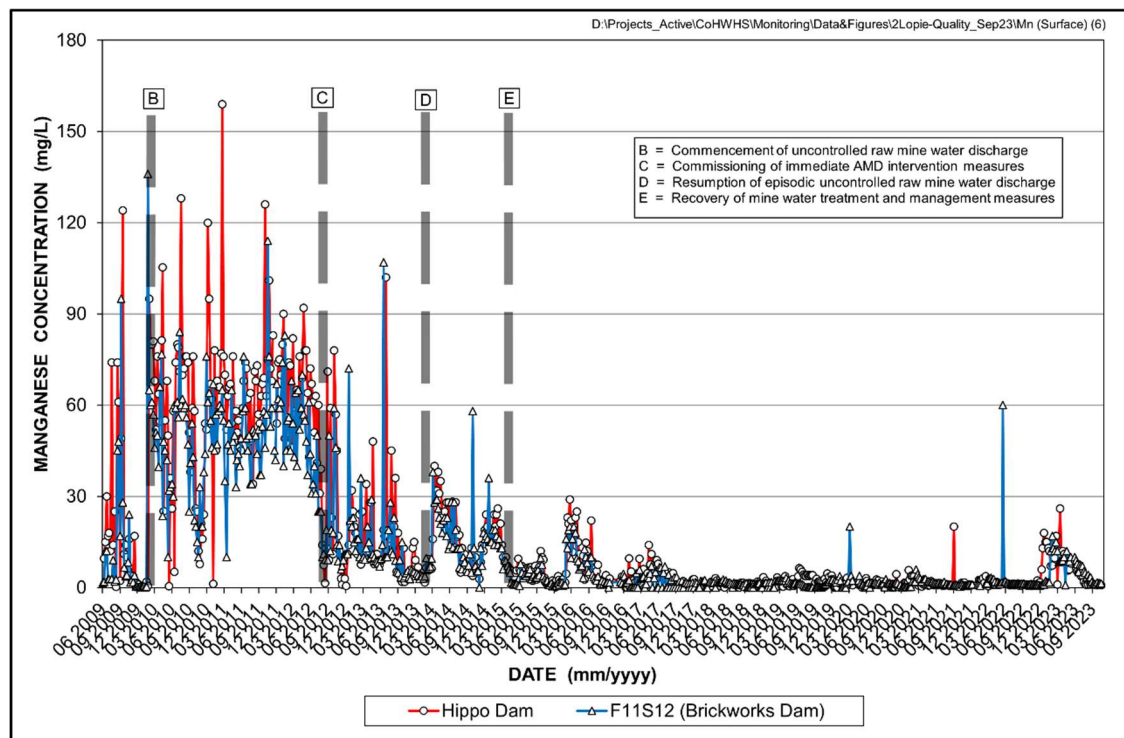
**Figure 12** Specific electrical conductivity pattern of Tweelopiespruit surface water in the period September 2004 to September 2023



**Figure 13** Sulphate pattern of Tweelopiespruit surface water in the period September 2004 to September 2023



**Figure 14** Iron pattern of Tweelopiespruit surface water in the period June 2009 to September 2023



**Figure 15** Manganese pattern in Tweelopiespruit surface water in the period June 2009 to September 2023



**Table 3** Summary statistics of period-related surface water chemistry variability in the Tweelopiespruit (latest data as at September 2023)

Variable	Statistical Parameter	Hippo Dam						F11S12 (Brickworks Dam)					
		A—B <sup>(1)</sup>	B—C <sup>(2)</sup>	C—D <sup>(3)</sup>	D—E <sup>(4)</sup>	E—F <sup>(5)</sup>	F— <sup>(6)</sup>	A—B <sup>(1)</sup>	B—C <sup>(2)</sup>	C—D <sup>(3)</sup>	D—E <sup>(4)</sup>	E—F <sup>(5)</sup>	F— <sup>FIS</sup>
pH (-log <sub>10</sub> a <sub>H+</sub> )	n	176	129	83	57	269	160	173	128	83	57	276	151
	5%ile	3.6	2.8	5.9	3.2	6.8	6.2	3.9	2.7	5.3	3.0	5.4	4.5
	Mean	—	—	—	—	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	4.9	7.9	7.5	6.9	3.0	7.0	5.0	6.7	5.7
	95%ile	9.3	5.7	7.6	7.1	8.7	8.2	7.4	3.9	7.4	7.4	7.7	7.1
	SD	1.5	1.0	0.8	1.6	0.7	0.8	0.9	0.4	0.9	1.7	0.7	0.8
	CoV (%)	22.0	30	11	32	9.0	11.4	14	14	13	32	10	14
SEC (mS/m)	n	175	129	83	57	269	160	172	128	83	57	276	151
	Mean	374	391	350	376	337	351	268	332	281	329	291	298
	Median	379	393	354	377	336	350	283	330	276	323	293	299
	95%ile	426	438	395	417	395	396	329	378	350	391	323	325
	SD	32	33	34	28	33	25	48	29	34	34	41	20
	CoV (%)	9	8	10	7	10	7	18	9	12	10	14	7
SO <sub>4</sub> (mg/L)	n	176	128	82	56	269	160	171	128	83	56	276	151
	Mean	2448	2846	2520	2585	2238	2336	1636	2264	1879	2137	1832	1550
	Median	2460	2815	2525	2541	2180	2310	1760	2240	1870	2075	1840	1896
	95%ile	2828	3220	2770	2950	2766	2770	2015	2593	2148	2640	2160	1900
	SD	262	226	193	231	295	302	349	245	268	274	222	2145
	CoV (%)	11	8	8	9	13	13	21	11	14	13	12	188
Fe (mg/L)	n	33	129	83	57	242	156	33	128	82	57	230	150
	Mean	4.7	168.4	2.5	8.9	0.1	0.10	0.3	72.9	0.47	4.9	0.0	0.03
	Median	0.4	163.0	0.03	0.10	0.0	0.02	0.2	64.0	0.08	0.04	0.0	0.01
	95%ile	13.8	365.2	3.1	52.6	0.1	0.33	0.8	186.3	1.00	25.7	0.1	0.1
	SD	18.8	116.2	13.10	19.5	0.1	0.31	0.3	57.7	1.9	12.2	0.0	0.03
	CoV (%)	399	69	528	220	187	323.35	94	79	407	2518	115	126
Mn (mg/L)	n	34	129	83	57	249	156	33	128	83	57	231	148
	Mean	18.1	62.7	16.5	17.3	3.8	3.0	10.3	50.3	14.4	16.1	3.0	3
	Median	9.8	65.0	11.0	16.0	2.2	1.1	2.7	50.0	10.0	14.0	1.8	1.3
	95%ile	74.0	95.0	56.1	32.6	11.9	12.3	46.2	76.0	45.0	30.4	9.8	11.3
	SD	27.6	23.5	18.0	9.1	4.6	4.3	19.4	17.6	15.8	9.9	3.6	5.8
	CoV (%)	153	38	109	53	120	144	188	35	110	61	117	182

(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 (6) 10/2020 – 09/2023

**Table 4** Synoptic overview of Bloubankspruit water chemistry at station A2H049 in the periods August 2002 to January 2010 and February 2010 to May 2018 and July 2022 to November 2022 (latest data as of September 2023)

Variable	Statistical Parameter																					SANS (2015a)(1)
	Period August 2002 to January 2010							Period February 2010 to May 2018							Period July 2022 to November 2022							
	n	5%ile	Mean	Median	95%ile	SD	CoV (%)	n	5%ile	Mean	Median	95%ile	SD	CoV (%)	n	5%ile	Mean	Median	95%ile	SD	CoV (%)	
pH (-log <sub>10</sub> a <sub>H+</sub> )	251	7.7	—	8.1	8.4	0.2	2	202	7.5	8.2	8.2	8.5	0.3	3.7	5	7.0	7.2	7.2	7.3	0.1	1.7	5.0–9.7
SEC (mS/m)	232	51.1	61.2	62.3	66.8	5	8	199	61.5	93.4	90.1	126	23.2	24.8	5	81.5	81.5	124.1	137.7	26.3	32.3	<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	5	570.9	875.5	898.8	1153.8	250.6	28.6	<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	34.3	5	47.9	147.0	152.2	281.5	105.2	71.6	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	5	72.1	149.9	180.3	212.0	66.3	44.3	n.s.
Na (mg/L)	185	19.1	27.5	27.7	34	4.7	17	166	28.3	41.7	40.5	58.4	10.1	24.3	5	21.7	48.5	57.4	59.3	19.5	40.2	<200
K (mg/L)	173	1.4	2.4	2.4	3.4	0.7	27	169	2.9	4.1	4	5.7	1	24.4	5	5.5	5.8	5.8	6.3	0.3	5.8	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	5	29.2	40.8	0.1	45.3	8.6	21.0	<300
SO <sub>4</sub> (mg/L)	191	63.4	85.8	83.9	110	15.1	18	189	96.8	284	247.8	475	132.7	46.7	5	290.2	398.3	412.3	501.4	91.2	22.9	<500
HCO <sub>3</sub> (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	5	0.0	134.7	142.9	159.0	32.0	23.8	n.s.
NO <sub>3</sub> +NO <sub>2</sub> (mg N/L)	214	3.294	4.74	4.414	7.085	1.19	25	193	3.5	5.6	5.4	8.3	1.6	27.7	5	2.6	5.8	5.6	8.8	2.8	47.6	<11
PO <sub>4</sub> (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	5	0.262	0.524	0.400	0.925	0.300	57.3	n.s.
Si (mg/L)	247	4.93	5.84	5.83	6.69	0.6	10	198	4.95	5.64	5.6	6.59	0.61	10.86	5	4.7	5.6	5.7	6.3	0.7	12.8	n.s.
Fe (mg/L)	69	0.006	0.035	0.014	0.12	0.056	163	61	0.004	0.019	0.012	0.072	0.024	126.3	4	0.000	0.019	0.021	0.025	0.007	36.1	<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	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.5
Al (mg/L)	65	0.001	0.06	0.014	0.091	0.262	437	60	0.003	0.019	0.009	0.057	0.026	136.8	4	0.007	0.030	0.016	0.071	0.034	115.5	<0.3

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

#### **4.2.2 Municipal Wastewater Impact**

The Blougatspruit is the conduit for municipal wastewater effluent into the COHWHS property. The reticence of local government to provide water quality data for wastewater released to the Blougatspruit from the municipal wastewater treatment works (WWTW) has been documented previously (e.g. Hobbs, 2016a; 2016b; 2017a). Water samples collected ~5 km downstream of the WWTW end-of-pipe (EoP) provide a measure of the bacteriological contamination in the Blougatspruit from this facility. This impact extends into the Bloubankspruit 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 several sites along the Blougatspruit, namely, BG@N14, BB@M and BB@NOE (**Table 5**). Additionally, several accounts of obnoxious odours, murky water foam, and recently raw sewerage, in the Blougatspruit and Bloubankspruit rivers have been received from local residents of the COHWHS property and reported to the MA, however the exact point of emergence of the water pollution has not been verified. Given the bulk volume of raw sewerage noted in these rivers, 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 Bloubankspruit.

The most recent results from chemical and microbiological analyses of water samples collected along the Blougatspruit (upstream and downstream of Percy Stewart WWTW) and along the Tweelopiespruit and Rietspruit are captured in **Table 5**.

Consistent with results reported for March 2023 by Mvandaba et al. (2023), the June 2023 and September 2023 microbiological results of water samples collect at BG@N14, BB@M, MRd and Pinocchio's Farm confirm the faecal contamination of surface water along the Blougatspruit, Bloubankspruit, Rietspruit and Tweelopiespruit, respectively. The most severe pollution is noted at BG@N14 and BB@M where the MPN count for *E.coli* exceeds 2419.6 per 100mL.

**Table 5** Water chemistry and microbiological results of samples collected at monitoring sites along the Blougatspruit, Bloubankspruit, Rietspruit and Tweelopiespruit in March 2023, June 2023 and September 2023.

Variable	BG Spring (Blougatspruit)	BB @ N14 (Blougatspruit)			BB @ M (Blougatspruit)			MRd (Rietspruit)			Pinocchio's Farm (Tweelopiespruit)			SANS 241	
	Sep 23	Mar 23	Jun 23	Sep 23	Mar 23	Jun 23	Sep 23	Mar 23	Jun 23	Sep 23	Mar 23	Jun 23	Sep 23	(2015a) <sup>(1)</sup>	
pH (–log <sub>10</sub> α <sub>H+</sub> )	7.8	7.8	7.3	7.5	7.7	7.1	7.4	8.2	4.4	4.1	7.9	6.2	5.5	5.0–9.7	
SEC (mS/m)	68	72	80	110	190	180	185	94	290	880	100	300	900	<170	
Ca (mg/L)	73	39	29	32	242	237	223	89	491	481	91	527	495	n.s.	
Mg (mg/L)	45	9.6	11	11	56	59	64	53	78	81	50	83	80	n.s.	
Na (mg/L)	3.7	53	67	105	80	87	97	34	118	125	35	126	124	<200	
K (mg/L)	<0.6	11	15	14	9	8.8	8.7	1.5	11	11	2	11	11	n.s.	
Cl (mg/L)	<2.0	54	65	98	49	57	64	37	52	50	38	55	52	<300	
SO <sub>4</sub> (mg/L)	26	53	81	94	854	801	802	262	1610	1706	298	1735	1725	<500	
HCO <sub>3</sub> (mg/L)	336	213	188	323	115	118	169	142	<1.0	<1.0	146	5.1	2.9	n.s.	
NO <sub>3</sub> +NO <sub>2</sub> (mg N/L)	0.17	0.12	<0.05	<0.05	3.9	0.43	<0.05	7	6.4	8.1	7.4	5.3	6.4	<11	
Si (mg/L)	7.5	5.7	6.5	7.6	5.6	5.7	6.2	6	3.4	2.9	5.8	3.5	3.1	n.s.	
Fe (mg/L)	0.03	1.5	1	2	0.82	0.43	0.81	0.17	0.18	0.11	0.04	0.1	0.04	<2	
Mn (mg/L)	<0.01	0.55	0.38	0.67	4.3	1.39	0.65	0.03	3.62	1.3	0.02	3.51	1.2	<0.5	
Al (mg/L)	<0.02	0.12	0.21	0.47	0.26	0.16	0.21	0.05	0.13	0.05	0.03	0.08	<0.02	<0.3	
Total coliform bacteria (MPN/100 ml)	1553.1 (>2419.6)	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	<10
E. coli (MPN/100 ml)	<1 (63.8)	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	517.2	547.5	298.7	108.1	106.7	201.4	n.d.	



