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 TO SEPTEMBER 2014

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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 area. The outcome of this project was captured 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 status reports. This report represents the 5th such report. It expands on the 4th status report, which covers the full-term period April 2013 to March 2014, by covering the mid-term monitoring period April to September 2014.

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 a wastewater impact. The outcome of monitoring activities as documented in this report consolidates the conceptual hydrophysical and hydrochemical model developed for the property in the situation assessment report. This has not revealed any major inconsistencies, nor has it exposed significant flaws that might call into question the scope of the water resources monitoring programme as originally formulated. The monitoring data and results reveal the following responses in the water resources environment.

- The exceptional rainfall in late summer of the 2013–'14 wet season explains the resumption of uncontrolled mine water discharge from the mine area in late-February 2014 similar to conditions that prevailed through the 2009–'10 and 2010–'11 wet seasons. The increased capacity of the mine water treatment plant to ~34 ML/d in mid-2013 was insufficient to contain and treat the volume of mine water issuing from the flooded underground mine workings following recharge.

- The instantaneous flow data record generated at the downstream end of the Bloubank Spruit system reveals the exceptionally high discharge experienced in February and March 2014. The latter is the 3rd highest in the 42-year gauging record for this catchment, and the 2013–'14 hydrological year has witnessed the 4th highest annual discharge after the 1977–'78, 2010–'11 and 2011–'12 hydrological years.

- The resumption of uncontrolled mine water discharge from the mine area in late-February 2014 was arrested in late-July 2014. This is evidenced in the recovery of surface water quality in the downstream reach of the Tweelopie Spruit to pre-March 2014 values which had resulted in the recovery of aquatic biota at the lower end of the Tweelopie Spruit.

- A single set of synoptic discharge measurements (SDMs) at two stations in the lower reach of the Riet Spruit confirmed historical results regarding losses of mine water impacted surface water to the karst aquifer of the Zwartkrans Compartment. The high discharge regime in the period March 2014 to July 2014 precluded the execution of SDMs.

- The impact of allogenic recharge from the losing reach of the Riet Spruit to the karst aquifer of the Zwartkrans Compartment is unequivocally mapped on the basis of elevated salinity and sulphate values in the groundwater. An earlier provisional assessment that forecast arrival of the 'contamination peak' at the Zwartkrans Spring by the end of 2013 has been shown to be early by three months. It has also subsequently been influenced by the resumption of raw mine water discharge from the mine area in late-February 2014.

- The water level of the Main Lake in Sterkfontein Caves reflects minor fluctuations (<0.5 m) in the elevation range 1 439 to 1 439.5 m amsl since late-2010. Representing the ambient groundwater

level elevation, it is expected to maintain this elevation as a result of both the greater sustained discharge of treated/neutralised mine water associated with the immediate and short-term mine water control and management interventions in the Western Basin, and the above-average groundwater recharge resulting from the exceptional precipitation experienced in February and March 2014. Congruence of the water table elevation with that of the channel of the Bloubank Spruit opposite the caves indicates that the Main Lake water level is unlikely to rise above this elevation.

- The quality of the Main Lake water in Sterkfontein Caves continues to reflect a muted influence from surface water impacted by mine water. The May 2014 electrical conductivity (EC) of 69 mS/m exhibits a small (~5%) increase over the August 2012 value of 66 mS/m. Nevertheless, a ~62% increase in the SO_4 concentration of the cave water from 78 to 126 mg/L in the same period reflects the influence of poorer quality surface water on the cave water. This observation alone is sufficient to warrant the vigilance of monitoring the cave water chemistry.

- The May 2014 EC (105 mS/m) and SO_4 (304 mg/L) levels of the Zwartkrans Spring water reflect modest increases of ~9% and ~21%, respectively, over the October 2013 values of 96 mS/m and 295 mg SO_4/L.

- The marginal location of Sterkfontein Caves in the karst hydrosystem remains the most plausible explanation for the muted impact exhibited by the cave water chemistry compared to that of the springwater.

- The municipal wastewater effluent discharged from the Percy Stewart Wastewater Treatment Works continues to manifest an unacceptable bacteriological quality in the downstream receiving reaches of the Bloubank Spruit system.

- The quality of the groundwater discharged by the high-yielding (individually >20 L/s) karst springs on the property has remained essentially unchanged from historical qualities, and exemplifies the original assessment that the majority of these sources will never experience a negative impact from the mine water source.

In conclusion, it is evident from the monitoring data and results that the karst environment of a portion of the Zwartkrans Compartment in the south-western quadrant of the COH WHS has experienced a significant deterioration in groundwater quality. Sulphate levels of as much as ~1 900 mg SO_4/L will definitely impact on the potability of groundwater-based water supplies in the area affected. The resumption of uncontrolled raw mine water discharge in late-February 2014 through to late-July 2014 has reversed the gradual improvement observed in the downstream water resources. The medium-term impact of this ‘event’ particularly on the groundwater resources, remains to be established.

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

SYMBOLS, ACRONYMS AND 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
DWA	Department of Water Affairs (formerly DWAF; Department of Water Affairs and Forestry)
DWS	Department of Water and Sanitation (formerly DWA; Department of Water Affairs)
EC	electrical conductivity
G1	Gold 1
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
RU/G1	Rand Uranium/Gold 1
SD	standard deviation
SDM	synoptic discharge measurement
TCTA	Trans-Caledon Tunnel Authority
t/d	ton(s) per day
TDS	total dissolved solids
WWTW	wastewater treatment works

1 INTRODUCTION, BACKGROUND AND 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). Subsequent monitoring activities have generated new data and additional insight that are documented in biannual reports (Hobbs, 2012; 2013a; 2013b; 2014). This document represents the fifth such report, which expands on the full-term monitoring report for the period April 2013 to March 2014 (Hobbs, 2014) by covering the mid-term period April to September 2014.

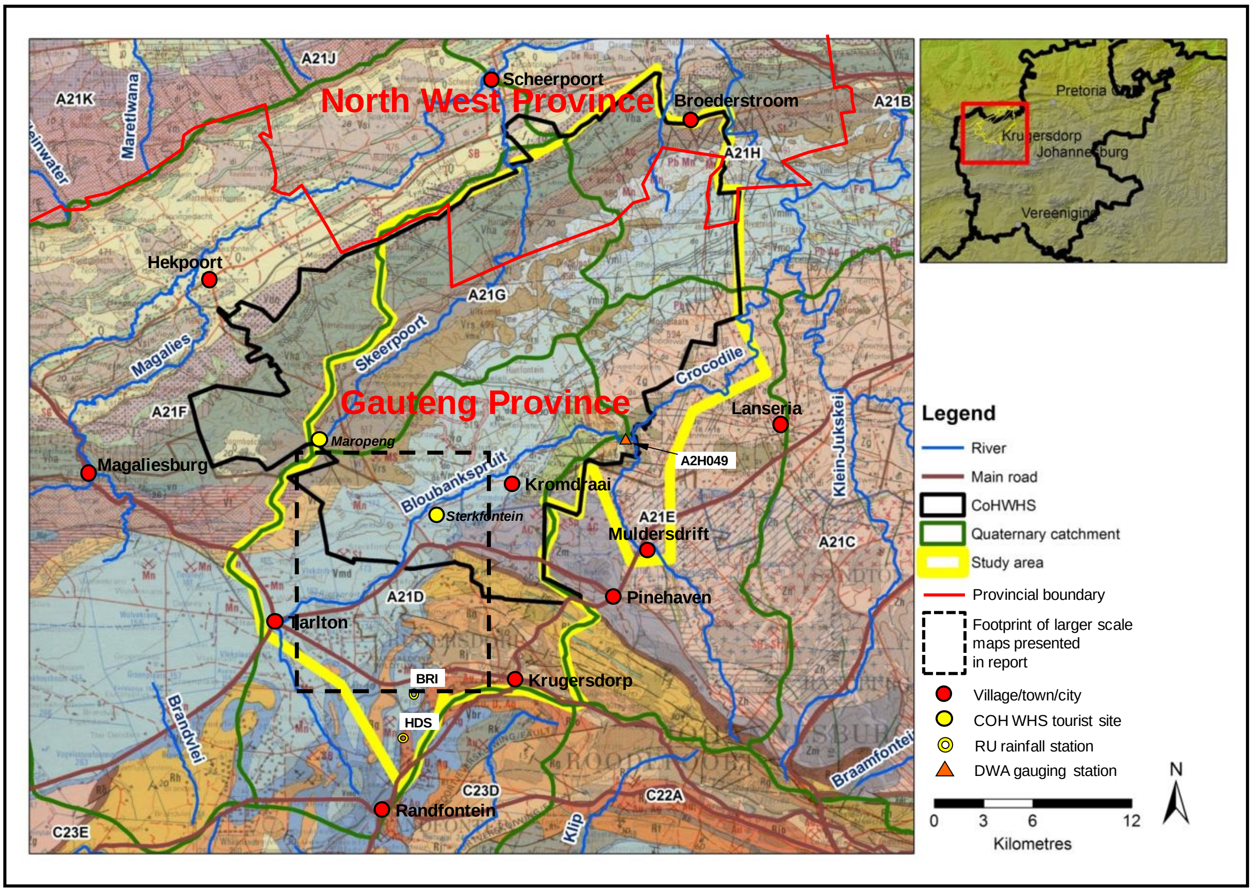


Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

2 TIMELINE OF KEY EVENTS

It is appropriate to contextualise the material presented and discussed in this report in terms of a timeline of key events. The timeline presented in **Figure 2** is an update of that presented in the previous biannual monitoring report (Hobbs, 2014).

The most recent landmark event on the timeline is the containment of uncontrolled mine water decant in late-July 2014. This follows a ~5-month period, commencing end-February 2014, during which both raw and treated/neutralised mine water was discharged into the environment following exceptionally heavy late summer rains (**Section 3**).

