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 2014 TO MARCH 2015

AUTHOR

P.J. Hobbs

(Pr.Sci.Nat.)

DATE

JUNE 2015

REPORT No.

CSIR/NRE/WR/ER/2015/0026/A

GWDMS No. & LIBRARY

252785 in PTA GENERAL

PREPARED FOR
Management Authority
Cradle of Humankind World Heritage Site
Gauteng Provincial Government

PREPARED BY
Council for Scientific and Industrial Research
Natural Resources & the Environment
PO Box 395, Pretoria, 0001

SUMMARY

The Management Authority (MA) of the Cradle of Humankind World Heritage Site (COH WHS) commissioned project BIQ005/2008 to develop a water resources monitoring programme for the property. The outcome of this project was documented in a comprehensive situation assessment report dated March 2011, and resulted in the implementation of a water resources monitoring programme for the property. The outcomes of the programme are reported bi-annually in water resources status reports. This document represents the 6th such report. It expands on the 5th status report, which covers the mid-term period April to September 2014, by covering the full-term monitoring period April 2014 to March 2015. This timeframe defines a financial year of the MA according to which annual contracts are managed.

An assessment of impacts on the water resources environment of the COH property must necessarily consider both a holistic view and a specific focus on those resources that are at greatest risk from an impact. In the context of the COH property, impacts are necessarily focussed on wastewater sources of which acid mine drainage rising in the Western Basin, and municipal effluent discharged from the Percy Stewart Wastewater Treatment Works, are of primary concern. The outcome of monitoring activities as documented in this report consolidates the conceptual hydrophysical and hydrochemical model originally developed for the property in the situation assessment report. The monitoring data and results reveal the following responses in the water resources environment.

- The 2014–’15 wet (summer) season is the driest since 2008–’09, experiencing ~15% less than the next lowest (2011–’12) season. These circumstances have translated into a below average recharge of the mine void, resulting in a reduced mine water discharge (decant) on surface that has assisted in reversing the negative impacts driven by the very wet 2013–’14 summer season.

- The 2013–’14 hydrological year witnessed the third highest runoff (~55 Mm^3) after the 1976–’77 and 2010–’11 hydrological years (~67 and ~59 Mm^3 respectively), in the 40-year historical gauging record of the Bloubank Spruit system.

- The re-commencement of uncontrolled raw mine water discharge from the mine area in February 2014 triggered a ~6-month period of impact on the downstream receiving hydrologic environment before returning to ‘more normal’ pre-2010 conditions in the second half of the reporting period. Even this portion of the record, however, is characterised by an erratic pattern of values especially evident in the pH record.

- Faecal coliform counts continue to reflect unacceptably high levels (median of 320 cfu/100 mL) in the lower reaches of the Bloubank Spruit system, highlighting the poor performance of the Percy Stewart Wastewater Treatment Works located further upstream.

- Although long-term groundwater level records indicate that groundwater elevations in the last five years are the highest in the ~30-year period of monitoring, a recent decline has also been observed in the Main Lake water level in Sterkfontein Caves, favouring access along the tourist path through the lower portion of the site.

- A comparison of the TDS load delivered to Hartbeespoort Dam by its major tributaries in the last five hydrological years, with that delivered in the period 1979–’80 to 2008–’09 (which

defines the period of negligible mine water impact), reveals an unmistakeable recent mine water impact in a regional context that is much less evident in a subregional context. This is attributed to the contribution of good to excellent quality dolomitic groundwater via high-yielding karst springs that rise on the COH property. Their bias in favour of the mine water receiving Bloubank Spruit naturally acts to reduce a mine water impact in a subregional context, whereas their moderating influence at a regional scale is masked by the similar or greater loads contributed by the larger Jukskei and Hennops rivers.

It is concluded that the water resources monitoring results documented in this report confirm the conceptual hydrophysical and hydrochemical model developed for the COH WHS in the situation assessment report. It has not revealed any major inconsistencies, nor has it exposed significant flaws that might question the water resources monitoring programme as originally formulated.

PJ Hobbs.

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

CONTENTS

Page

FIGURES

TABLES

ANNEXURES

Annexure A Quantification of stream flow loss rate in the Riet Spruit between stations F11S12 and MRd

Annexure B Record of electrical conductivity and pH measurements made at stations F11S12 and MRd on the occasion of flow gauging measurements (SDMs), also showing derived SO_4 and TDS concentrations

Annexure C Recent water chemistry associated with the major karst springs in the Cradle of Humankind

SYMBOLS, ACRONYMS & ABBREVIATIONS

~	approximately
>	greater than
<	less than
%	per cent (parts per hundred)
%ile	percentile
°C	degree(s) Centigrade
Δh	change in head
a_h	hydrological year
AMD	acid mine drainage
amsl	above mean sea level
bc	below collar
BRI	Black Reef Incline
bs	below surface
ca.	circa (about)
cfu	coliform forming units
COH WHS	Cradle of Humankind World Heritage Site
CoV	coefficient of variation
DWS	Department of Water & Sanitation [formerly the Department of Water Affairs (DWA)]
EC	electrical conductivity
G1	Gold 1 (previous owner of the original REGM)
HDS	high density sludge
kg	kilogram(s)
km	kilometre(s)
L/d	litre(s) per day
LoD	locus of decant
L/s	litre(s) per second
L/s/km	litre(s) per second per kilometre
m	metre(s)
m^2/d	square metre(s) per day
MA	Management Authority
MCLM	Mogale City Local Municipality
meq/L	milliequivalent(s) per litre
mg/L	milligram(s) per litre
mg/s	milligram(s) per second

ML/d	megalitre(s) per day
mm	millimetre(s)
m^3/s	cubic metre(s) per second
Mm^3	million cubic metre(s)
Mm^3/a	million cubic metres per annum
MPN	most probable number
mS/m	milliSiemens per metre
n	count
pp	pages
REGM	Randfontein Estates Gold Mine
RU	Rand Uranium (earlier owner of the original REGM)
SD	standard deviation
SDM	synoptic discharge measurement
SG	Sibanye Gold (current owner of the original REGM)
SOC	State of Conservation
TCTA	Trans-Caledon Tunnel Authority
t/d	ton(s) per day
TDS	total dissolved solids
UNESCO	United Nations Educational, Science and Cultural Organisation
WHC	World Heritage Committee
WWTW	wastewater treatment works

1 INTRODUCTION, BACKGROUND & CONTEXT

The Management Authority (MA) of the Cradle of Humankind World Heritage Site (COH WHS) commissioned project BIQ005/2008 to develop a water resources monitoring programme for the property (**Figure 1**). This delivered a situation assessment of the surface water and groundwater resource environments (Hobbs, 2011) that redefined the understanding of especially the geometry of the hydrogeologic environment. Subsequent monitoring activities have generated new data and additional insight that are documented in bi-annual reports (Hobbs, 2012; 2013a; 2013b; 2014a; 2014b). This document represents the sixth such report, which expands on the mid-term monitoring report for the period April to September 2014 by covering the full-term period April 2014 to March 2015.

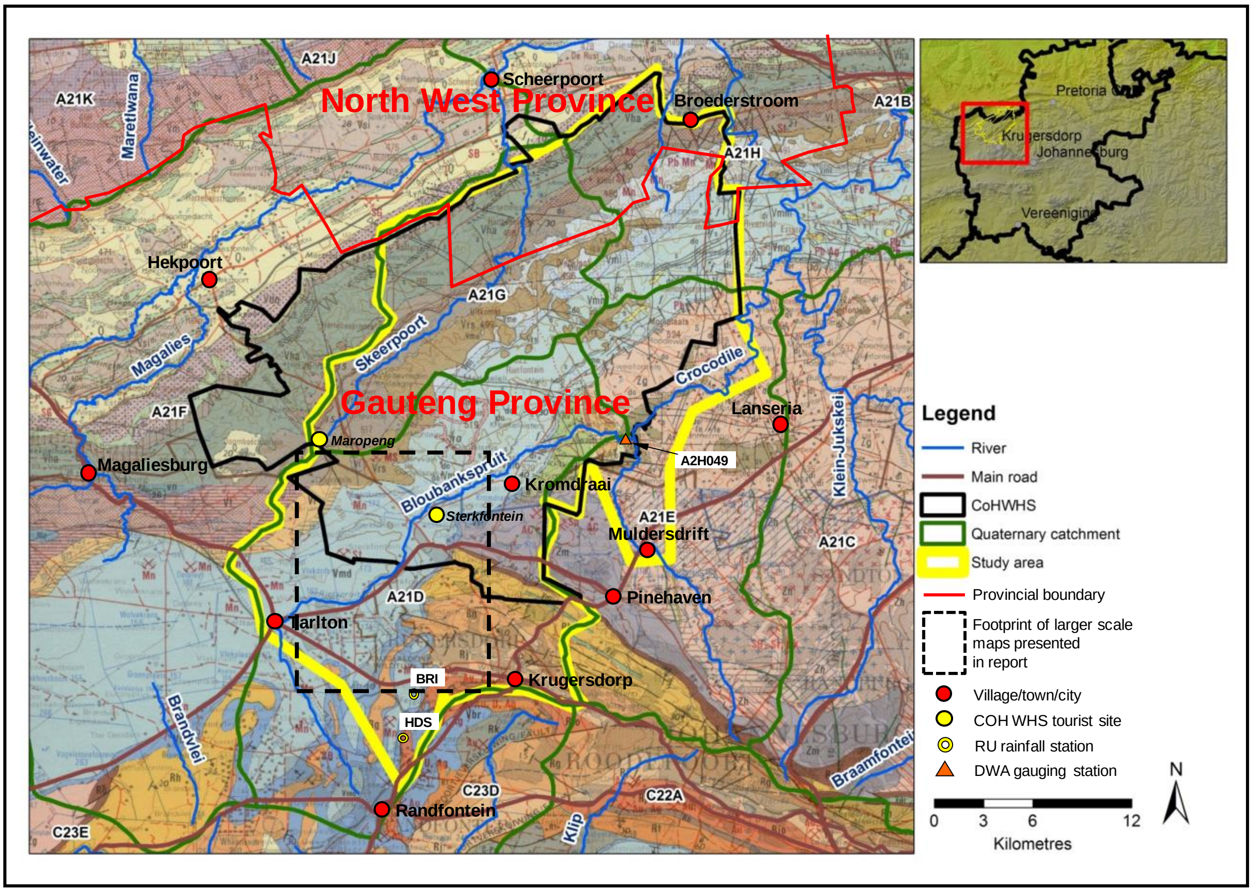


Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

2 TIMELINE OF KEY EVENTS

It is considered appropriate to contextualise the material presented and discussed in this report in terms of an updated timeline of key events relevant to the reporting period. The timeline presented in **Figure 2** begins with the inscription of the COH property as a World Heritage Site in 1999. The most recent landmark event on the timeline is the acceptance by UNESCOs World Heritage Committee (WHC) at its 39th session on 27 January 2015, of the State of Conservation (SOC) report (document WHC-15/39.COM/7B) submitted by the State Party (DEA et al., 2014). In its Draft Decision 39 COM 7B.44, the WHC commends the State Party on activities so far undertaken to improve water management on the property and implement systems and programmes to mitigate the impacts of acid mine drainage.

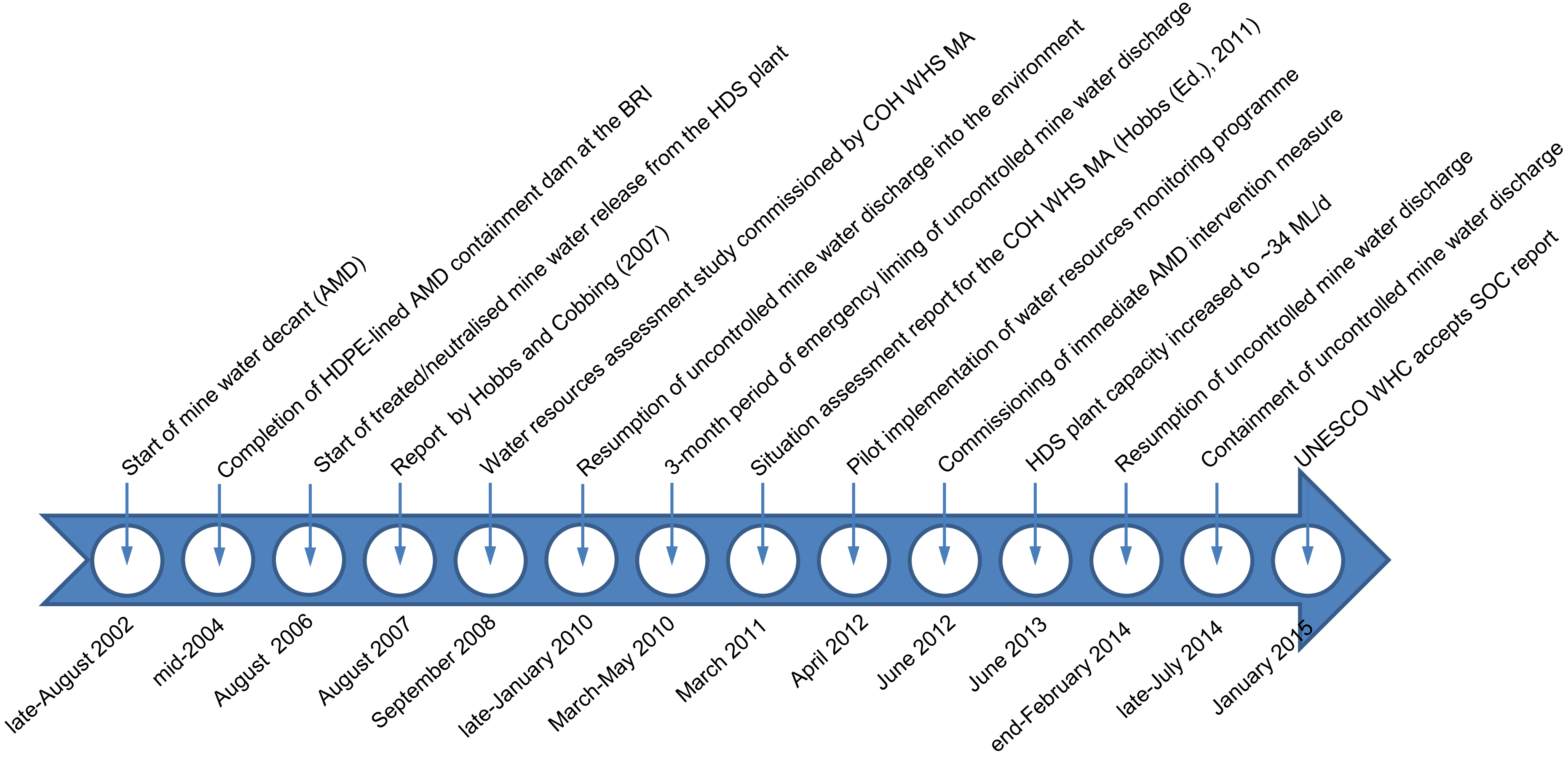


Figure 2 Updated timeline of events relevant to this report

3 RAINFALL

The monthly precipitation record for the period October 2008 to March 2015 of the Sibanye Gold (SG) rainfall station HDS (**Figure 3**) reveals the wetter than normal 2010–’11 and 2013–’14 summer rainfall seasons (**Figure 4**) and, by comparison, the drier than normal 2014–’15 summer. The data also confirm the observations (Hobbs, 2012; 2013b) that monthly rainfall to the north of the continental divide (e.g. at the Black Reef Incline and at Sterkfontein Caves) is generally ~10–15% less than that measured at station HDS on the divide (**Figure 5**).

Also shown in **Figure 3** and **Figure 4** are the contemporary rainfall data recorded by the DWS cumulative gauging station located at Sterkfontein Caves. Data for the period June 2010 to March 2015 were provided by the DWS. An analysis of the common monthly rainfall record (n = 58) for the HDS and Sterkfontein Caves stations indicates a good correlation ($R^2 = 0.89$) (**Figure 5**).

Of particular significance is the fact that the 2014–’15 wet season is the driest (by some margin) since 2008–’09 (**Figure 4**). In the case of the HDS station, the rainfall of 487 mm is ~15% less than the next lowest (575 mm in the 2008–’09 wet season). Similarly, in the case of Sterkfontein Caves, the 457 mm is ~16% less than the next lowest (542 mm in the 2011–’12 wet season). These circumstances describe a significantly lower (below average) rate of recharge to the flooded underground mine void, and explain the considerably reduced volume of AMD issuing in the locus of decant. The increased capacity of the mine water treatment plant to ~34 ML/d in June 2013 (**Figure 2**) was sufficient to contain and treat the volume of mine water issuing more recently from the flooded underground mine workings, successfully curtailing the discharge of raw mine water into the environment.

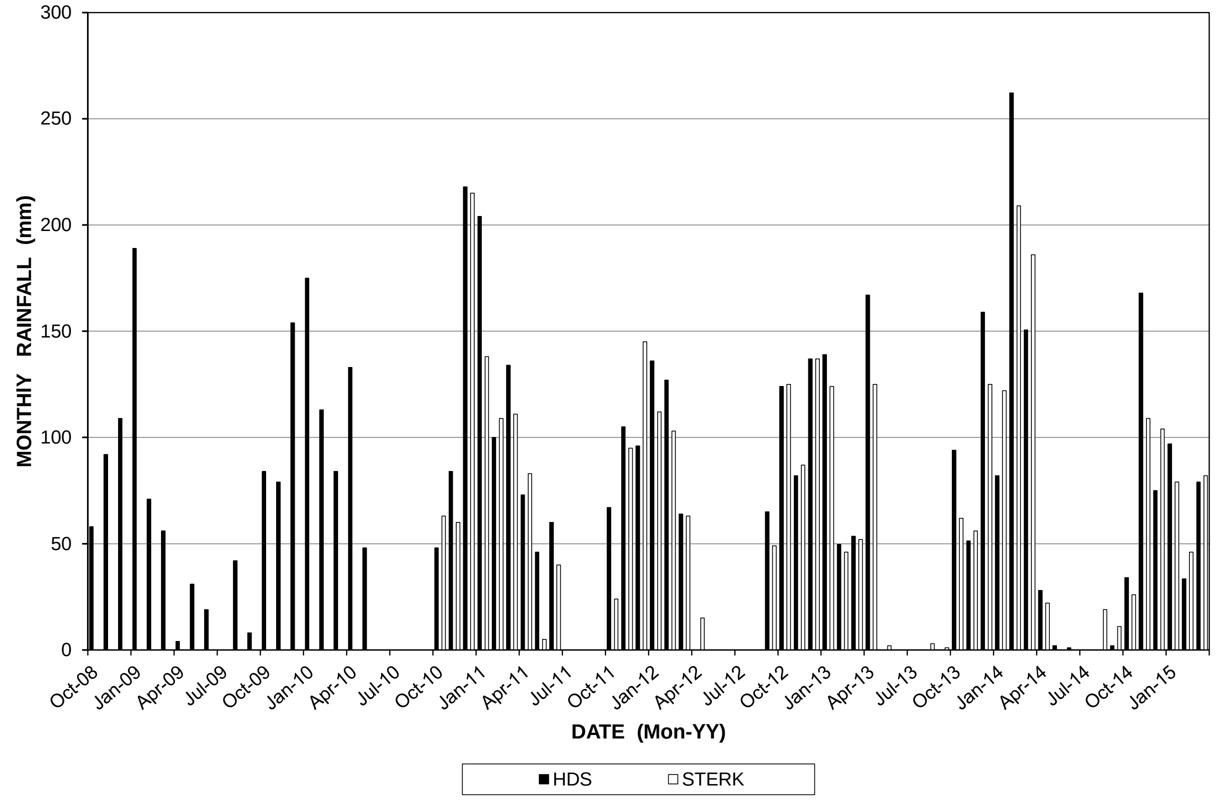


Figure 3 Monthly precipitation at the SG rainfall monitoring station HDS and the available contemporary record for the Sterkfontein Caves station in the period October 2008 to March 2015

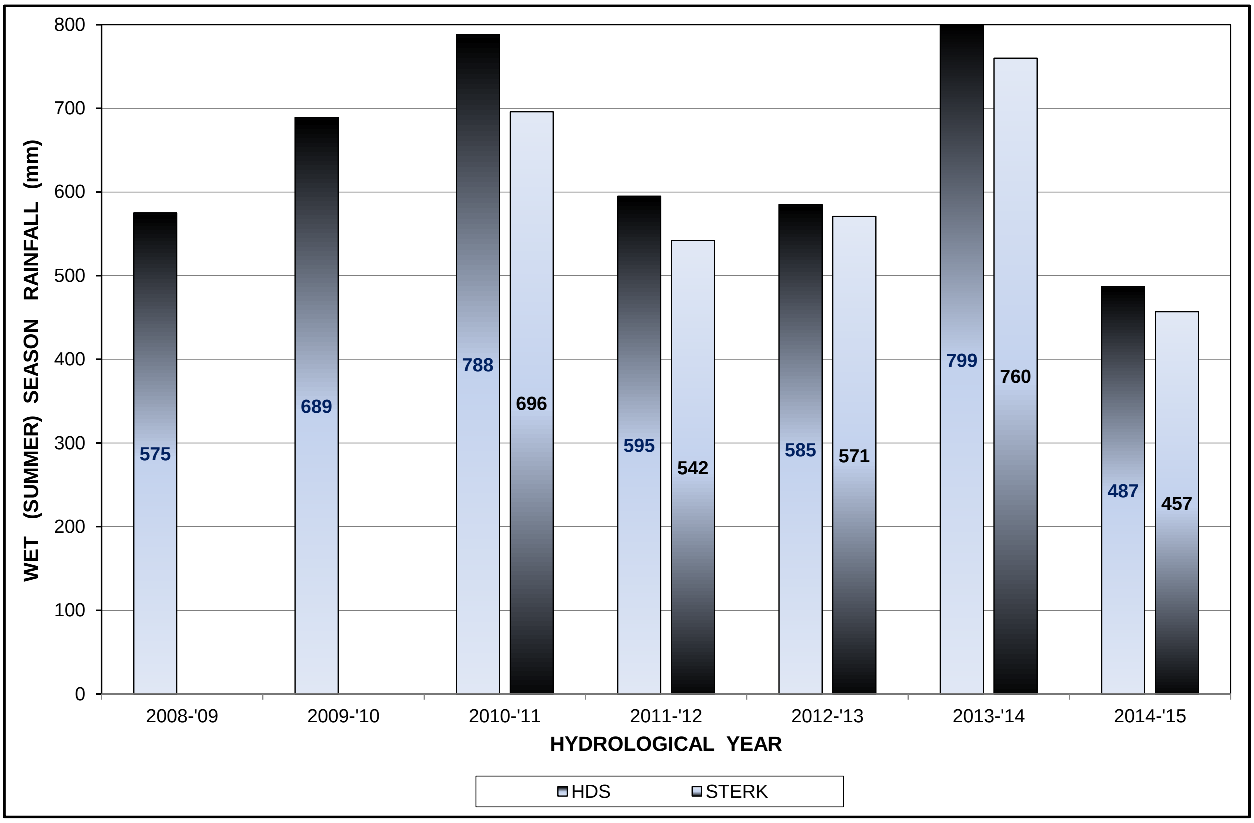


Figure 4 Total wet season (summer) rainfall at the HDS plant in the past seven hydrological years, also showing the comparison with that for the available contemporary Sterkfontein Caves record

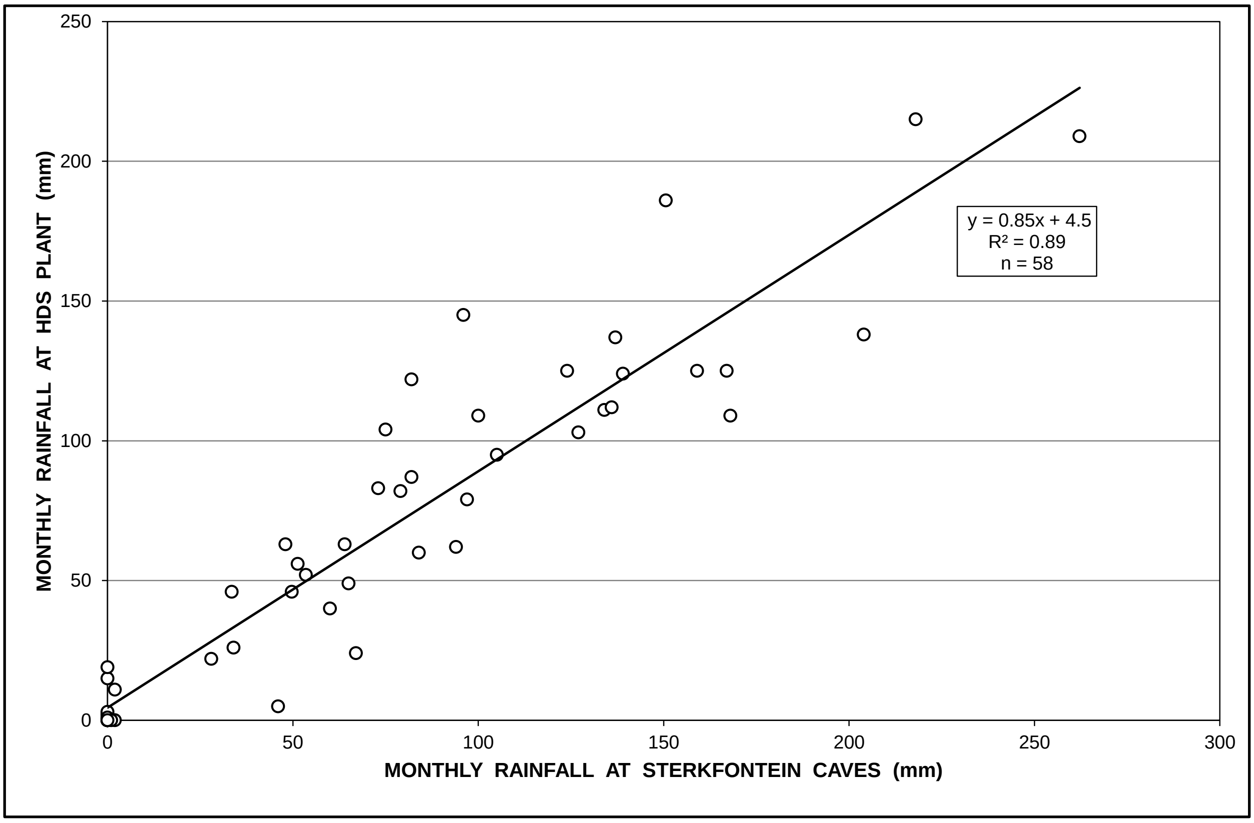


Figure 5 Correlation of monthly rainfall at Sterkfontein Caves with that at the HDS plant in the mine area

4 SURFACE WATER HYDROLOGY

4.1 Physical Hydrology

4.1.1 Surface Water Discharge

The discharge of the Bloubank Spruit system is gauged by the DWS at station A2H049 located ~700 m before the confluence with the Crocodile River (**Figure 1**). The >40-year record of this catchment (quaternary A21D) provides the monthly discharge statistics presented in **Table 1**.