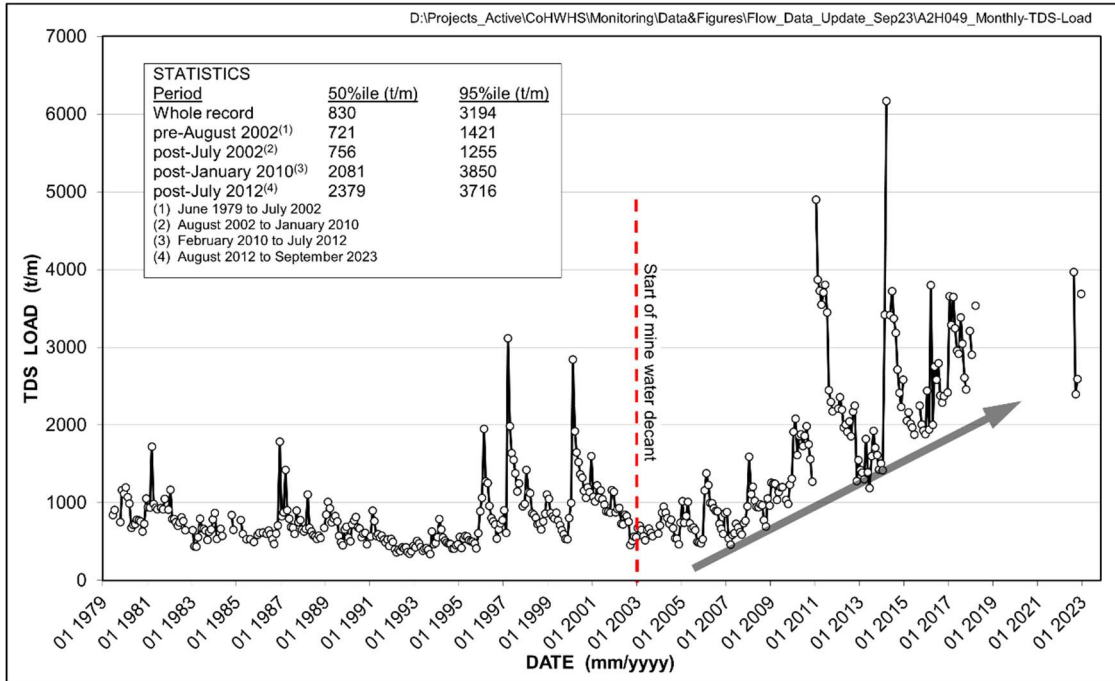
**Figure 17** Raw sewerage was observed along the causeway of the Blougatspruit at BG@N14 in June 2023.

#### 4.4 Salt Load

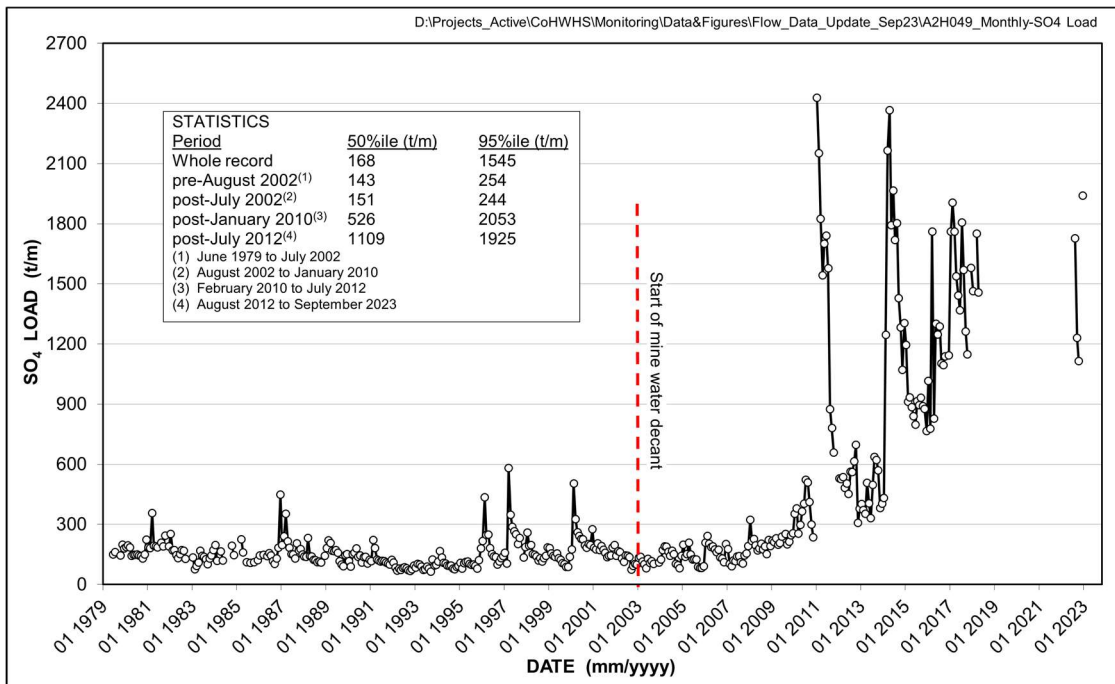
The combination of flow and hydrochemical data allows for a re-assessment of the total dissolved solids (TDS) (**Figure 18**) and  $\text{SO}_4$  (**Figure 19**) load pattern and trend manifested at station A2H049. The hydrochemical data from station A2H049 has recently been updated by DWS for the period July 2022 to November 2022. The DWS attributed the suspension of scheduled updates between May 2018 and July 2022 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). The recent gaps in the data have been attributed to instrument failure (Botes, October 2023).

The six-year period gap of missing data between May 2018 and July 2022 presents a challenge with comprehensively interpreting the long-term monthly trend in the TDS load delivered by the Bloubankspruit (**Figure 18**). However the statistics presented indicate 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).

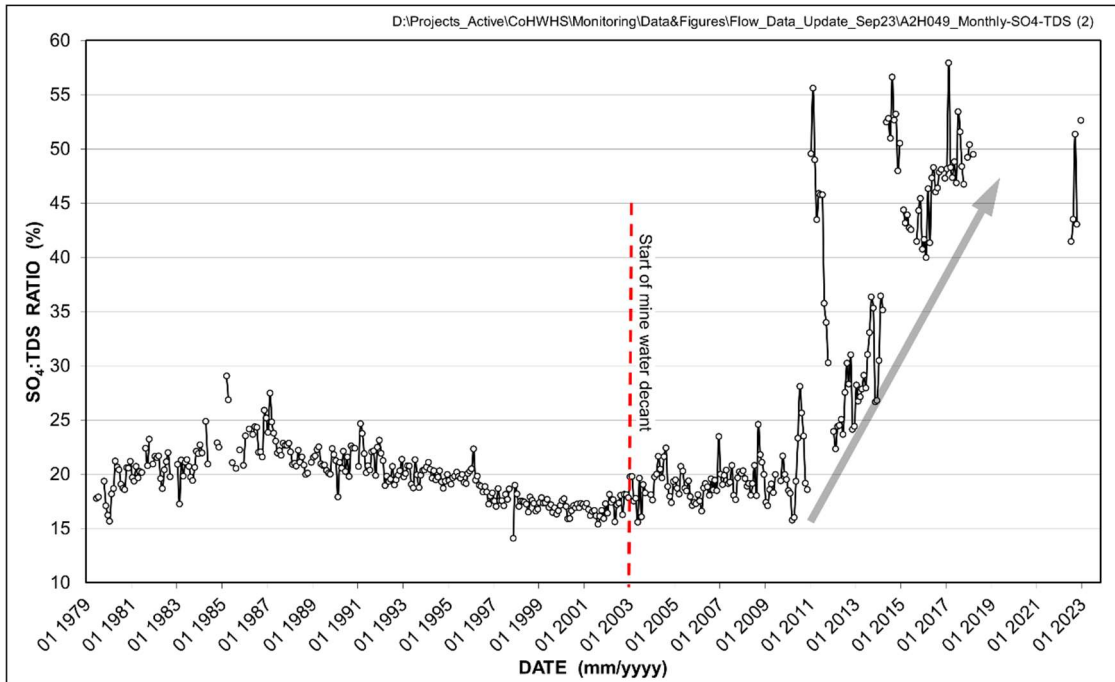
Similarly, the long-term monthly trend in the  $\text{SO}_4$  load delivered by the Bloubankspruit (**Figure 19**) mimics the TDS load pattern (**Figure 18**) in the period since early-2010. The most recent period (August 2012 to September 2023) exhibits a lower median value of 1925 t/m compared to the 2053 t/m of the preceding period (February 2010 to July 2012). These circumstances indicate that the most recent period experienced lower sulphate loads than previously. **Figure 20** and **Figure 21** reflect more recent  $\text{SO}_4$ : TDS ratio values in the range 41 to 52%.



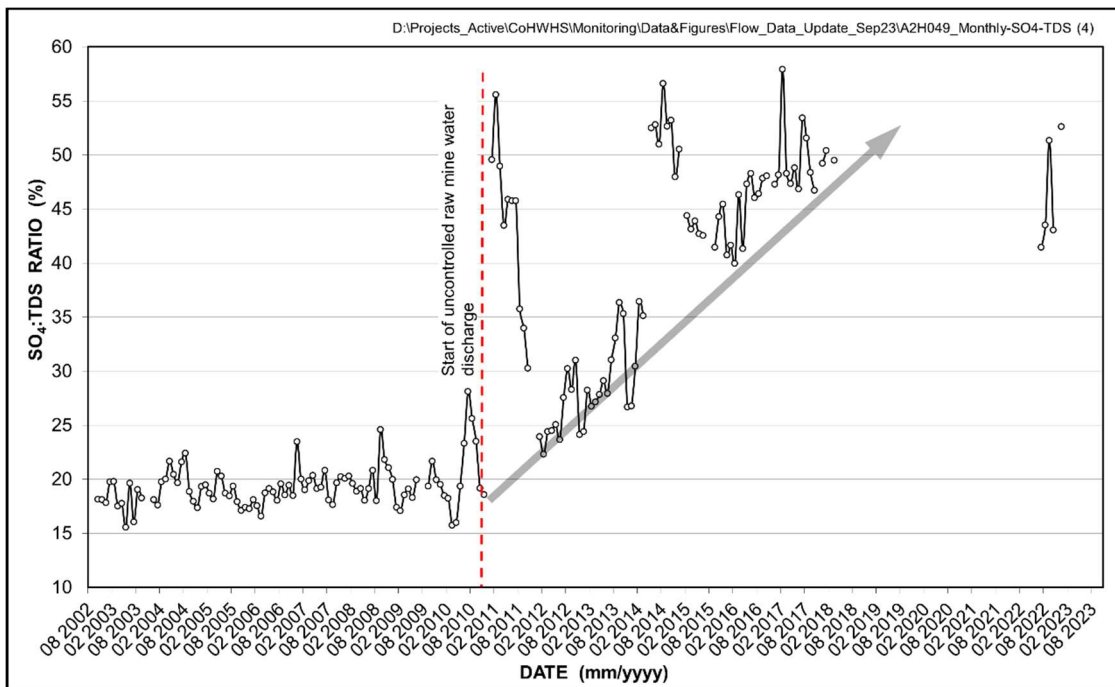
**Figure 18** Long-term (June 1979 to September 2023) monthly TDS load pattern and trend in the Bloubankspruit at station A2H049



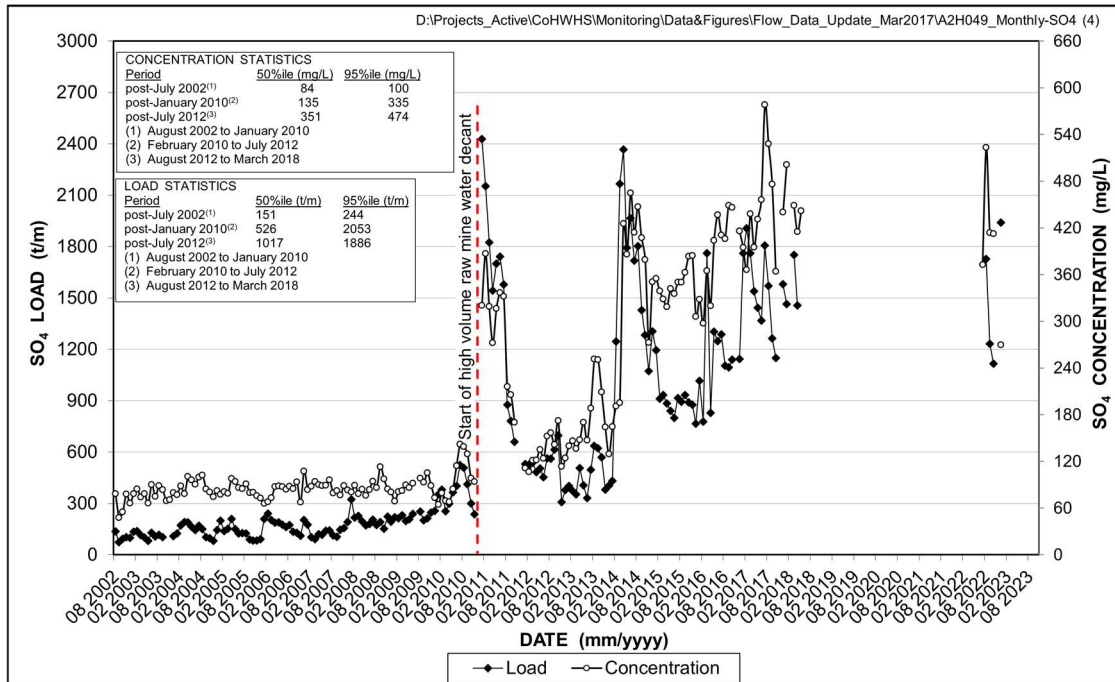
**Figure 19** Long-term (June 1979 to September 2023) monthly SO<sub>4</sub> load pattern and trend in the Bloubankspruit at station A2H049