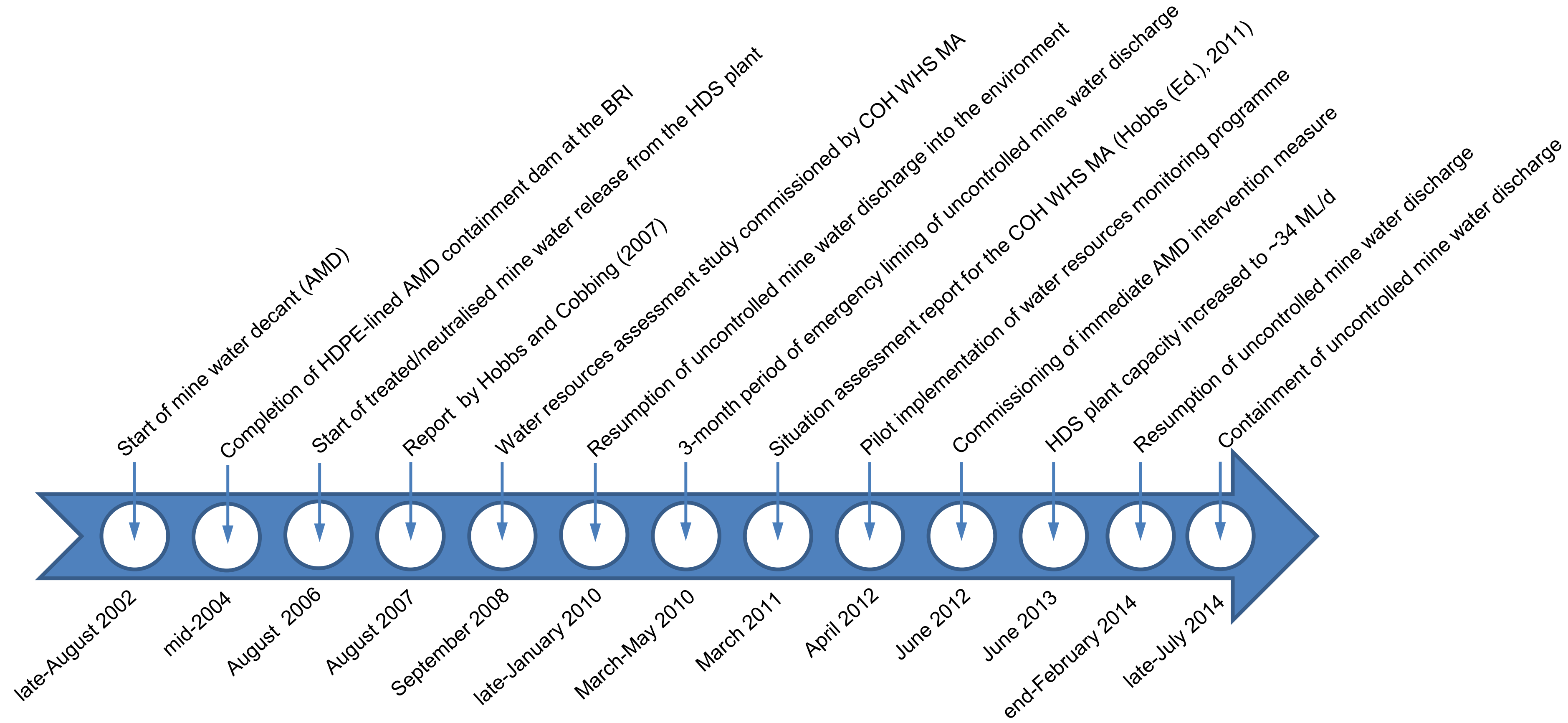


Figure 2 Updated timeline of events relevant to this report

3 RAINFALL

The monthly precipitation record for the period October 2008 to September 2014 of the SibanyeGold (formerly Gold 1) rainfall station HDS (**Figure 3**) reveals the wetter than normal 2010–'11 and 2013–'14 summer rainfall seasons (**Figure 4**). The rainfall data also confirm previous observations (Hobbs, 2013b; 2014) that monthly rainfall to the north of the continental divide (e.g. at Sterkfontein Caves) is generally ~12–14% 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 at the Sterkfontein Caves gauging station operated and maintained by the DWS. An analysis of the common monthly rainfall record (n = 51) for the HDS and Sterkfontein Caves stations indicates a good correlation ($R^2 = 0.90$) (**Figure 5**).

Of particular significance is the similarity reflected by the 2010–'11 and 2013–'14 wet season records (**Figure 4**). Some 52% of the 2013–'14 summer rainfall at Sterkfontein Caves (396/760 mm) and the HDS plant (413/799 mm), occurred in February and March of 2014. These circumstances explain the resumption of uncontrolled mine water discharge from the mine area in late-February 2014 similar to the situation that prevailed through the 2009–'10 and 2010–'11 wet seasons (Hobbs, 2013a; 2013b). The increased capacity of the mine water treatment plant to ~34 ML/d in June 2013 (**Figure 2**) remained insufficient to contain and treat the volume of mine water issuing from the flooded underground mine workings following significant ingress-related recharge.

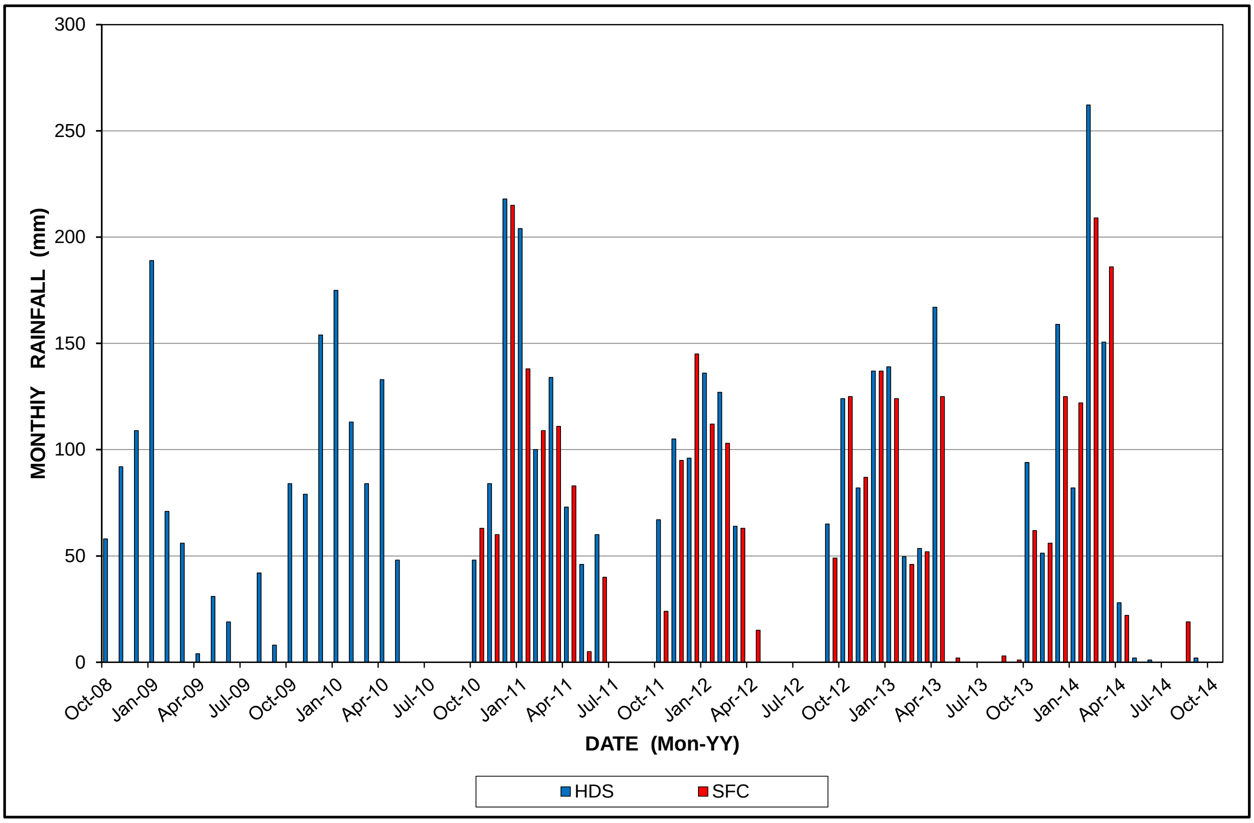


Figure 3 Monthly precipitation at the SibanyeGold rainfall monitoring station HDS in the period October 2008 to September 2014, also showing the available record for the Sterkfontein Caves station

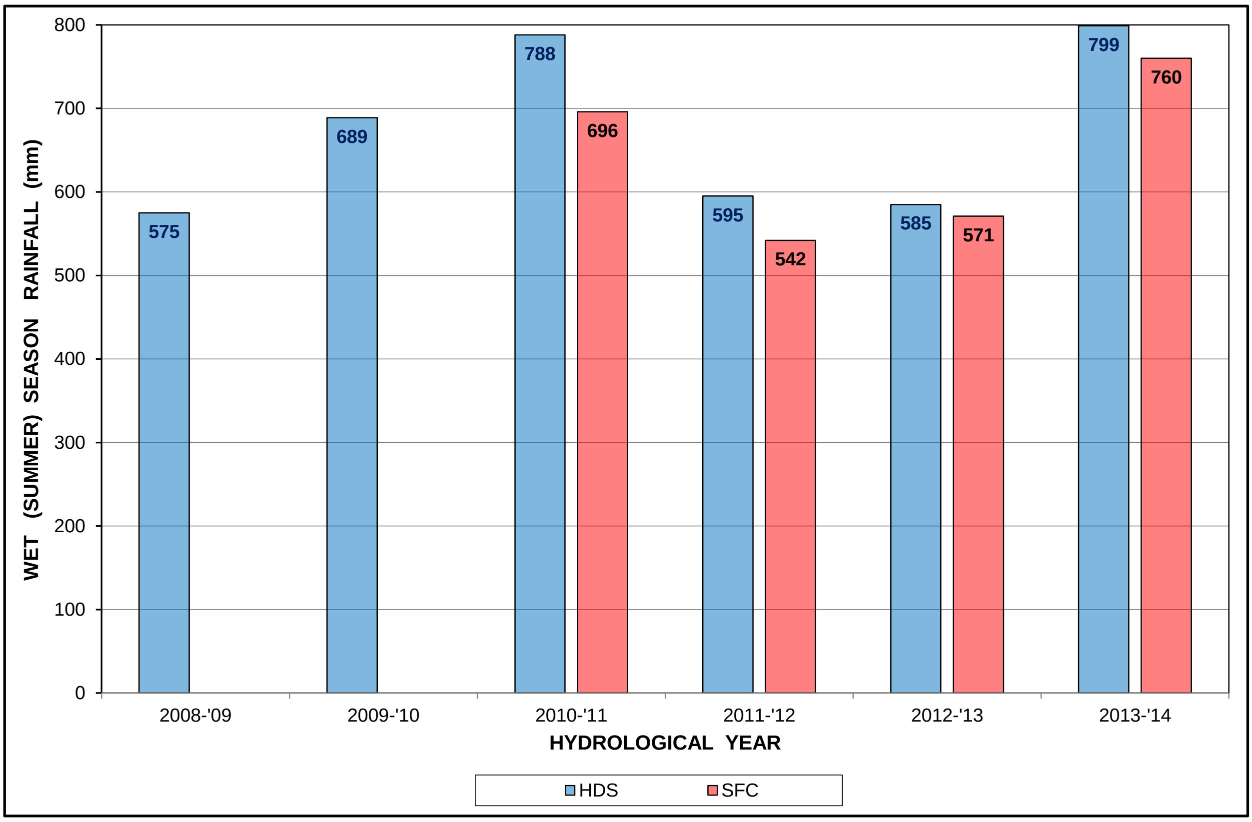


Figure 4 Total wet season (summer) rainfall at the HDS facility in the past six hydrological years, also showing the comparison with that for the available Sterkfontein Caves record

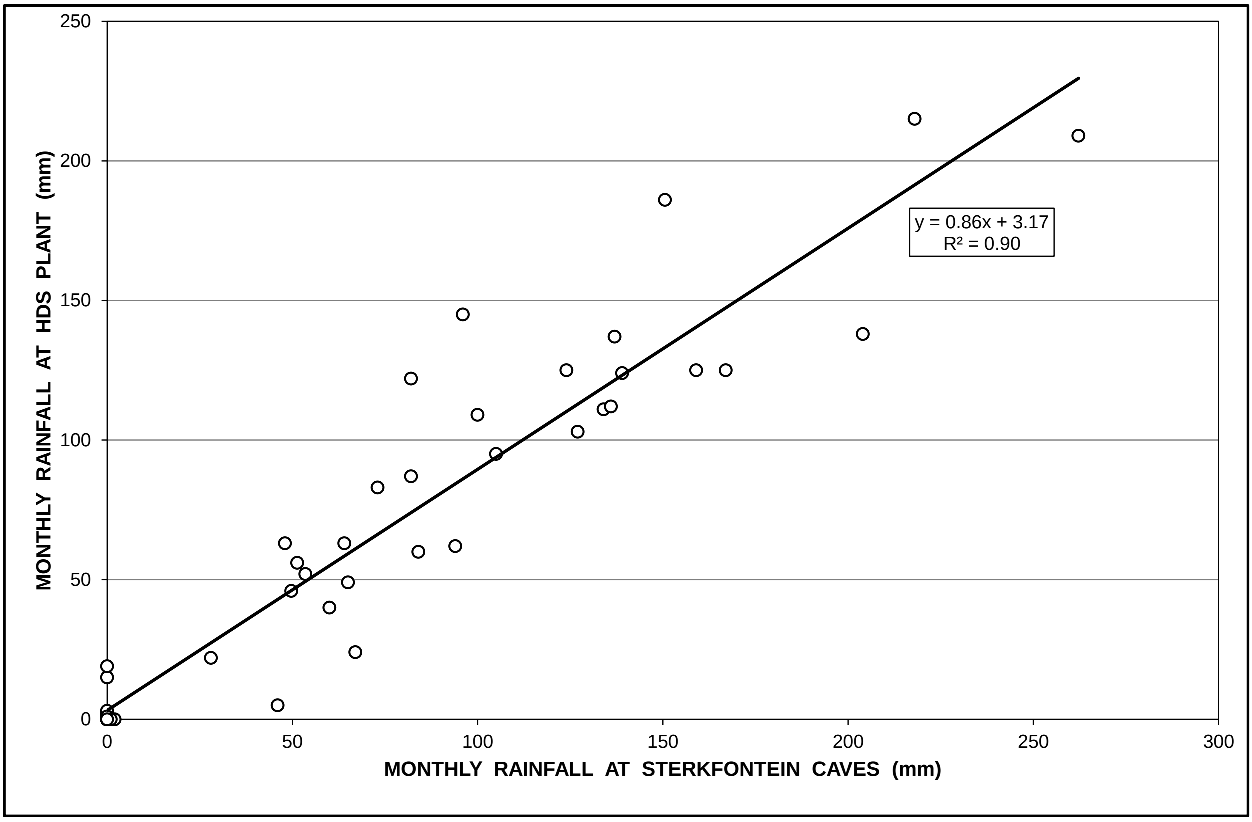


Figure 5 Correlation of monthly rainfall at Sterkfontein Caves with that at the HDS facility in the mine area