Table 1 Statistical analysis of Bloubank Spruit monthly discharge data gauged at station A2H049 in the period October 1972 to March 2015

Variable	**Month**											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	41	41	42	42	43	43	42	41	42	42	41	41
Minimum	0.682	0.815	0.711	0.721	0.706	0.828	0.886	0.847	0.894	0.939	0.890	0.770
5%ile	0.784	0.846	1.041	1.097	0.898	1.049	1.179	0.980	0.952	0.956	0.911	0.799
Mean	1.847	1.858	2.259	2.696	2.645	2.967	2.390	2.245	2.058	2.024	1.903	1.770
Median	1.556	1.740	1.962	2.419	1.951	2.489	1.953	1.800	1.721	1.639	1.597	1.442
95%ile	3.873	2.961	4.526	5.425	6.424	8.131	5.491	4.926	4.203	4.126	3.660	3.510
Maximum	4.211	4.577	5.900	12.079	10.619	11.351	6.081	5.373	5.166	4.754	4.055	4.342
SD	0.935	0.840	1.117	1.958	1.938	2.236	1.326	1.220	0.993	0.945	0.879	0.891
CoV (%)	50.6	45.2	49.5	72.6	73.3	75.4	55.5	54.4	48.2	46.7	46.2	50.3

All units are Mm^3 unless otherwise indicated.

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

The discharge per hydrological year (a_h) shown in **Figure 6** indicates that the 2013–'14 hydrological year witnessed the 3rd highest runoff (54.6 Mm^3) after the 66.9 Mm^3 of the 1977–'78 and the 59.1 Mm^3 of the 2010–'11 hydrological years in the historical record of this catchment. By comparison, the 2012–'13 hydrological year produced a modest discharge of only ~33.4 Mm^3 commensurate with the modest contemporaneous summer (wet season) rainfall of ~580 mm (**Figure 4**).

The instantaneous monthly flow pattern at station A2H049 for the complete record October 1972 to March 2015 is shown in **Figure 7**. This reveals a comparatively constant lowest value of 0.25 m^3/s. Evident in the hydrograph (**Figure 7**) are distinct recession curves following peak discharge events. Station A2H049, however, is not only located a substantial distance (5–10 km) downstream of its principal perennial sources, the Zwartkrans and Kromdraai springs, but also receives the discharge of other 'lesser' springs (e.g. the Plover's Lake and Aquamine springs) and ephemeral tributaries such as the Honingklip and Tweefontein spruits. These circumstances negate a correlation between spring discharge and rainfall.

A closer inspection of the instantaneous flow data record generated at station A2H049 (**Figure 7**) reveals the early portion of a typical recession curve following the exceptionally high discharge experienced in March 2014. These circumstances, in particular the absence of high monthly discharge rates in the course of the 2014–'15 wet season, underpin the more recent successful control and management of mine water discharge from the mine area.

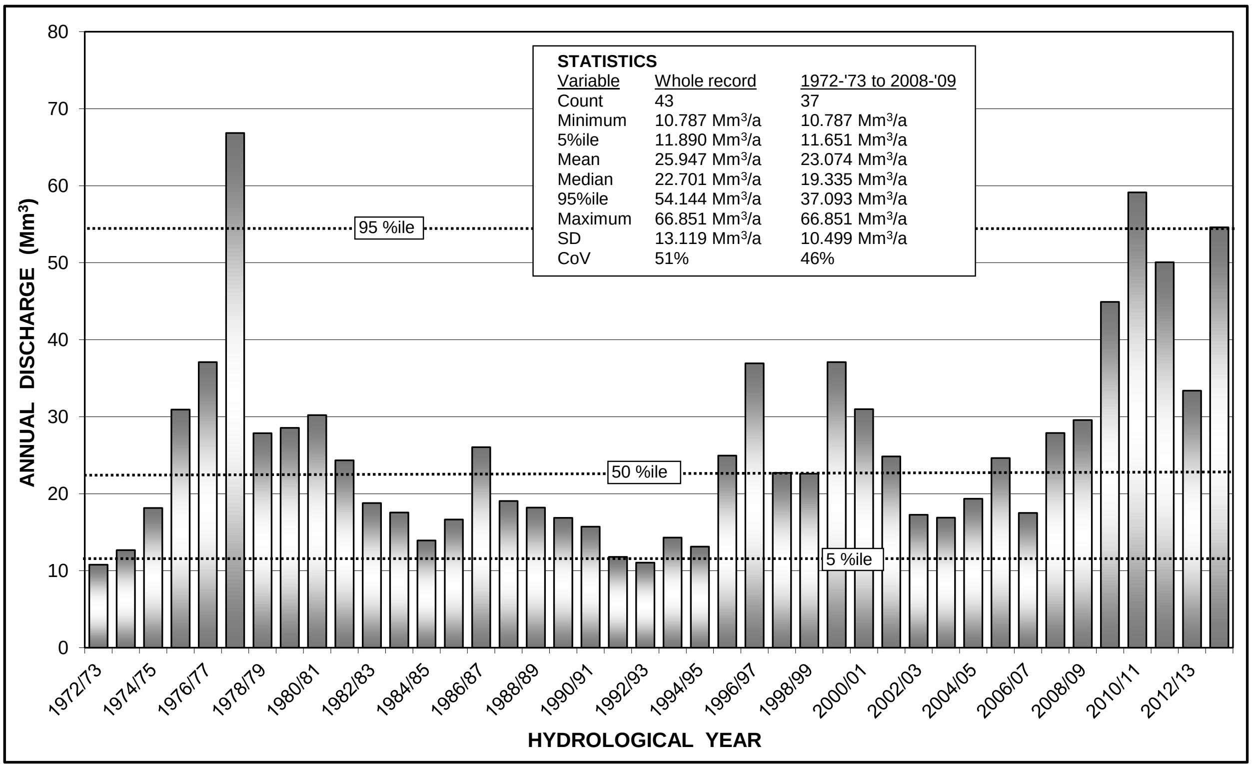


Figure 6 Graph of Bloubank Spruit annual (a_h) discharge gauged at station A2H049 in the period October 1972 to September 2014

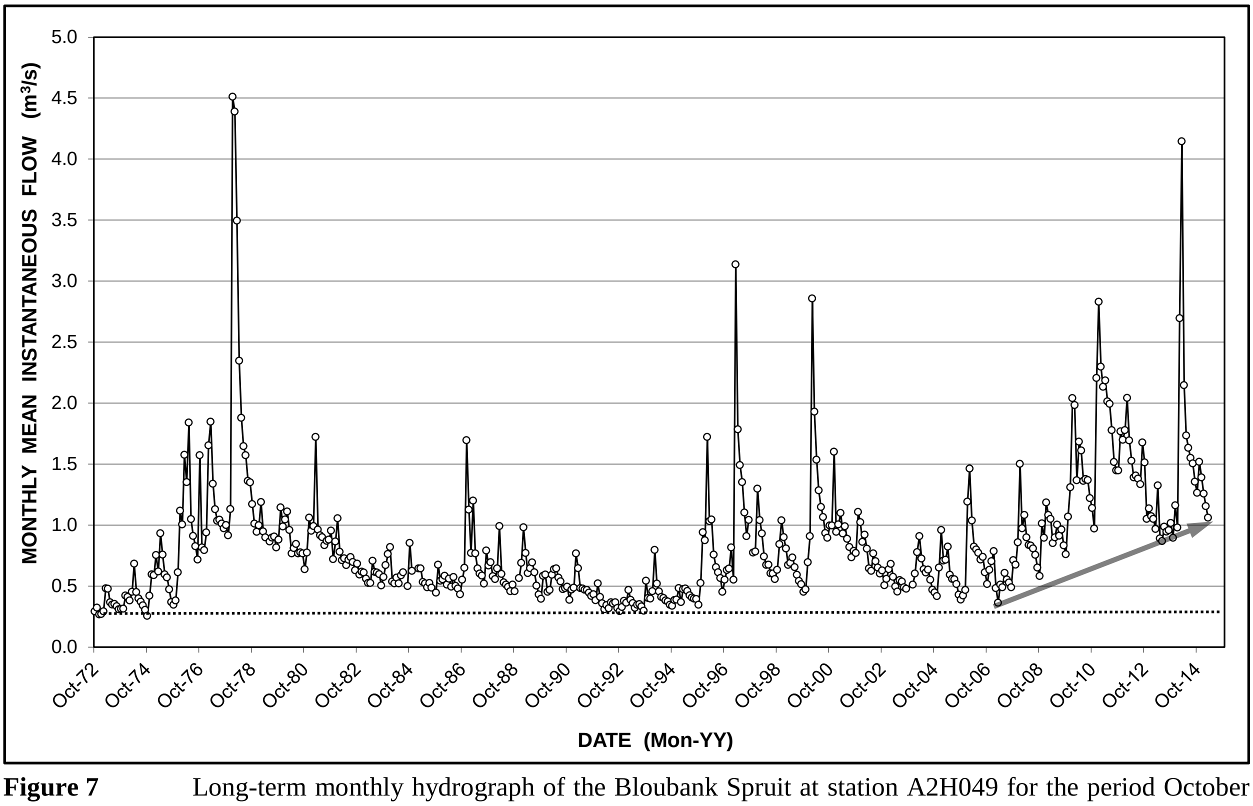
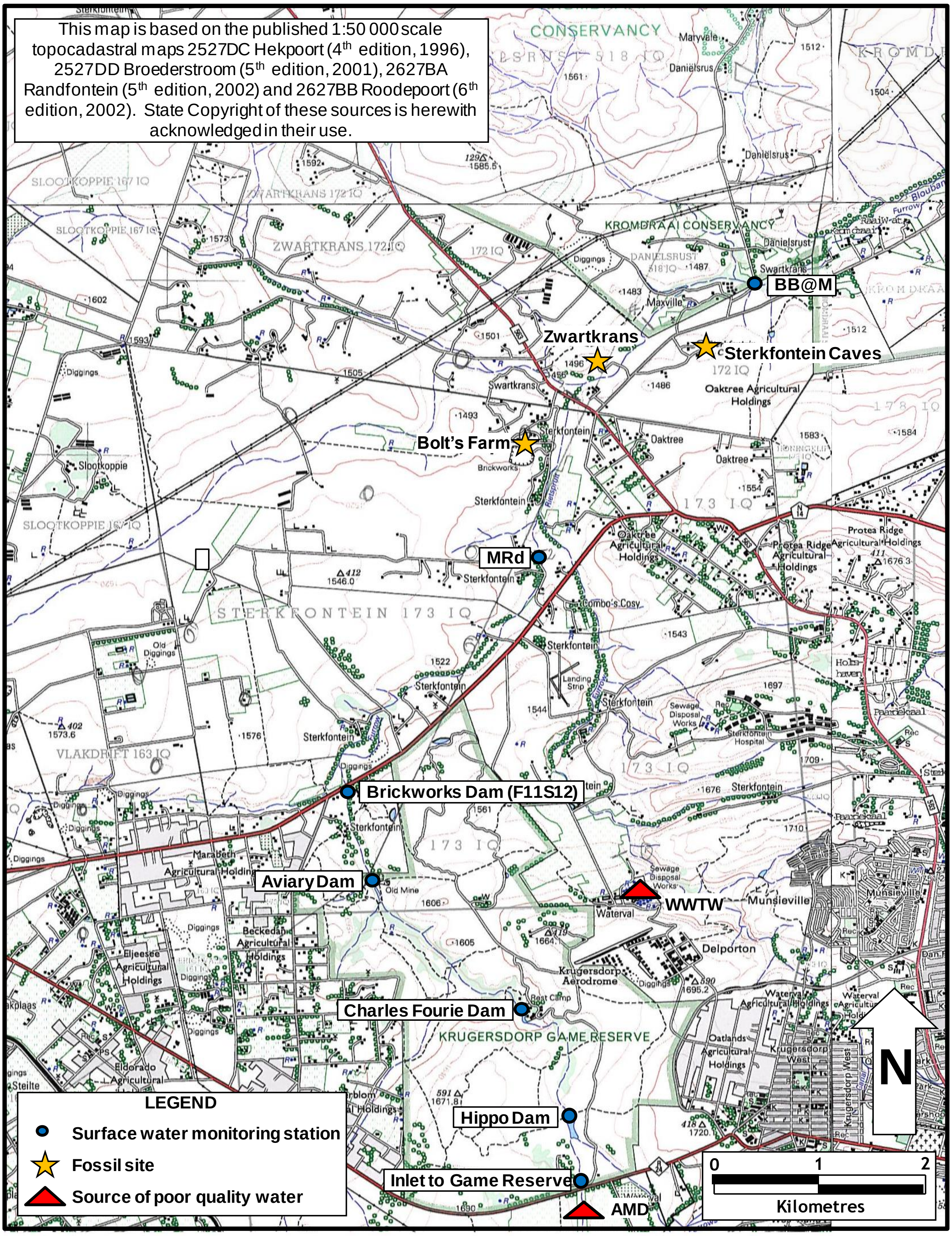


Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to March 2015

4.1.2 Surface Water Fluxes

In-stream synoptic discharge measurements (SDMs) made on 30 occasions (**Annexure A**) at stations F11S12 at the lower end of the Tweelopie Spruit, and MRd ~3.9 km further downstream on the Riet Spruit (**Figure 8**), quantify and elucidate the magnitude of surface water loss to the karst aquifer.



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

Figure 8 Locality map of surface water quantity and quality monitoring stations

The graphs of the SDM results (**Figure 9** and **Figure 10**) confirm previous measurements that indicate a minimum ingress converging at a value of ~15 ML/d, equivalent to ~45 L/s/km.

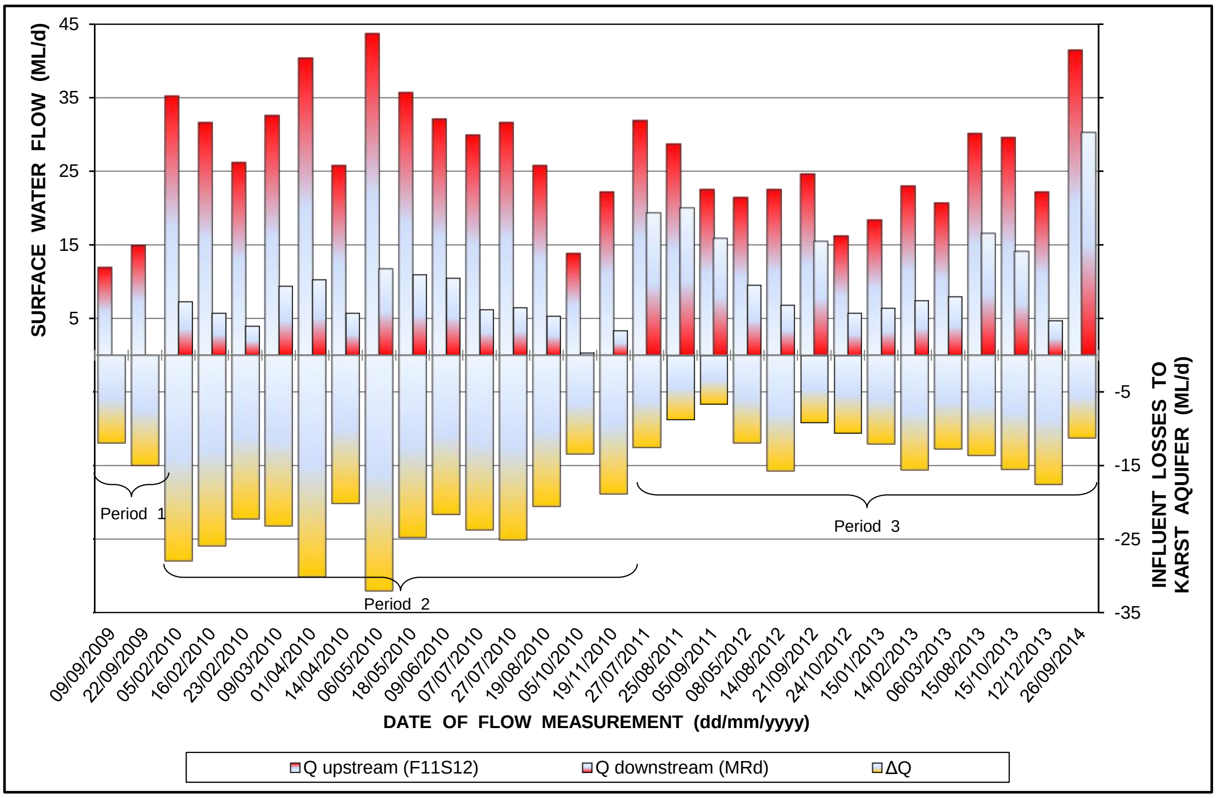


Figure 9 Graph of stream flow and influent losses to the karst aquifer in the lower Riet Spruit valley

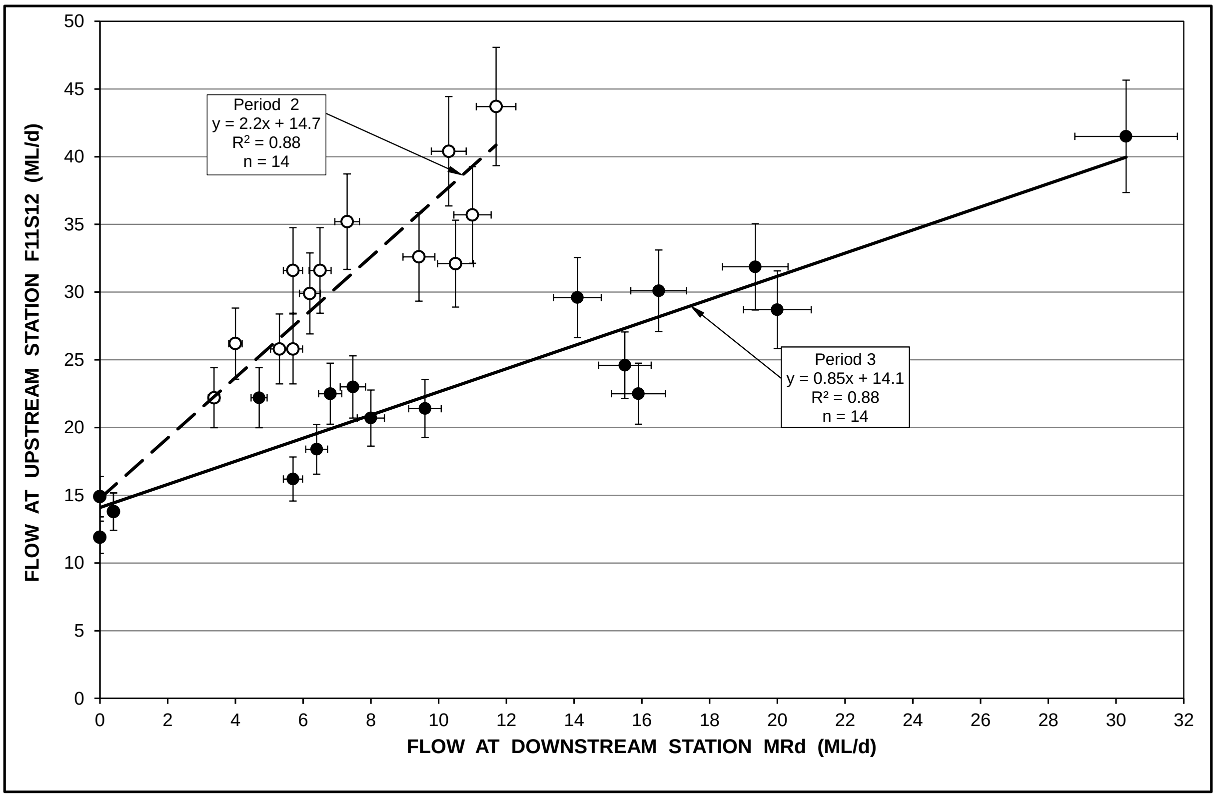


Figure 10 Correlation of stream flow at stations F11S12 and MRd in the Riet Spruit valley, with error bars denoting ±10% at F11S12 (vertical) and ±5% at MRd (horizontal)

It is evident that the different slopes of the Period 2 and Period 3 regression lines (**Figure 10**) indicates a significant ~94% reduction in allogenic recharge from ~70 ML/d (~208 L/s/km) to ~36 ML/d (~107 L/s/km) between these two distinct time periods. Whilst this is promising for the receiving karst aquifer under circumstances where the quality (chemistry) of this water is strongly influenced by a mine water component, an explanation of this phenomenon remains elusive.

4.2 Chemical Hydrology

4.2.1 Tweelopie Spruit and Riet Spruit

The chemistry of surface water in the Tweelopie Spruit continues to be monitored by Sibanye Gold at five localities from where it leaves the mine property down to its confluence with the Riet Spruit at Glen Almond north of the Krugersdorp Game Reserve (KGR), a distance of ~6.6 km. These stations are identified in **Figure 8** as (a) the inlet to the KGR, (b) the Hippo Dam, (c) the Charles Fourie Dam, (d) the Aviary Dam and (e) the Brickworks Dam (station F11S12). The weekly monitoring of the variables pH, electrical conductivity (EC) and sulphate (SO_4) dates back to May 2004. The results of this monitoring, excluding the inlet to the KGR location[1], the Charles Fourie Dam[2] and the Aviary Dam[3], are presented in **Figure 11** (pH), **Figure 12** (EC), **Figure 13** (SO_4), **Figure 14** (Fe) and **Figure 15** (Mn).