**Figure 20** Long-term (June 1979 to March 2018) trend in the SO<sub>4</sub>: TDS ratio at station A2H049



**Figure 21** Pattern and trend of the SO<sub>4</sub>: TDS ratio at station A2H049 since the start of mine water decant in the Western Basin in mid-2002



**Figure 22** Monthly SO<sub>4</sub> concentration and load pattern and trend in the Bloubankspruit at station A2H049 since mid-2002

## 5 GROUNDWATER HYDROLOGY

### 5.1 Physical Hydrogeology

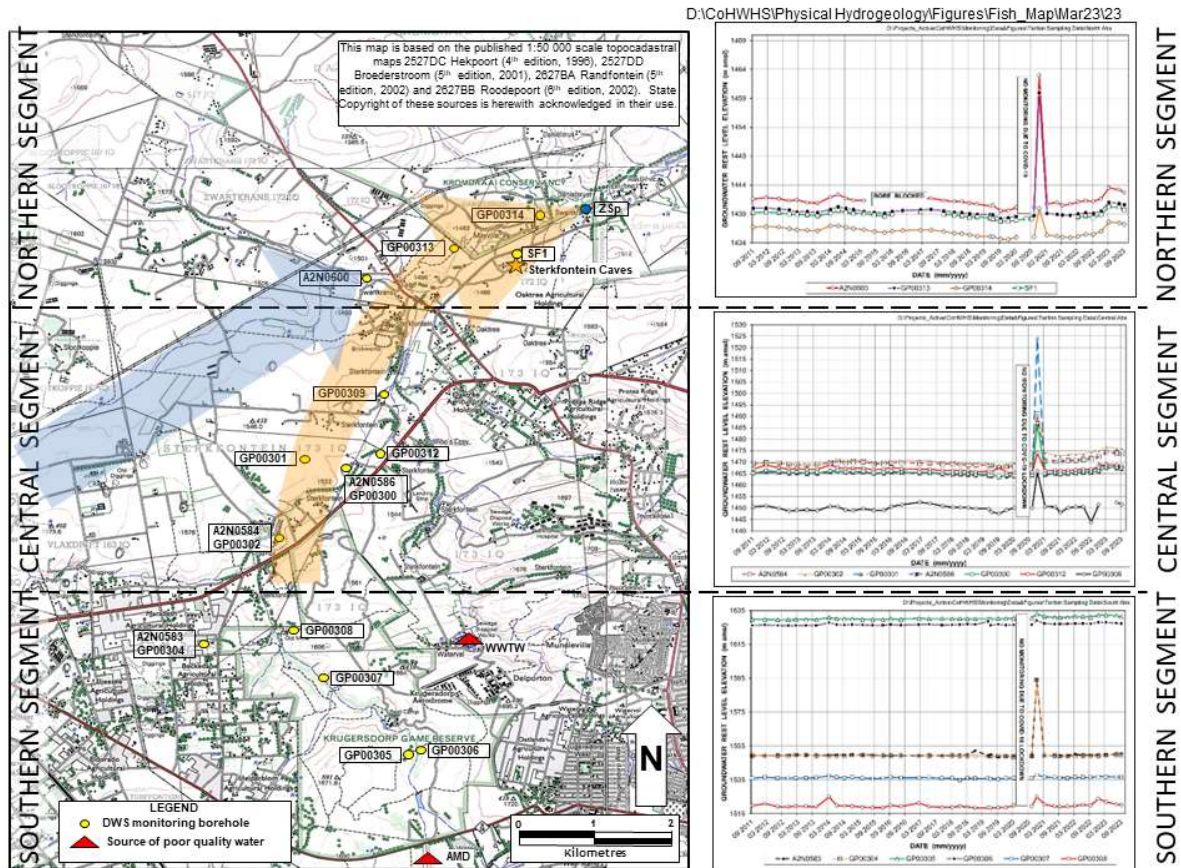
#### 5.1.1 Monitoring Framework

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 using 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 between April 2020 and September 2020, therefore there exists a permanent data gap between April 2020 and September 2020. Furthermore, while the MA-commissioned water resources monitoring programme was on halt between September 2020 and August 2022, the DWS conducted three monitoring runs in July 2021, September 2021 and March 2022, respectively. The latest results represented herein were captured in September 2022, December 2022, March 2023, July 2023 and September 2023.

#### 5.1.2 Sub-regional Groundwater levels

The groundwater hydrographs shown in **Figure 23** illustrate a slight decrease in the groundwater level elevations in the northern and central segments between March 2023 and September 2023. Barring the marked decrease in the groundwater level for station GP00308, the groundwater elevations in the southern segment display relatively stable to minimally decreasing values. The lake water level in Sterkfontein Cave at the north-eastern discharge end of the Zwartkrans Basin most clearly reflects the

general decrease 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

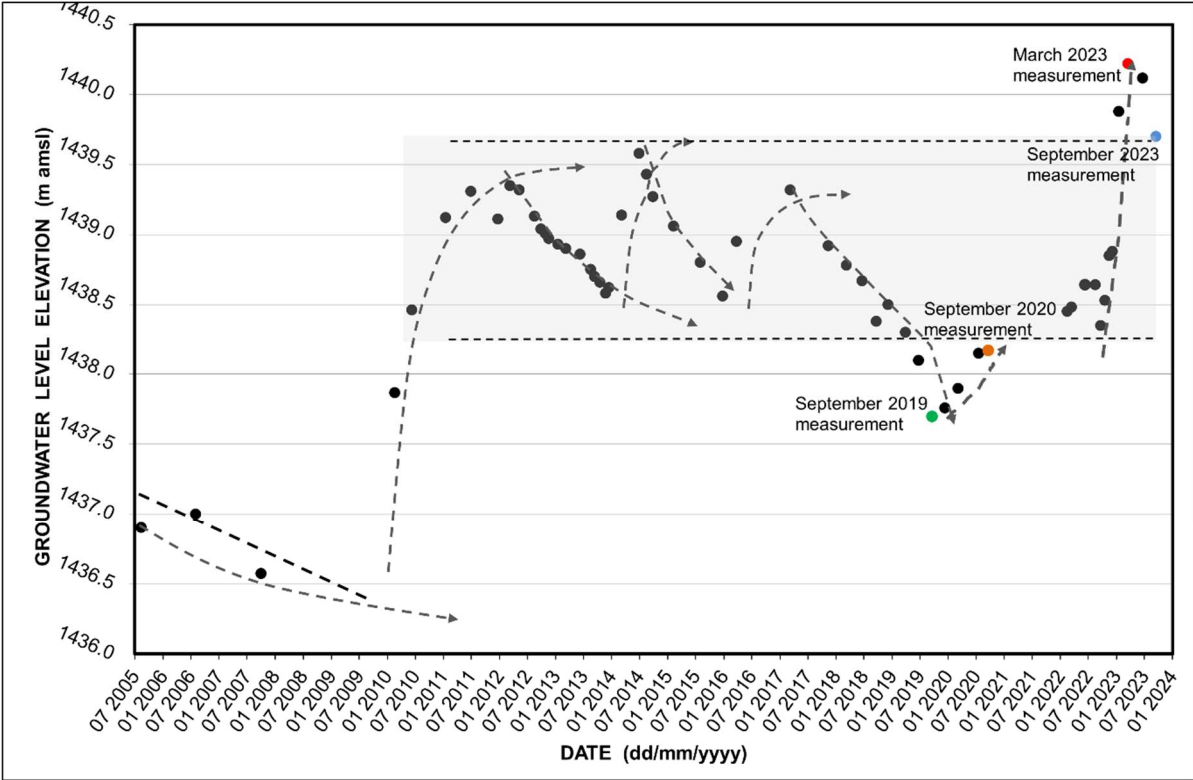
### 5.1.3 Sterkfontein Cave Water Level

The global importance of Sterkfontein Cave, recognized as the primary fossil site within the property, places a spotlight on any potential impact affecting this site. An especially notable event occurred between 2010 and early 2012 when the cave water level experienced a substantial rise of approximately 3 m. This increase raised concerns and prompted a detailed exploration of the cave water level's hydrostatic behavior, extensively examined by Hobbs and De Meillon (2017).

The cave water level's response over the last 14 years is visually represented in **Figure 24**. The hydrograph depicts fluctuations since mid-2010, totaling approximately 1 m, with elevations varying within the range of  $1439 \pm 0.5$  metres above mean sea level (amsl). It has been hypothesized that the cave lake will persist at this level in the future due to continuous higher discharge rates in the upper tributaries of the Bloubankspruit, namely the Tweelopies/Rietspruit system and the Blougatspruit. These tributaries drive allogenic groundwater recharge from mine water and municipal wastewater, respectively, into the Zwartkrans Basin (Hobbs et al., 2018).

However, noteworthy deviations from this expected trend occurred in September 2018, December 2018, March 2019, and September 2019 when groundwater levels reached their lowest points since the end of

2010. Notably, the groundwater elevation measured in September 2023 stands at 1439.70 m amsl, indicating a decrease of approximately 0.52 m compared to March 2023. This decline in groundwater level aligns with the observed decrease in groundwater rest level elevation in the central and northern segments of the COHWHS property, as illustrated in **Figure 23**. These findings shed light on the evolving hydrodynamic conditions, providing crucial insights into the groundwater dynamics within the property.



**Figure 24** Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the lake water level in Sterkfontein Cave; blue dot represents September 2023 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

Every six months, the discharge from the dolomitic springs in the COHWHS is measured. The end of the wet (March/April) and dry (September/October) seasons are targeted as the optimal measuring times for the bi-annual measurement frequency. This is to analyse 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 6**) of the ten identified springs at a biannual frequency. The ‘measured discharge’ (**Table 6**) 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:

- A discharge of 0.102 m<sup>3</sup>/s (9.44 ML/d) was recorded for the Zwartkrans Spring during the September 2023 monitoring run, which is significantly lower than the discharge of 0.34 m<sup>3</sup>/s (i.e. 29.32 ML/d) recorded during the March 2023 monitoring run. However, the continual direct abstraction from a borehole near to the spring, as highlighted by Bugar *et al.* (2018) and Mvandaba *et al.* (2019), suggests that the Zwartkrans spring's true contribution to the river flow and the discharge calculated as a result may be compromised.

- The combined yield of the springs on the Plover's Lake and NIROX properties was measured to be 0.15 m<sup>3</sup>/s (~12.96 ML/d) during the March 2023 monitoring run. The discharge measured in September 2022 was ~73% less at 0.071 m<sup>3</sup>/s (7.489 ML/d).
- A comparison of the discharge recorded for the Nouklip Spring in March 2023 and the discharge measured in September 2023 indicates a decrease of 2.53 ML/d (~12%). Similarly, the Nash Spring seemingly experienced a decrease in streamflow of ~9.84 ML/d. According to Hobbs *et al.* (2011), the Tweefontein spring contributes to the discharge of the Nouklip spring by providing autogenic recharge to the Diepkloof Compartment. However, as previously stated by Mvandaba *et al.* (2020b), the gauging sites used for the Tweefontein and Nash spring discharge measurements provide a partial account of the flow in the respective systems. The direct hydraulic relationship between the springs has not been quantified under the purview of this study, despite the groundwater flow routes in each karst compartment on the COHWHS property having been characterized and illustrated (Hobbs, 2011; **Figure 27**).
- The discharge of the Broederstroom spring was gauged ~10 m downstream from the eye of the spring in September 2023. The measurement site is a concrete furrow where water from the Broederstroom spring collects as it flows downstream (**Figure 26**). A discharge of 0.18 m<sup>3</sup>/s (1.97 ML/d) was measured during the September 2023 monitoring run. Given the direct abstraction from the spring, it remains uncertain whether this measurement provides a true reflection of the yield of the spring. In future sampling operations, an appropriate uncertainty factor (~ 10-15%) might be applied to the measured spring discharge to account for the indeterminate measurement.

The most substantial discharges were recorded at the Zwartkrans, Nash, and Nouklip springs, producing approximately 9.44 ML/d, 18.64 ML/d, and 10 ML/d, respectively, in September 2023. However, it is essential to acknowledge the significant uncertainty associated with the Zwartkrans spring discharge due to continuous and direct extraction from the spring's eye during flow measurements.

It is important to note that the specific responses of these individual springs to variations in rainfall and discharge across the COHWHS property have not been precisely quantified to date. Such an analysis would necessitate the comprehensive quantification of all processes influencing channel transmission losses, encompassing factors like water usage and evapotranspiration rates. These intricate considerations are vital for a more precise understanding of the springs' behaviour in response to changing environmental conditions, paving the way for enhanced management strategies within the COHWHS property.