4 SURFACE WATER HYDROLOGY

4.1 Physical Hydrology

4.1.1 Catchment Discharge

The discharge of the Bloubank Spruit system (quaternary catchment A21D) is gauged by the DWS at station A2H049 located ~700 m before its confluence with the Crocodile River (**Figure 1**). The >40-year record 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 September 2014

Variable	**Month**											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	40	40	41	41	42	42	42	41	42	42	40	40
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	0.845	1.040	1.097	0.897	1.040	1.179	0.980	0.952	0.956	0.910	0.798
Mean	1.809	1.810	2.223	2.680	2.647	2.964	2.390	2.245	2.057	2.024	1.850	1.726
Median	1.546	1.710	1.884	2.409	1.949	2.461	1.953	1.800	1.721	1.639	1.555	1.386
95%ile	3.882	2.872	4.539	5.460	6.472	8.265	5.513	4.926	4.201	4.127	3.645	3.511
Maximum	4.211	4.577	5.900	12.079	10.619	11.100	6.081	5.373	5.166	4.754	4.055	4.342
SD	0.914	0.783	1.106	1.980	1.961	2.241	1.328	1.220	0.993	0.945	0.821	0.857
CoV (%)	50.5	43.3	49.8	73.9	74.1	75.6	55.5	54.4	48.2	46.7	44.4	49.6

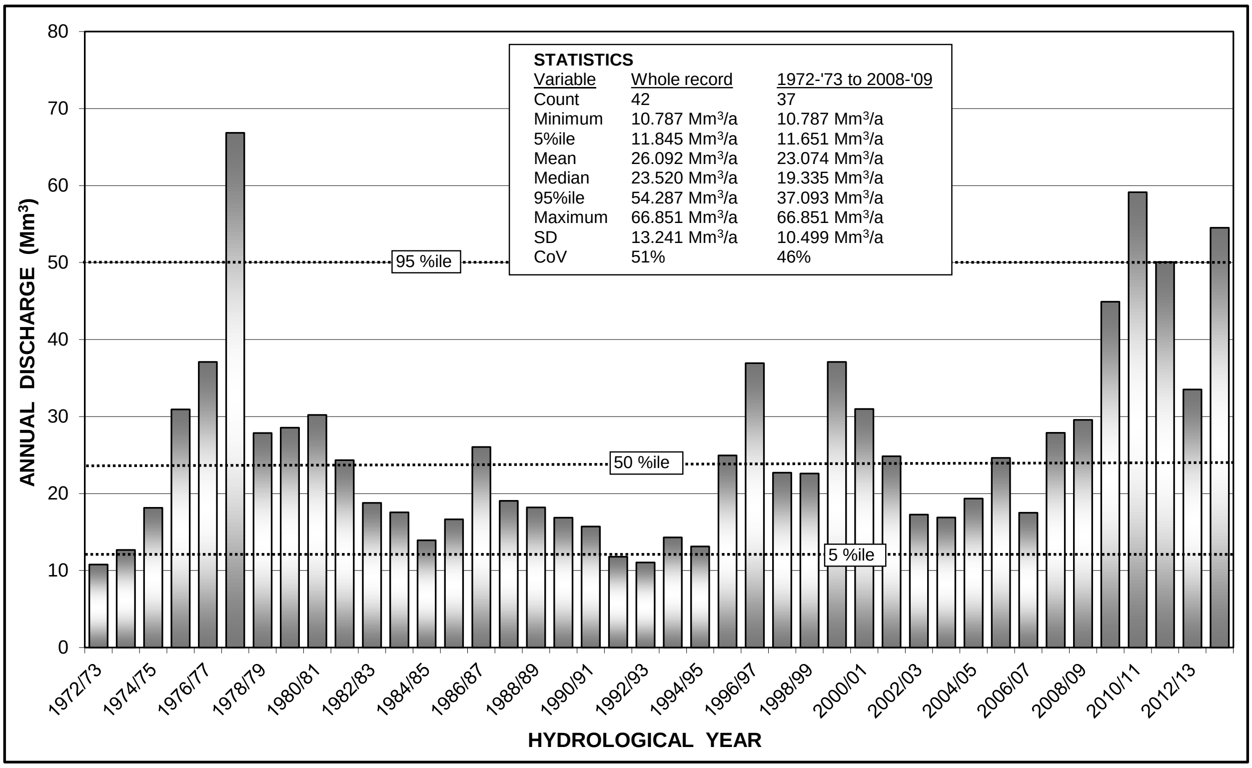
All units are Mm^3 unless otherwise indicated.

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

The discharge per hydrological year (a_h) illustrated in **Figure 6** indicates that four of the last five hydrological years experienced the 2nd, 3rd, 4th and 5th highest runoff of 59.1, 54.5, 47.0 and 44.9 Mm^3 after the 66.9 Mm^3 of the 1977–'78 hydrological year, in the historical gauging record of this catchment.

The instantaneous monthly flow pattern at station A2H049 for the complete record October 1972 to September 2014 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 record generated at station A2H049 (**Figure 7**) reveals the exceptionally high discharge experienced in March 2014. At ~4.2 m^3/s, this is the 3rd highest in the historical record for this station after January and February 1978, and reflects the abnormally wet 2013–'14 summer (**Figure 4**) experienced regionally. These circumstances are also evidenced in the resumption of uncontrolled mine water discharge from the mine area in late-February 2014.



STATISTICS

Variable	Whole record	1972-'73 to 2008-'09
Count	42	37
Minimum	10.787 Mm³/a	10.787 Mm³/a
5%ile	11.845 Mm³/a	11.651 Mm³/a
Mean	26.092 Mm³/a	23.074 Mm³/a
Median	23.520 Mm³/a	19.335 Mm³/a
95%ile	54.287 Mm³/a	37.093 Mm³/a
Maximum	66.851 Mm³/a	66.851 Mm³/a
SD	13.241 Mm³/a	10.499 Mm³/a
CoV	51%	46%

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

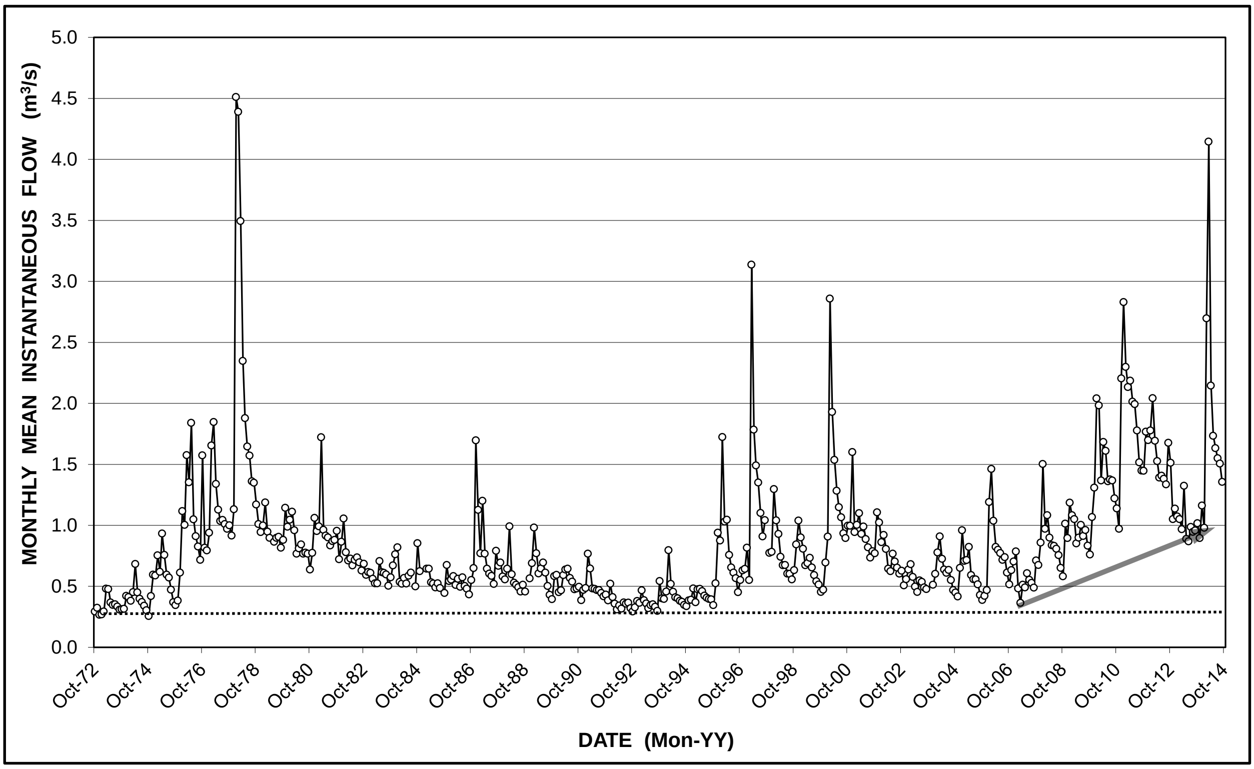


Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to September 2014

4.1.2 Surface Water Fluxes

Previous biannual monitoring reports (Hobbs, 2012; 2013a; 2013b and 2014) have presented the results of numerous in-stream synoptic discharge measurements (SDMs) made at stations F11S12 and MRd (**Figure 10**). These measurements have quantified the magnitude of surface water loss to the karst aquifer of the Zwartkrans Compartment in the form of allogenic recharge.

The SDM data presented in Annexure A indicate that the second-to-last such measurement was made on 12 December 2013. The resumption of uncontrolled raw mine water discharge in late-February 2014 generated high discharge conditions in the receiving Tweelopie Spruit and Riet Spruit drainages. These conditions militated against SDMs at stations F11S12 and MRd in much of the reporting period relevant to this report. The high discharge conditions resulted in severe erosion of the gravel road crossing the culverts at station MRd. Repair of this damage has included the installation of an additional four culverts (**Plate 1**) that has further complicated the execution of SDMs at this location.

Despite the above circumstances, a SDM on 26 September 2014 supports the historical SDM results. The complete record (**Annexure A**) provides the results illustrated in **Figure 8** and **Figure 9**. These indicate that the circumstances described by the comprehensive historical record have not changed materially in the course of the reporting period relevant to this report. This is evidenced by the observation that the flow loss rate of 33 L/s/km (11.2 ML/d) associated with the most recent SDM is similar to the median loss rate of ~35 L/s/km (11.8 ML/d) associated with Period 3 of the historical record. Additionally, the correlation coefficient associated with the Period 3 data has improved from the R^2 = 0.81 associated with this period as reported for the previous reporting period (see Figure 10 in Hobbs, 2014), to R^2 = 0.88 as shown in **Figure 9**.