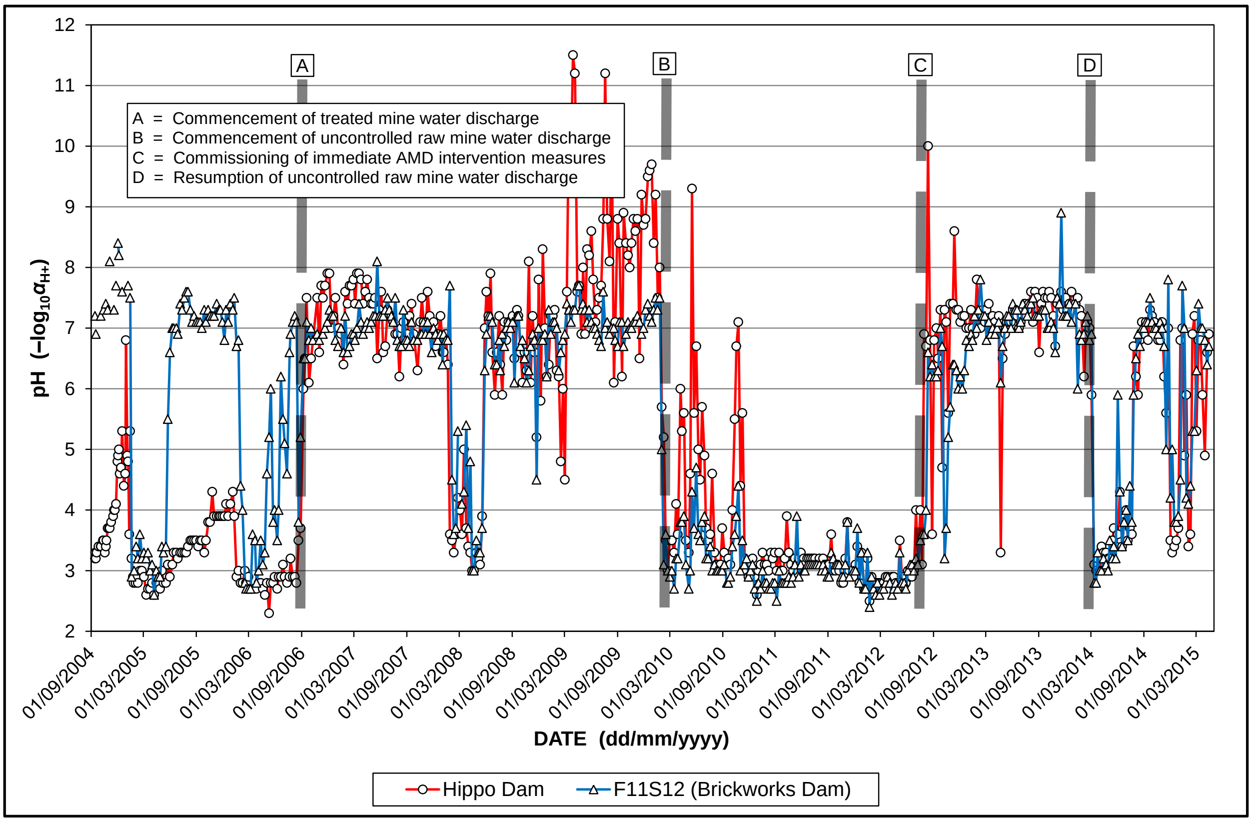


Figure 11 Pattern of Tweelopie Spruit pH values in the period September 2004 to March 2015

---

[1] These data are excluded for their close proximity to the Hippo Dam location, and consideration of the fact that the residence time of this water in the Hippo Dam renders the data for the latter location more representative of the surface water entering the Tweelopie Spruit.

[2] These data are excluded as their value to the assessment presented in this report is redundant.

[3] These data are excluded as they reflect excellent congruence with the Brickworks Dam (F11S12) data.

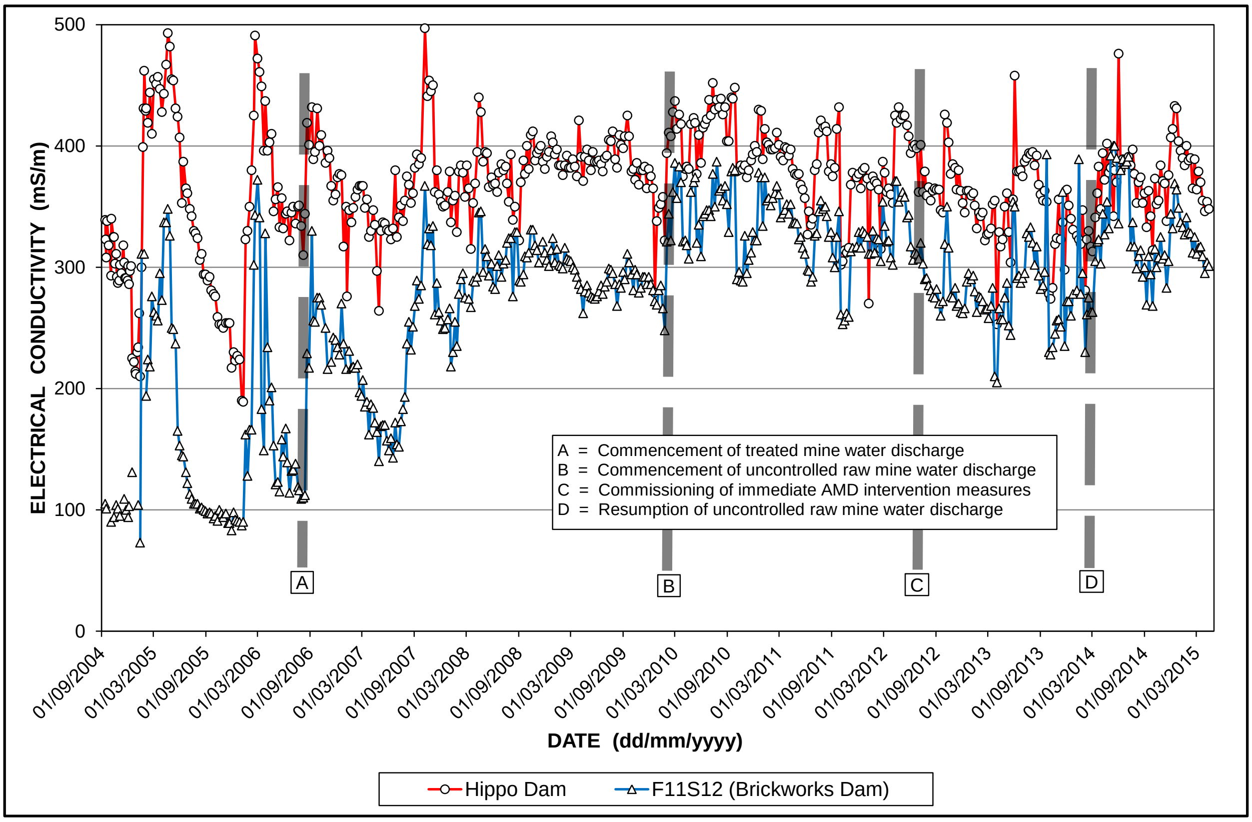


Figure 12 Pattern of Tweelopie Spruit EC values in the period September 2004 to March 2015

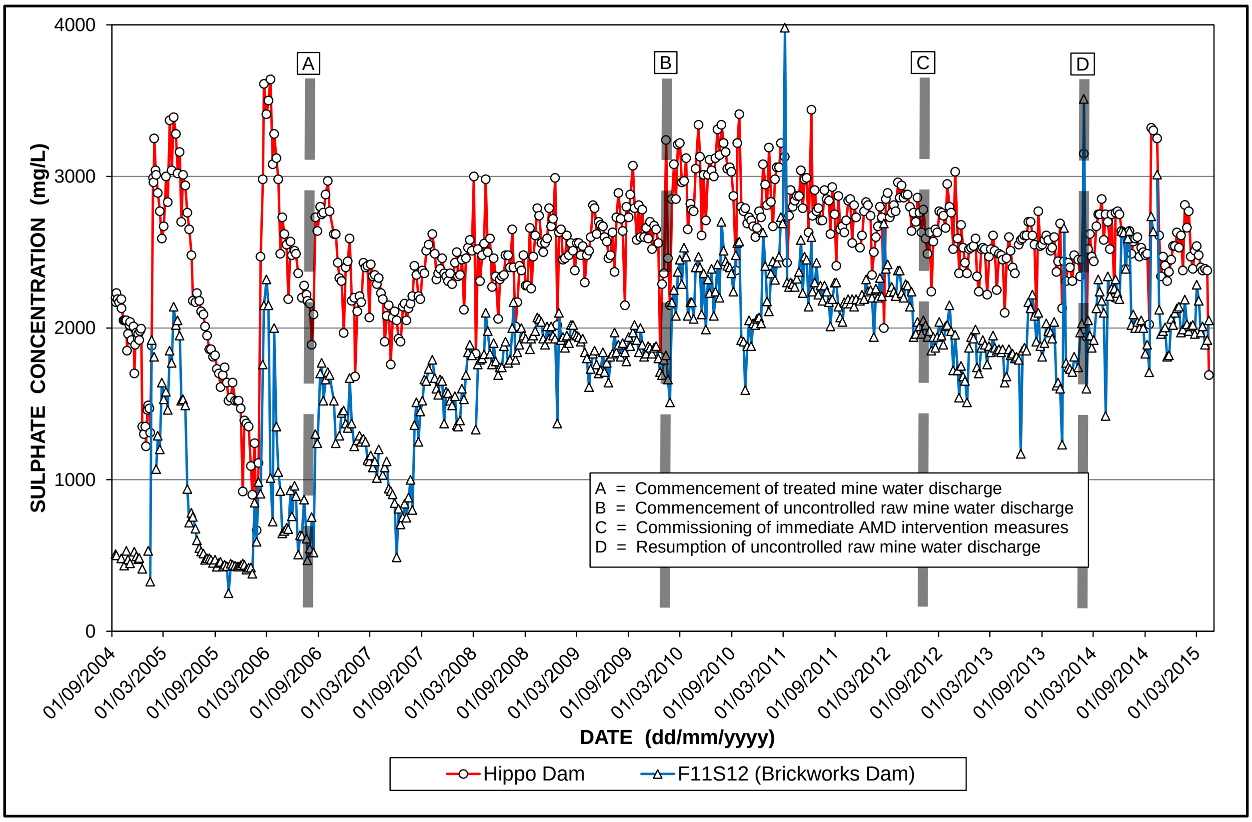


Figure 13 Pattern of Tweelopie Spruit SO_4 values in the period September 2004 to March 2015

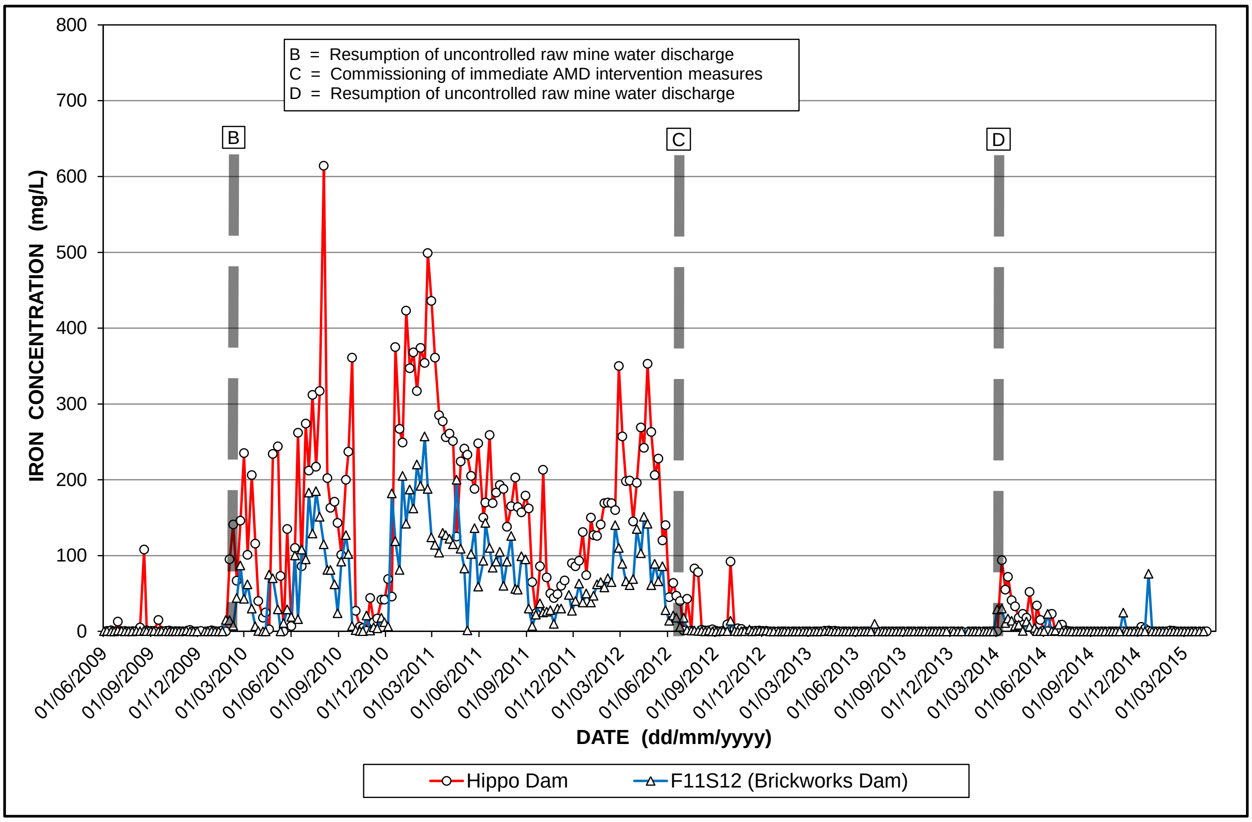


Figure 14 Pattern of Tweelopie Spruit Fe values in the period June 2009 to March 2015

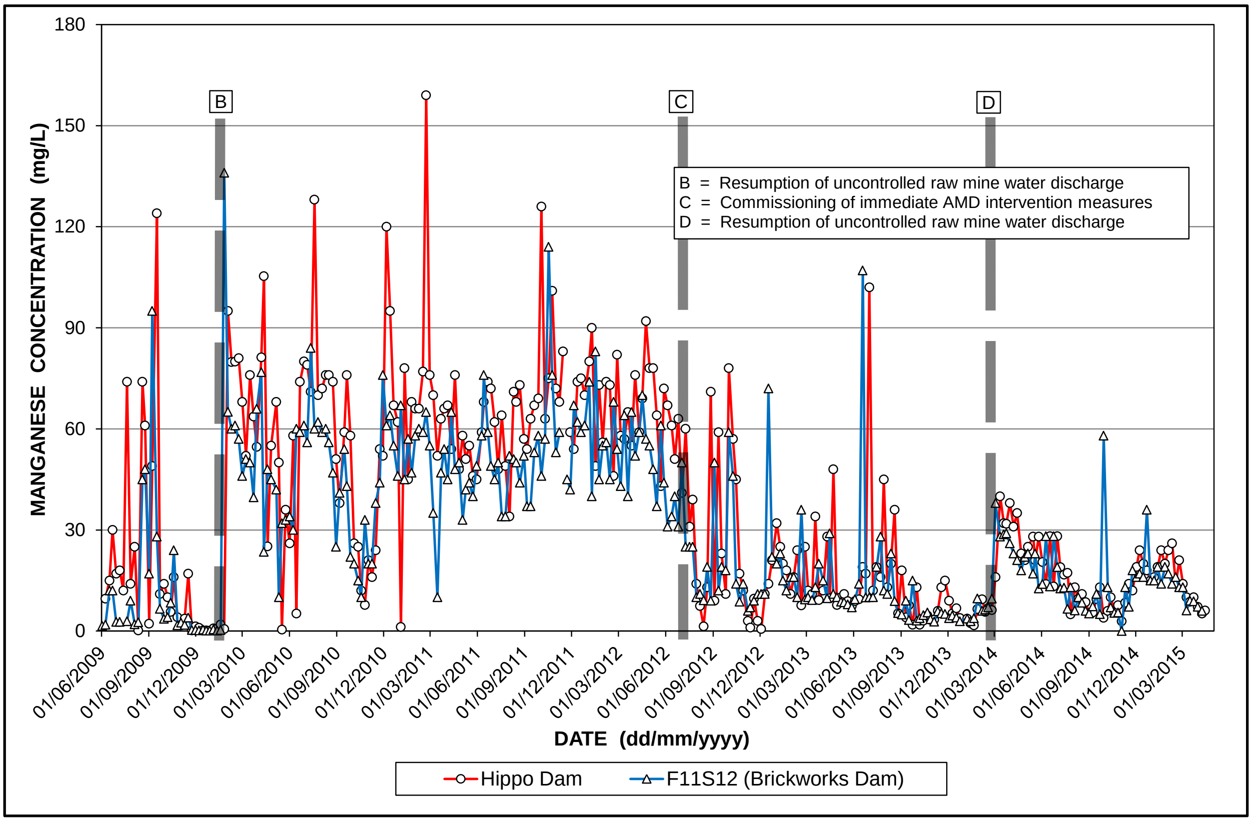


Figure 15 Pattern of Tweelopie Spruit Mn values in the period June 2009 to March 2015

The patterns revealed in **Figure 11** to **Figure 15** reflect the variation and trend in the respective variable values in surface water through the KGR over time. The period(s) of most severe and sustained mine water impact have previously been discussed in Hobbs (2014b). Of relevance to the period spanned by this report is the somewhat equivocal pattern reflected in the most recent portion of the record, i.e. since November 2014. This is particularly evident in the pH values (**Figure 11**), which reveal regular excursions to pH values <5 interspersed with circumneutral values. These circumstances qualify the observation that water quality conditions in the Tweelopie Spruit had recovered to pre-March 2014 conditions by the end of the previous reporting period (Hobbs, 2014b). This qualification finds support in the analysis of the data sets for each of the four periods of record A–B, B–C, C–D and D– defined by the divisions recognised in **Figure 11** to **Figure 15**, and which returns the information presented in **Table 2**.

The information presented in **Table 2** reveals the following salient differences between the data sets; (a) the greater variability in pH values at both stations associated with period D–, (b) the generally greater variability in analyte concentrations at the upstream Hippo Dam station compared to the F11S12 station, and (c) the typically lower analyte concentrations at the downstream F11S12 station compared to the Hippo Dam station.

Table 2 Summary statistics of period-related surface water chemistry variability in the Tweelopie Spruit

Variable	**Statistical Parameter**	**Hippo Dam**				**F11S12 (Brickworks Dam)**			
		A—B(1)	**B—C(2)**	**C—D(3)**	**D—(4)**	**A—B(1)**	**B—C(2)**	**C—D(3)**	**D—(4)**
pH $(-\log_{10}\alpha_{\mathrm{H+}})$	n	176	129	83	57	173	128	83	57
	5%ile	3.6	2.8	5.9	3.2	3.9	2.7	5.3	3.0
	Mean	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	4.9	6.9	3.0	7.0	5.0
	95%ile	9.3	5.7	7.6	7.1	7.4	3.9	7.4	7.4
	SD	1.5	1.0	0.8	1.6	0.9	0.4	0.9	1.7
	CoV (%)	22.0	29.7	11.4	32.2	14.1	13.7	13.0	32.1
EC (mS/m)	n	175	129	83	57	172	128	83	57
	Mean	374	391	350	376	268	332	281	329
	Median	379	393	354	377	283	330	276	323
	95%ile	426	438	395	417	329	378	350	391
	SD	32	33	34.1	28	48	29	34	34
	CoV (%)	8.5	8.4	9.7	7.4	18.0	8.7	12.2	10.4
SO_4 (mg/L)	n	176	128	82	56	171	128	83	56
	Mean	2 448	2 846	2 520	2 585	1 636	2 264	1 879	2 137
	Median	2 460	2 815	2 525	2 541	1 760	2 240	1 870	2 075
	95%ile	2 82810	3 220	2 770	2 950	2 015	2 593	2 148	2 640
	SD	262	226	193	231	349	245	268	274
	CoV (%)	10.7	7.9	7.6	9.0	21.3	10.8	14.3	12.8
Fe (mg/L)	n	33	129	83	57	33	128	82	57
	Mean	4.7	168.4	2.490	8.9	0.3	72.9	0.466	4.9
	Median	0.4	163.0	0.030	0.1	0.2	64.0	0.075	0.04
	95%ile	13.8	365.2	3.090	52.6	0.8	186.3	1.000	25.7
	SD	18.8	116.2	13.146	19.5	0.3	57.7	1.896	12.2
	CoV (%)	399.1	69.0	527.9	219.9	94.4	79.1	407.2	250.8
Mn (mg/L)	n	34	129	83	57	33	128	83	57
	Mean	18.1	62.7	16.5	17.3	10.3	50.3	14.4	16.1
	Median	9.8	65.0	11.0	16.0	2.7	50.0	10.0	14.0
	95%ile	74.0	95.0	56.1	32.6	46.2	76.0	45.0	30.4
	SD	27.6	23.5	18.0	9.1	19.4	17.6	15.8	9.9
	CoV (%)	152.5	37.6	109.3	52.8	187.6	35.1	110.1	61.4

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

The EC, pH and SO_4 values measured (and derived in the case of SO_4) on the occasion of each SDM reported for stations F11S12 and MRd in **Annexure B**, are graphed in **Figure 16** (EC), **Figure 17** (pH) and **Figure 18** (SO_4).

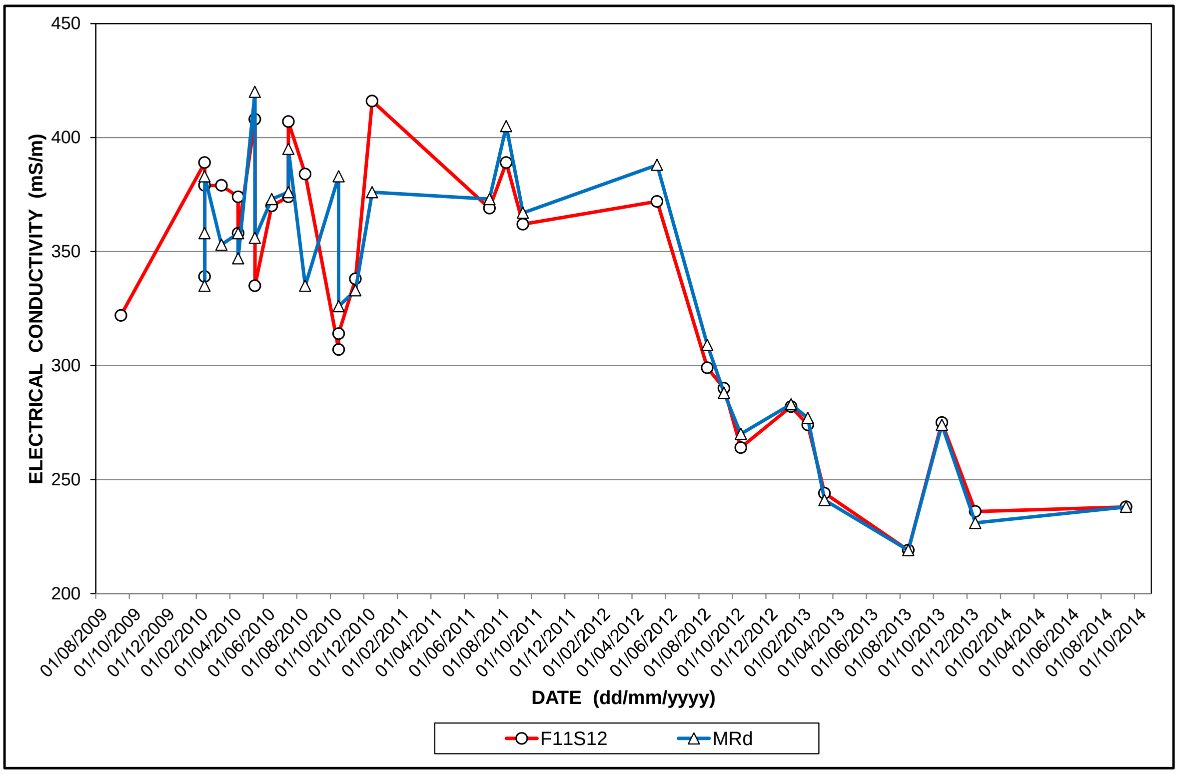


Figure 16 Pattern of EC values at stations F11S12 and MRd as reported in **Annexure B**

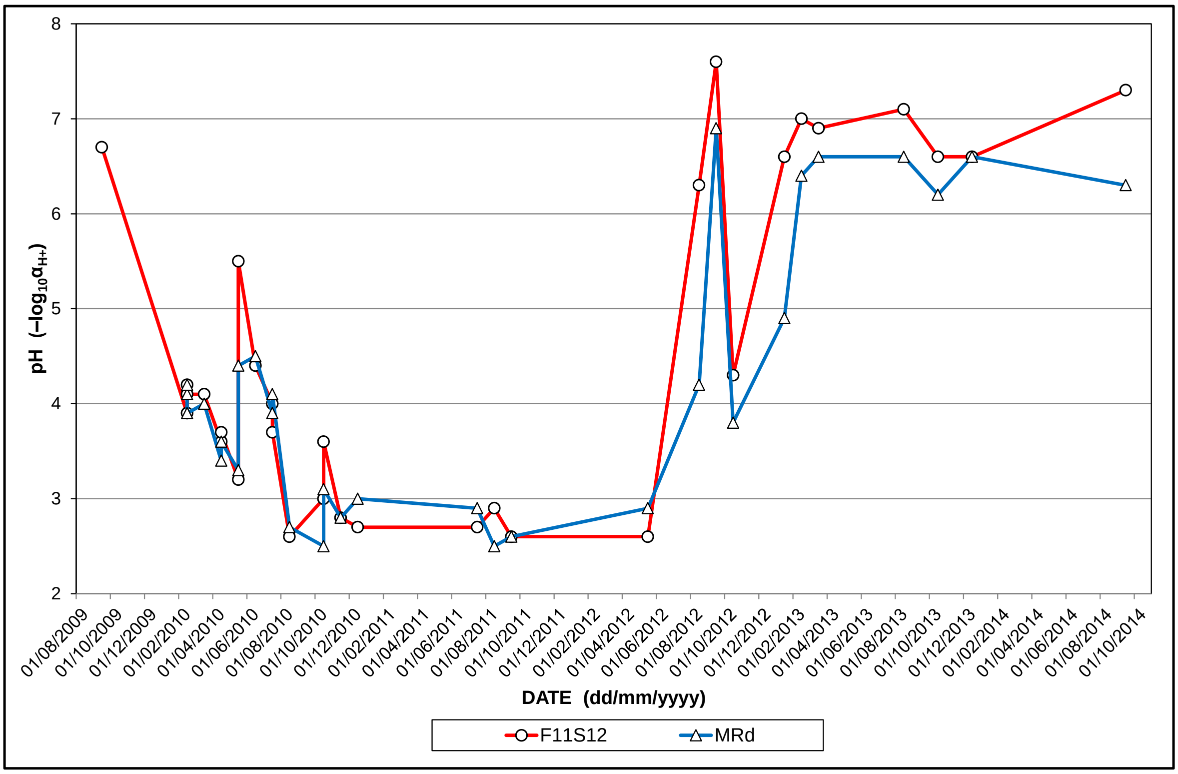


Figure 17 Pattern of pH values at stations F11S12 and MRd as reported in **Annexure B**