**Figure 26** The concrete furrow near the eye of the Broederstroom spring where water collects as it flows downstream

**Table 6** Dolomitic spring discharge measured in March 2023 and September 2023

Spring	Compartment	Measured Discharge (Mar)		Spring Discharge (Sep 22)		Measured Discharge (Mar 23)		Spring Discharge (Mar 23)		Previous Discharge Volume <sup>1</sup>	
		(m <sup>3</sup> /s)	(ML/d)	(m <sup>3</sup> /s)	(ML/d)	(m <sup>3</sup> /s)	(ML/d)	(m <sup>3</sup> /s)	(ML/d)	(m <sup>3</sup> /s)	(ML/d)
Zwartkrans (upstream)	Zwartkrans	1.3	111.85	0.34	29.32	1.30	111.85	0.102	9.44	~0.1	~8.6
Zwartkrans (downstream)		1.63	141.17			1.63	141.17				
Plover's Lake	Krombank	0.07 <sup>(2)</sup>	6.78 <sup>(2)</sup>	0.15	12.96	0.06	5.54	0.15	12.96	~0.06	~5.2
Plover's Lake (culvert)		0.01	0.71			0.09	7.43				
Kromdraai (upstream)	Krombank	–	–	–	–	–	–	–	–	~0.28	~24.1
Kromdraai (downstream)		0.86	75.01			1.29	111.56				
Danielsrust	Danielsrust	0.07	5.75	0.07	5.75	0.07	5.75	0.07	5.75	~0.03	~2.4
Nouklip	Diepkloof	0.25	21.17	0.25	21.17	0.216	18.64	0.216	18.64	~0.14	~12.4
Tweefontein	Tweefontein	0.004	0.44	0.004	0.44	0.04	3.82	0.04	3.82		
Nash	Uitkomst	0.23	19.88	0.23	19.88	0.116	10.04	0.116	10.04		
Broederstroom	Broederstroom	0.03	2.35	0.03	2.345	0.18	1.97	0.18	1.97	~0.02	~1.8

<sup>(1)</sup> After Hobbs (2011)

<sup>(2)</sup> Measured at Plover's Lake 'control site'

## 5.2 Chemical Hydrogeology

### 5.2.1 DWS Monitoring Framework

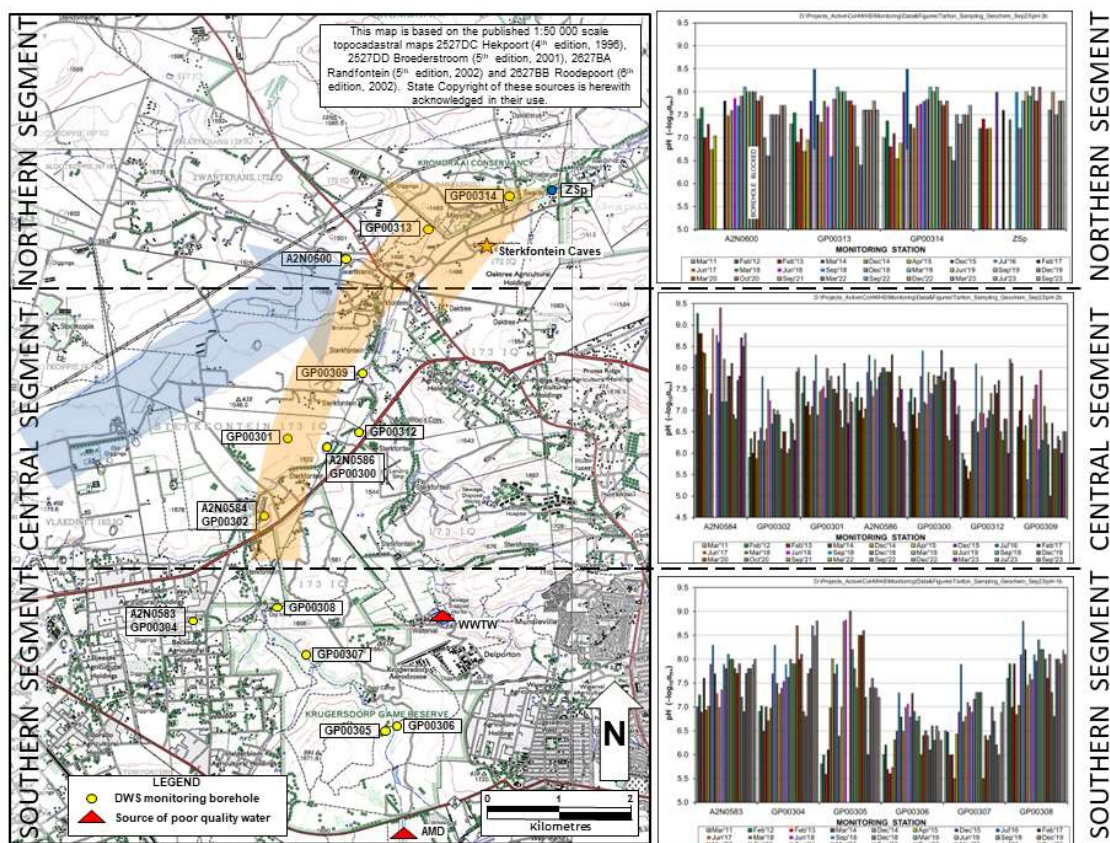
The DWS groundwater monitoring programme in the south-western portion of the property was substantially expanded with the establishment of an additional 13 monitoring boreholes in late-2010. These stations (identified by the alpha-numeric code GP00####) supplement the four stations (identified by the alpha-numeric code A2N0####) that are the legacy of the mid-1980s DWAF study (Bredenkamp *et al.*, 1986) in the region. In 2022, the borehole near the Zwartkrans Spring (26.008220 S, 27.745 E) was added to the DWS monitoring programme as site A2N0811. 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**). Following the resumption of the MA-commissioned monitoring programme, the DWS has conducted monitoring in September 2022, December 2022, March 2023, July 2023 and September 2023. The most recent chemical analyses of groundwater provided for the south-western portion of the property are as at September 2023.

### 5.2.2 Mine Water Impact

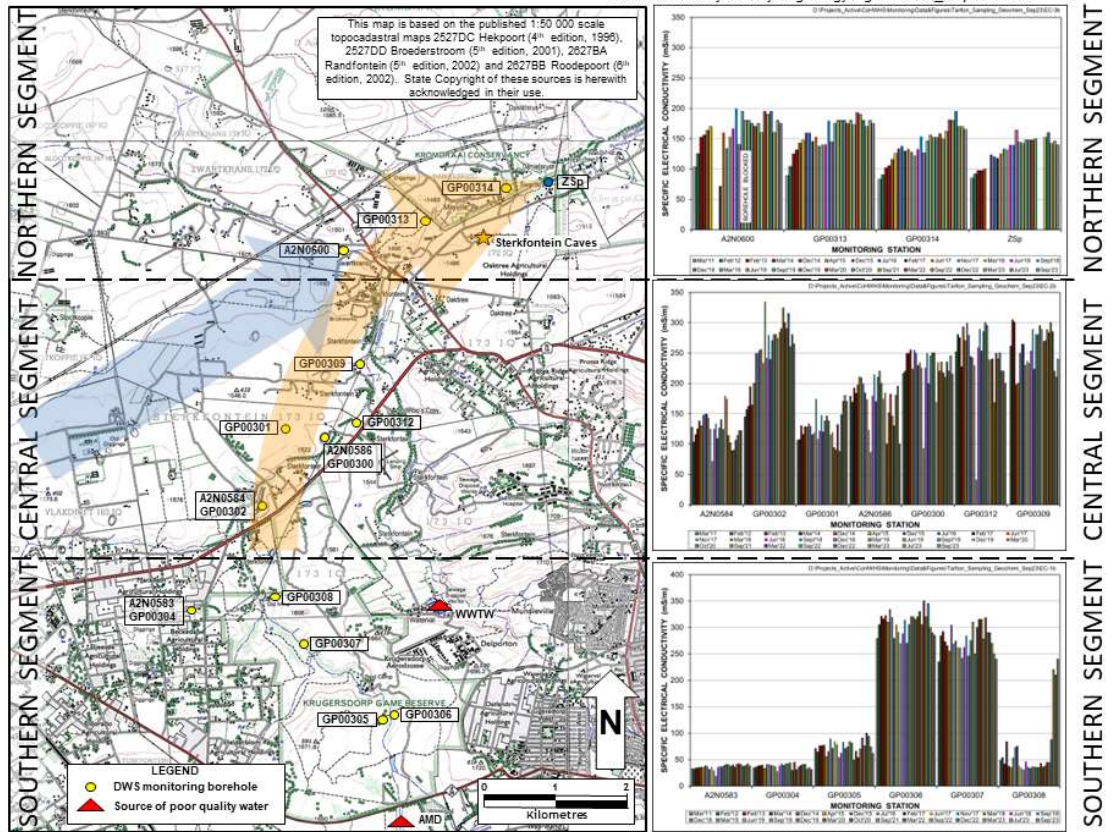
The magnitude of the mine water impact on the karst aquifer in the Zwartkrans Basin is illustrated in **Figure 27** and **Figure 28** with the aid of bar graphs for the chemical variables pH and SEC respectively. Spatially, the bar graphs in **Figure 27** reflect a general progressive decrease in pH, from south to north within the southern, central and northern segments. The pH trendlines at individual stations however show seasonal variability, albeit marginal. Across all the monitoring stations, there is a notable increase (~13%) in pH from March 2022 to September 2022, whereas in previous years there has been up to ~4% increase. Recent pH values in the southern segment bracket the range 6.0 to 8.7, and those in the central segment range from 6.0 to 8.7. In the northern segment, the most recent pH values are in the range 7.5 to 7.6. Due to the dissolution of carbonate rocks, the pH of karst groundwater is buffered and nearly neutral across all the groundwater sites.

The specific electrical conductivity (salinity) of groundwater sampled in the southern and central segments of the study area 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. Seemingly, the proximity of the Tweelopiesruit and Rietspruit to these sites may have an impact on the salinity of groundwater in these segments. In the northern segment, however, the spatial salinity trend along the flow path is a declining one, however at each of the stations, with the exception of the Zwartkrans Spring, an increasing trend in salinity is apparent. The recent (March 2023) salinity values are constrained to the range 142 to 170 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**.

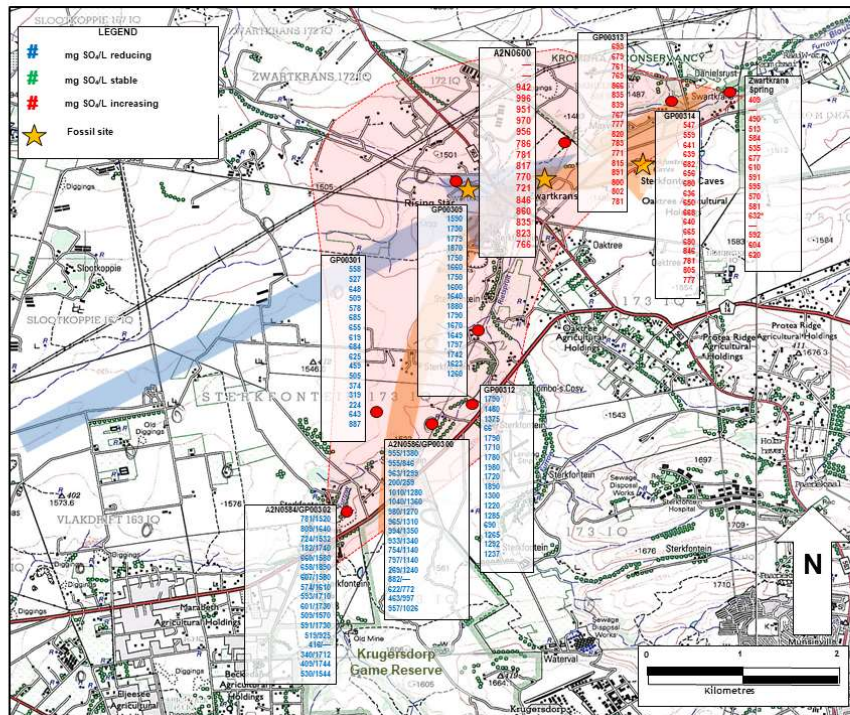
The extent of the mine water impact on the karst aquifer of the Zwartkrans Basin is shown in **Figure 29**, and provides an indication of the sulphate trend at each monitoring station in terms of up, stable or down in the recent past, by comparing the July 2016, February 2017, November 2017, March 2018, June 2018, September 2018, December 2018, March 2019, June 2019, September 2019, December 2019, March 2020, October 2020, July 2021, September 2022, December 2022, March 2023, June 2023 and September 2023 values. The trendlines from July 2016 to March 2023 indicate that sulphate levels in ambient groundwater have generally reduced at the southwestern (ingress) end of the impacted zone, but are still increasing at the north-eastern (discharge) end. There is however variability at individual stations and typically the sulphate values at the north-eastern end of the study area are lower than at the sites closer to the mine locations.



**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 (1<sup>st</sup> value), February 2017 (2<sup>nd</sup> value), November 2017 (3<sup>rd</sup> value), March 2018 (4<sup>th</sup> value), June 2018 (5<sup>th</sup> value), September 2018 (6<sup>th</sup> value), December 2018 (7<sup>th</sup> value), March 2019 (8<sup>th</sup> value), June 2019 (9<sup>th</sup> value), September 2019 (10<sup>th</sup> value), December 2019 (11<sup>th</sup> value), March 2020 (12<sup>th</sup> value), October 2020 (13<sup>th</sup> value), July 2021 (14<sup>th</sup> value), September 2022 (15<sup>th</sup> value), December 2022 (16<sup>th</sup> value), March 2023 (17<sup>th</sup> value), July 2023 (18<sup>th</sup> value) and September 2023 (19<sup>th</sup> 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

The water quality of the groundwater which forms the underground lake in the Sterkfontein Cave is typically monitored on a quarterly basis. However, the Cave has been inaccessible since March 2023. The management personnel for the Sterkfontein Aves property indicated that the roof of the Cave collapsed due to the heavy rainfall experienced between in the early months of the wet season, November 2022 to February 2023. **Table 6** therefore presents the water chemistry results of samples collected in March 2019, June 2019, September 2019, December 2019, March 2020, September 2020, September 2022 and December 2022. The results from September 2022 and December 2022 remain largely consistent with the historic values reported for this site and none of the chemistry variables reported for, exceed the respective SANS (2015a) health-related limits for potable water. The microbiological quality of the water is however compromised by the increased total coliform bacteria which exceeds the standard health-related limits across all sample results and thus reflects the impact of poorer quality surface water on the karst groundwater. The moderately alkaline pH value reflects the continuing neutralising capacity of the carbonate strata. Because the Sterkfontein Cave is situated away from the main groundwater flow vector towards Zwartkrans Spring, mine water has less of an effect on the lake's water chemistry.