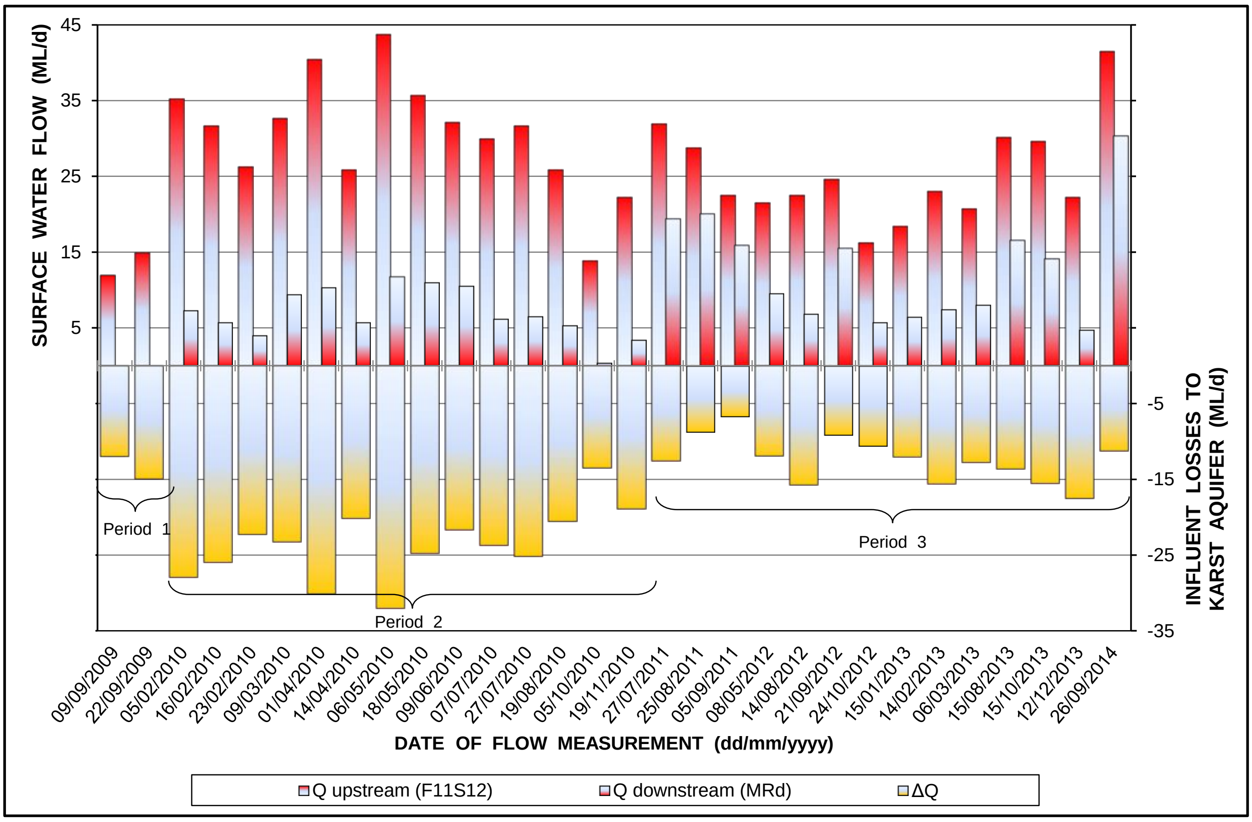


Figure 8 Graph of stream flow and losses to the karst aquifer in the lower Riet Spruit valley

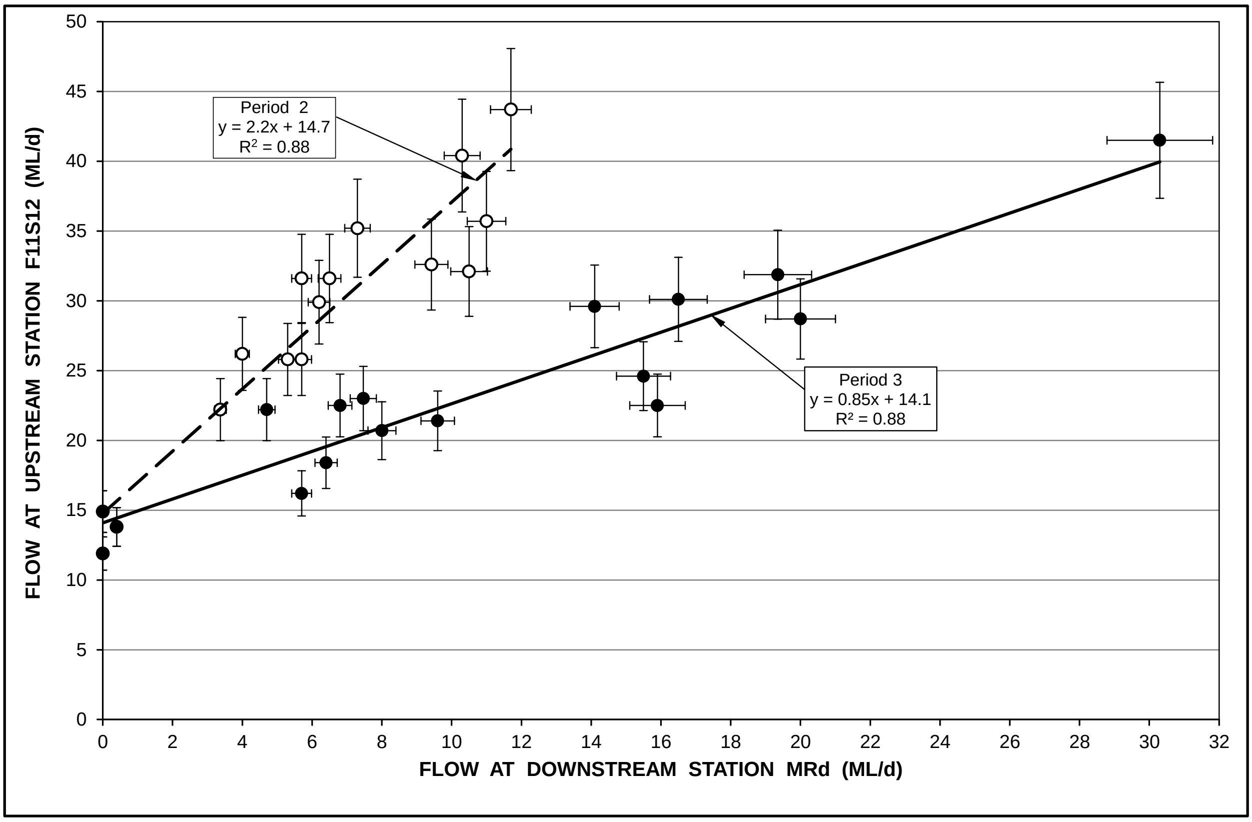
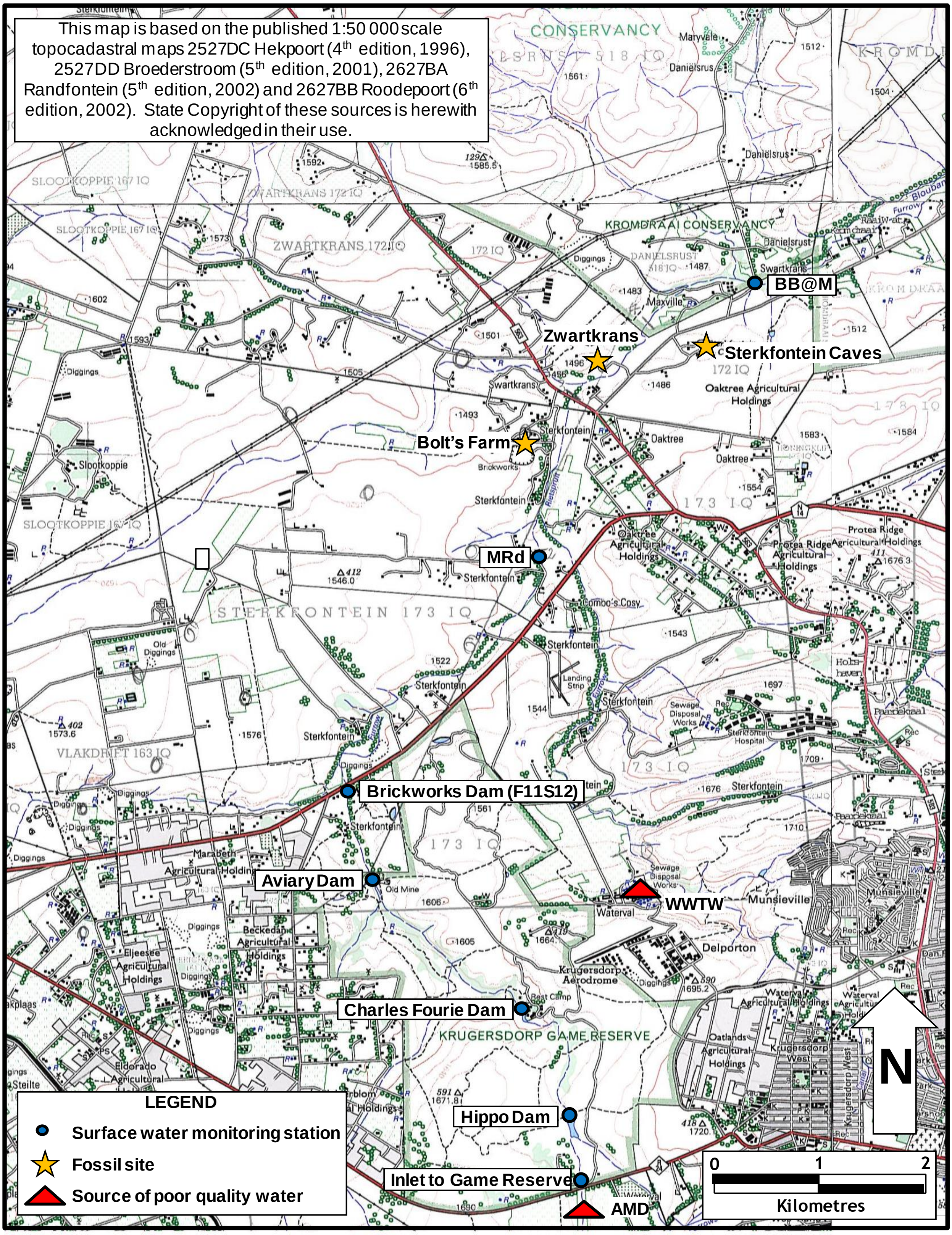


Figure 9 Correlation of stream flow at stations F11S12 and MRd in the Riet Spruit valley (respective regression lines explained in text and **Figure 8**), with error bars denoting ±10% at F11S12 (vertical) and ±5% at MRd (horizontal)

Plate 1 View of the four new culverts constructed at station MRd to accommodate high discharge conditions in the Riet Spruit arising from uncontrolled mine water discharges via the Tweelopie Spruit; the original culvert is at far left of view (photo Phil Hobbs, date 26/09/2014)



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

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

4.2 Chemical Hydrology

4.2.1 Tweelopie Spruit and Riet Spruit

The chemistry of surface water in the Tweelopie Spruit is monitored by SibanyeGold (formerly Gold 1) 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 10** 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 (DWS station F11S12). The weekly monitoring of the variables pH, electrical conductivity (EC) and 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) and **Figure 13** (SO_4).

The patterns revealed in these graphs indicate the variation and trend in the respective variable values that are manifested in surface water chemistry through the KGR over time. It is clear from **Figure 11**, and to a lesser degree from **Figure 12** and **Figure 13**, that the most severe and sustained impact of mine water on the receiving surface water environment of the Tweelopie Spruit that commenced in February 2010 (period B–C), was mitigated in the period C–D by the commissioning in June 2012 of the immediate mine water management and control measures. This is unequivocally shown in the somewhat shorter record of Fe (**Figure 14**) and Mn (**Figure 15**) values. The more recent context illustrated in **Figure 11** to **Figure 15** is the resumption of uncontrolled mine water discharge since late-February 2014 and, significantly, the containment of this situation by late-July 2014. The recovery to pre-March 2014 water quality conditions in the Tweelopie Spruit has been maintained to compilation of this report.

A scrutiny of the differences between the four periods of record (A–B, B–C, C–D and D–) defined by the divisions recognised in **Figure 11** to **Figure 15**, returns the information presented in **Table 2** and illustrated in **Figure 16**. The similar vertical scales for the two sets of graphs in **Figure 16** facilitates a direct comparison of the data between the two stations. The graphs not only illustrate the differences, most notably the ‘poorer’ values in the B–C and D– periods of more severe mine water impact, but also reveal other salient aspects such as

- the generally greater variability in analyte concentrations at the upstream Hippo Dam station compared to the F11S12 station,
- the typically lower analyte concentrations at the downstream F11S12 station compared to the Hippo Dam station, and
- the slightly lower analyte median values associated with period D– compared with period B–C, suggesting a lesser mine water quality impact on the receiving environment especially in regard to Fe and Mn in the most recent period of uncontrolled raw mine water discharge.