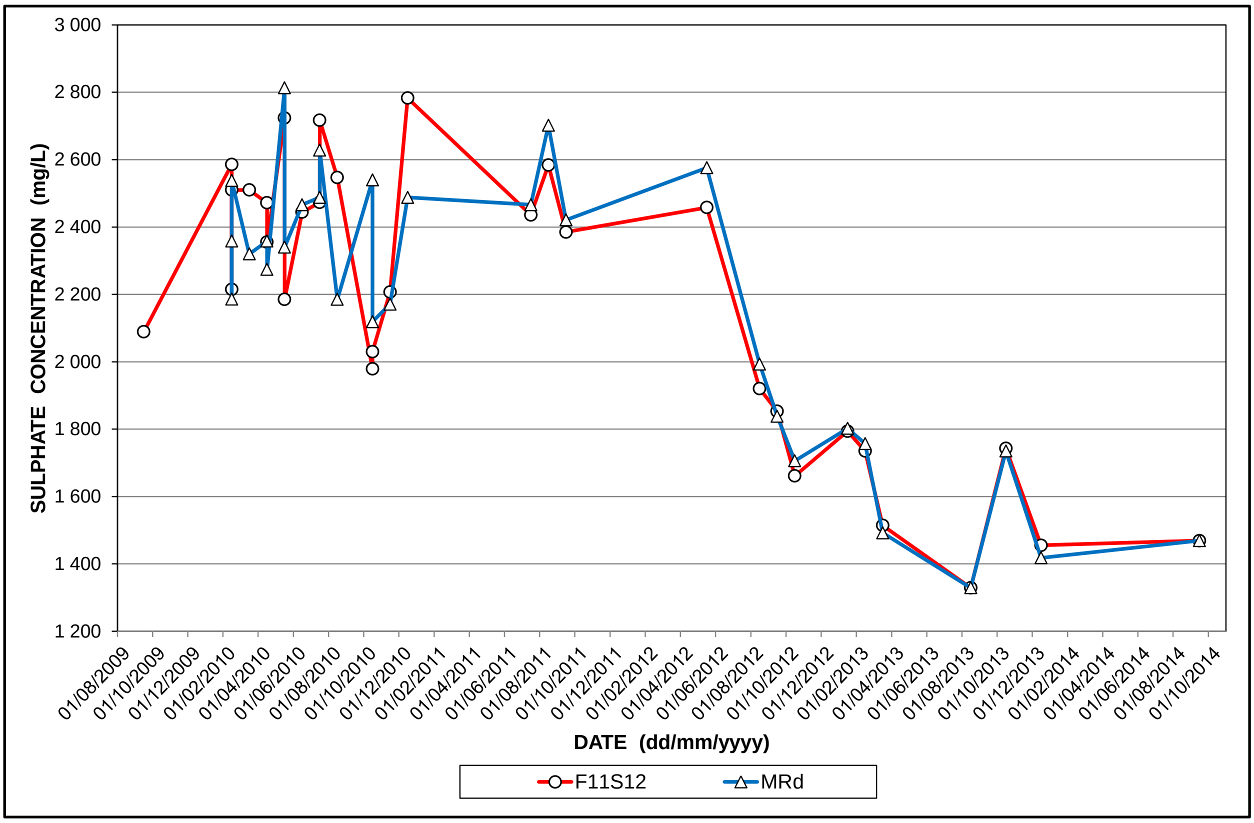


Figure 18 Pattern of SO_4 values at stations F11S12 and MRd as reported in **Annexure B**

The EC and pH data reflect the elevated salinity values (>350 mS/m) and low pH values (<3) that characterised the mine water impacted surface water lost to the karst aquifer (**Section 4.1.2**) in the period mid-2010 to mid-2012. Similarly, **Figure 18** reflects the elevated contemporaneous SO_4 levels (>2 000 mg/L) in this water.

The improvement in water quality since mid-2012 is equally evident. This is revealed by the standard deviation (SD) and coefficient of variation (CoV) values reported in **Table 2** for EC and SO_4 at station F11S12 for the period D–. These circumstances have prevailed to March 2015, the exception being pH as has been reported earlier.

4.2.2 Bloubank Spruit

An analysis of the surface water chemistry data for DWS flow gauging station A2H049 at the lower end of the Bloubank Spruit system, provides the synoptic overview presented in **Table 3**. The median and mean electrical balance (EB) values afford the analytical results a high degree of confidence. The 95%ile EB value of 9.5% suggests the increasing inaccuracy of analyses at higher SO_4 concentrations, as the 95%ile SO_4 value exceeds the median value by ~123%. None of the variables/analytes reported in **Table 3** exceed the respective SANS (2011a; 2011b) health-related limit where specified.

Table 3 Synoptic overview of Bloubank Spruit water chemistry at station A2H049 in the period May 1979 to March 2015

Variable	**Statistical Parameter**							**SANS**
	n	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	**(2011a)(1)**
pH ($-\log_{10}\alpha_{H+}$)	1 016	7.4	—	8.2	8.5	0.3	4	5.0–9.7
EC (mS/m)	1 075	51.2	60.5	60.5	70.7	8.7	14	<170
TDS (mg/L)	1 075	355.7	4358.9	444.0	508.4	63.3	14	<1 200
Ca (mg/L)	935	43.5	55.6	53.8	76.6	14.0	25	n.s.
Mg (mg/L)	934	25.2	32.9	32.6	42.0	5.6	17	n.s.
Na (mg/L)	907	10.0	22.3	22.1	34.2	7.4	33	<200
K (mg/L)	915	0.7	2.0	1.8	3.6	0.9	47	n.s.
Cl (mg/L)	940	20.1	32.1	32.3	41.1	6.1	19	<300
SO_4 (mg/L)	935	65.3	97.9	84.2	188.6	58.2	59	<500
HCO_3 (mg/L)	933	143.9	190.6	196.2	219.5	26.0	14	n.s.
NO_3+NO_2 (mg N/L)	978	2.997	4.564	4.397	6.347	1.707	37	<11
PO_4 (mg P/L)	1 007	0.005	0.093	0.055	0.315	0.105	113	n.s.
Si (mg/L)	1 010	5.07	5.97	5.96	6.83	0.81	14	n.s.
Fe (mg/L)	117	0.004	0.029	0.014	0.118	0.047	164	<2
Mn (mg/L)	117	0.001	0.112	0.002	0.145	0.640	572	<0.5
Al (mg/L)	112	0.003	0.044	0.011	0.091	0.201	457	<0.3
EB (%)	844	–1.5	3.6	3.6	9.5	3.9	109	±5

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

The surface water quality monitoring carried out at the Nedbank Olwazini Estate complex (station NOE in **Figure 19**) provides a valuable 'reference' of nutrient and bacteriological water quality in the lower reaches of the Bloubank Spruit. This is particularly relevant under circumstances where discharge quality data for the Percy Stewart Wastewater Treatment Works remains embargoed by the local municipality. The NOE monitoring has further significance for its location in proximity to where the Bloubank Spruit leaves the karst environment, traversing older strata down to its confluence with the Crocodile River. The NOE data therefore represent almost exclusively that of water which drains the karst portion of the catchment. The pH values and nutrient (NO_3-N, PO_4-P and COD) and bacterial levels in Bloubank Spruit water at the NOE complex in the period January 2009 to March 2015[4] (6 years) are given in **Table 4**. The temporal pattern of the pH and bacterial variables is illustrated in **Figure 20**.

Table 4 Analysis of Bloubank Spruit water nutrient and bacterial content at the NOE property in the period January 2009 to March 2015

Variable / Analyte	**Statistical Parameter**								**SANS**	**TWQR(2)**
	n	**1%ile**	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	**(2011a)(1)**	**TWQR(3)**
pH ($-\log_{10}\alpha_{H+}$)	67	—	7.5	—	8.0	8.6	0.3	4	5.0–9.7	—
NO_3 (mg N/L)	58	—	2.7	7.5	7.0	**14.9**	3.6	48	<11	—
O-PO_4 (mg P/L)	67	—	0.0	0.4	0.3	0.9	0.3	94	n.s.	—
COD (mg/L)	49	—	6.4	53.9	42.0	156.0	50.7	94	n.s.	—
N:P (ratio)(4)	55	—	6.8	36.8	28.8	116.2	35.3	96	—	—
Faecal coliforms (cfu/100 mL)	67	**39**	**57**	**875**	**320**	**4 529**	1 745	200	≤10 in 1% of samples	≤200(2) ≤130(3)

(1) Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person.
(2) Target Water Quality Range for livestock watering as per DWAF (1996a).
(3) Target Water Quality Range for recreational water use as per DWAF (1996b).
(4) Derived from NO_3-N and PO_4-P values.
Bold text denotes value exceeds standard limit as described in note (1).

---

[4] The record contains a gap spanning the period November 2014 to February 2015 (inclusive).

The faecal coliform count as far downstream as the NOE property reflects elevated levels even at the 1%ile level (**Table 4**). The association of higher faecal coliform levels with rainfall is evident in **Figure 20**. This suggests that significant municipal wastewater impacts on surface water bacteriological quality are driven by rainfall. The mean and median faecal coliform values of 875 and 320 cfu/100 mL respectively (**Table 4**), are compared to February 2013 *E. coli* levels of 980 and 1 553 MPN/100 mL obtained at the stations BG@N14 and BB@M (**Figure 19**) located further upstream. The lower NOE values match the decreasing pattern associated with ‘distance from source’ reported by Hobbs (2011). Nevertheless, the results indicate severe non-conformance of faecal coliforms (and therefore almost certainly also of *E. coli*) in regard to potable, animal and recreational use at the NOE site in the Bloubank Spruit catchment. This situation undoubtedly worsens progressively with distance upstream.

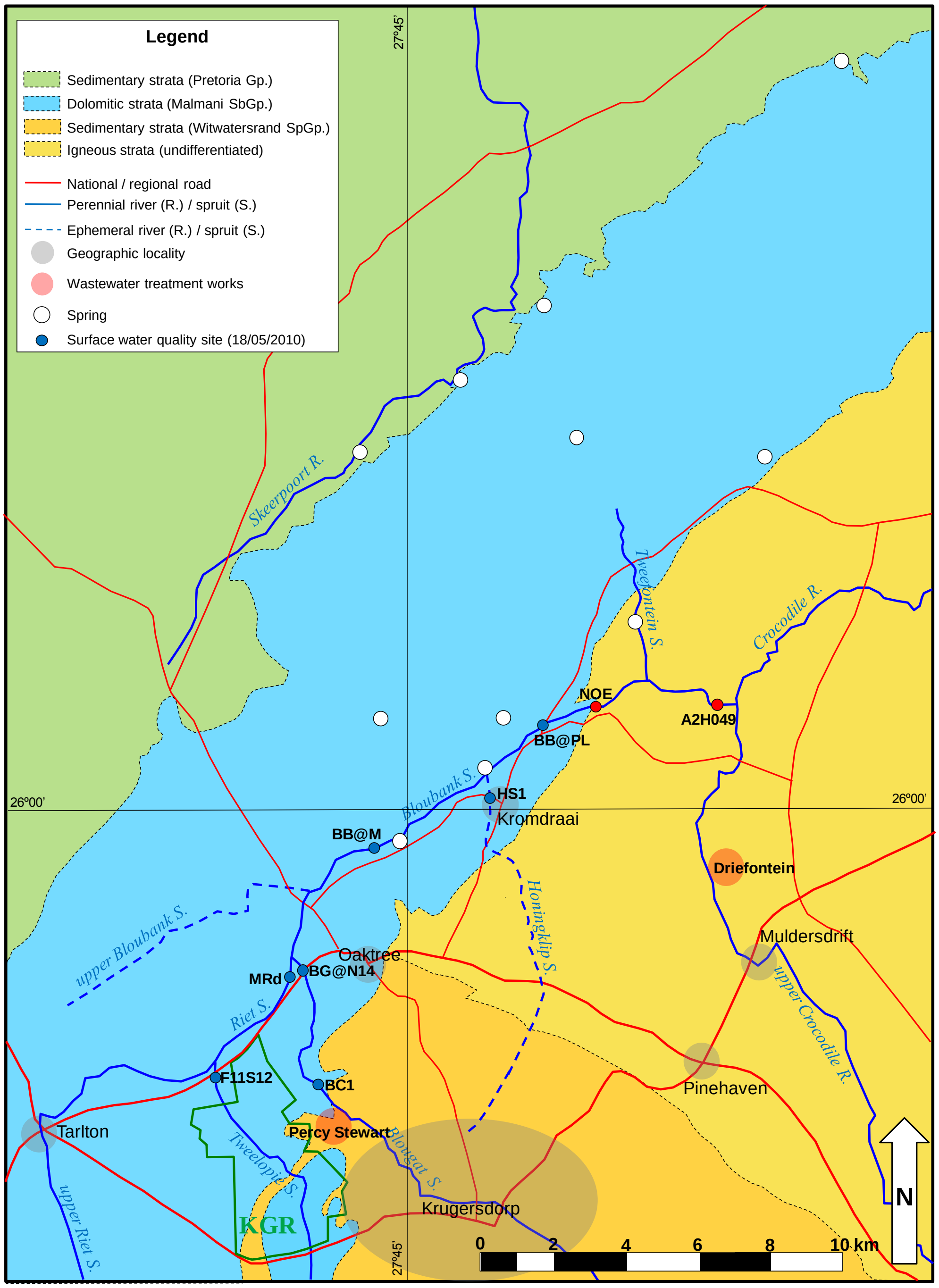
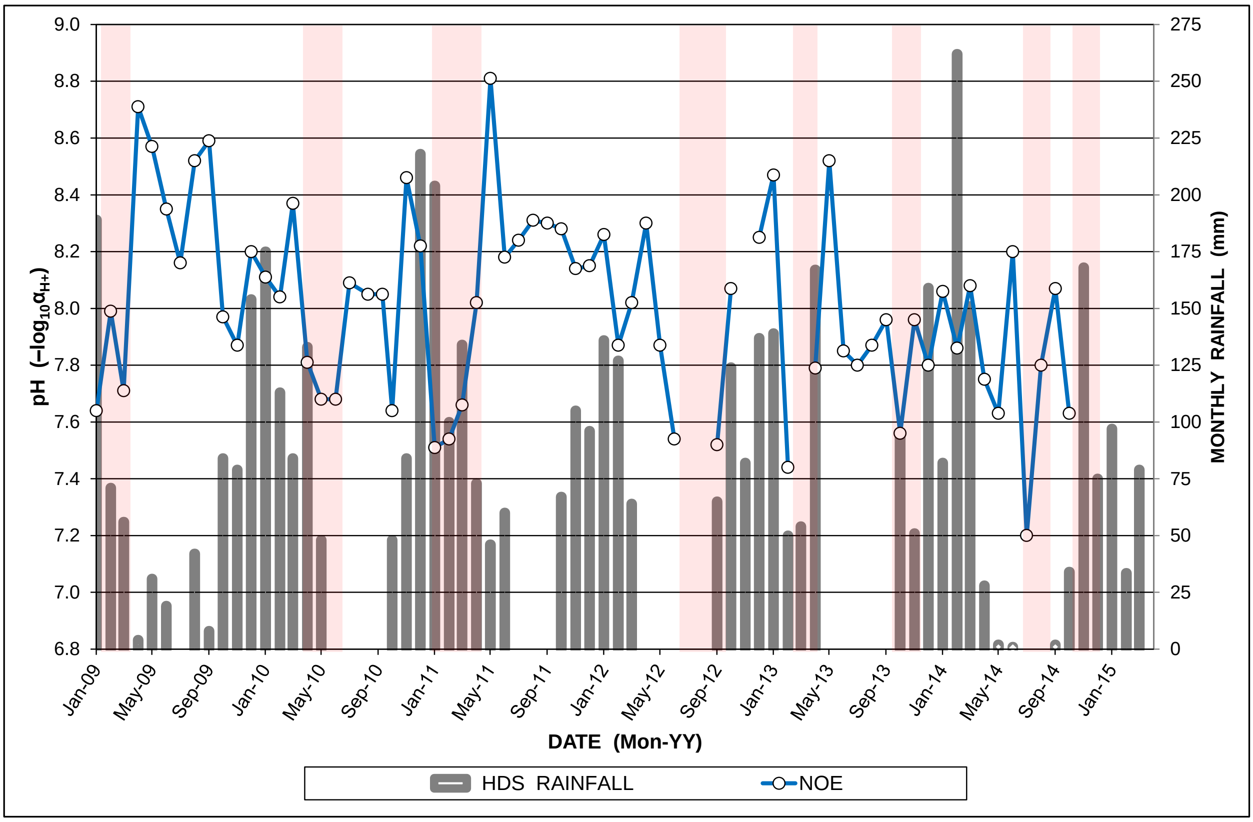


Figure 19 Surface water quality sampling sites in the study area



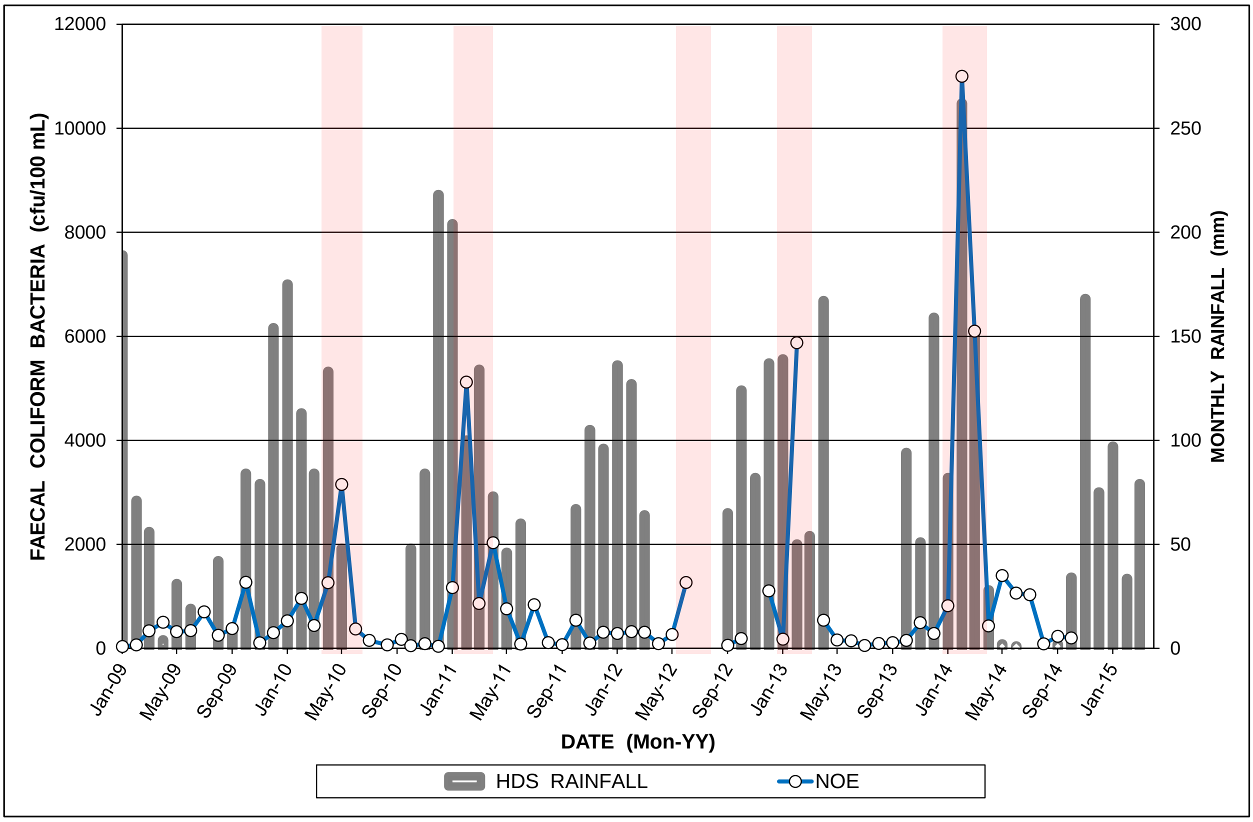


Figure 20 Correlation (vertical shaded columns) of pH (top) and faecal coliform bacteria (bottom) levels in the Bloubank Spruit at the NOE property with rainfall in the headwaters of the catchment

4.3 Salt Load

4.3.1 Riet Spruit

The combination of stream flow losses (**Annexure A**) and associated TDS and SO_4 concentrations (**Annexure B**) between stations F11S12 and MRd, allows for the derivation of the TDS and SO_4 loads lost to the karst aquifer. These are illustrated in **Figure 21** and **Figure 22** respectively.

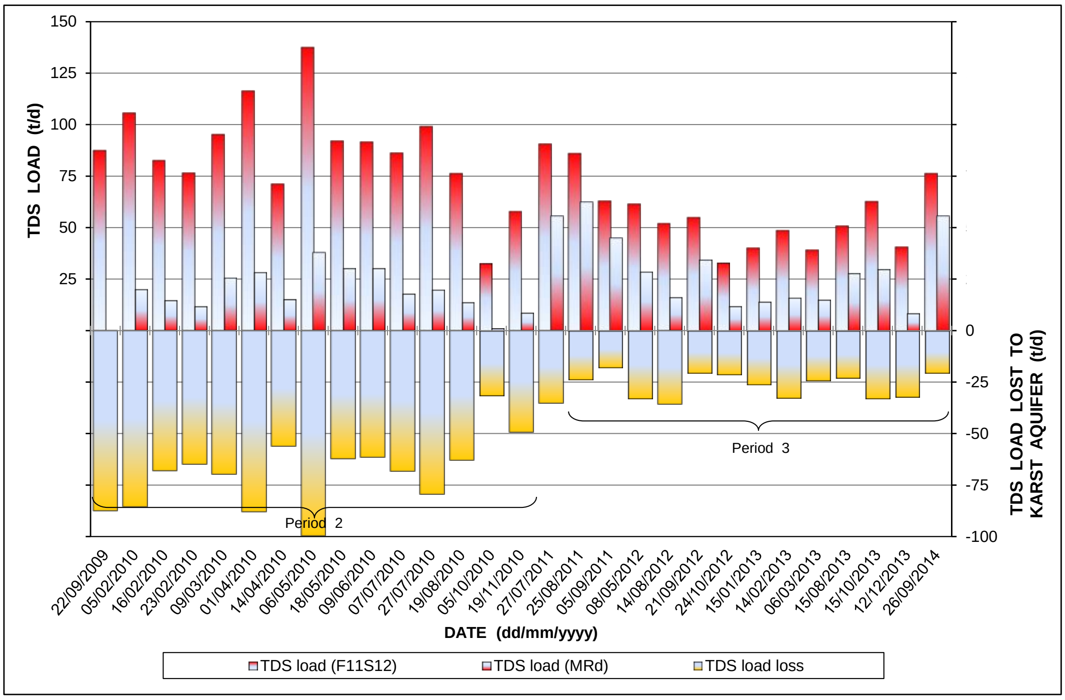


Figure 21 Graph of surface water TDS load lost to groundwater in the loosing reach of the Riet Spruit

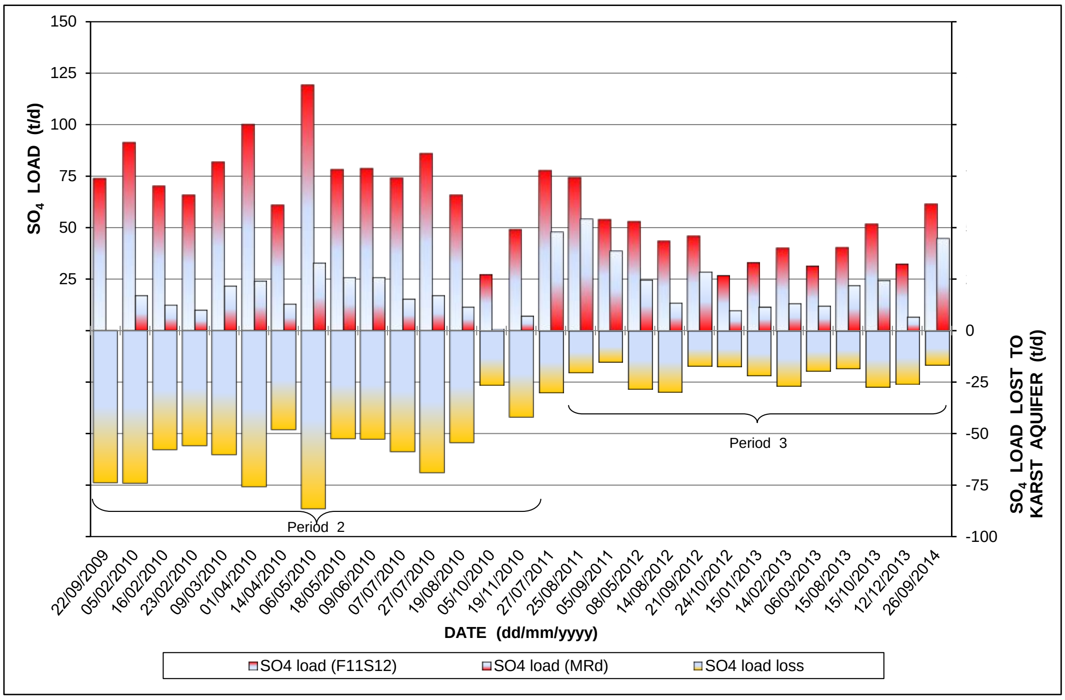


Figure 22 Graph of surface water SO_4 load lost to groundwater in the loosing reach of the Riet Spruit

The concern previously expressed for the quality of the water entering the karst aquifer is echoed in the respective median TDS and SO_4 loads associated with this allogenic recharge. These loads amount to ~68 t TDS/d and ~58 t SO_4/d in Period 2, and ~25 t TDS/d and ~21 t SO_4/d in Period 3. These losses represent ~80% of the median TDS and SO_4 loads passing station F11S12 in Period 2, and ~53% of the median TDS and SO_4 loads passing this station in Period 3.