**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, September 2020, September 2022 and December 2022.

Variable	Mar 19	Jun 19	Sep 19	Dec 19	Mar 20	Jul 20	Sep 20	Sep 22	Dec 22	SANS (2015a) <sup>(1)</sup>
pH (-log <sub>10</sub> [OH <sup>+</sup> ])	8	8.1	8.1	8.2	7.9	4.7	7.9	8	8.2	5.0–9.7
SEC (mS/m)	92	92	95	94	100	90	100	96	94	<170
Ca (mg/L)	90	89	88	89	91	95	88	88	70	n.s.
Mg (mg/L)	53	54	54	53	50	58	51	51	51	n.s.
Na (mg/L)	35	37	33	34	35	38	33	35	35	<200
K (mg/L)	1.5	1.6	1.5	1.5	2	1.5	1.3	1.5	1.5	n.s.
Cl (mg/L)	37	37	36	37	38	37	37	36	36	<300
SO <sub>4</sub> (mg/L)	273	271	259	262	298	286	267	262	270	<500
HCO <sub>3</sub> (mg/L)	148	146	148	142	146	160	145	147	147	n.s.
NO <sub>3</sub> +NO <sub>2</sub> (mg N/L)	7.1	7	6.6	7	7.4	7.6	7	7.1	7.6	<11
Si (mg/L)	5.9	7	5.8	6	5.8	5.6	6	6.3	5.9	n.s.
Fe (mg/L)	0.02	0.31	0.02	0.17	0.04	<0.01	0.03	0.03	<0.02	<2
Mn (mg/L)	<0.01	0.32	<0.01	0.03	0.02	0.02	0.01	<0.01	<0.03	<0.5
Al (mg/L)	0.03	0.14	0.02	0.05	0.03	0.02	0.02	<0.01	<0.02	<0.3
Total coliform bacteria (MPN/100 ml)	1046.2	125.9	35.5	248.1	547.5	78	32.3	78.9	1299.7	<10
E. coli (MPN/100 ml)	<9.8	4.1	<1.0	3.1	3.1	<1	<1	14.4	12.2	n.d.

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

n.s. no standard

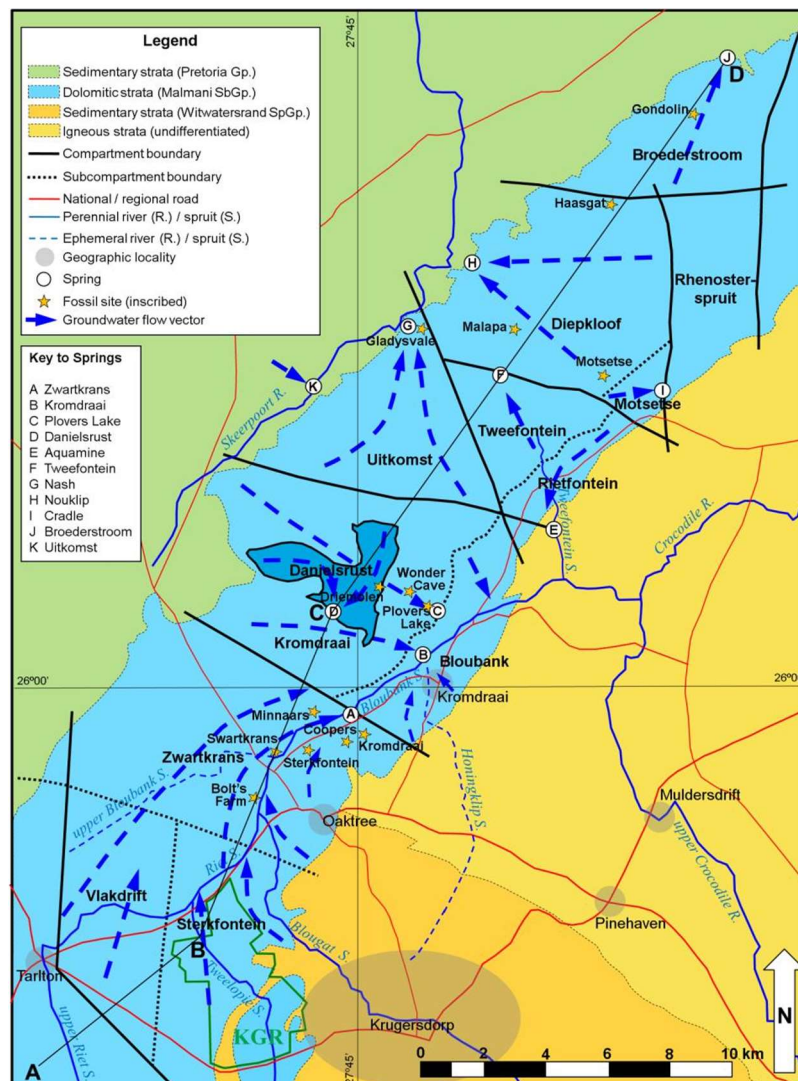
n.d. not detected

#### 5.2.4 Dolomitic Springs

As part of Project GT/WHS/021/2022 the CSIR is responsible for the bi-annual water quality monitoring of the dolomitic springs in the study area (**Figure 30**). Sampling occurred in March 2023 and September 2023, with the corresponding results outlined in **Table 7**. Additionally, **Section 5.2** provides a comparison between historical and recent water quality data concerning the Zwartkrans Spring.

Apart from the Zwartkrans and Aquamine springs, the waters from the main dolomitic springs are of good quality for the chemistry parameters indicated for the sample data between March 2023 and September 2023. Consistent with the results from March 2023 (Mvandaba et al. 2023), the results from the chemical analysis of water sampled from the Zwartkrans Spring indicate probable impact from mine water due to the elevated sulphate levels surpassing established health-related limits (SANS 241:1, 2015a). The groundwater from the Aquamine Spring exhibits relatively higher concentrations of manganese, iron, and aluminium - the pronounced concentrations of these minerals at this locality were noted in previous reports (Mvandaba et al., 2020b; Mvandaba et al., 2023). Manganese, iron and aluminium occur naturally in karst sediments, therefore the 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) and, or runoff.

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. In water resource management, the count of total coliform bacteria and *E. coli* is used as an indicator of the sanitary quality of water and the degree of pollution. Total coliform bacteria are common in natural environments, i.e., they are naturally occurring in soil, vegetation and aquatic ecosystems and therefore may not necessarily be harmful to the environment. However, an elevated count of total coliform does indicate vulnerability to contamination by more harmful microorganisms of affected water resources. *E. coli*, particularly, is a strain of coliform bacteria that is only found in the intestines of mammals, including humans, and can therefore enter natural environments via poorly treated municipal effluent (sewerage), stormwater runoff, manure used in agricultural practises and dropping from domestic animals and wildlife. The South African Water Quality Guidelines (DWAf, 1996) do not have an applicable target water quality range for coliform in aquatic ecosystems, however, the drinking water guidelines (SANS 241:1, 2015) stipulate less than 10 MPN/100 mL (<10 MPN/100 mL) for total coliforms and zero detection for *E. coli*. According to the World Health Organization (2011), a count of 1– 10 MPN/100 ml is regarded as low risk; 11–100 MPN/100 ml is moderate risk while an *E. coli* count greater than 100 MPN/100 ml is adjudged high risk. *E. coli* counts greater than 1000 MPN/100 ml are considered to be extreme high risk. The most impacted site, the Kromdraai Spring exhibited high levels of total coliform bacteria but moderate faecal contamination. Due to the position of the Kromdraai spring being within the channel of the Bloubankspruit, some intermixing may occur between groundwater emerging from the spring and surface water within the Bloubankspruit, impacting on the observed results. The results from the other dolomitic springs showed minimal *E. coli* contamination and can therefore be considered to be at low risk.



**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 and microbiological results of samples collected at the major dolomitic springs during March 2023 and September 2023

Variable	Zwartkrans Spring		Kromdraai Spring		Plovers Lake Spring		Danielsrust Spring		Aquamine Spring		Tweefontein Spring		Nash Spring		Nouklip Spring		Broederstroom Spring		SANS (2015a)(1)
	Mar 23	Sep 23	Mar 23	Sep 23	Mar 23	Sep 23	Mar 23	Sep 23	Mar 23	Sep 23	Mar 23	Sep 23	Mar 23	Sep 23	Mar 23	Sep 23	Mar 23	Sep 23	
pH (-log10αH+)	7.6	7.8	7.7	8.1	7.8	8.1	8	8	8.4	8	8	8.1	8	8.1	8	8.1	8.3	7.9	5.0–9.7
SEC (mS/m)	144	144	74	70	38	70	29	30	49	54	41	39	25	26	37	38	40	56	<170
Ca (mg/L)	163	153	70	66	23	66	31	30	53	61	44	41	26	27	40	41	43	57	n.s.
Mg (mg/L)	79	76	41	39	25	39	18	19	32	35	28	25	15	16	23	25	27	35	n.s.
Na (mg/L)	59	54	22	19	2.3	19	1.5	1.5	3.4	3.3	1.4	1.2	1.3	1.3	1.1	1.1	1.7	1.3	<200
K (mg/L)	<3	2.1	1.1	0.9	<0.6	0.9	<0.6	<0.6	0.8	0.9	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	n.s.
Cl (mg/L)	44	42	25	23	<2.0	23	<2.0	3.3	6.6	3.3	2.7	<2.0	<2.0	<2.0	2.4	<2.0	3.3	<2.0	<300
SO4 (mg/L)	602	553	175	154	16	154	6.7	6.6	13	8.5	12	7.5	2.4	1.8	6.4	5.6	16	19	<500
Alkalinity as CaCO3 (mg/L)	146	146	157	164	196	164	145	142	261	283	216	198	133	133	199	198	203	267	n.s.
NO3+NO2 (mg N/L)	8.4	8.5	4	3.9	0.65	3.9	0.61	0.76	0.36	0.21	0.6	0.71	0.17	0.18	0.31	0.34	0.53	0.58	<11
Si (mg/L)	7.3	6.7	6.2	5.9	6.5	5.9	5.9	5.5	7	7.2	5.3	5	5.4	5.4	5.2	5.3	4.2	5	n.s.
Fe (mg/L)	0.03	0.01	0.31	0.02	0.07	0.02	<0.01	0.03	0.6	0.89	<0.01	0.12	<0.01	0.02	<0.01	0.04	0.1	0.02	<2
Mn (mg/L)	0.02	<0.01	0.15	<0.01	0.14	<0.01	<0.01	<0.01	0.12	0.52	0.02	0.3	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.5
Al (mg/L)	0.06	<0.02	0.15	<0.02	0.05	<0.02	<0.02	<0.02	0.3	0.43	<0.02	0.04	<0.02	0.04	<0.02	<0.02	0.06	<0.02	<0.3

Total coliform bacteria (MPN/100 ml)	920.8	48.7	>2419.6	1373.9	32.3	50.4	1413	45.7	>2419.6	>2419.6	1553.1	387.3	55.6	32.7	45.7	50.4	123.6	14.6	<10
E.coli (MPN/100 ml)	1	<1	74.8	29.5	2	<1	2	<1	387.3	2	59.1	8.6	5.2	4.1	<1	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

## 6 RIVER HEALTH ASSESSMENT

In accordance with the SLA that governs project GT/WHS/021/2022, the water resources monitoring programme includes an assessment of river health on the COHWHS property on the basis of macroinvertebrate biomonitoring and toxicity screening assays. This assessment is typically conducted biannually at the end of the dry/wet seasons i.e. September and March. During the 2022/2023 sampling period, the samples were collected on three separate occasions (i.e. 19-22 September 2022, 5-7 December 2022 and 13-16 March 2023). Due to health concerns, the operator was unable to conduct macroinvertebrate sampling during the first monitoring period (i.e., September 2022), hence only toxicity test samples were obtained at the four sampling sites. In order to make up for the missed macroinvertebrate sampling, biomonitoring was carried out in December 2022 at two of the four sites, namely BB@M and BB@NOE. However, due to earlier flooding events in the region (Krugersdorp News, 2022) which resulted in destabilized riverbanks, high flow and turbidity, the operator was unable to conduct macroinvertebrate sampling at the BB@NOE site over safety concerns. During the March 2023 monitoring trip, the river conditions were conducive for both macroinvertebrate monitoring and aquatic toxicity testing to be conducted and the results of the biomonitoring are discussed herein.

The assessment of macroinvertebrates in rivers is widely recognized as a means of determining the condition or health of rivers. Benthic macroinvertebrates are particularly recognized as valuable organisms for bioassessments, due to their visibility to the naked eye, ease of identification, rapid 'seasonal' life cycle and their largely sedentary habits (Dickens and Graham, 2002). Bioassessment techniques have been developed over the last three decades with varying complexity and region of implementation. The South African Scoring System 5 (SASS 5) developed by Chutter (1994) went through a refinement process which now forms the backbone of the National River Health Programme. The principal changes made include the tighter definition of technique and the sampling and analytical methods as well as the introduction of quality control procedures. Other changes include the list of macroinvertebrates used in this method.