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[1] These data are excluded due to their close proximity to the Hippo Dam, 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] The Charles Fourie Dam is excluded because its data is not mundane to the assessment presented in this report, and because most readers are not concerned with how much data is evaluated, but whether the data speaks to the specific agenda of the individual reader.

[3] The Aviary Dam is excluded due to the excellent congruence with values obtained at the Brickworks Dam.

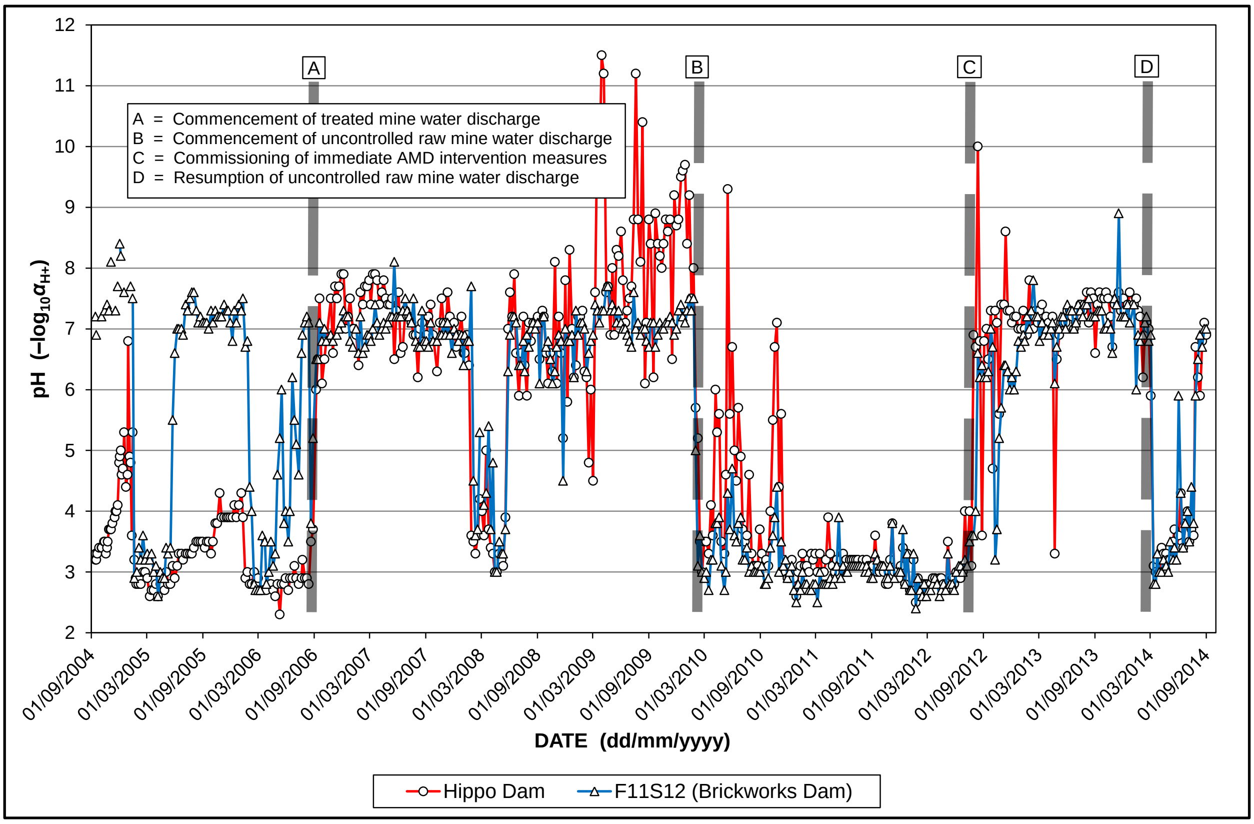


Figure 11 Pattern of pH values in the Tweelopie Spruit in the period September 2004 to September 2014

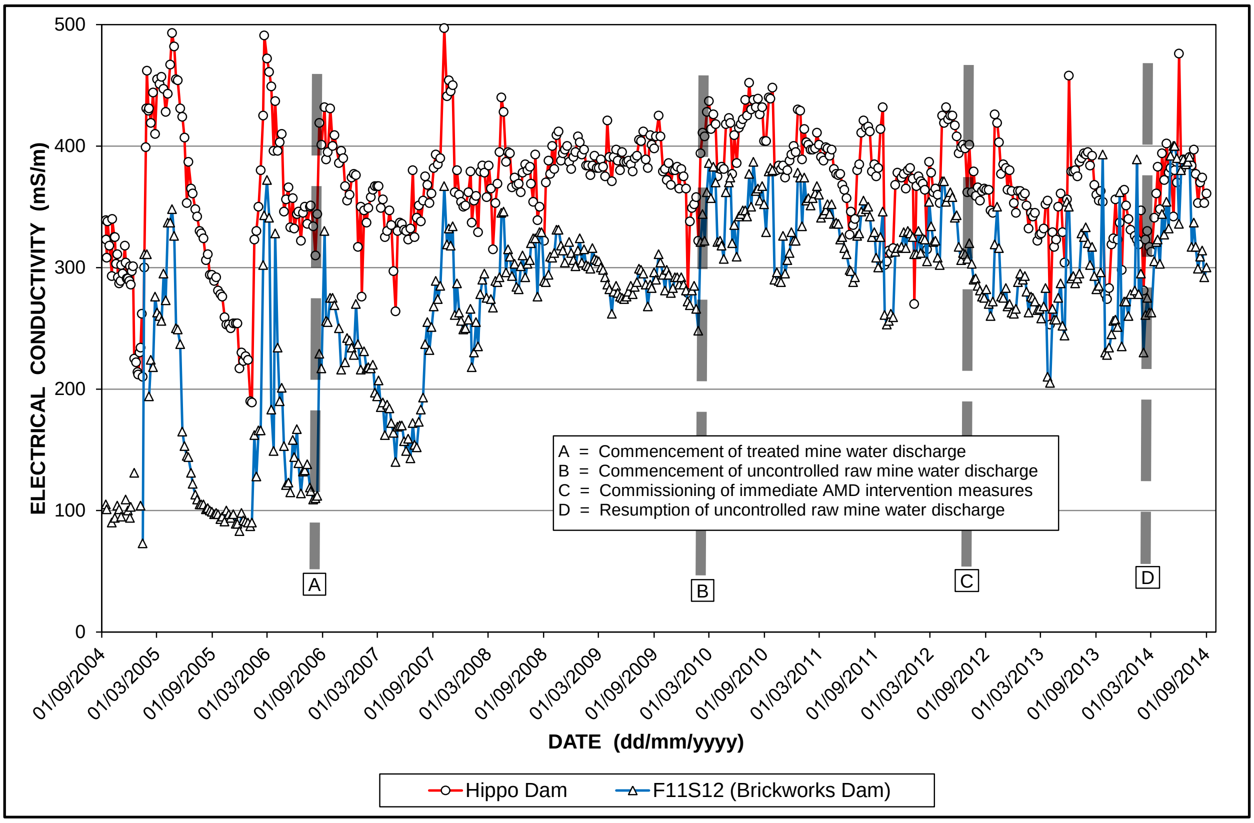


Figure 12 Pattern of electrical conductivity values in the Tweelopie Spruit in the period September 2004 to September 2014

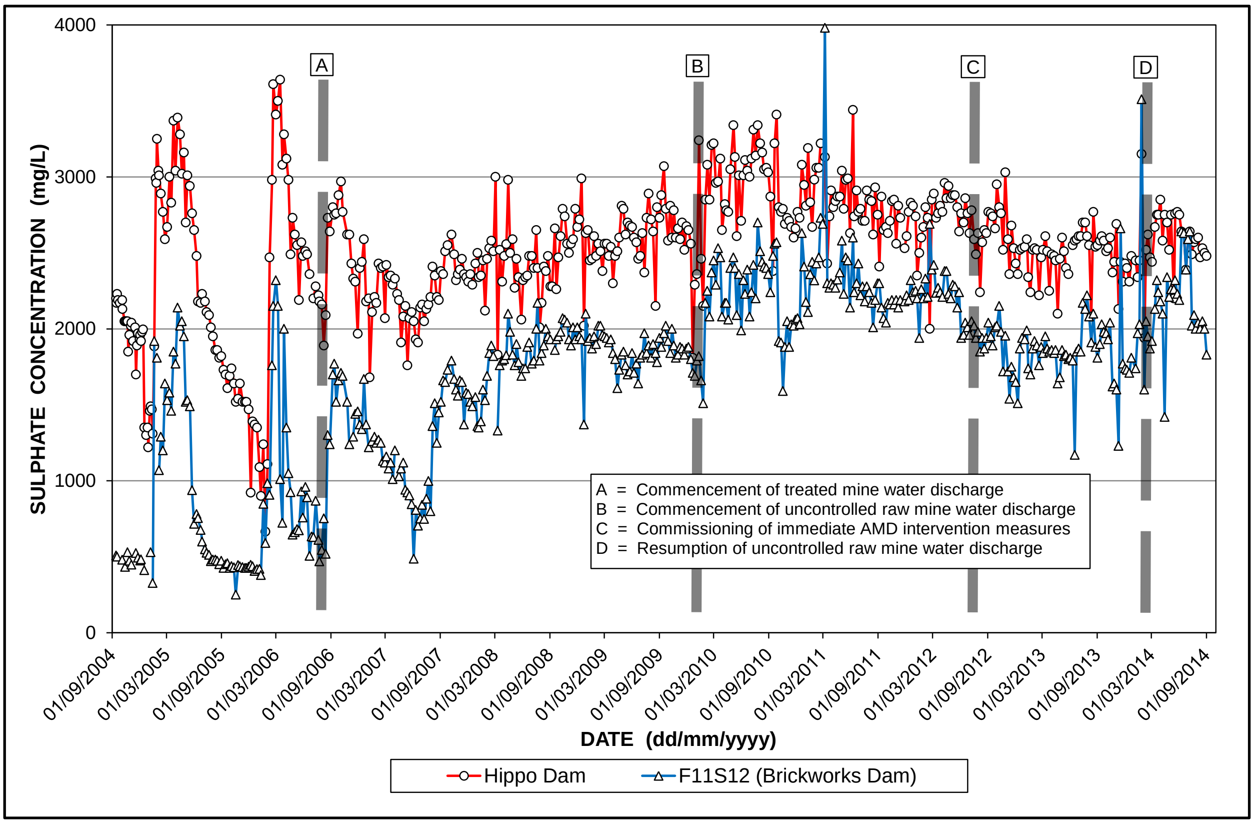


Figure 13 Pattern of SO_4 values in the Tweelopie Spruit in the period September 2004 to September 2014