4.3.2 Bloubank Spruit

The combination of flow and hydrochemical data similarly affords a re-assessment of the TDS (**Figure 23**) and SO_4 (**Figure 24**) load pattern and trend manifested at station A2H049. The ratio of SO_4 to TDS illustrated in **Figure 25** similarly reflects the rather dramatic difference between the pre- and post-2009 circumstances precipitated by the resumption of uncontrolled mine water discharge into the Bloubank Spruit system.

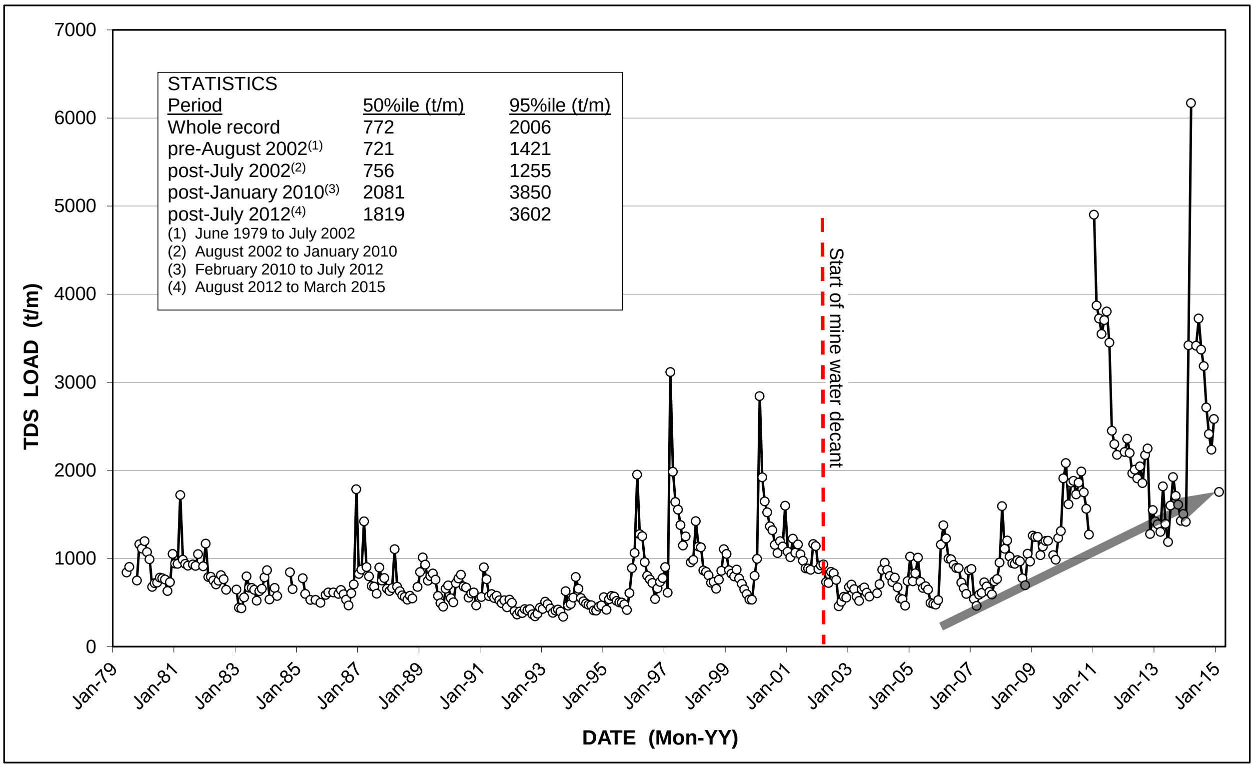
The long-term monthly trend in the TDS load delivered by the Bloubank Spruit (**Figure 23**) indicates an increasing TDS load (as indicated by the visually inserted arrows) since early-2007. The text box in **Figure 23** lists the median and 95%ile values associated with different periods of record. The post-September 2009 period reveals the greatest difference, which is readily attributable to the very high salt loads experienced in the 2010–'11 hydrological year. The long-term monthly trend in the SO_4 load delivered by the Bloubank Spruit (**Figure 24**) mimics the TDS load pattern (**Figure 23**) in the period since early-2007. This is unsurprising under circumstances where SO_4 comprises ~62% of the major ion concentration in mine water.

A further analysis of the potential impact of AMD on the chemistry of surface water at the downstream end of the Bloubank Spruit system is based on the SO_4**:**TDS ratio at station A2H049. This is illustrated in **Figure 25** for the long-term record, and in **Figure 26** for the period since the start of decant.

The closer inspection in **Figure 27** of the SO_4 data recorded at station A2H049 indicates an approximate trebling of the SO_4 concentration (from ~100 mg/L to ~300 mg/L) between mid-2010 and early-2015. This is also reflected in the SO_4**:**TDS ratio, which increases from ~20% to ~50% in this timeframe (**Figure 26**).

An inspection of **Figure 23** reveals that the TDS load passing station A2H049 ca. January 2014 represents the highest in the historical record, surpassing the January 2011 value by >1 000 t/m. By comparison, **Figure 24** reveals that the SO_4 load passing this station at this time represents the second highest in the historical record, falling ~300 t/m short of the January 2011 value. Under circumstances where **Figure 7** shows that the ca. January 2014 discharge at A2H049 exceeds that in January 2011 by ~40%, it is evident that the more recent mine water chemical influence is substantially mitigated at A2H049 compared to that experienced in 2010–'11. This is also reflected in **Figure 27**, which shows that the ca. January 2014 SO_4 concentrations at A2H049 are ~50% of those recorded in January 2011.

The obvious and immediate cause-and-effect revealed in the response of surface water chemistry to mine water impacts reflected in **Figure 23** to **Figure 27**, remains obtuse and delayed in regard to the response of groundwater chemistry to similar impacts (**Section 5.2**).

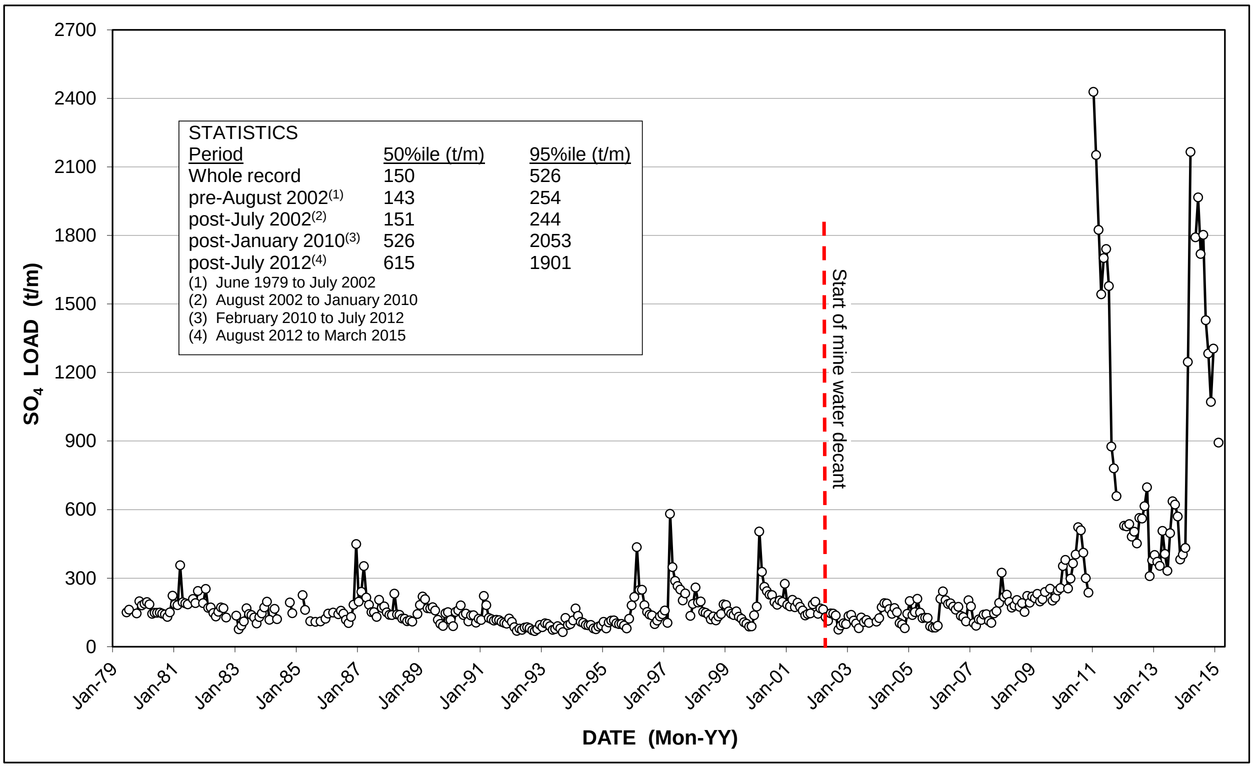


STATISTICS

Period	50%ile (t/m)	95%ile (t/m)
Whole record	772	2006
pre-August 2002(1)	721	1421
post-July 2002(2)	756	1255
post-January 2010(3)	2081	3850
post-July 2012(4)	1819	3602

(1) June 1979 to July 2002
(2) August 2002 to January 2010
(3) February 2010 to July 2012
(4) August 2012 to March 2015

Figure 23 Long-term (June 1979 to March 2015) monthly TDS load pattern and trend in the Bloubank Spruit at station A2H049



STATISTICS

Period	50%ile (t/m)	95%ile (t/m)
Whole record	150	526
pre-August 2002(1)	143	254
post-July 2002(2)	151	244
post-January 2010(3)	526	2053
post-July 2012(4)	615	1901

(1) June 1979 to July 2002
(2) August 2002 to January 2010
(3) February 2010 to July 2012
(4) August 2012 to March 2015

Figure 24 Long-term (June 1979 to March 2015) monthly SO_4 load pattern and trend in the Bloubank Spruit at station A2H049

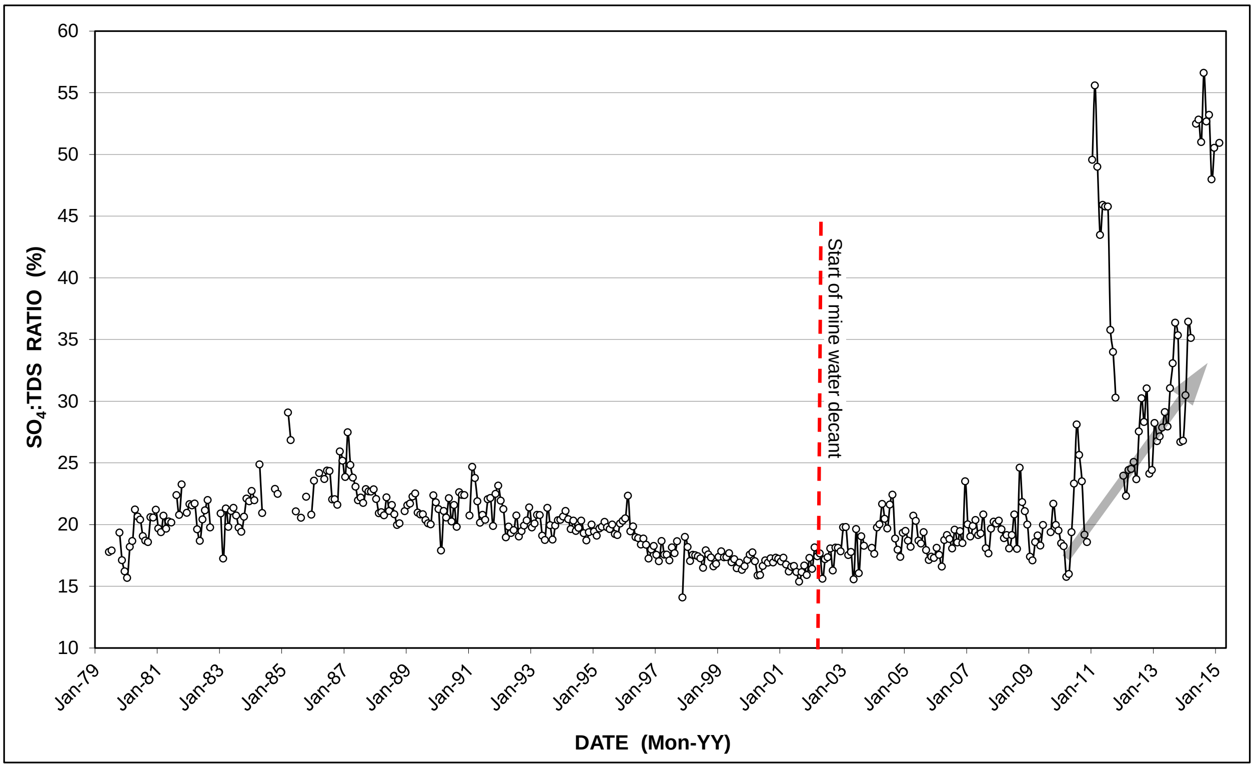


Figure 25 Long-term (June 1979 to March 2015) trend in the SO_4:TDS ratio at station A2H049

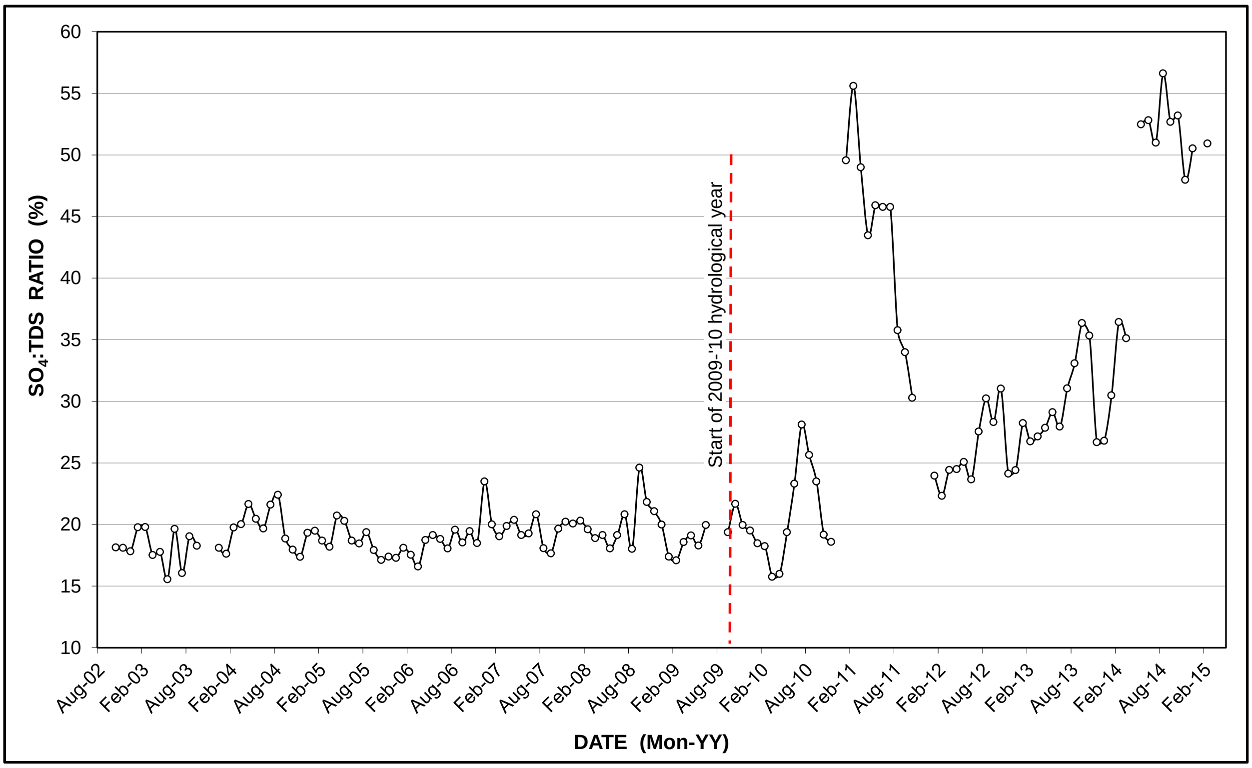


Figure 26 Pattern and trend of the SO_4:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin

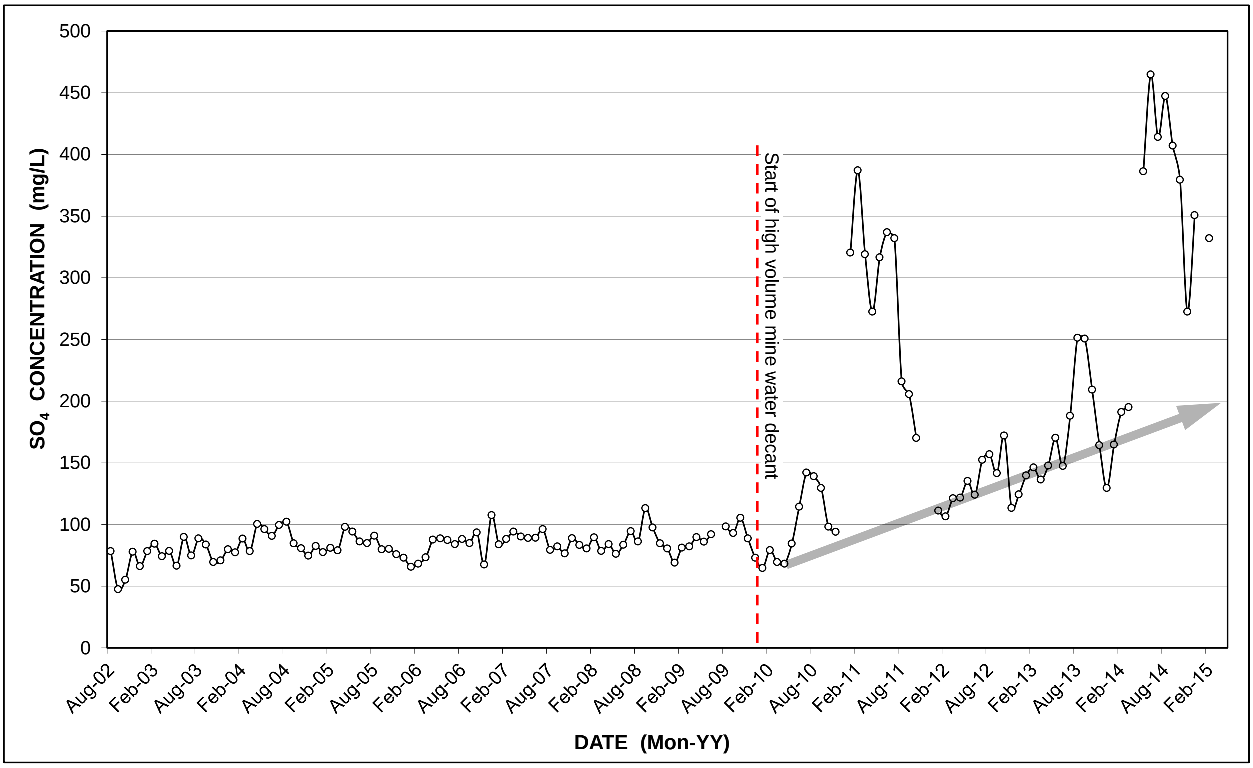


Figure 27 Pattern and trend of the SO_4 concentration at station A2H049 since the start of mine water decant in the Western Basin

The SO_4 concentration in the surface water more recently passing station A2H049 (**Figure 27**) shows a decline toward the gradually rising trend that started in the 2009–'10 hydrological year. It is since mid-2010 that the recent large and uncontrolled AMD discharges resulted in a significant change in the chemical composition of surface water leaving the Bloubank Spruit system. This confirms that a significantly greater mine water component, and in particular raw mine water, characterised the surface water chemistry in the middle and lower reaches of the Bloubank Spruit system than before mid-2010. The subregional and regional influence of these circumstances on the recent TDS loads delivered by individual drainages in the Hartbeespoort Dam catchment to this impoundment, are explored on the basis of comparison with the long-term record in **Section 6**.

5 GROUNDWATER HYDROLOGY

5.1 Physical Hydrogeology

5.1.1 Groundwater Levels

The behaviour of groundwater levels associated with the karst aquifer is reflected in the long-term water level records for DWS monitoring boreholes in the study area. An assessment of these data returns the statistics presented in **Table 5** and graphical representations shown in **Figure 28**. A comparison with the previous data set reported in Hobbs (2014b) reveals differences (where present) only in the second decimal. An analysis of the %ile change in head (Δh) data yields a 25%ile value of 3.7 m, a mean value of 5.0 m, and a 75%ile value of 6.5 m. Most of these hydrographs are compared in **Figure 29**, which indicates two distinct groupings, namely Group A (**Figure 30**) occupying an elevation of

>1 530 m amsl, and Group B (**Figure 31**) occupying an elevation <1 490 m amsl. The >40 m elevation difference reflects their spatial distribution between two different compartments/subcompartments.