SASS 5 is suitable for the assessment of river water quality and river health and may be used to (Roux, 1997):

- a) Assess the ecological state of aquatic ecosystems.
- b) Assess the spatial and temporal trends in ecological state
- c) Assess emerging problems
- d) Set objectives for rivers
- e) Assess the impact of developments
- f) Predict changes in the ecosystems due to developments
- g) Contribute to the determination of the Ecological Reserve (National Water Act, 1998).

Laboratory toxicity tests are used worldwide in order to manage environmental resources such as water quality and are highly considered to be the first step in a tired approach in establishing guidelines for setting up maximum acceptable concentrations of specific pollutants (Muller and Palmer, 2004). The use of bioassays incorporating complex mixtures has proven to be a relevant and complimentary tool in evaluating adverse toxic effects of effluents and receiving waters (Rand *et al.*, 1995; Grothe *et al.*, 1996). The techniques are site specific, and account for both point and non-point sources of aquatic contamination and uncharacteristic sources of toxicity and can detect their potentially unknown interactions (Smolders *et al.*,

2003; Martins *et al.*, 2007). However, no single toxicity test has proven to be suitable to assess all adverse ecological effects because individual organisms differ in susceptibility and sensitivity to different chemicals (Rand *et al.*, 1995; DWAF, 2003). Therefore, several different bioassays at different levels of biological complexity and trophic levels need to be used simultaneously to adequately assess if a potential hazard is posed (Jergentz *et al.*, 2004).

Such approaches used internationally in water quality monitoring programmes include the whole effluent toxicity (WET), used in the USA, the direct toxicity assessment (DTA), used in the UK and the 'totale effluent milieu' hygiene (TEM) or 'whole effluent environmental risk' approach, used in the Netherlands (DWAF 2003). These approaches are based on similar fundamental concepts by using an array of acute or chronic toxicity test endpoints and in certain instances such as TEM, include in addition other indirect hazard parameters such as oxygen depletion potential, bioaccumulation and mutagenicity to ascertain ecological effects of pollutants.

The Department of Water and Sanitation (DWS) have adopted a multifaceted approach referred to as the 'direct estimation of ecological effect potential' (DEEEP) which includes these international approaches (using TEM as a foundation) and has become an integral first-tier tool used in the ecological hazard assessment of complex waste discharges (DWAF, 2003). The DEEEP approach uses representative organisms from different trophic levels of the food chain (fish, invertebrates, algae and bacteria) and endpoints (both lethal and sublethal) to reflect the overall impact of toxicants, with provision to define acceptable ecological hazards providing protection of aquatic ecosystems (Jooste and Herbst 2004). More recently the same suite of hazard assessment methods was selected for inclusion in the National Toxicity Monitoring Programme (NTMO) for surface water (DWAF, 2005). The main objectives of the NTMO are to monitor South African water resources in terms of (a) the toxic effects of selected organisms and (b) selected potentially toxic substances. Therefore, there are three rapid and relatively inexpensive internationally standardized toxicity bioassays that form part of the DEEEP and NTMP were adapted and incorporated into the present study. These include (1) the water flea (*Daphnia magna*) lethality test, (2) the algal (*Selenastrum capricornutum*) growth inhibition test, (3) the bacteria (*Vibrio fischeri*) inhibition test. Differential responses of organisms such as these represent diverse physiological capabilities and niches in aquatic systems that can help focus field studies where non-target effects due to off-site movement, for example of acid mine drainage and wastewater effluents, are suspected. Water fleas (*Daphnia* spp.) are routinely employed to detect chemical pollution in river waters on the basis of their toxicity (Rand *et al.*, 1995). *Daphnia* sp. has been used for many years as 'standard aquatic species test species in toxicity testing. Unicellular algae form the basis of the energy flow in the aquatic trophic chain and show great advantage for use in estimating the toxicity of effluents and receiving waters (Sbrilli *et al.*, 2005). They are relatively sensitive to a variety of pollutants and are easy to handle and have a short life cycle Rioboo *et al.*, 2001). The bioluminescence inhibition assay is based on a marine gram negative bacterium, *Vibrio fischeri*. Light production is directly proportional to the metabolic activity of the bacterial population and any inhibition of enzymatic activity due to toxicity or cell death causes a corresponding decrease in bioluminescence produced by the colony (EBPI, 2022).

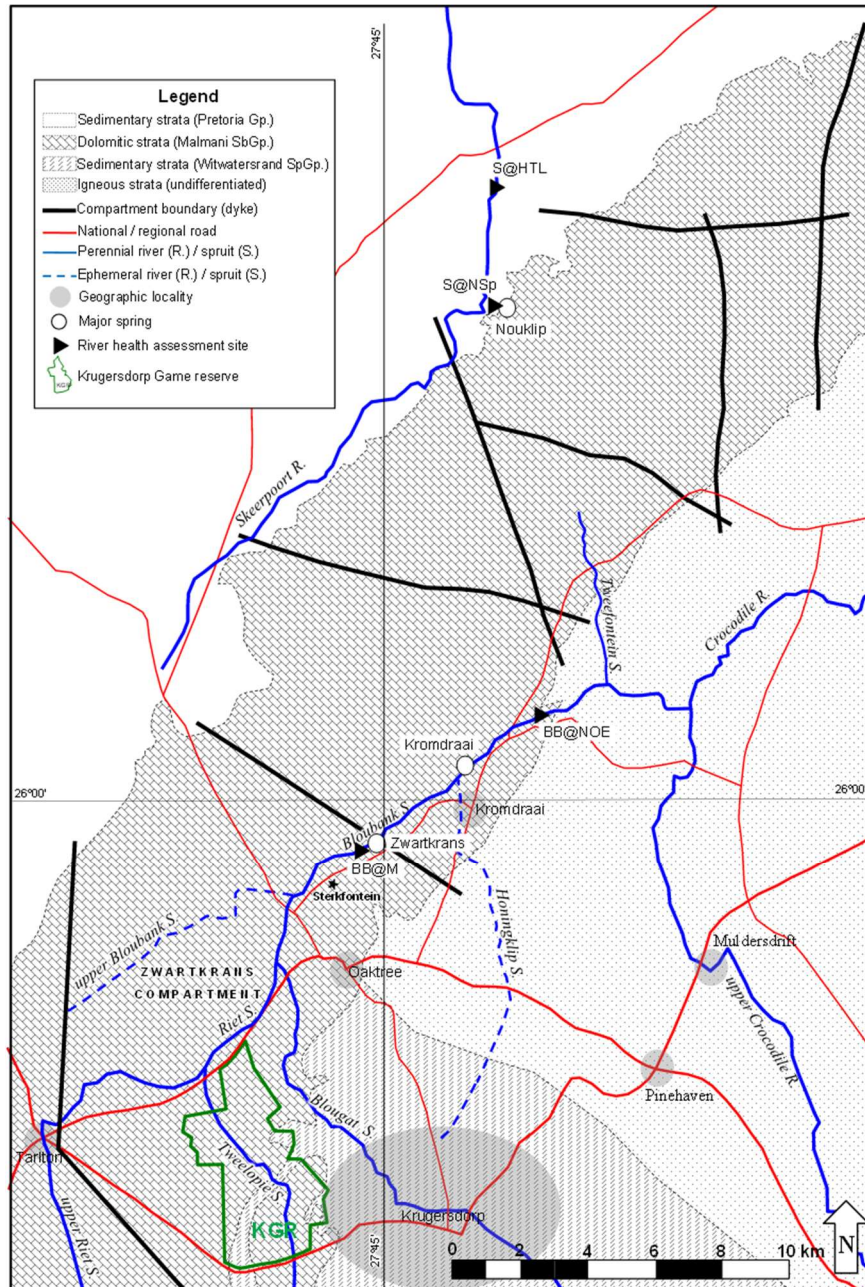
The river health assessment targets two sites on the largely natural Skeerpoort River and two sites on the impacted Bloubankspruit. The sites on the Skeerpoort River are labelled S@NSp and S@HTL, while the sites on the Bloubankspruit are respectively labelled BB@M and BB@NOE (**Figure 31**).

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 Bloubankspruit, 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 Bloubankspruit 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 was surveyed prior the establishment of the COHWHS water resources monitoring programme . 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 COHWHS.



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

## 6.1 Assessment & Data Analysis

The assessment entailed the application of the integrated habitat assessment system 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	SASS5 Score	ASPT Score	Band / Category Name	Description
<b>A</b>	>104-180	>5.8-8	Natural	Unmodified natural
<b>B</b>	>71-104	>4.8-5.8	Good	Largely natural with few modifications
<b>C</b>	>53-71	>4.2-4.5	Fair	Moderately modified
<b>D</b>	>42-53	0-4.2	Poor	Largely modified
<b>E/F</b>	0-42		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 current macroinvertebrate biomonitoring results have indicated an improvement in the general river health and ecological category at both sites on the Skeerpoort River, i.e. S@NSp and S@HTL, despite the noticeable disturbance at the S@HTL site due to cutting away of the natural vegetation and disturbance of the instream habitat as evidenced by the presence of stones, gravel and as a result of fast-flowing water due to flooding. Upstream on the Bloubankspruit, while there was a clear decline in the quality of water and instream habitat at the BB@M site, the ecological category remained the same. As a result of the recent flood events in the study area, the streamflow at the BB@NOE site was found to be too turbid and deep to allow safe assessment of the river health. However, water samples for the assessment of the toxicity, chemistry and microbiological quality were collected.

**Table 9** Synoptic river health assessment outcome for September 2023.

SITE	Date	Ecological category	Condition	Description
S@NSp	13/03/2023	<b>B</b>	Good	Largely natural with few modifications
S@HTL	15/03/2023	<b>A</b>	Natural	Unmodified natural
BB@M	16/03/2023	<b>E/F</b>	Seriously modified	Seriously modified
BB@NOE	14/03/2023	Macroinvertebrate biomonitoring could not be conducted		

### 6.2.2 Comparison with Historical Results and General Observations

#### 6.2.2.1 Skeerpoort River

##### S@NSP

In **Table 10**, seasonal sampling (spring and summer) is compared for site S@NSp. The inclusion of this site in the river health assessment aims to analyse the suitability of site S@HTL as a reference site for the COHWHS property even though it is located downstream of the karst area.

The surrounding area is largely undisturbed, natural vegetation. A few hundred metres upstream there was evidence of heavy erosion from flooding and cutting of the natural vegetation which could easily affect the invertebrate sampling scores. In the current monitoring period (March 2023), the number of taxa was the least in all sampling period due to lack of good habitat for macroinvertebrates sampling.

The River Health Category rating for this site in March 2023 was B (good) with an ASPT score of 5.8 – 5.9. It is expected that this particular site will continue to oscillate between a Category B and C.

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: Grootspuit (tributary of the Skeerpoort River)							
Date	Ecological category	SASS associated scores						Dominance *	
		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	<i>Baetidae</i>
26/09/2018	B	95	15	6.3	73	10	238	Predators	<i>Corixidae</i>
26/03/2019	C	99	17	5.8	75	12	160	Predators	<i>Gomphidae</i>
16/09/2019	C	70	12	5.8	70	12	169	Predator	<i>Pleidae</i>
02/03/2020	B	138	21	6.6	66	14	338	Predator	<i>Palaemonidae</i>
14/09/2020	C	53	14	4.5	59	12	229	Predator	<i>Simuliidae</i>
19/09/2022	<i>Sampling could not be conducted</i>								
14/03/2023	B	31	6	5.17	40	8	NA	Predator	<i>Baetidae</i>
14 03 2023	B	31	6	5.17	40	8	NA	Predator	<i>Baetidae</i>
14 09 2023	A	102	15	6.8	40	8	NA	Predator	<i>Baetidae</i>

## S@HTL

In **Table 11** seasonal sampling for site S@HTL is compared. The River Health Category generally borders between A (Natural), and B (Good) while it was categorized as D only in one occasion.

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. 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. The current ASPT score was the highest of all sampling runs.