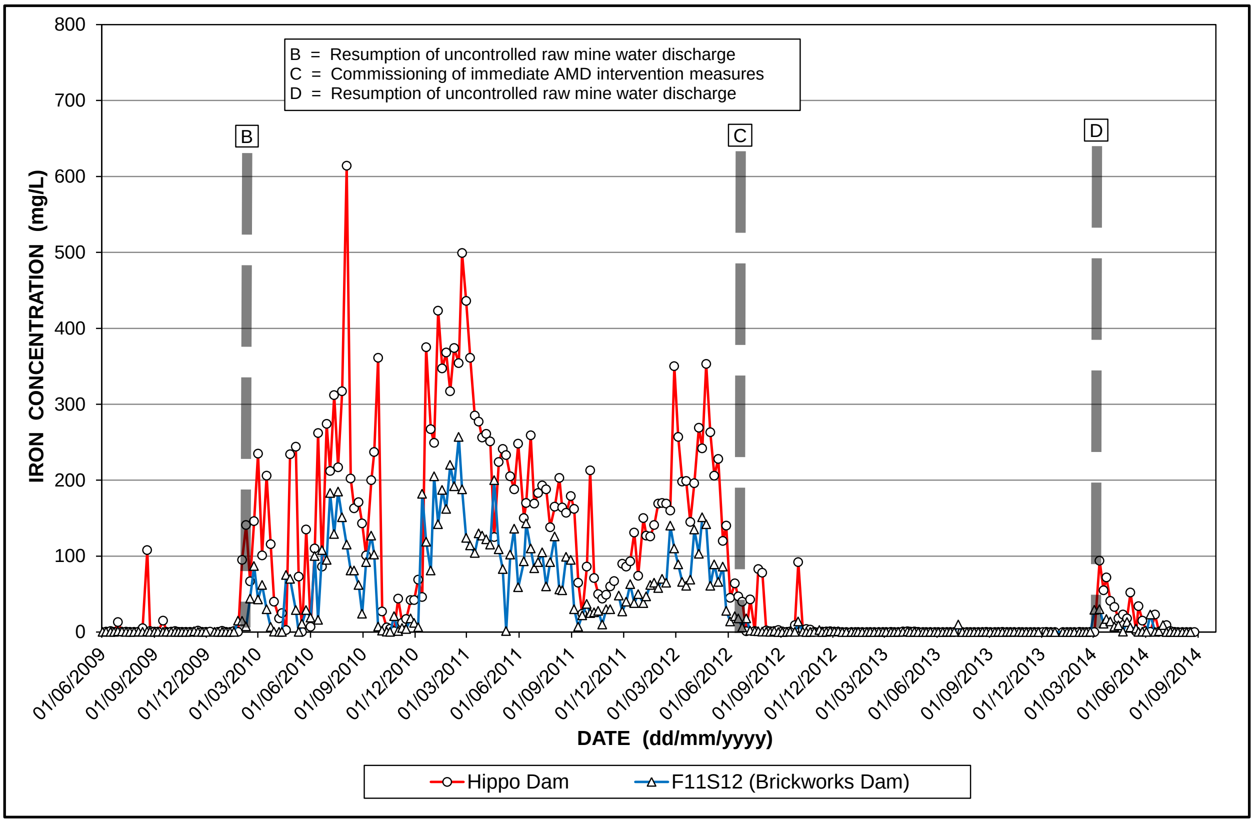


Figure 14 Pattern of Fe values in the Tweelopie Spruit in the period June 2009 to September 2014

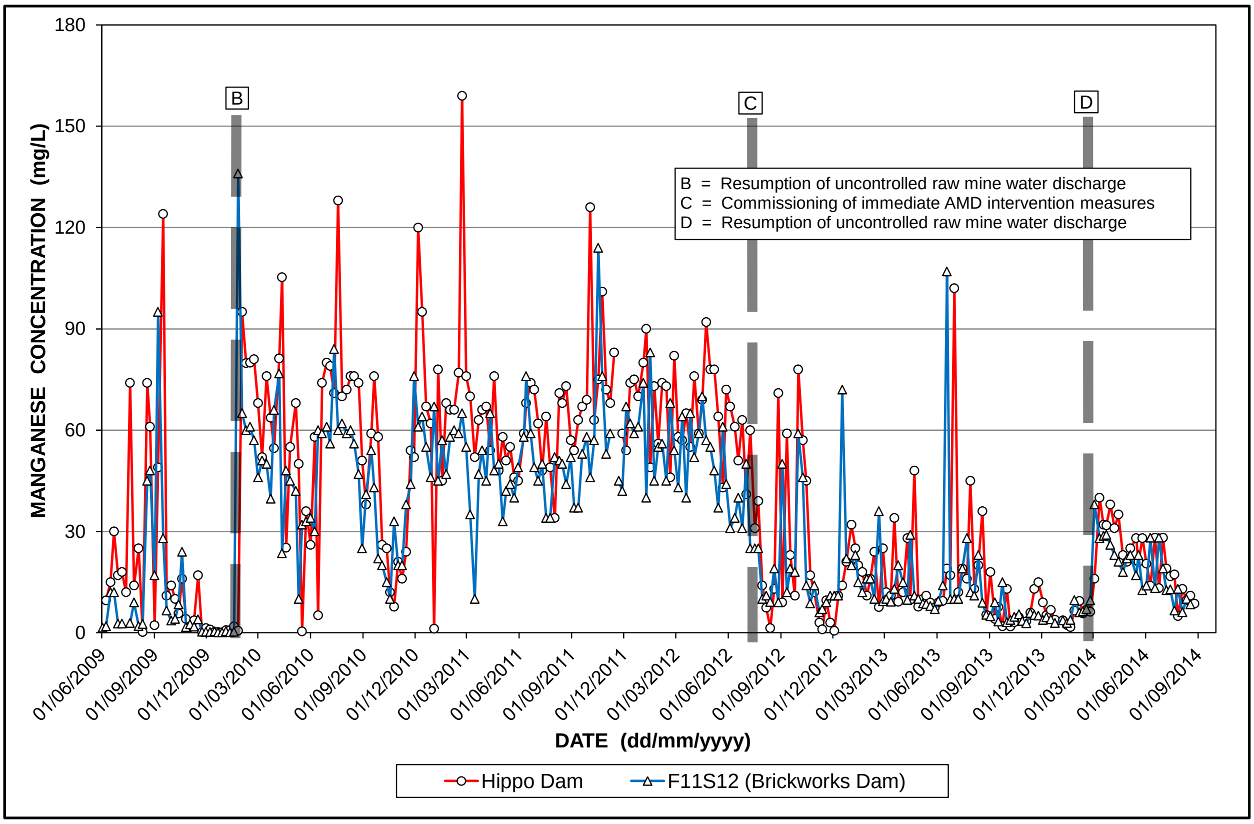


Figure 15 Pattern of Mn values in the Tweelopie Spruit in the period June 2009 to September 2014

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 $(-\log_{10}\alpha_{H+})$	n	175	129	83	20	173	128	83	20
	5%ile	3.6	2.8	5.9	3.0	3.9	2.7	5.3	2.8
	Mean	—	—	—	—	—	—	—	—
	Median	7.2	3.2	7.2	3.4	6.9	3.0	7.0	3.4
	95%ile	9.3	5.7	7.6	4.0	7.4	3.9	7.4	4.5
EC (mS/m)	n	174	129	83	20	172	128	83	20
	5%ile	324	320	285	342	167	288	230	305
	Mean	374	391	350	382	268	332	281	356
	Median	379	393	354	383	283	330	276	349
	95%ile	426	438	395	406	329	378	350	400
SO_4 (mg/L)	n	175	128	82	20	171	128	83	20
	5%ile	2 017	2 511	2 221	2 381	893	1 947	1 600	1 990
	Mean	2 445	2 846	2 520	2 638	1 636	2 264	1 879	2 260
	Median	2 460	2 815	2 525	2 655	1 760	2 240	1 870	2 250
	95%ile	2 810	3 220	2 770	2 774	2 015	2 593	2 148	2 640
Fe (mg/L)	n	33	129	83	20	33	128	82	20
	5%ile	0.1	6.5	0.004	0.2	0.1	1.2	0.006	0.1
	Mean	4.7	168.4	2.490	24.6	0.3	72.9	0.466	8.8
	Median	0.4	163.0	0.030	18.0	0.2	64.0	0.075	6.7
	95%ile	13.8	365.2	3.090	73.0	0.8	186.3	1.000	29.1
Mn (mg/L)	n	34	129	83	20	33	128	83	20
	5%ile	0.2	22.2	1.9	13.9	0.1	20.7	3.3	12.6
	Mean	18.1	62.7	16.5	25.5	10.3	50.3	14.4	21.9
	Median	9.8	65.0	11.0	26.5	2.7	50.0	10.0	22.5
	95%ile	74.0	95.0	56.1	38.1	46.2	76.0	45.0	29.5

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

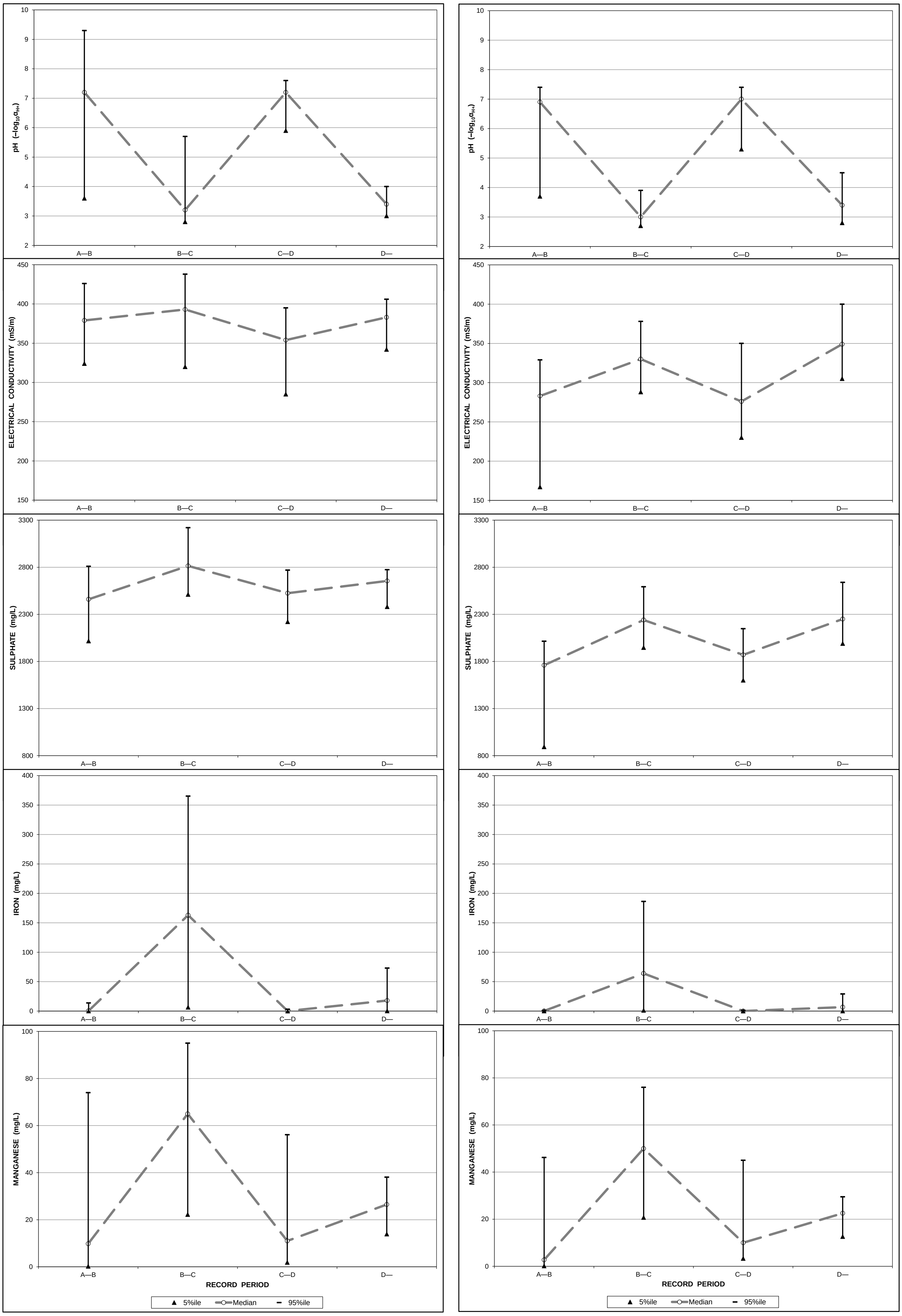


Figure 16 Period-related surface water chemistry variation in the Tweelopie Spruit for the variables (from top to bottom) pH, EC, SO_4, Fe and Mn at the Hippo Dam (left) and F11S12 (right) stations (data from **Table 2**)

The conductivity, 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 17** (EC), **Figure 18** (pH) and **Figure 19** (SO_4) The EC and pH data reflect the elevated salinity values (>350 mS/m) and low pH values (<3) that characterised the surface water lost to the karst aquifer (**Section 4.1.2**) in the period mid-2010 to mid-2012. Similarly, **Figure 19** reflects the elevated contemporaneous SO_4 levels (>2 000 mg/L) in this water. The improvement since mid-2012 is equally evident.