Table 5 Salient statistics for long-term DWS groundwater level monitoring data

Station	**Groundwater Rest Level (m bc)**							**Record Period(1)**
	n	**5%ile**	**Mean**	**Median**	**95%ile**	**Max Δh(2)**	**%ile Δh(3)**	
A2N0580	276	–59.95	–54.53	–54.30	–51.02	11.13	8.94	05/1985–02/2015
A2N0582	210	–42.91	–40.11	–40.15	–35.77	8.53	7.14	05/1985–12/2010
A2N0583	235	–45.54	–44.95	–44.88	–44.40	1.84	1.14	05/1985–02/2015
A2N0584	274	–28.09	–25.42	–26.13	–21.23	8.19	6.86	05/1985–03/2015
A2N0586	290	–28.67	–26.22	–27.14	–21.33	8.54	7.34	05/1985–02/2015
A2N0589	169	–29.90	–28.89	–28.97	–27.92	3.85	1.98	05/1985–06/2010
A2N0590	190	–36.46	–34.60	–35.11	–31.50	6.11	4.96	05/1985–02/2015
A2N0592	280	–78.53	–76.89	–77.33	–73.62	6.33	4.91	06/1985–02/2015
A2N0594	183	–74.41	–72.79	–72.80	–70.86	4.91	3.55	01/1985–09/2008
A2N0598	89	–63.32	–58.76	–58.84	–53.53	12.17	9.79	07/1985–05/2010
A2N0600	209	–25.38	–23.91	–24.38	–21.23	5.07	4.16	04/1989–02/2015
A2N0602	235	–55.95	–54.28	–54.82	–51.04	6.44	4.91	06/1987–02/2015
A2N0605	203	–63.65	–62.48	–62.75	–60.18	4.16	3.48	04/1989–12/2014
A2N0606	73	–69.51	–67.07	–67.03	–64.84	5.11	4.66	08/1989–12/2014
A2N0607	171	–70.68	–66.97	–66.90	–64.18	8.09	6.50	10/1993–02/2015

(1) From month of first measurement to month of most recent available measurement as at March 2015 update from DWS; shaded rows denote stations no longer in service

(2) Difference between minimum and maximum values (not shown in this table)

(3) Difference between the 5%ile and 95%ile values

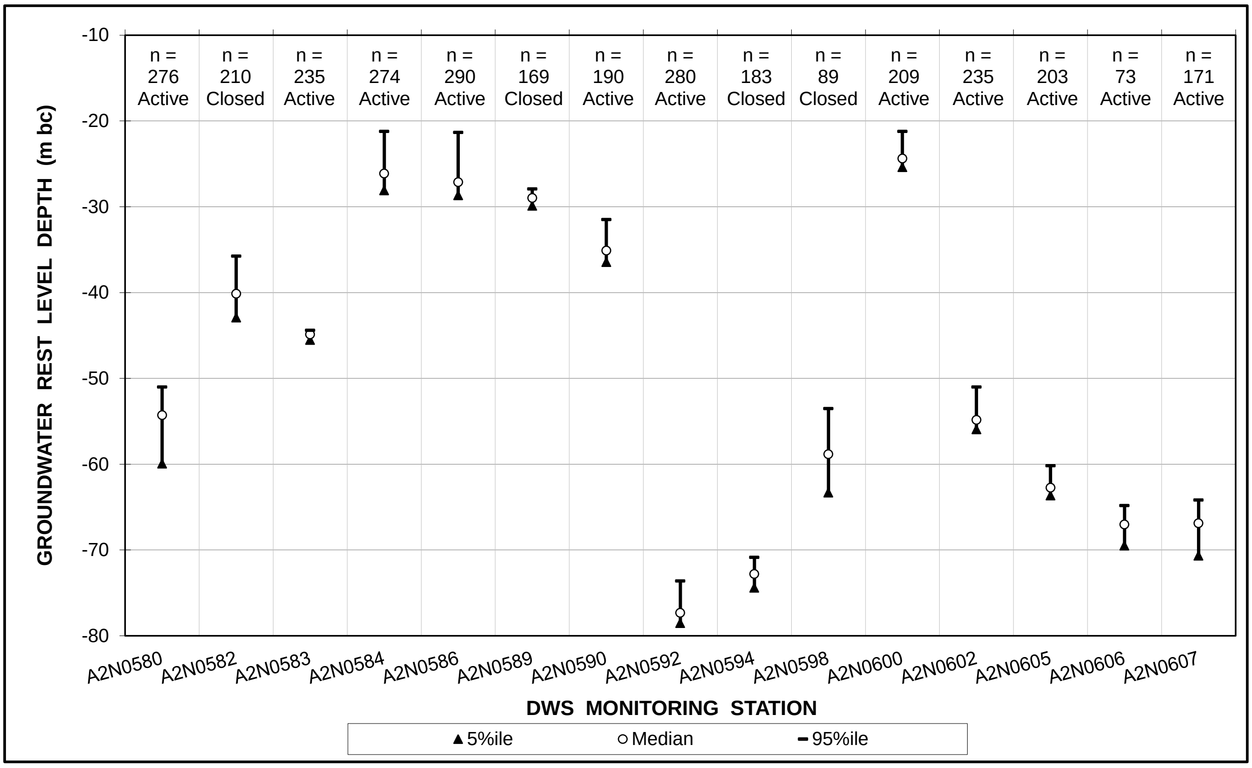


Figure 28 Graphic comparison of the statistical hydrographic response observed in the DWS long-term groundwater level monitoring stations in the period 1985 to 2015 (data from **Table 5**)

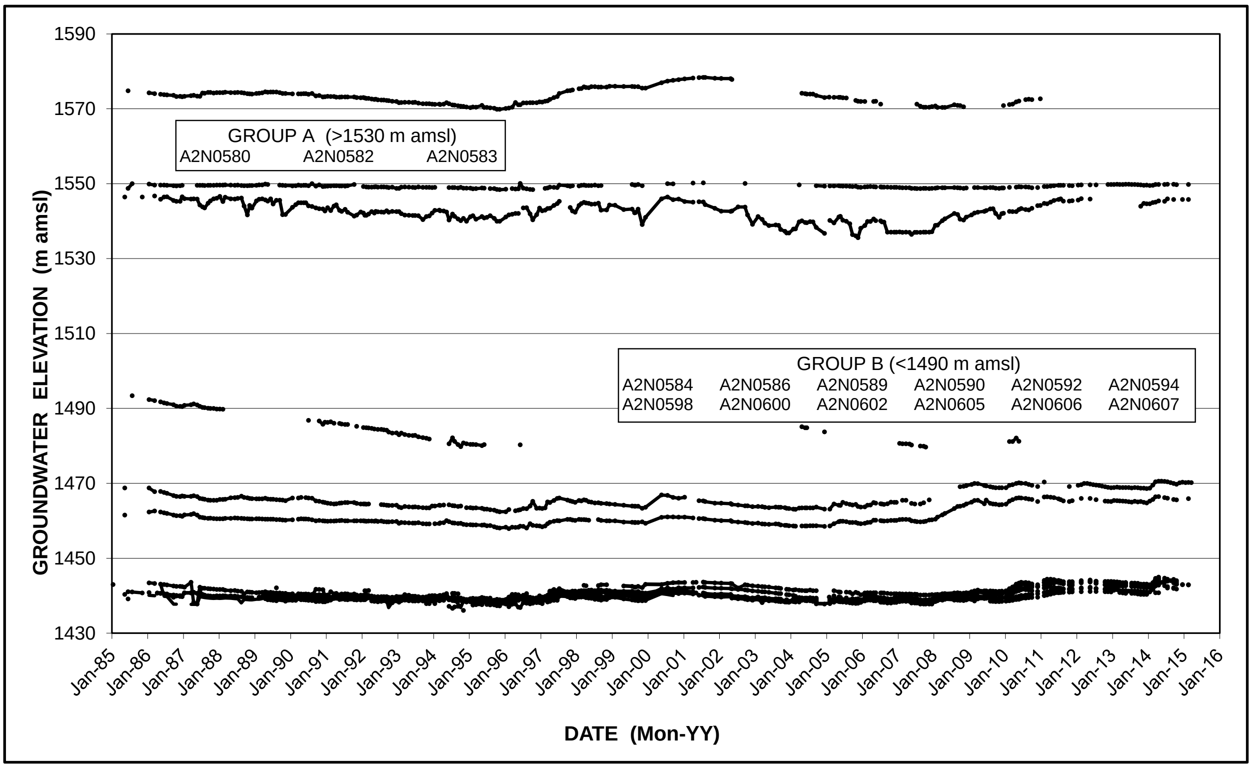


Figure 29 Long-term groundwater level response pattern in DWS monitoring boreholes

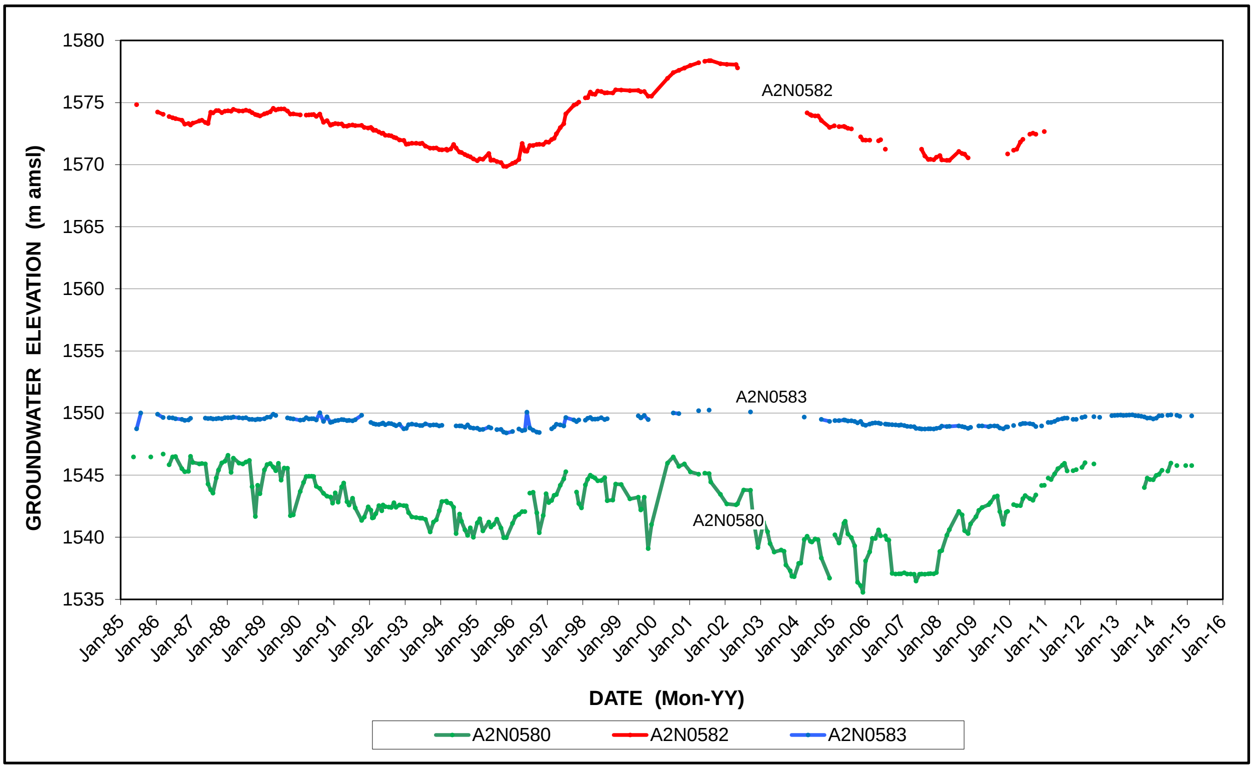


Figure 30 Long-term groundwater level response pattern in Group A boreholes from **Figure 29**

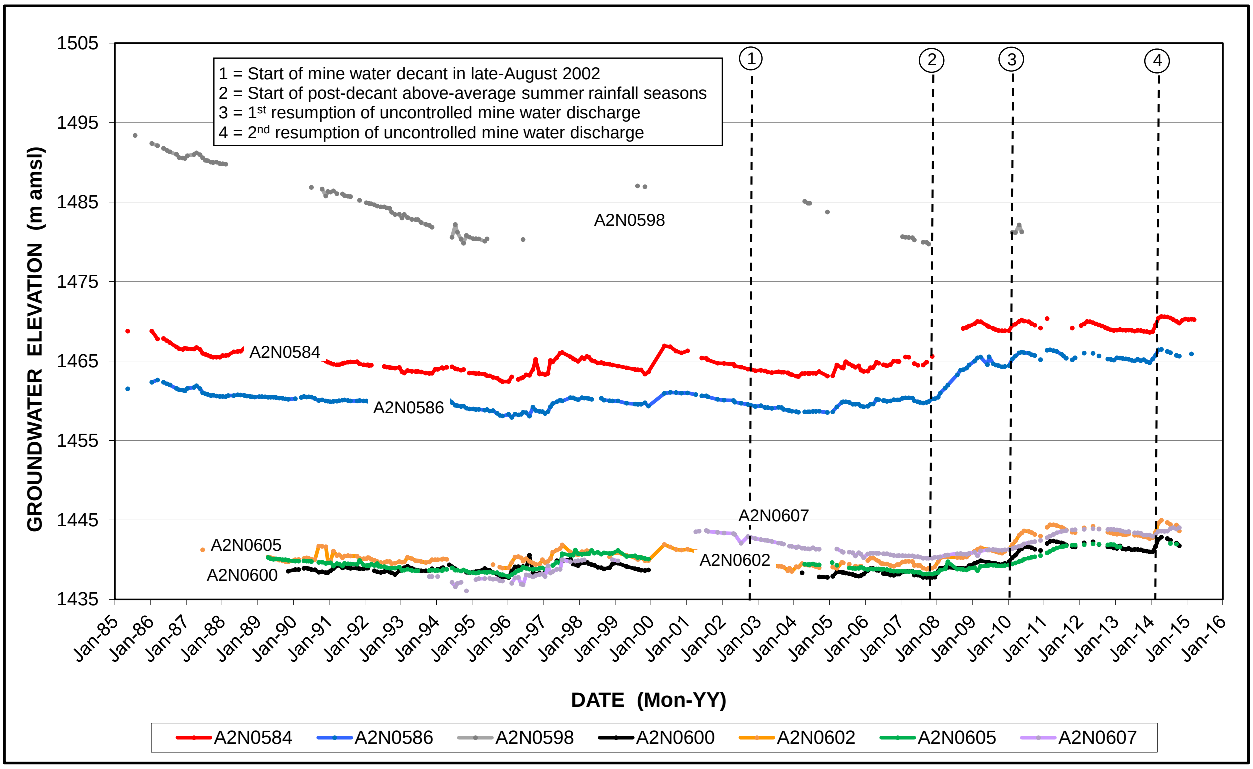
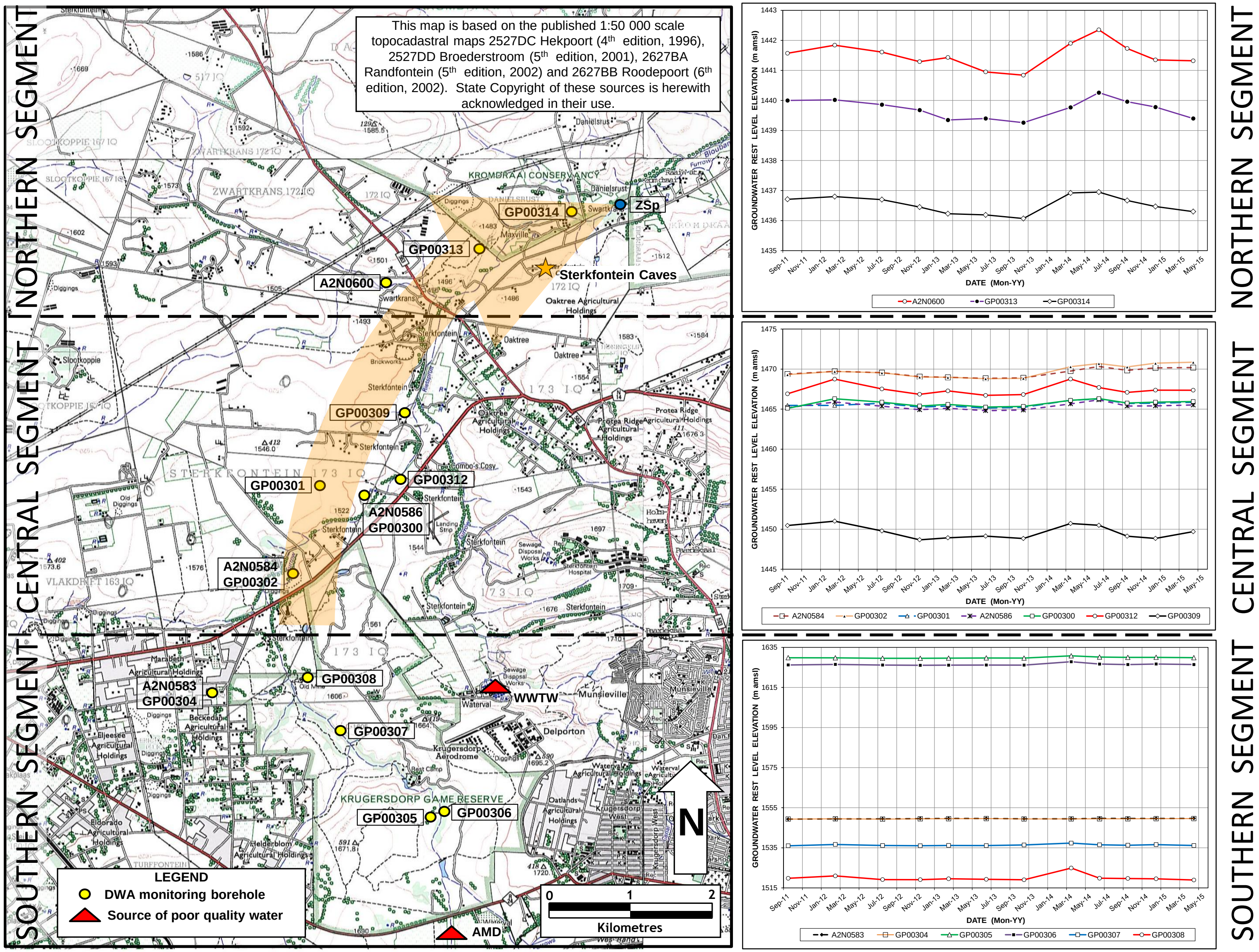


Figure 31 Long-term groundwater level response pattern in Group B boreholes from **Figure 29**

The unprecedented rise in the groundwater level observed in stations A2N0584 and A2N0586 since late-2007 (**Figure 31**) reflects the impact of exceptional recharge associated with raw and/or treated mine water being lost from the Riet Spruit downstream of the Tweelopie Spruit confluence (**Section 4.1.2**). Both these stations are located in proximity to the Riet Spruit (**Figure 32**). These circumstances were precipitated by the wet summers experienced in the region starting with the 2007–'08 hydrological year, and resulting in treated mine water discharges in excess of 25 ML/d to the Tweelopie Spruit. The additional contribution of raw mine water to this discharge in the much wetter 2010–'11 and 2013–'14 rainy seasons (**Figure 4**) has, on occasion, increased the allogenic flow in this drainage to >60 ML/d. It is therefore not surprising that the long-term hydrographs presented in **Figure 31**, in particular those of stations A2N0584, A2N0586 and A2N0600, indicate that groundwater elevations in the last five years are the highest in the ~30-year record of measurements. The exception in this regard (station A2N0598) is readily explained by the position of this borehole ~2.9 km west of the Tweelopie Spruit / Riet Spruit confluence. This position places it upstream of the hydraulic influence exerted by allogenic recharge along the losing reach of the Riet Spruit. The modification of the natural hydrologic and hydrogeologic balances brought about by the elevated and sustained mine water discharges (both treated/neutralised and/or raw mine water) will certainly alter the long-term natural groundwater level recession pattern and trend especially in the lower reaches of the Zwartkrans Compartment. It is postulated that this impact on the physical manifestation of groundwater change will result in higher baseflows in the Bloubank Spruit system in the future. The magnitude of this increase is still anticipated to be in the order of 15–20% (2.9–3.9 Mm^3/a) as reported previously (Hobbs, 2014b).

An inspection of the more recent potentiometric response in DWS monitoring boreholes located downstream of the mine area is presented in **Figure 32.** The boreholes are grouped into a southern, a central and a northern segment to distinguish between their location in the downstream receiving hydrogeologic environment. This distinction is particularly evident in the absolute groundwater level elevations that describe a decrease from south to north both within and between the respective segments.



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

Figure 32 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); arrow denotes principal direction of impacted groundwater flow

5.1.2 Sterkfontein Caves Water Level

The international significance of Sterkfontein Caves as the flagship fossil site in the COH WHS focuses attention on any perceived impact on this site. A recent substantial rise in the cave water level caused Maropeng āAfrika (the authority responsible for managing the tourist component of the site) to reroute the tourist path through the caves to successively higher elevations. Against this background, the circumstances that inform this phenomenon warrant separate discussion.

In sympathy with the observed rise in water levels in the Zwartkrans Compartment in the more recent past (**Section 5.1.1**), a similar response is observed in the Sterkfontein Caves. The associated trend is shown in **Figure 33**, and suggests that the cave lake (referred to as the Main Lake by Martini et al., 2003) water level might have started rising in mid-2009. After a ~3 m rise peaking at an elevation of ~1 439.4 m amsl in mid-2012, a decline by ~0.8 m to an elevation of ~1 438.6 m amsl by late-2013 was interrupted by a rise of ~1 m to an elevation of ~1 439.6 m amsl by mid-2014. The most recent rise is associated with the very wet 2013–'14 summer (**Section 3**) and its broader impacts in the form of natural (autogenic) and mine water (allogenic) recharge. Most recently, the cave lake water level has resumed a decline to an elevation of ~1 439 m amsl in February 2015.

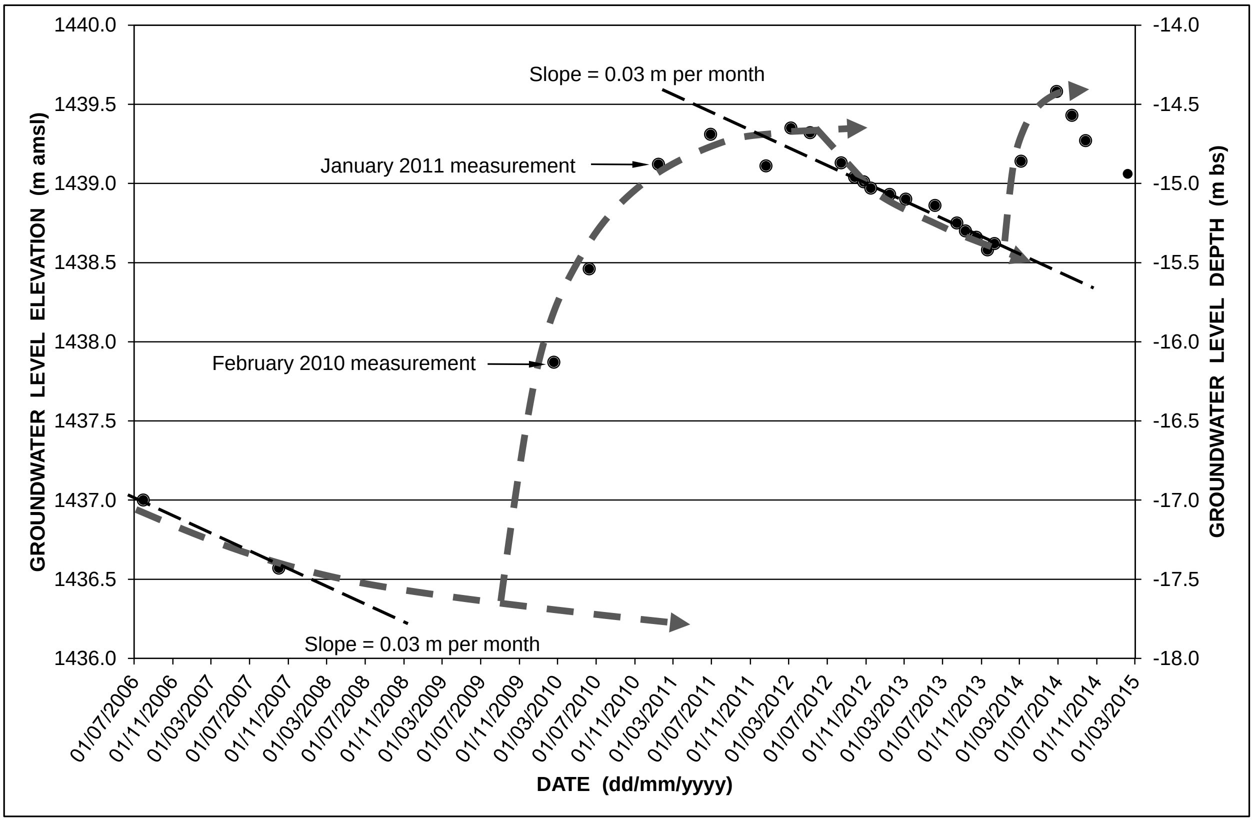


Figure 33 Groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the cave lake water level in Sterkfontein Caves

The elevation of 1 439.6 m amsl (**Figure 33**) is similar to that assigned to the Bloubank Spruit channel to the north of the caves. This suggests that the cave water level reaches equilibrium at this elevation (equal to a depth of ~14.5 m bs in borehole SF1), when the karst water table intersects the stream channel of the Bloubank Spruit. Significantly, the recent maximum rise of ~3 m which gave rise to this condition, agrees well with the zone of perceived most aggressive carbonate re-solution that defines the more recent speleogenetic evolution of the cave system as observed by Martini et al. (2003).

It is postulated that the cave lake will maintain a high water level into the future because of sustained above-normal discharge in the upper tributaries of the Bloubank Spruit, and associated allogenic groundwater recharge in the Zwartkrans Compartment. This is premised on the greater sustained discharge of treated/neutralised mine water associated with the immediate and short-term AMD control and management interventions in the Western Basin (DWA, 2011).

5.2 Chemical Hydrogeology

5.2.1 Monitoring Framework

The DWS groundwater monitoring programme in the south-western portion of the property was substantially expanded with the establishment of an additional 13 monitoring boreholes in late-2010. These stations (identified by the alpha-numeric code GP00###) supplement the four stations (identified by the alpha-numeric code A2N0###) that are the legacy of the mid-1980s DWAF study (Bredenkamp et al., 1986) in the region. The distribution of the monitoring network is shown in **Figure 34** and **Figure 35**. Whereas the older stations support a quasi-continuous monitoring record dating back to 2003, the record of the newer stations commences in March 2011. It is the fruits of this monitoring that forms the basis for evaluating the impact of mine water on the receiving karst environment (**Section 5.2.2**).