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

Site: S@HTL		River: Skeerpoort River							
Date	Ecological category	SASS associated scores						Dominance *	
		SASS5	Taxa	ASPT	IHAS	Highest Sensitivity	Total Invertebrates	Dominant Feeding Group	Dominant Taxa
##/01/2014 <sup>1</sup>	A	~200 <sup>2</sup>	~34 <sup>2</sup>	~6.0 <sup>2</sup>	-	-	-	-	-
13/02/2018	A	185	27	6.9	72%	13	653	Collector-Gatherers	<i>Tricorythidae</i>
17/10/2018	B	170	29	5.9	73%	12	524	Collector-Gatherers	<i>Baetidae</i>
25/03/2019	B	170	28	6.1	76%	13	437	Predators	<i>Baetidae</i>
17/09/2019	B	99	16	6.2	70	12	354	Predators	<i>Baetidae and Pleidae</i>
02/03/2020	A	90	13	6.9	77%	15	399	Predators	<i>Pleidae</i>
15/09/2020	D	70	16	4.3	69%	12	328	Predators	<i>Baetidae</i>
19/09/2022	Sampling could not be conducted								
14/03/2023	A	103	14	7.36	82%	12	NA	NA	<i>Caenidae</i>
14 09 2023	A	99	14	7.07	82%	12	NA	NA	<i>Caenidae</i>

1 From Fourie *et al.* (2014); <sup>2</sup> Approximate value interpolated from bar graph in Fourie *et al.* (2014)

#### 6.2.2.2 Bloubankspruit

#### 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)

Site BB@M typically has in the past showed a variety of good habitat with large areas of sand, stones in current, and leafy vegetation. However, as shown in the Table 12, there is a clear trend in the deterioration of aquatic habitats (biotopes)..The River Health Category remains similar to the previous sampling campaign as it scored E/F. Furthermore, it was noticeable that the ASTP score was the worst compared to the previous sampling campaigns while the habitat quality was very poor of all the sampling trips due to site destruction owing to recent flooding

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

Date	Ecological category	SASS associated scores						Dominance	
		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	<i>Tricorythidae</i>
24/10/12	E/F	35	10	3.5	72	12	524	Collector-Gathers	<i>Baetidae</i>
06/03/13	E/F	52	13	4	74	13	437	Predator	<i>Baetidae</i>
15/08/13	E/F	34	9	3.8	65	12	277	Predators	<i>Baetidae</i> and <i>Pleidae</i>
12/12/13	E/F	38	10	3.8	61				
13/02/18	E/F	27	8	3.4	67	13	653	Collector-Gathers	<i>Tricorythidae</i>
25/09/18	E/F	48	11	4.4	71	12	524	Collector-Gathers	<i>Baetidae</i>
28/03/19	E/F	46	12	3.8	66	13	437	Predator	<i>Baetidae</i>
16/09/19	E/F	36	10	3.6	65	12	277	Predators	<i>Baetidae</i> and <i>Pleidae</i>
04/03/20	E/F	27	8	3.9	56%	6	735	Predators	<i>Chironomidae</i> , <i>Ceratopogonidae</i> and <i>Culicidae</i>
16/09/20	E/F	13	4	3.2	75	5	382	Predators	<i>Chironomidae</i>
19/09/22		Sampling could not be conducted							
06/12/22	E/F	35	12	2.9	49	6	861	Predators	<i>Chironomidae</i>
16/03/23	E/F	15	6	2.5	55	5	861	Predators	<i>Chironomidae</i>
13 09 2023	E/F	16	6	2.6	35	5	861	Predators	<i>Chironomidae</i>

**BB@NOE**

As illustrated in **Table 13**, the ecological state of the Bloubankspruit at the Nedbank Olwazini has been observed to be variable over the various monitoring periods. Less diversified than the upstream site, the instream habitat at this location is largely made up of heavy stones and rocks that pose a safety threat to the river health assessor. There is a little sand, and the overhanging vegetation is often limited. The SASS 5 and ASPT scores continue to be low, as seen 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: Bloubankspruit							
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	<i>Hydropsychidae</i>
16/05/12	E/F	41	10	4.1	59	6	269	Collector-Gatherers	<i>Baetidae</i>
24/10/12	C	59	11	5.4	61	12	230	Collector-Gatherers	<i>Baetidae</i>
06/03/13	B	60	10	6.0	55	12	225	Collector-Gatherers	<i>Baetidae</i>
12/12/13	D	32	6	5.3	53	12	329	Collector-Gatherers	<i>Baetidae</i>
13/02/18	D	57	12	4.8	58	12	234	Collector-Gatherers	<i>Baetidae</i>
25/09/18	E/F	30	8	3.8	55	6	275	Predators	<i>Corixidae</i>
25/03/19	E/F	33	8	4.1	54	6	178	Predators	<i>Simuliidae</i>
17/09/19	E/F	64	14	4.6	58	8	781	Predators	<i>Ceratopogenidae</i> and <i>Chironomidae</i>
04/03/20		Sampling could not be conducted							
16/09/20	E/F	38	11	3.4	50	6	320	Predators	<i>Chironomidae</i>
19/09/22		Sampling could not be conducted							
06/12/22		Sampling could not be conducted							
04/03/23		Sampling could not be conducted							

Previous results indicate the deterioration in the system as the ecological category is consistently in the E/F category. IN the last three monitoring runs of 2022/23, the river health assessment at this site could not be conducted 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.

### 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 Bloubankspruit. The additional site for these tests includes BG@N14 which is the upstream of BB@M. In order to determine the short-term toxicity potential of water samples from the chosen sites, organisms on three different trophic levels—the 15-minute vibrio fischeri test, acute 48-hour D. magna tests, and 72-hour S. capricornutum tests—were carried out under static conditions. Tables B.1, B.2, and B.3 of Annexure B summarize the test circumstances and test acceptability requirements.

Physicochemical parameters were measured at the start and the end of the tests with a hand-held Hach HQ 40D multi-parameter (temperature, pH, electrical conductivity and dissolved oxygen) meter. The results for the three tests are summarised below.

#### 15-minute *Vibrio fischeri* test

Physical parameters measured at the start and end of each test with a hand-held Hach HQ 40D multi parameter meter, are summarised in **ANNEXURE B**. 15-minutes for the V. fischeri luminescence inhibition (-) / stimulation (+) test after a 15-minute exposure period were as follows: S@HTL test sample: 4.33%; S@NSP test sample: 3.28%; BB@M test sample: -17.29%, B@NOE test sample: -5.66% and BG@N14 test sample: -23.75%. Inhibition of > 20% indicates toxicity and stimulation of > 20% indicates potential eutrophication. In all the sites, there was an indication of toxicity at BG@N14; There was a clear trend of toxicity and/or eutrophication potential at both rivers. There was inhibition at Bloubankspruit with the highest inhibition occurring in site BG@N14 while at Skeerpoort River sites there was minimal stimulation. Tests were accepted as the % CV was > 3%.

#### 48-hour *Daphnia magna* test

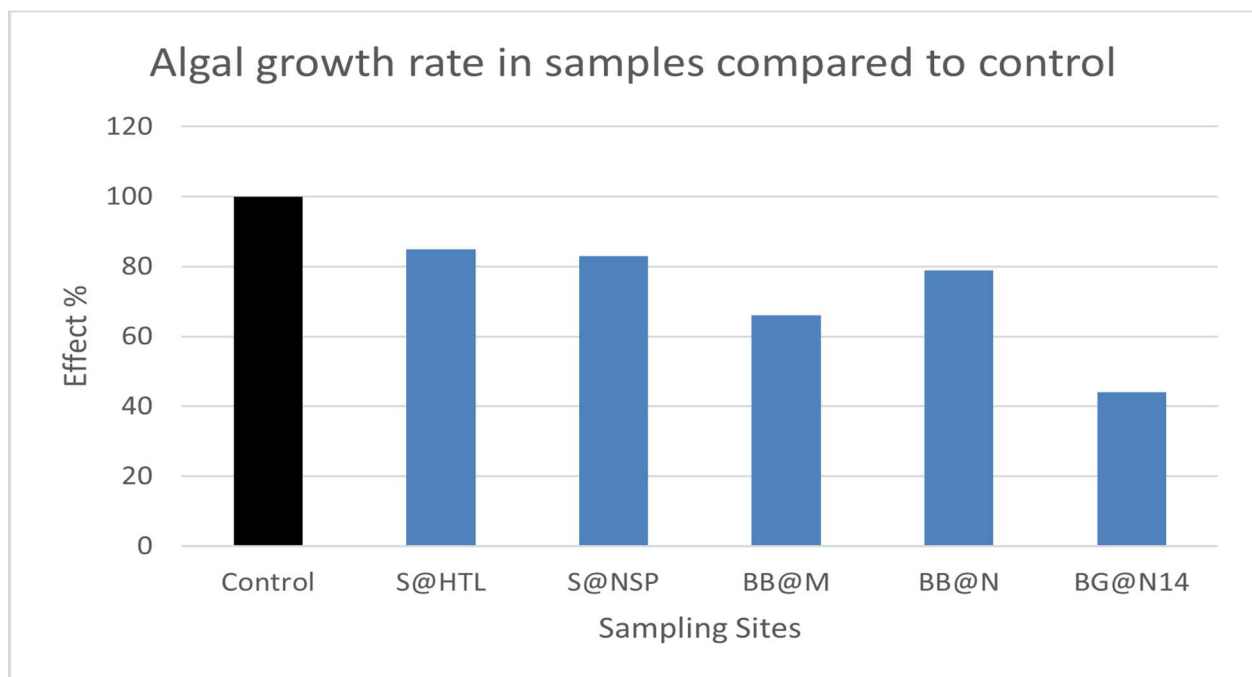
**Table 14** summarises the results of D. magna exposed to the undiluted test samples S@HTL, S@NSP, BB@M and B@NOE. S@HTL, S@NSP, BB@M, B@NOE and BG@N14. The tests were accepted as no mortality ( $\leq 10\%$ ) was observed in the Control. At the end of the exposure period (48 hours), the highest mortality was found in sample BG@N14 and BB@M of which the mortality percentage was 30% and 15% respectively. The mortality percentage remained low at Skeerpoort samples.

**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	1	5
	48	2	10
BB@M	24	2	10
	48	3	15
BG@N14	24	2	10
	48	6	30

### 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 with growth inhibition less than 20% are S&HTL, S@NSP and BB@M. While BG@N14 and BB@M were potentially considered toxic as growth rate of less than 80% was detected. This was significant in BG@N14 as the growth rate was 44.37% compared to Control.



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

### 6.2.3 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)<sup>1</sup> 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.

<sup>1</sup> 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 BG@N14 (*S. Capricornatum* test). Samples at BB@M and BG@N14 were considered potentially toxic as growth rate of less than 80% was detected which indicated acute hazard and slight acute hazard, respectively. There was a clear trend of toxicity potential at BB@M and BG@N14 than the rest of the samples across all the toxicity tests.

## Phytotestkit and Ostracodtoxit F

The Ostracodtoxit F test results for Bloubankspruit river sites (i.e. BB@M and BG@N14) were all above 20% in natural variation. Growth of ostracods exposed to sediment were inhibited by between 9% and 78% of which BG@N14 and BB@M were the highest. Furthermore, the highest mortality occurred in two Bloubankspruit river sites (See Table 16). The phytotoxkit exposure results have shown a similar trend amongst all the sampling sites. The Bloubankspruit sites showed the highest inhibition compared to the other sites.

**Table 16:** Results from Ostracodtoxit F and Phytotestkit tests for each sampling site. Results above the 20% natural variation indicated in bold (inhibition/mortality and stimulation).

Sampling site	Phytotestkit test			Ostracodtoxit F test	
	<i>L. sativum</i>	<i>S. alba</i>	<i>S. saccharatum</i>	Mortality	Growth inhibition
BB@M	-12.05	<b>-32.06</b>	-9.29	<b>22%</b>	<b>-66%</b>
BG@N14	-17.23	<b>-40.6</b>	-14.92	<b>47%</b>	<b>-78%</b>
S@HTL	1.05	-3.82	15.77	11%	-13%
S@NSP	2.15	-7.01	12.14	7%	-9%
BB@NOE	9.25	1.32	8.79	7%	19%

## 6.2.4 Discussion on River Health

The assessment of macroinvertebrates underscores the adverse influence of anthropogenic activities in Bloubankspruit, resulting in a decline in taxa and total SASS5 scores. This decline is prominently reflected in the recent and past biomonitoring results, particularly evident in the E/F rating. Effluent pollution has significantly deteriorated the health of both Bloubankspruit sites, with ASTP exhibiting the lowest health levels across all sampling campaigns. Field observations have noted turbid river water in Bloubankspruit, affirming the impact of recent flooding and potential effluent discharge into the system. Nevertheless, there has been a notable improvement in the ecological category of S@HTL and S@NSP compared to previous assessments.

This study incorporated toxicity tests that proved invaluable in gauging the potential toxicity of contaminated river water and sediment. The current toxicity results reveal a consistent pattern of toxicity in both Bloubankspruit River and Skeerpoor River. Specifically, Bloubankspruit River demonstrated toxic effects on bacteria (*Vibrio fischeri*), algae (*Selenastrum capricornutum*), ostracod neonates, and Phytotox (using three test plant seeds: *Sorghum saccharatum*, *Lepidium sativum*, and *Sinapis alba*). Notably, BG@N14 exhibited toxicity to bacteria, surpassing 20% inhibition compared to the control. In contrast, S@HTL and S@NSP showed no signs of toxicity in the *V. fischeri* test. Algal toxicity was observed at BB@M and BG@N14, where inhibition was below 80% compared to the control. Higher toxicity and mortality rates in ostracod neonates were also witnessed at BB@M and BG@N14. However, insignificant toxicity potential was noted for *Daphnia magna* during this sampling trip.

These toxicity tests, coupled with the macroinvertebrates assessment, unequivocally highlight the severe anthropogenic impacts affecting Bloubankspruit sites within the catchment. Proper rehabilitation of existing wastewater treatment activities is imperative to prevent or minimize future effluent-related impacts. The outcomes of this assessment underscore the urgency of improved management and maintenance of wastewater treatment works (WWTWs). Additionally, they emphasize the significance of macroinvertebrates monitoring and toxicity tests in evaluating river health status, toxicity potential, and identifying potential pollution hotspots. These insights underscore the importance of vigilant monitoring and proactive management practices to safeguard the ecological integrity of these vital waterways.

## 7 DISCUSSION & CONCLUSIONS

The *status quo* of the water resources environment of the COHWHS property, during the period April 2023 to September 2023, can be summarized as follows:

The analysis of the hydrological data spanning from 2009 to 2022 reveals significant fluctuations in the Cradle of Humanity World Heritage Site (COHWHS) hydrological patterns. Notably, the hydrological years 2015 and 2019 were marked as the driest periods on record, showcasing wet season rainfall measurements of 487 mm and 450 mm for the HDS station and 446 mm and 489 mm for the SC station, respectively. In contrast, the years 2020 and 2023 experienced substantial rainfall, with wet season measurements reaching 718 mm and 1028 mm for the HDS station and 864 mm and 414 mm for the SC station, respectively. However, it is imperative to acknowledge the limitations in the available rainfall dataset, such as the absence of updated data from Sterkfontein Cave since January 2023, which hinders a comprehensive assessment of rainfall's impact on surface and groundwater resources.

Furthermore, the hydrological year 2023 stands out as exceptional, recording a discharge of

approximately 77.5 Mm<sup>3</sup>, the highest since October 1972. This substantial discharge aligns with flash floods reported between November 2022 and March 2023, following intense rainfall events. These findings underline the increased frequency of heavy rainfall events in the region since 2010.