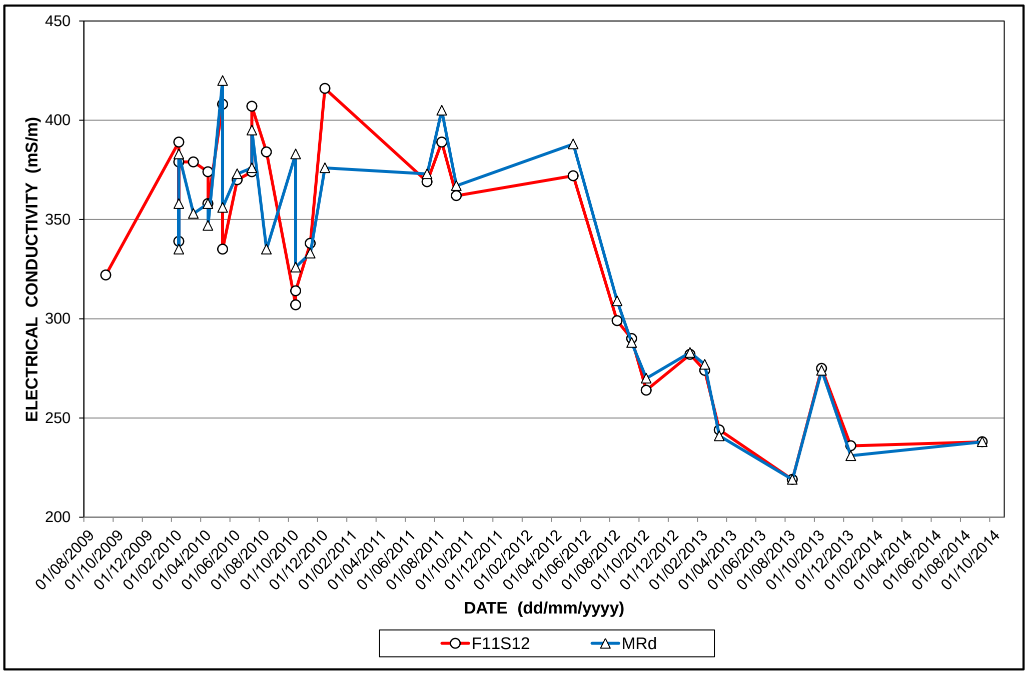


Figure 17 Pattern and trend of electrical conductivity of surface water at stations F11S12 and MRd on occasion of the SDMs reported in **Annexure B**

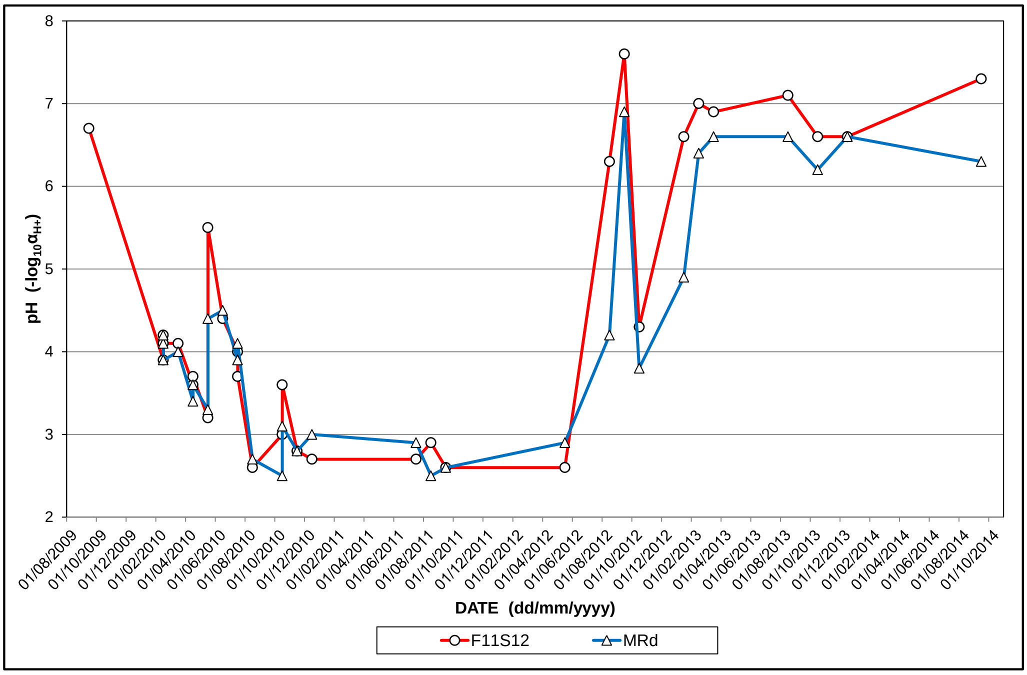


Figure 18 Pattern and trend of pH of surface water at stations F11S12 and MRd on occasion of the SDMs reported in **Annexure B**

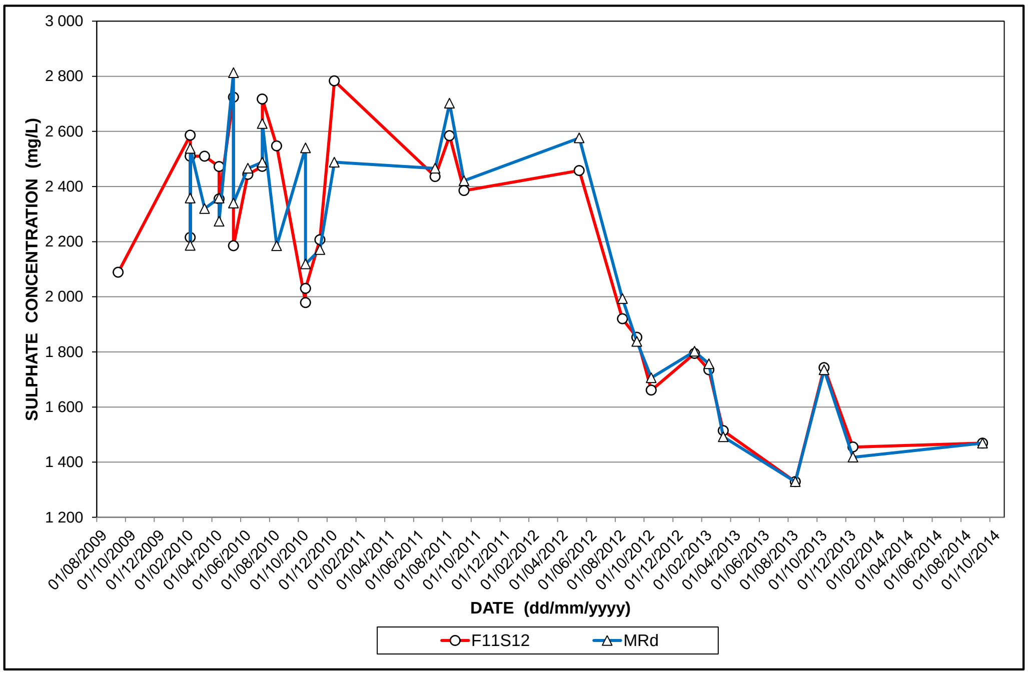
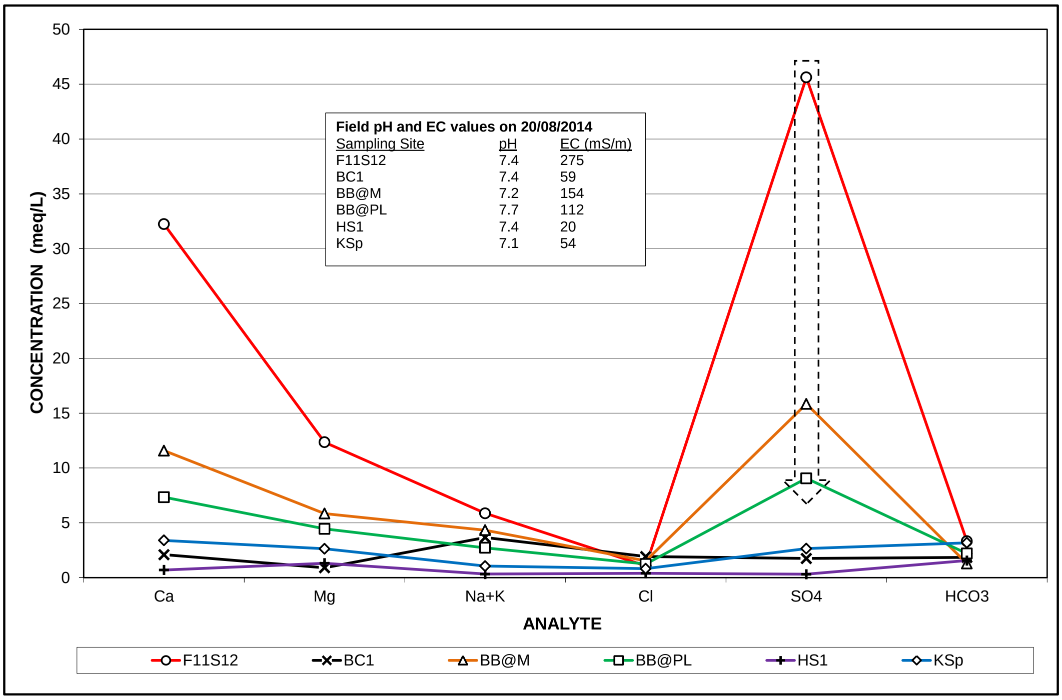


Figure 19 Pattern and trend of SO_4 in surface water at stations F11S12 and MRd on occasion of the SDMs reported in **Annexure B**

4.2.2 Bloubank Spruit

A set of surface water samples collected from the Bloubank Spruit and its major tributaries on 20 August 2014 provides a synoptic overview of the surface water quality in this drainage system on the day of sampling. The results are presented in **Figure 20**, and clearly reveal the improvement in water quality (reflected primarily in the SO_4 values) from station F11S12 to station BB@PL.



Field pH and EC values on 20/08/2014

Sampling Site	pH	EC (mS/m)
F11S12	7.4	275
BC1	7.4	59
BB@M	7.2	154
BB@PL	7.7	112
HS1	7.4	20
KSp	7.1	54

Figure 20 Synoptic graphical comparison of surface water chemistry in the Bloubank Spruit system on 20/08/2014; see **Figure 21** for station localities

The results reflect the strong mine water impact at station F11S12 at the lower end of the Tweelopie Spruit (**Figure 21**) manifested in the Ca–SO_4 composition at this locality. The results also reflect the transition from this composition with passage through stations BB@M and BB@PL to a typical CaMg–HCO_3 dolomitic character represented by the Kromdraai Spring (KSp) groundwater. Of particular relevance is the ~80% decrease in SO_4 concentration (arrowed in **Figure 20**) from 45.62 meq/L (2 191 mg/L) at station F11S12 to 9.06 meq/L (435 mg/L) at station BB@PL. This observation underscores the mitigating influence that the contribution of good to excellent quality karst springwater exerts on the mine water influence. The results further reveal the Na–Cl composition of the water at station BC1 located on the Blougat Spruit downstream of the Percy Stewart WWTW (**Figure 21**).

A summary of the statistics that characterise the surface water chemistry recorded by the DWS at flow gauging station A2H049 at the lower end of the Bloubank Spruit system is presented in **Table 3**. The median and mean electrical balance values afford the analytical results a high degree of confidence. The 95%ile value of 9.5% suggests the increasing inaccuracy of analyses at higher SO_4 concentrations. None of the variables recorded in **Table 3** exceed the respective SANS (2011a) health-related limit where specified.