5.2.2 Mine Water Impact

5.2.2.1 Local Karst Environment

The local karst environment is defined by the ~9 800 ha Zwartkrans Compartment, which occupies only ~19% of the COH footprint (~52 000 ha), and ~36% of the ~26 860 ha karst footprint of the property. This part of the property bears the brunt of any mine water impact from allogenic discharge via the Tweelopie Spruit, and allogenic recharge along the losing reach of the receiving Riet Spruit.

The groundwater chemistry data generated by the monitoring programme in the Zwartkrans Compartment provides an indication of the extent and magnitude of the mine water impact on the karst aquifer in this portion of the COH. This is illustrated in **Figure 34** and **Figure 35** with the aid of bar graphs for the chemical variables pH and EC respectively.

The bar graphs in **Figure 34** reflect the general progressive decrease in pH from south to north within the central and northern segments. This pattern is reflected both in the individual stations and in a spatial context, although the latter is heavily influenced by proximity to the influent (losing) reach of the Riet Spruit in the central segment.

The bar graphs in **Figure 35** similarly reflect the general progressive increase in salinity from south to north within the central segment. In the northern segment, however, the spatial trend along the flow path is a declining one, even though all of the stations individually reflect an increase in salinity. The significant influence exerted by proximity to the Riet Spruit in the central segment is again evident. As in the case of pH (**Figure 34**), this influence is least at the southern margin (stations A2N0584 and

GP00302), and increases down-gradient to station GP00309. This pattern reflects the north to north-easterly flow path followed by the allogenic recharge of mine water in the karst aquifer.

The historical pattern and trend of groundwater EC and SO_4 levels in proximity to the losing reach of the Riet Spruit is reflected in the longer term monitoring data associated with the paired stations A2N0584 / GP00302 and A2N0586 / GP00300, and station A2N0600. These are presented in **Figure 37**, and reveal the pattern and trend of EC and SO_4 levels that define the footprint of the mine water impact in the karst aquifer.

The postulated commencement of the rise in concentrations ca. September 2008 is based on the SO_4 response at station A2N0584 located the furthest upstream along the Riet Spruit. It might be expected that a response at the downstream stations (especially A2N0600) would manifest later because of travel times in the subsurface. The variable of concern is SO_4, which exceeds the SANS (2011a; 2011b) standard health-related limit of 500 mg/L (**Table 3**) in all five instances.

It would also appear from **Figure 37** that recent SO_4 levels along the Riet Spruit exhibit a levelling off after the “spike” observed in 2014, whereas the SO_4 level at the downstream station A2N0600 has only recently peaked. These circumstances are attributed to the most recent discharge of raw and treated mine water from the mine area. The SO_4 response at A2N0600 reflects the more distal location of this station in the pseudoplume.

The distribution of SO_4 concentrations associated with the stations represented in the central and northern segments of **Figure 34** and **Figure 35**, is shown in **Figure 36**. This provides an indication of the extent of this impact, as well as the SO_4 trend in terms of up, stable or down compared to the previous (September 2014) values. It is apparent that the trend at the “upstream” stations (A2N0584, A2N0586, GP00312 and GP00309) is generally down, at the “midstream” stations (A2N0600 and GP00313) is generally stable, and at the “downstream” stations (GP00314 and ZSp) is generally up. These circumstances are interpreted as reflecting the passage of a “slug” of AMD-impacted groundwater through the aquifer. An inspection of **Figure 37** suggests that the introduction of this “slug” occurred in early-2014.

5.2.2.2 Broader Karst Environment

The broader karst environment is defined by the ~26 860 ha footprint of karst strata that underlies the COH property. The quality of groundwater in this environment is adequately described by the hydrochemistry of groundwater discharged by the major karst springs in the COH. These are identified in **Annexure C** together with the most recent water chemistry results associated with each feature. The results are compared to historical values in **Figure 38**. Except for the Zwartkrans Spring, the comparisons reveal the similarity of the recent springwater chemistries with the historical compositions reported by Hobbs (2011).

The Zwartkrans Spring water chemistry shows comparatively little difference between the May 2014 and February 2015 sampling events. Nevertheless, the ~13% increase in SO_4 concentration (from 6.33 to 7.16 meq/L) is in keeping with the rising trend observed at monitoring station GP00314 (**Figure 36**).

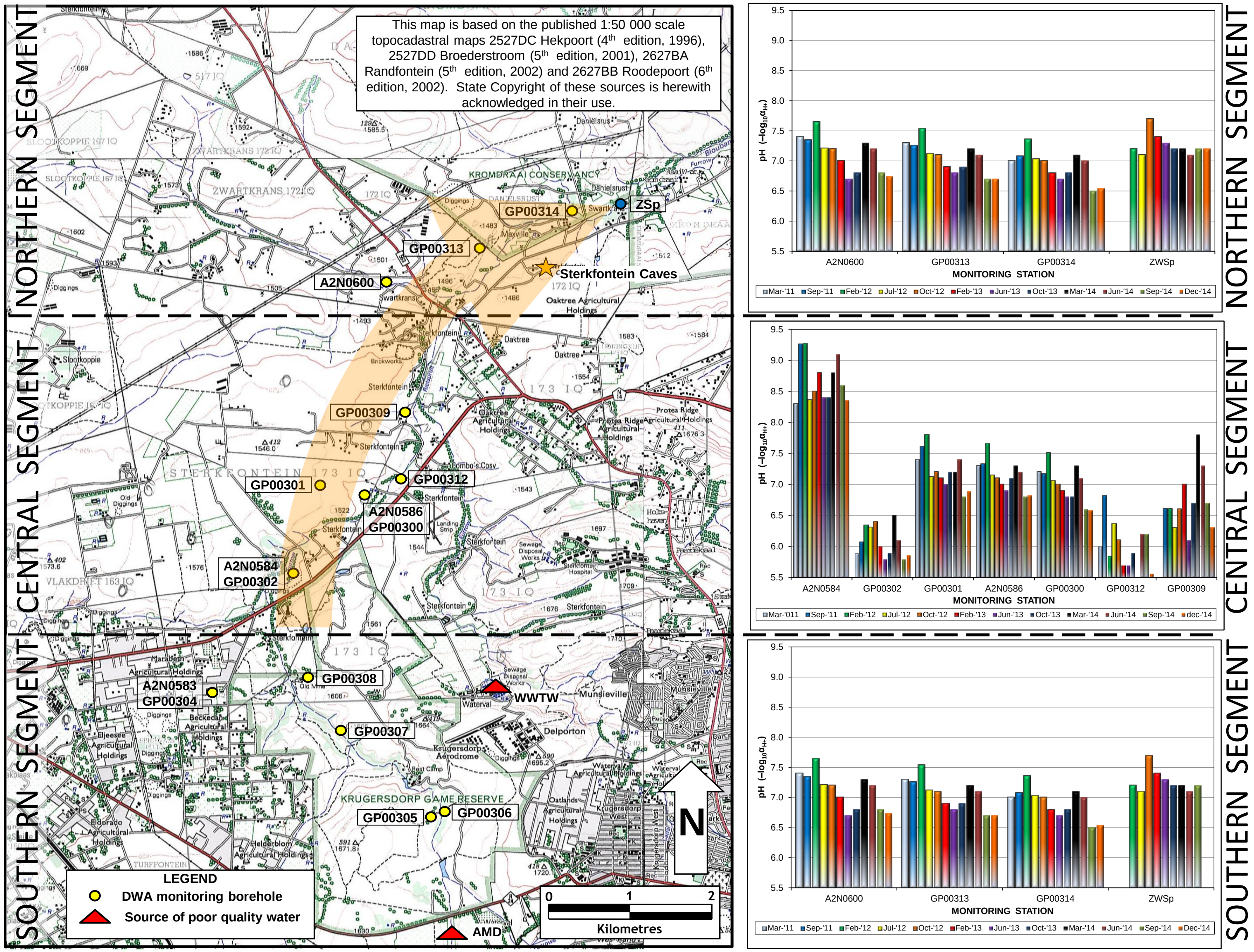
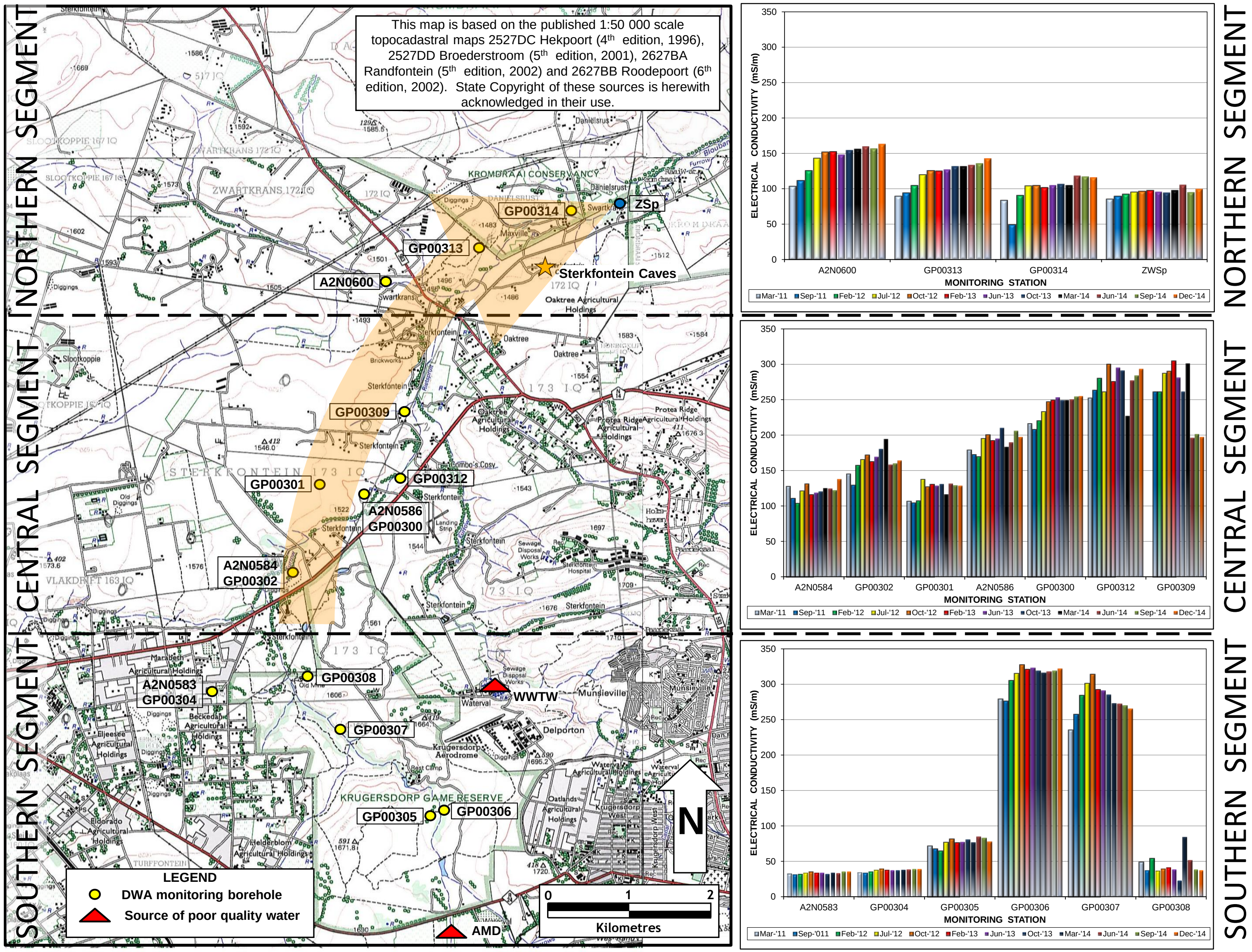


Figure 34 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow



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

Figure 35 Distribution of DWS monitoring boreholes with EC pattern and trend as bar graphs; arrow denotes principal direction of impacted groundwater flow

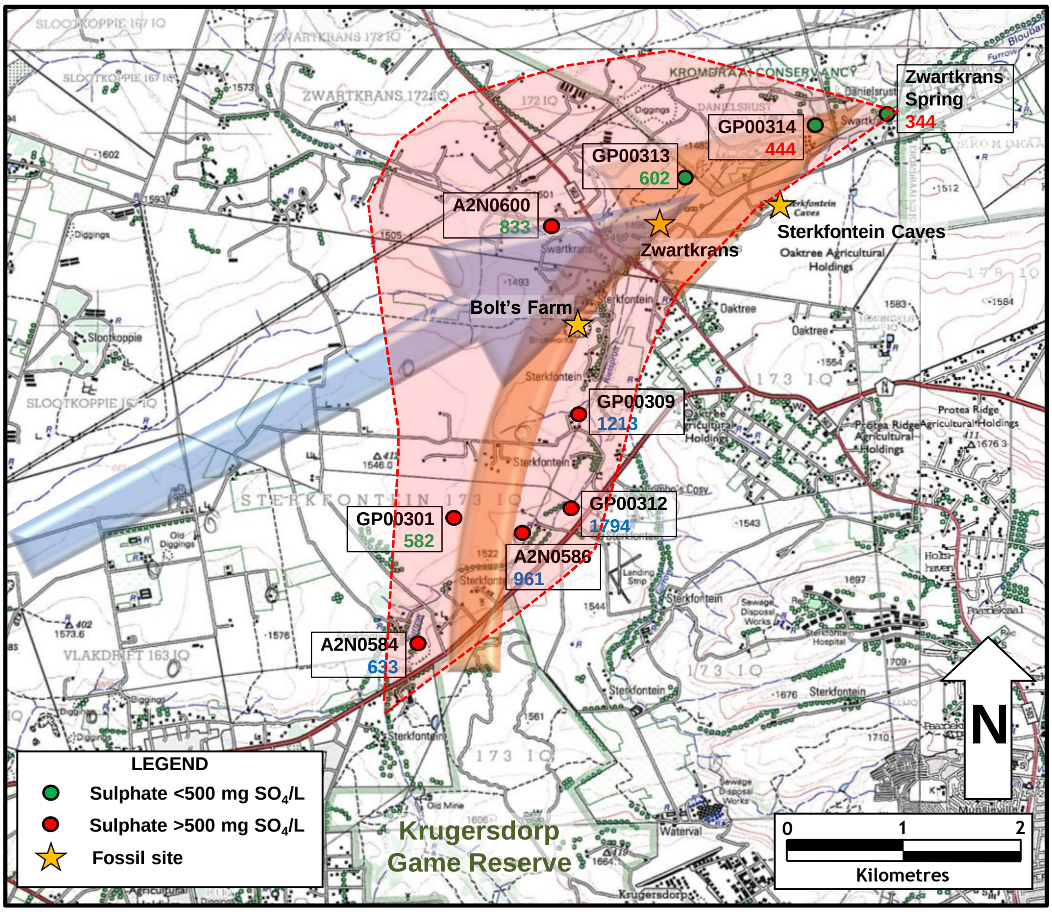


Figure 36 Distribution of SO_4 concentrations in groundwater of the Zwartkrans Compartment in December 2014, also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow), the postulated footprint (shaded area) of a mine water impact in the karst aquifer, and SO_4 trend since September 2014 as UP (red text), STABLE (green text) or DOWN (blue text)

6 HOLISTIC MINE WATER IMPACT APPRAISAL

6.1 Introduction

The appraisal was accomplished by evaluating the discharge and chemical data associated with the DWS gauging stations shown in **Figure 39**. The shortest of these records that defines the period of mutual record for both discharge and chemistry data for all the stations, dates back to the 1979–'80 hydrological year.

The periods of analysis used for comparison are defined as (a) the long-term record ending with the 2008–'09 hydrological year, and (b) the recent record spanning the 2009–'10 to 2013–'14 hydrological years. The reason for this choice of record periods is illustrated in **Figure 25** and **Figure 27**. These figures indicate that the last five hydrological years witnessed a consistently higher SO_4:TDS ratio and SO_4 concentration, respectively, than the pre-2009–'10 values, reflecting a greater impact from mine water discharges rising in the Western Basin.

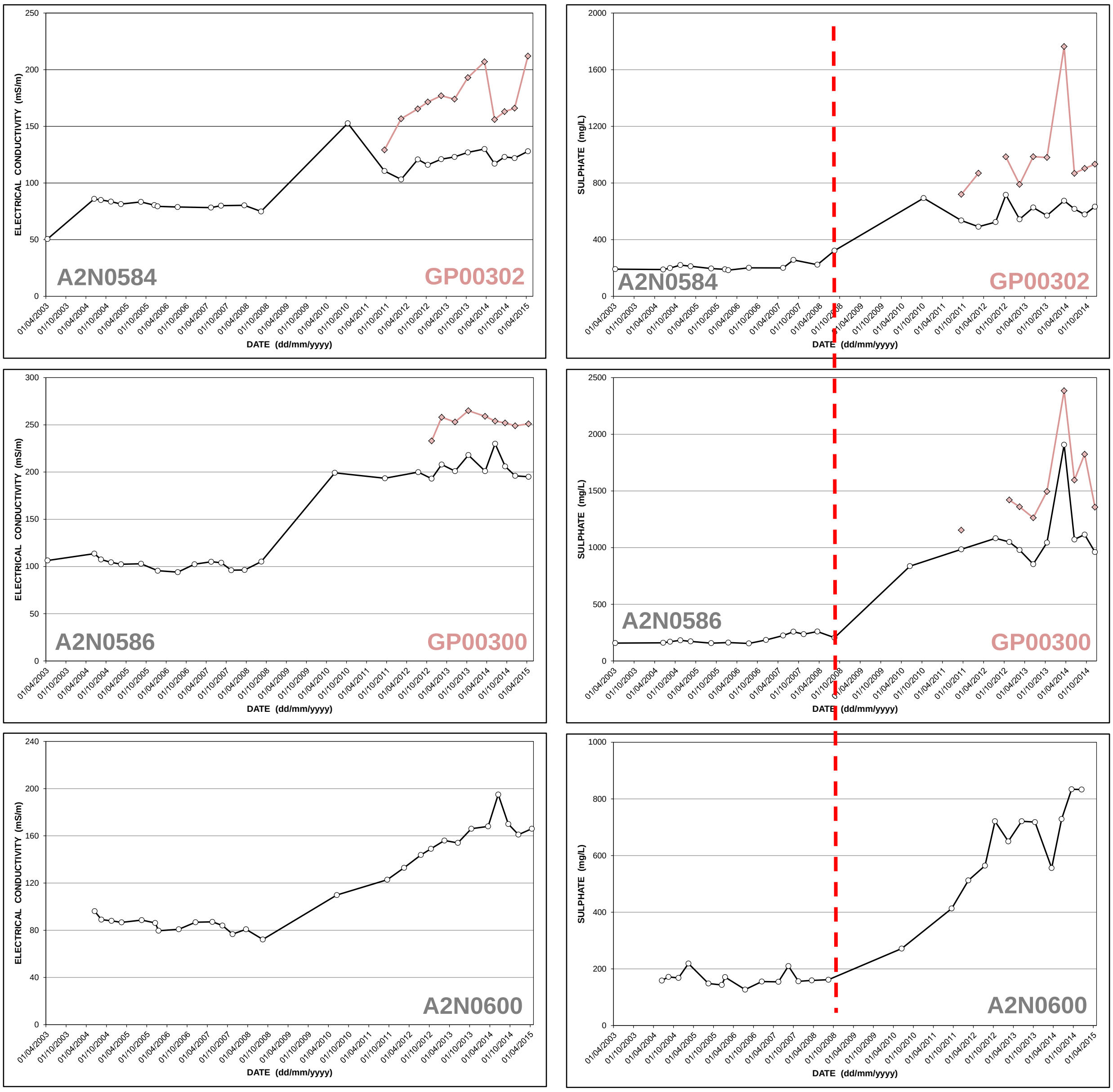


Figure 37 Long-term pattern and trend of EC (left) and SO_4 (right) in karst groundwater from paired DWS monitoring stations A2N0584 / GP00302 and A2N0586 / GP00300, and station A2N0600; note common time scales and postulated commencement of rise in concentrations (vertical pecked line)

6.2 Discharge Dynamics

6.2.1 Surface Water

The appraisal first considers the subregional surface water discharge associated with stations A2H034 (Skeerpoort River), A2H049 (Bloubank Spruit) and A2H050 (upper Crocodile River) in the two periods of record. The results illustrated in **Figure 40** reveal the considerably greater median discharge of ~96 Mm^3/a delivered in the recent period, compared to the ~39 Mm^3/a of the long-term record. Despite the difference in discharge, the Bloubank Spruit contribution is ~51% in both periods.

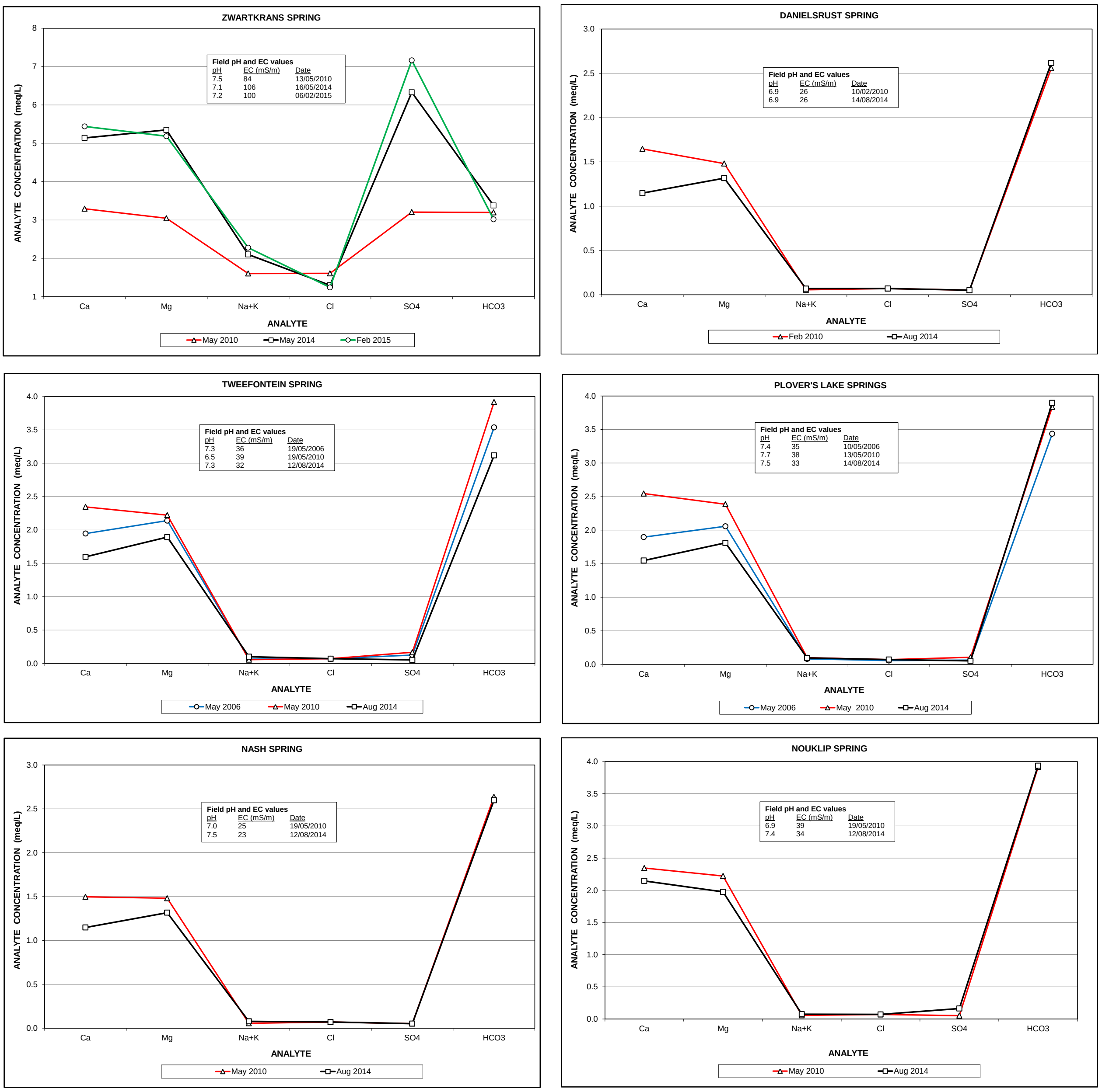


Figure 38 Graphical comparison of recent and historical springwater chemistry in the COH

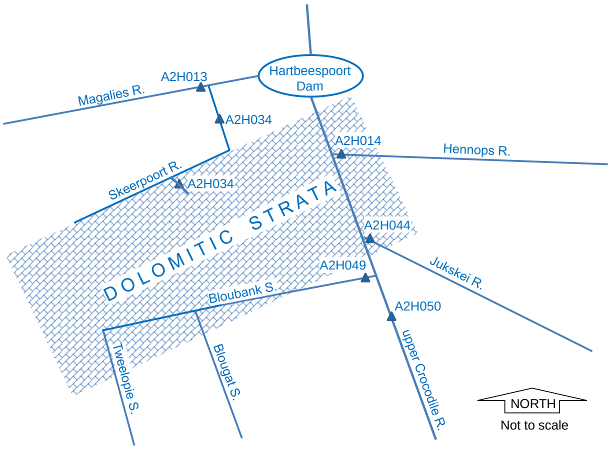


Figure 39 Schematic diagram of surface drainage and gauging network superimposed on karst footprint

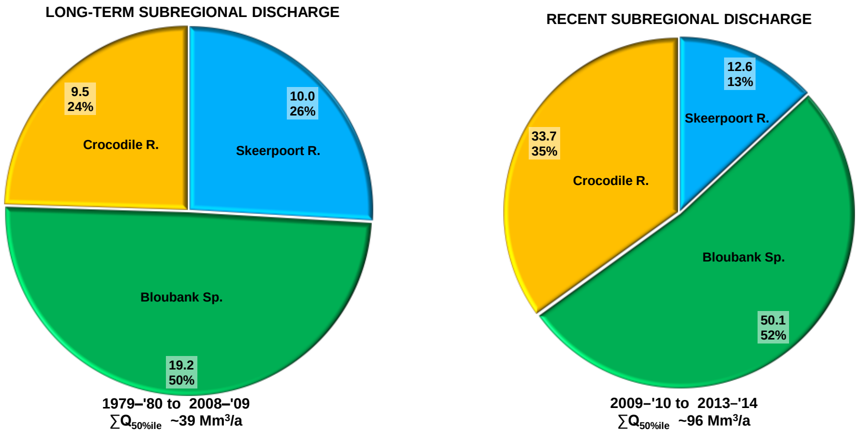


Figure 40 Comparison of long-term and recent subregional discharge

An analysis of the regional surface water discharge in the two periods of record is illustrated in **Figure 41**. The results again reveal the considerably greater median discharge of ~597 Mm^3/a delivered in the recent period, compared to the ~245 Mm^3/a of the long-term record. As in the subregional context described above, the contribution (8%) of the Bloubank Spruit remains similar, an observation that in this instance also applies to all of the regional drainages.