Microbiological analysis in June 2023 and September 2023 confirmed faecal contamination in surface water along the Blougatspruit, Bloubankspruit, Rietspruit, and Tweelopiespruit, notably severe at BG@N14 and BB@M sites where E.coli counts exceeded 2419.6 per 100mL. The dolomitic springs generally exhibited excellent water quality, except for the Zwartkrans and Aquamine springs, showing possible mine water impact and elevated concentrations of manganese, iron, and aluminium, respectively. However, microbiological quality across all springs, including the Sterkfontein Cave lake, was compromised, exceeding standard health-related limits for total coliform bacteria and E.coli.

Macroinvertebrate monitoring revealed a consistent deterioration in the ecological health of the Bloubankspruit system, particularly evident at the BB@M site in March 2023 and September 2023, corroborated by toxicity tests highlighting toxic effects at BG@N14, BB@M, and BB@NOE sites. In contrast, an improvement in river health was observed at S@NSp and S@HTL sites along the Skeerpoort River during the recent monitoring run.

In conclusion, the results from this water resources monitoring report validate the suitability of the existing monitoring program and the hydrological model developed by Hobbs (2011) for COHWHS. However, the integrity of the monitoring program is compromised by multiple gaps in the datasets. Addressing these gaps is crucial for a comprehensive understanding of the COHWHS hydrological system. Therefore, it is imperative to enhance efforts to ensure continuous monitoring and up-to-date maintenance of institutional databases, ensuring the accuracy and reliability of future assessments.

## **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 Tirelo Setsome (A2H049: Hydrometry) in the provision of water resources monitoring data is also recognised and appreciated. Gratitude is extended to Mr Erling Fischer of Sibanye-Stillwater for the provision of 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.

## 9 REFERENCES

- Bredenkamp, D.B., van der Westhuizen, C., Wiegmanns, 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.

**Krugersdorp News, 9 December 2022.** Flooding Havoc Across the West Rand: Places to Avoid in Krugersdorp. Accessed on 19 May 2023 at <https://krugersdorpnews.co.za/495815/flooding-havoc-across-the-west-rand-places-to-avoid-in-krugersdorp/>.

**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. 2020a.** *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.

**Mvandaba, V., Kapangaziwiri, E. and Shadung, J. 2020b.** *Surface water and groundwater resources monitoring, Cradle of Humankind World Heritage Site, Gauteng Province, South Africa: Water resources status report for the period April 2020 to September 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	15/03/2023
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	
Gerriidae	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			
Ceratopogonidae		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	13/03/2023
Oligochaeta	1		1		45		
Potamonautidae	8		8		5	1	1
Atyidae					8		
Palaemonidae					120		
Hydracarina	1	4		3			
Plecoptera					1		
Baetidae	40	30	6	5	10	29	36
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	8
Hydrometridae					1	14	
Naucoridae			12				1
Notonectidae				3	1		
Pleidae	1	2	6	107			
Veliidae	10	15	10	6	88	11	
Ecnomidae					7		
Hydropsychidae		30	3		9		
Psychomyiidae				3		3	
Gyrinidae	12						
Psephenidae	6	1	2				
Ceratopogonidae			2				
Chironomidae	3			6	8	4	6
Dixidae					8	9	
Simuliidae		12		12	9		
Tabanidae	1		3			9	
Tipulidae		2				110	
Ancylidae	1		2				
Planorbinae*		1					
Hydraenidae							5

#### A.4 Site BB@M

The upstream site on the Bloubankspruit 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 Bloubankspruit. 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 Bloubankspruit

**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	06/12/2022	15/03/2023
Turbellaria		1	8	4	15	44	8	2
Leeches	1		1				1	
Oligochaeta		1		6	2		5	1
Crustacea	3	1	2	6				
Potamonautidae	40	40		8				
Baetidae		40	10	12	19		10	
Coenagrionidae		10		3			11	8
Aeshnidae		8	3					
Gomphidae		1	6					
Corixidae	30							
Gerridae	4	3	12					
Pleidae			1	7				
Ecnomidae	40	100	20	18				
Veliidae	1							
Hydropsychidae	100	200	300	55	38			
Psychomyiidae			3	15				
Gyrinidae			1					
Ceratopogonidae				161	120	1	1	
Chironomidae				33	219	330	450	460
Culicidae					180			
Simuliidae				29	5		370	280
Physidae					7	7	10	
Ancylidae				4				
Coelenterata								
Hirunidae								
Libellulidae							1	
Belostomatidae							1	
Dytiscidae							1	

#### A.5 Site BB@NOE

Site BB@NOE is located on the Bloubankspruit ~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 Bloubankspruit. 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 Bloubankspruit

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

<b>BB@NOE</b>	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).

<b>Summary of toxicity test</b>	
Test system	<i>Daphnia</i> test
Test species	<i>Daphnia magna</i>
Age of test organisms	Less than 48h old
Trophic level	Grazer
Toxicity level	Acute toxicity
Test procedure	USEPA, 2002
<b>Summary of test conditions for the <i>Daphnia magna</i> acute toxicity test</b>	
Test type	Static-renewal
Water temperature	20 °C ± 1 °C; or 25 °C ± 1 °C
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%

### **Phytotoxicity test**

The toxicity classification of the sediment and pore water samples is generally performed using direct-contact tests Phytotoxkit (sediment) and Phytotestkit (pore water). In all tests the pore water samples were tested at one concentration without dilution. Sediment samples were not used in this round of analysis due to insufficient sampling of sediment as sediment tox training took place after the sampling trip, therefore phytotestkit (pore water samples) was conducted instead of Phytotoxkit (sediment samples).

Phytotoxkit and phytotestkit are generally applied for the sediment and pore water toxicity classification using three test plant seeds: *Sorghum saccharatum*, *Lepidium sativum* and *Sinapis alba*. The measures parameters were inhibition of seed germination and root length inhibition in the tested sediment/pore water in comparison with the control sediment/redistilled water. The test was conducted in accordance with the procedure recommended by the manufacturer (Phytotoxkit, 2004). The studied sediment samples (90 cm<sup>3</sup>) were placed on test plates (21 15.5 0.8 cm). In the Phytotestkit assay the lower compartment of the test plate is not filled with soil, but with a foam pad and thick filter paper which is subsequently soaked with the chemical compound under analysis. This alternative test procedure allows you to determine any significant visible effect of chemical compounds on plants, without adding the chemical(s) to a soil substrate. 20 cm<sup>3</sup> of the pore water was slowly spread over the entire surface of the white filter paper in order to hydrate the filter paper completely. The bottom part of the test plates with sediment/pore water samples were covered by a black filter paper, and ten test seeds were placed in a row at 1 cm below the middle ridge of the plate. The plates prepared in this way were incubated in a horizontal position at 25 °C in darkness for 72 h. A photo of the test plate was then taken with a digital camera and transferred to a computer. Root lengths were subsequently measured using the "Image Tools" image analysis program. The test was replicated three times for each test plant. The percent inhibition of seed germination (IG) and inhibition of root growth (IR) for the plant were calculated.

### **Ostracod test exposure**

Ostracod exposure tests were conducted as 6 replicates per site sample and 1 control per sample by using reference sediment (consisting of washed marine sediment less than 2 mm in size) according to the standard operating procedures of the test kit (Ostracodtoxkit F, 2001) and the ISO (2012) method. Ostracod neonates were exposed to test sediments (6 days in darkness at 25°C ± 2°C). Upon completion of the test period, all surviving ostracods were collected and photographs were taken with a compound microscope (with a built-in digital camera) using a micrometre cover slip as a reference point. Using the UTHSCSA ImageTool (Version 3) software, growth inhibition of surviving ostracods exposed to test sediments was determined in relation to the control exposure. Mortality data were also noted. Data from the two sediment bioassays were analysed using Microsoft Excel.

### **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)<sup>1</sup> 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, 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.

<sup>1</sup> 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 (March 2023).

Sites	Time	Temperature	pH	EC	Oxygen
Control	0	21	7.99	301	7.66
	48	20.9	7.61	298	6.47
S@HTL	0	21.4	7.44	409	7.82
	48	21.4	7.18	425	7.88
S@HTC	0	20.9	7.42	352	7.8
	48	21.4	7.48	347	7.9
BB@M	0	21.8	6.99	1489	7.45
	48	20.7	7.1	1477	7.19
BG@N14	0	21.5	6.54	1457	7.69
	48	21.9	6.98	1449	7.18
BB@NOE	0	21.1	7.31	1266	7.45
	48	20.9	7.39	1301	7.22

## PREVIOUS TOXICITY TESTING RESULTS

### 15-minute *Vibrio fischeri* test (September 2022)

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: 3.58%; S@NSP test sample: 5.95%; BB@M test sample: -14.29% and B@NOE test sample: -7.72%. Inhibition of > 20% indicates toxicity and stimulation of > 20% indicates potential eutrophication. In all the sites, there was no indication of toxicity or potential eutrophication; However there was contrasting results on both rivers. There was inhibition at Bloubank Spruit with the highest inhibition occurring in site BB@M while at Skeerpoort River sites there was minimal stimulation. Tests were accepted as the % CV was > 3%.

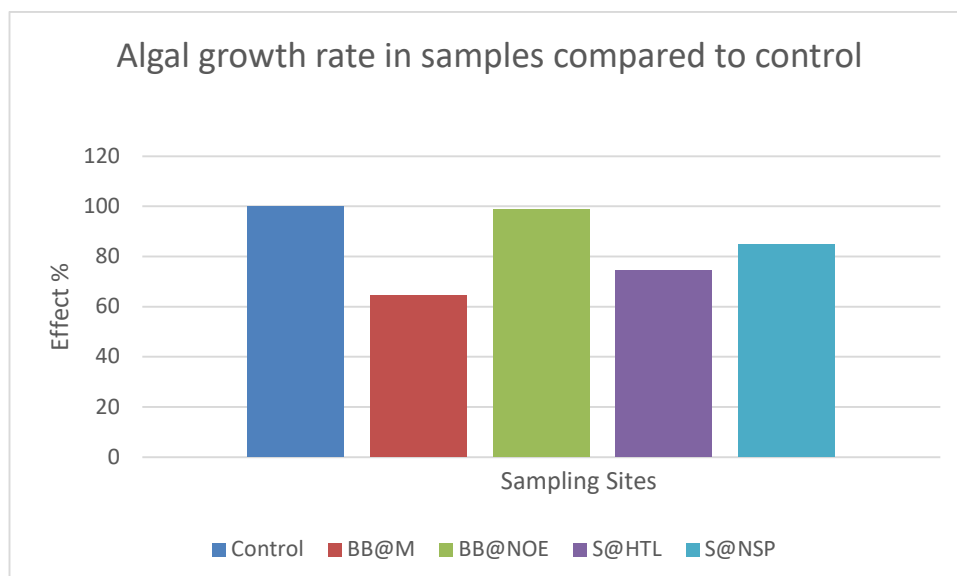
### 48-hour *Daphnia magna* test (September 2022)

**Error! Reference source not found.** 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 ( $\leq 10\%$ ) was observed in the Control. At the end of the exposure period (48 hours), the highest mortality was found in sample BB@M and BB@NOE of which the mortality percentage was 30% and 20% respectively. The mortality percentage remained low at Skeerpoort Spruit samples.

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	1	5
	48	4	20
BB@M	24	2	10
	48	6	30

### 72-hour *Selenastrum capricornutum* test (September 2022)

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 and S@HTL were potentially considered toxic as growth rate of less than 80% was detected. This was significant in BB@M as the growth rate was 64.37% compared to Control.



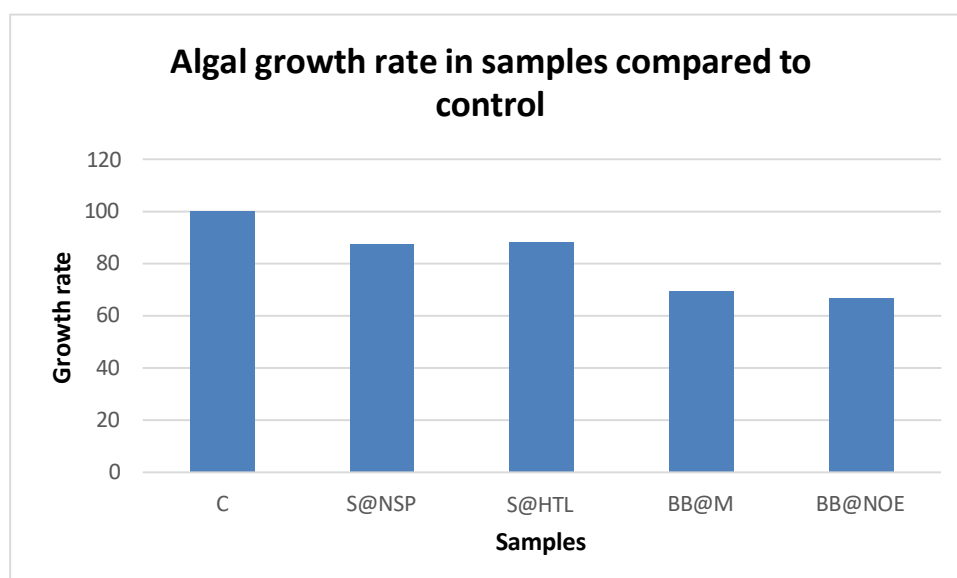
### V. fischeri test (September 2020)

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%.

### 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).

<b>Sample</b>	<b>Time (hrs)</b>	<b>Mortality (No. of organisms)</b>	<b>Mortality (%)</b>
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

  
23 November 2023



Vuyelwa Mvandaba  
MSc (Hydrology)  
Researcher (Hydrology, Geohydrology)  
Tel: +27 12 841 4641  
Cell: +27 72 778 9691  
Email: vmvandaba@csir.co.za  
www.csir.co.za