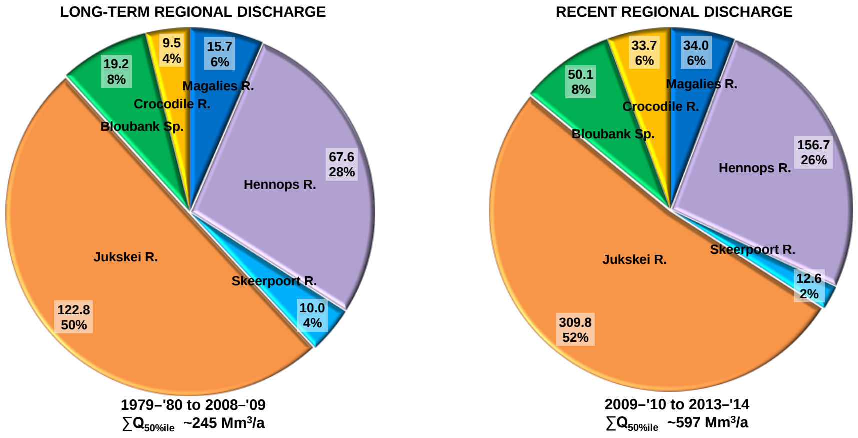


Figure 41 Comparison of long-term and recent regional discharge

6.2.2 Groundwater

The aggregate discharge of major springs contributing to flow in the Bloubank Spruit and Skeerpoort River amounts on average to ~506 L/s (~16 Mm^3/a) and ~361 L/s (~11.4 Mm^3/a) respectively. Together these discharges represent ~14% of the ~190 Mm^3 full supply capacity of Hartbeespoort Dam. A characteristic of springs draining the late Archaean and early Proterozoic carbonate strata of the South African interior is their relatively constant flows. Martini (2006) refers to “very regular discharges at resurgences”. This is in contrast to the ‘flashy’ nature of springs that drain the telogenetic and much younger European karst formations (Florea and Vacher, 2006). This characteristic is attributed to the crucial hydrologic functions and roles played by the epikarst and vadose zone also in the regional karst system in the COH. In this regard, Klimchouk (2004) recognises the retardation of throughflow and mixing of recharge in its often lengthy and tortuous pathway to the aquifer as one of the principal factors.

A possible springwater contribution to the upper Crocodile River discharge was not considered. Although the quartzitic strata of the Witwatersrand Supergroup that form the continental divide are known to support numerous springs, their individual discharges are typically small compared to those draining the Malmani Subgroup dolomitic strata. Further, their discharge is also more variable than that of the much higher-yielding karst springs. This is attributed to a combination of more rapid response to recharge from rainfall and a lower storativity that characterises the mainly fractured host aquifer.

6.3 Total Dissolved Solids Load

6.3.1 Surface Water

An analysis of the subregional TDS loads reveals a recent median value (~120 kilotons per annum or kt/a) that is ~6 times greater than the long-term value (~19 kt/a). Further, that the relative load contributed by the Bloubank Spruit in each period of record is similar, increasing from the long-term 74% to 79% more recently, despite the almost 7-fold increase (from ~14 to ~96 kt/a) in actual load.

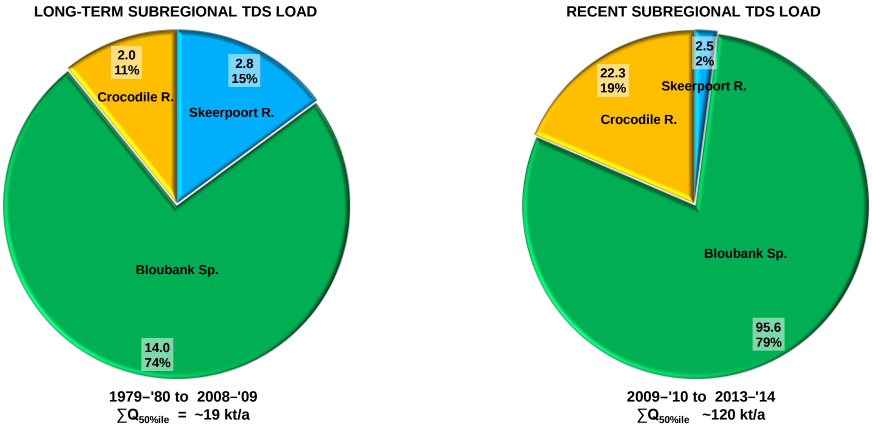


Figure 42 Comparison of long-term and recent subregional TDS load

A different picture emerges when the relative TDS load contributions of each regional drainage in the two periods of record (**Figure 43**) are considered. The dominance of the Jukskei and Hennops rivers in the long-term (77% aggregate contribution) reduces to 60% in the recent period of record. The reduction is balanced primarily by the 16% increase in the load contributed by the Bloubank Spruit.

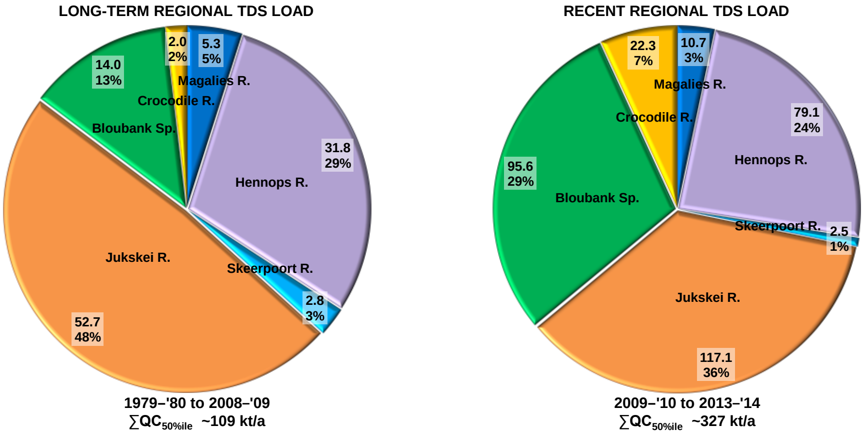


Figure 43 Comparison of long-term and recent regional TDS load

Viewed from another perspective, the roughly 1 to 6 ratio of long-term subregional to regional TDS load reduces to roughly 1 to 3 in the recent period of record. This illustrates the recent significant increase in the subregional contribution driven mainly by that of the Bloubank Spruit system attributable to a mine water impact.

6.3.2 Groundwater

The TDS load contributed by groundwater to the Bloubank Spruit and Skeerpoort River via spring discharges is not subject to significant temporal variations in either median flow or TDS. Although the latter varies from spring to spring, that delivered by each spring is comparatively uniform.

The springs discharging into the Bloubank Spruit deliver an aggregate and relatively constant groundwater-derived TDS load of ~7.8 kt/a to this system, and those discharging into the Skeerpoort River a load of ~3.0 kt/a. The latter is in reasonable agreement with both the long-term and the recent surface water subregional values of ~2.8 kt/a and ~2.5 kt/a (**Figure 42**). This is to be expected from a primarily groundwater-driven surface drainage. Although the ~7.8 kt/a groundwater-derived TDS load of the Bloubank Spruit is not dwarfed by the long-term surface water regional value of ~14 kt/a (**Figure 43**), it certainly is by the recent value of ~95.6 kt/a (**Figure 43**).

6.4 Summary

An analysis of the discharge and water chemistry records associated with the main drainages in the Hartbeespoort Dam catchment for an historical (1979–'80 to 2008–'09) and a recent (2009–'10 to 2013–'14) period of record provides an informative measure of the temporal mine water impact in both a subregional and a regional context. The derivation of a TDS load for each record period and spatial scale reveals an unmistakeable recent mine water impact in a regional context that is much less evident in a subregional context. This is attributed to the contribution of good to excellent quality dolomitic groundwater via high-yielding karst springs that rise on the COH property. Biased in favour of the mine water receiving Bloubank Spruit, this contribution naturally acts to reduce a mine water impact in a subregional context. Its moderating influence at a regional scale is masked by the similar or greater loads contributed by larger drainages than the Bloubank Spruit.

7 OBSERVATIONS AND CONCLUSION

The karst environment of a portion of the Zwartkrans Compartment in the south-western quadrant of the property, which previously reflected a significant deterioration in groundwater quality, shows a slight reduction in SO_4 levels in the "upstream" reaches and an increase in the "downstream" reaches in the December 2014 monitoring results compared to the September 2014 results. These circumstances are interpreted to reflect the passage of an AMD-impacted groundwater "slug" through the aquifer introduced during a short period of uncontrolled mine water discharge in early-2014. Further observations are listed as follows:

- The 2014–'15 wet (summer) season is the driest since 2008–'09, experiencing ~15% less than the next lowest (2011–'12) season. These circumstances have translated into a below average recharge of the mine void, resulting in a reduced mine water discharge (decant) on surface that has assisted in reversing the negative impacts driven by the very wet 2013–'14 summer season.

- The 2013–'14 hydrological year witnessed the third highest runoff (~54 Mm^3) after the 1976–'77 and 2010–'11 hydrological years (66.9 and 59.1 Mm^3 respectively), in the 40-year historical gauging record of Bloubank Spruit system.

- The re-commencement of uncontrolled raw mine water discharge from the mine area in February 2014 triggered a ~6-month period of impact on the downstream receiving hydrologic environment before returning to 'more normal' pre-2010 conditions in the second half of the reporting period. Even this portion of the record, however, is characterised by an erratic pattern of values especially evident in the pH record.

- Faecal coliform counts continue to reflect unacceptably high levels (median of 320 cfu/100 mL) in the lower reaches of the Bloubank Spruit system, highlighting the poor performance of the Percy Stewart Waste Water Treatment Works located further upstream.

- Although long-term groundwater level records indicate that groundwater elevations in the last five years are the highest in the ~30-year period of monitoring, a recent decline has also been observed in the Main Lake water level in Sterkfontein Caves, favouring access along the tourist path through the lower portion of the site.

- A comparison of the TDS load delivered to Hartbeespoort Dam by its major tributaries in the last five hydrological years, with that delivered in the period 1979–'80 to 2008–'09 (which defines the period of negligible mine water impact), reveals an unmistakeable recent mine water impact in a regional context that is much less evident in a subregional context. This is attributed to the contribution of good to excellent quality dolomitic groundwater via high-yielding karst springs that rise on the COH property. Their bias in favour of the mine water receiving Bloubank Spruit naturally acts to reduce a mine water impact in a subregional context, whereas their moderating influence at a regional scale is masked by the similar or greater loads contributed by the larger Jukskei and Hennops rivers.

It is concluded that the water resources monitoring results documented in this report confirm the conceptual hydrophysical and hydrochemical model developed for the COH WHS in the situation assessment report. It has not revealed any major inconsistencies, nor has it exposed significant flaws that might question the water resources monitoring programme as originally formulated.

8 ACKNOWLEDGEMENTS

The compilation of this report would not have been possible without the contribution of DWS field personnel Theo Moolman and Nico de Meillon in the collection of field data. The services of the DWS staff Shouneez Chaka (GeoRequests), Marica Erasmus (Resource Quality Services) and Dioka Masego and Sekgomane Busisiwe (HydstraSupport) in the provision of water resources monitoring data is also recognised and appreciated. The Sibanye Gold staff Basie van der Walt, Chris Steyn and Karen du Plessis are thanked for the provision of monitoring data collected by this mining house. Water quality data collected at the Nedbank Olwazini Estate was kindly provided by Harold Carpenter and Don Cock.

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

DEA, MA and CSIR 2014. *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).* Report to the UNESCO World Heritage Committee. Department of Environmental Affairs, Management Authority and CSIR. December 2014. 12 pp.

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.

DWAF 1996a. *South African Water Quality Guidelines. Volume 5: Agricultural Use : Livestock Watering.* 2nd edition. Department of Water Affairs and Forestry. Pretoria. 163 pp.

DWAF 1996b. *South African Water Quality Guidelines. Volume 2: Recreational Water Use.* 2nd edition. Department of Water Affairs and Forestry. Pretoria. 85 pp.

Florea, L.J and Vacher, H.L. 2006. *Springflow hydrographs: Eogenetic vs. telogenetic karst*. Ground Water. Vol 44. No 3**.** pp 352-361.

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.

Klimchouk, A. 2004. *Towards defining, delimiting and classifying epikarst: Its origin, processes and variants of geomorphic evolution*. Speleogenesis and Evolution of Karst Aquifers. Issue 4. 13 pp. Sourced on 19/12/2012 at http://www.speleogenesis.info/directory/karstbase/pdf/seka_pdf4501.pdf

Martini, J.E.J. 2006. *Karsts and caves*. pp 661–668. In **Johnson, M.R., Anhaeusser, C.R. and Thomas, R.J. (Eds.).** *The Geology of South Africa.* GSSA/CGS, Johannesburg/Pretoria. 691 pp. ISBN: 978-1-919908-77-9

Martini, J., Wipplinger, P.E., Moen, H.F.G. and Keyser, A. 2003. *Contribution to the speleology of Sterkfontein Cave, Gauteng Province, South Africa.* International Journal of Speleology. Vol 32. No 1/4. pp 43–69. Available at http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1223&context=ijs

SANS 2011a. *South African National Standard (SANS) 241-1. Drinking water. Part 1: Microbiological, physical, aesthetic and chemical determinands*. Edition 1. Standards South Africa. Pretoria. 14 pp.

SANS 2011b. *South African National Standard (SANS) 241-2. Drinking water. Part 2: Application of SANS 241-1*. Edition 1. Standards South Africa. Pretoria. 14 pp.

PJHobbs.

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

ANNEXURE A

QUANTIFICATION OF STREAM FLOW LOSS RATE IN THE RIET SPRUIT BETWEEN STATIONS F11S12 AND MRd

Date	Flow @ F11S12 (ML/d)	Flow @ MRd (ML/d)	Flow Loss (ML/d)	Flow Loss Rate(1) (L/s/km)	
09/09/2009	11.9 ± 1.2	0	11.9	35	
22/09/2009	14.9 ± 1.5	0	14.9	44	
05/02/2010	35.2 ± 3.5	7.3 ± 0.4	27.9	83	Period 2
16/02/2010	31.6 ± 3.2	5.7 ± 0.3	25.9	77	
23/02/2010	26.2 ± 2.6	4.0 ± 0.2	22.2	66	
09/03/2010	32.6 ± 3.3	9.4 ± 0.5	23.2	69	
01/04/2010	40.4 ± 4.0	10.3 ± 0.5	30.1	89	
14/04/2010	25.8 ± 2.6	5.7 ± 0.3	20.1	60	
06/05/2010	43.7 ± 4.4	11.7 ± 0.6	32.0	95	
18/05/2010	35.7 ± 3.6	11.0 ± 0.6	24.7	73	
09/06/2010	32.1 ± 3.2	10.5 ± 0.5	21.6	64	
07/07/2010	29.9 ± 3.0	6.2 ± 0.3	23.7	70	
27/07/2010	31.6 ± 3.2	6.5 ± 0.3	25.1	74	
19/08/2010	25.8 ± 2.6	5.3 ± 0.3	20.5	61	
05/10/2010	13.8 ± 1.4	0.4	13.4	40	
19/11/2010	22.2 ± 2.2	3.4 ± 0.2	18.8	56	
27/07/2011	31.9 ± 3.2	19.4 ± 1.0	12.5	Period 3	37
25/08/2011	28.7 ± 2.9	20.0 ± 1.0	8.7		26
05/09/2011	22.5 ± 2.3	15.9 ± 0.8	6.6		20
08/05/2012	21.4 ± 2.1	9.6 ± 0.5	11.9		35
14/08/2012	22.5 ± 2.3	6.8 ± 0.3	15.7		47
21/09/2012	24.6 ± 2.5	15.5 ± 0.8	9.1		27
24/10/2012	16.2 ± 1.6	5.7 ± 0.3	10.5		31
15/01/2013	18.4 ± 1.8	6.4 ± 0.3	12.0		36
14/02/2013	23.0 ± 2.3	7.5 ± 0.4	15.5		46
06/03/2013	20.7 ± 2.1	8.0 ± 04	12.7		38
15/08/2013	30.1 ± 3.0	16.5 ± 0.8	13.6		40
15/10/2013	29.6 ± 3.0	14.1 ± 0.7	15.5		46
12/12/2013	22.2 ± 2.2	4.7 ± 0.2	17.5		52
26/09/2014	41.5 ± 4.2	30.3 ± 1.5	11.2		33
Count	30	30	30	14	14
Minimum	11.9	0.0	6.6	39.8	19.6
Mean	26.9	9.3	17.6	69.8	36.7
Median	26.0	7.4	15.6	69.6	36.4
Maximum	43.7	30.3	32.0	95.0	51.9

(1) Based on a distance of ~3.9 km between localities
Error margin of ±10% at F11S12 and ±5% at MRd

ANNEXURE B

RECORD OF ELECTRICAL CONDUCTIVITY AND pH MEASUREMENTS MADE AT STATIONS F11S12 AND MRd ON THE OCCASION OF FLOW GAUGING MEASUREMENTS (SDMs), ALSO SHOWING DERIVED SO_4 AND TDS CONCENTRATIONS

Date	**Station F11S12**				**Station MRd**			
	EC (mS/m)	**SO_4⁽¹⁾ (mg/L)**	**TDS⁽²⁾ (mg/L)**	**pH ($-\log_{10}\alpha_{H+}$)**	**EC (mS/m)**	**SO_4⁽¹⁾ (mg/L)**	**TDS⁽²⁾ (mg/L)**	**pH ($-\log_{10}\alpha_{H+}$)**
22/09/2009	322	2 089	2 479	6.7				
05/02/2010	389	2 586	2 997	3.9	358	2 358	2 759	4.1
16/02/2010	339	2 215	2 610	4.2	335	2 186	2 581	4.2
23/02/2010	379	2 510	2 918	4.1	383	2 538	2 948	3.9
09/03/2010	379	2 510	2 918	4.1	353	2 320	2 720	4.0
01/04/2010	374	2 472	2 878	3.6	358	2 358	2 759	3.4
14/04/2010	358	2 355	2 757	3.7	347	2 274	2 672	3.6
06/05/2010	408	2 724	3 142	3.2	420	2 813	3 234	3.3
18/05/2010	335	2 185	2 580	5.5	356	2 340	2 741	4.4
09/06/2010	370	2 444	2 849	4.4	373	2 466	2 872	4.5
07/07/2010	374	2 473	2 880	4.0	376	2 488	2 895	3.9
27/07/2010	407	2 717	3 134	3.7	395	2 628	3 042	4.1
19/08/2010	384	2 547	2 957	2.6	335	2 185	2 580	2.7
05/10/2010	307	1 979	2 364	3.0	383	2 540	2 949	2.5
19/10/2010	314	2 030	2 418	3.6	326	2 119	2 510	3.1
19/11/2010	338	2 207	2 603	2.8	333	2 171	2 564	2.8
18/12/2010	416	2 783	3 203	2.7	376	2 488	2 895	3.0
27/07/2011	369	2 436	2 841	2.7	373	2 466	2 872	2.9
25/08/2011	389	2 584	2 995	2.9	405	2 702	3 119	2.5
05/09/2011	362	2 385	2 787	2.6	367	2 421	2 826	2.6
08/05/2012	372	2 458	2 864	2.6	388	2 576	2 988	2.9
14/08/2012	299	1 920	2 302	6.3	309	1 993	2 379	4.2
21/09/2012	290	1 853	2 233	7.6	288	1 838	2 218	6.9
24/10/2012	264	1 661	2 033	4.3	270	1 706	2 079	3.8
15/01/2013	282	1 794	2 171	6.6	283	1 802	2 179	4.9
14/02/2013	274	1 735	2 110	7.0	277	1 757	2 133	6.4
06/03/2013	244	1 514	1 879	6.9	241	1 492	1 856	6.6
15/08/2013	219	1 329	1 686	7.1	219	1 329	1 686	6.6
15/10/2013	275	1 743	2 118	6.6	274	1 735	2 110	6.2
12/12/2013	236	1 455	1 817	6.6	231	1 418	1 779	6.6
26/09/2014	238	1 469	1 833	7.3	238	1 469	1 833	6.0
Count	31	31	31	31	30	30	30	30
Minimum	219	1 329	1 686	2.6	219	1 329	1 686	2.5
Mean	332	2 167	2 560	4.6	332	2 1660	2 559	4.2
Median	339	2 215	2 610	4.1	350	2 297	2 696	4.4
Maximum	416	2 783	3 203	7.6	420	2 813	3 234	6.9

(1) $SO_4 = 7.38*EC - 287$ to derive a theoretical representative SO_4 value
(2) EC * 7.7 to derive a theoretical representative TDS value

ANNEXURE C

RECENT WATER CHEMISTRY ASSOCIATED WITH THE MAJOR KARST SPRINGS IN THE CRADLE OF HUMANKIND

Variable/analyte	**Unit**	**Spring**						
		Zwartkrans	**Danielsrust**	**Plover's Lake**	**Kromdraai**	**Tweefontein**	**Nouklip**	**Nash**
Date	dd/mm/yyyy	06/02/2015	14/08/2014	14/08/2014	20/08/2014	12/08/2014	12/08/2014	12/08/2014
Temperature	°C	19.1	19.6	20.1	19.4	20.5	21.4	21.3
Electrical conductivity	mS/m	99.8	22.6	32.6	54.1	31.9	34.3	22.8
pH	$-\log_{10}\alpha_{H+}$	7.2	7.4	7.5	7.1	7.3	7.4	7.5
Eh	mV	–25.0	–60.0	–61.0	–42.1	–61.5	–61.4	–69.3
ORP	mV	–13.5	–17.1	–20.3	–10.6	–16.9	–20.1	–22.0
Calcium	mg Ca/L	109	23	31	68	32	43	23
Magnesium	mg Mg/L	63	16	22	32	23	24	16
Sodium	mg Na/L	51	1.3	1.9	23	1.6	1.4	1.5
Potassium	mg K/L	2.3	<1	<1	1.9	1.2	<1	<1
Chloride	mg Cl/L	44	<5	<5	29	<5	<5	<5
Sulphate	mg SO_4/L	344	<5	<5	127	<5	7.8	<5
Total alkalinity	mg $CaCO_3$/L	151	131	195	159	156	197	130
Fluoride	mg F/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Nitrate + nitrite	mg N/L	9.2	0.29	0.3	3.9	7.7	5.6	0.41
Ortho-phosphate	mg PO4/L)	—	<0.2	<0.2	<0.2	0.27	0.5	0.27
Silica	mg Si/L	5.8	5.2	5.8	5.7	4.8	4.9	5
Iron (total)	mg Fe/L	<0.02	<0.02	<0.02	0.049	<0.02	0.022	<0.02
Manganese (total)	mg Mn/L	<0.005	<0.005	<0.005	0.16	0.006	<0.005	<0.005