Table 3 Statistical analysis of Bloubank Spruit water chemistry data associated with station A2H049 for the period May 1979 to August 2014

Variable	**Statistical Parameter**							**SANS (2011a)**(1)
	n	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	
pH ($-\log_{10}\alpha_{H^+}$)	966	7.4	—	8.2	8.5	0.3	4	5.0–9.7
EC (mS/m)	1 071	51.2	60.4	60.5	69.5	8.4	14	<170
TDS (mg/L)	1 071	355.5	438.1	443.9	495.5	61.9	14	<1 200
Ca (mg/L)	888	42.9	54.2	53.6	63.5	11.5	21	n.s.
Mg (mg/L)	886	25.1	32.5	32.4	37.9	5.0	15	n.s.
Na (mg/L)	880	10.0	21.9	21.8	33.4	7.1	32	<200
K (mg/L)	880	0.7	1.9	1.8	3.5	0.9	47	n.s.
Cl (mg/L)	892	20.0	31.8	32.1	40.8	6.0	19	<300
SO_4 (mg/L)	889	65.1	91.3	83.6	134.1	43.9	48	<500
HCO_3 (mg/L)	883	145.8	191.5	197.1	219.3	24.6	13	n.s.
NO_3+NO_2 (mg N/L)	923	3.0	4.6	4.4	6.4	1.7	38	<11
PO_4 (mg P/L)	962	0.005	0.093	0.054	0.317	0.106	115	n.s.
Si (mg/L)	962	5.08	5.98	5.98	6.82	0.81	14	n.s.
Fe (mg/L)	116	0.004	0.029	0.014	0.118	0.047	164	<2
Mn (mg/L)	116	0.001	0.113	0.002	0.145	0.643	569	<0.5
Al (mg/L)	111	0.003	0.044	0.011	0.091	0.202	456	<0.3
EB (%)	840	–1.4	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 21**) 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 effluent quality data for the Percy Stewart WWTW remains unavailable.

The NOE monitoring has further significance for its location in proximity to where the Bloubank Spruit drainage leaves the dolomitic environment and traverses older strata down to its confluence with the Crocodile River. Unlike the water chemistry record for station A2H049, therefore, the NOE water chemistry record represents almost exclusively that of water which drains the karst portion of the catchment (ignoring the ephemeral and typically much smaller discharge of the Honingklip Spruit tributary).

The pH values and nutrient (NO_3-N, PO_4-P and COD) and bacterial concentrations in Bloubank Spruit water at the NOE complex in the period January 2009 to September 2014 (5 years) are given in **Table 4**. The temporal patterns of the pH and bacterial variables are illustrated in **Figure 22**.

Table 4 Analysis of Bloubank Spruit water nutrient and bacterial content at the NOE property in the period January 2009 to September 2014

Variable /	**Statistical Parameter**								**SANS**	**TWQR(2)**
Analyte	**n**	**1%ile**	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	**(2011a)(1)**	**TWQR(3)**
pH ($-\log_{10}\alpha_{H+}$)	66	—	7.5	—	8.0	8.6	0.3	4	5.0–9.7	—
NO_3 (mg N/L)	57	—	2.7	7.5	7.1	**14.9**	3.6	48	<11	—
O-PO_4 (mg P/L)	66	—	0.02	0.4	0.3	1.1	0.4	94	n.s.	—
COD (mg/L)	48	—	6.4	54.6	43.0	158.3	5103	93	n.s.	—
N**:**P (ratio)(4)	54	—	6.8	37.1	28.8	116.5	35.5	96	—	—
Faecal coliforms (cfu/100 mL)	66	**36**	**57**	**882**	**315**	**4 627**	1 757	199	≤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).

It is concerning that the faecal coliform count as far downstream as the NOE property continues to reflect elevated concentrations even at the 1%ile level (**Table 4**). The association of higher faecal coliform concentrations with rainfall is exemplified in the February 2014 values (**Figure 22**). This observation suggests that significant municipal wastewater impacts on the bacteriological quality of surface water in the Bloubank Spruit system, are driven by rainfall.

The mean and median faecal coliform values of 882 and 315 cfu/100 mL respectively (**Table 4**), are compared to August 2014 *E. coli* levels of >2 419[4] MPN/100 mL obtained at the stations BC1, BB@M and BB@PL located further upstream (**Figure 21**). The lower NOE values are commensurate with the decreasing trend associated with 'distance from source' reported by Hobbs (2011). Nevertheless, the results indicate a severe non-conformance of faecal coliforms, and therefore almost certainly also of *E. coli*, in regard to potable, animal and recreational use of the surface water at the NOE position in the Bloubank Spruit system. This situation undoubtedly worsens progressively with distance upstream.

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[4] Undiluted sample, negating a count of the true *E. coli* levels.

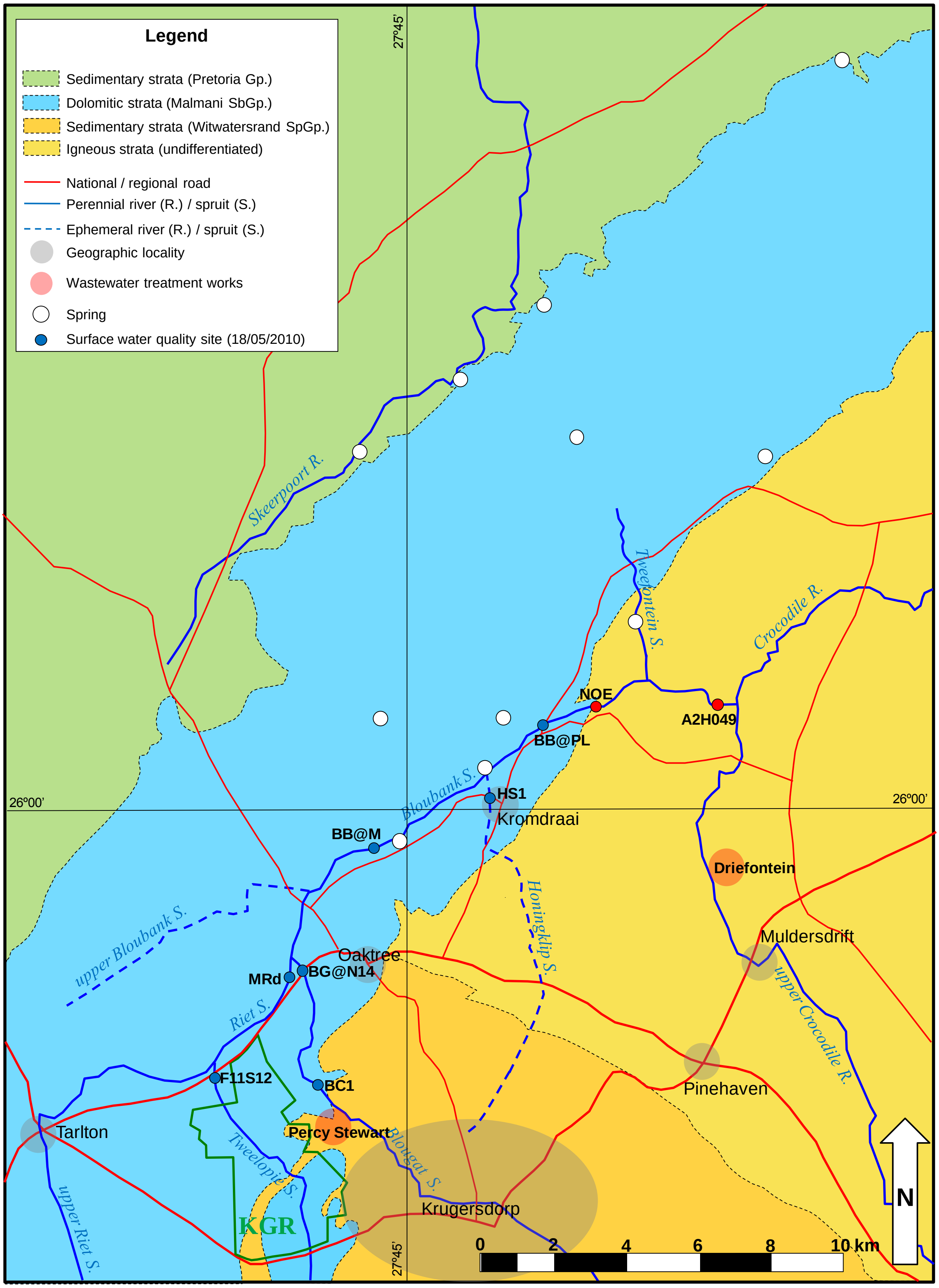


Figure 21 Surface water quality sampling sites in the study area

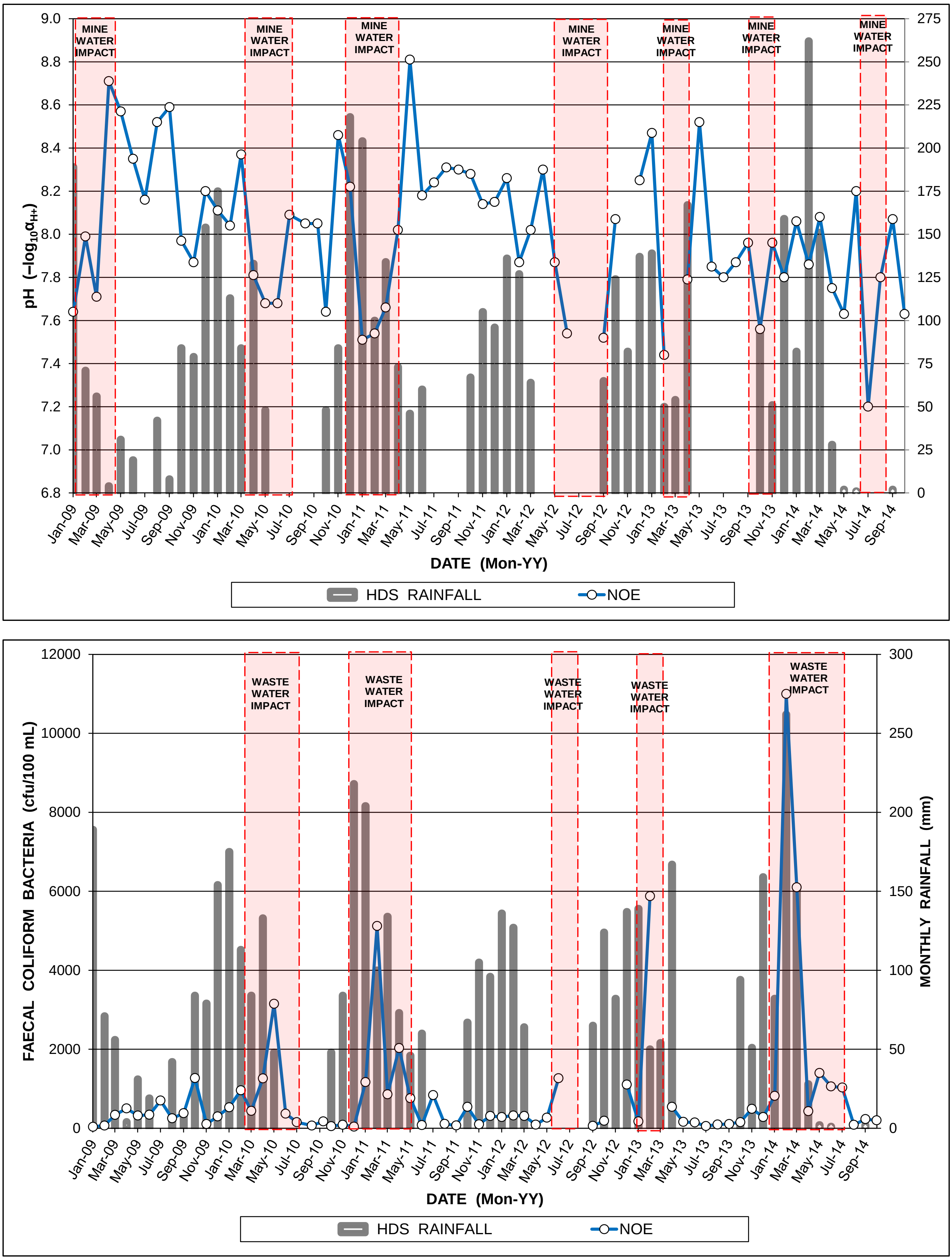


Figure 22 Correlation of pH (top) and faecal coliform bacteria (bottom) levels in the Bloubank Spruit at the NOE property with rainfall in the headwaters of the catchment

4.3 Salt Load

4.3.1 Riet Spruit

The combination of quantified stream flow losses (**Annexure A**) and associated TDS levels and sulphate concentrations (**Annexure B**) between stations F11S12 and MRd, allows for the derivation of the TDS and SO_4 loads lost to the karst aquifer as illustrated in **Figure 23** and **Figure 24**, respectively.

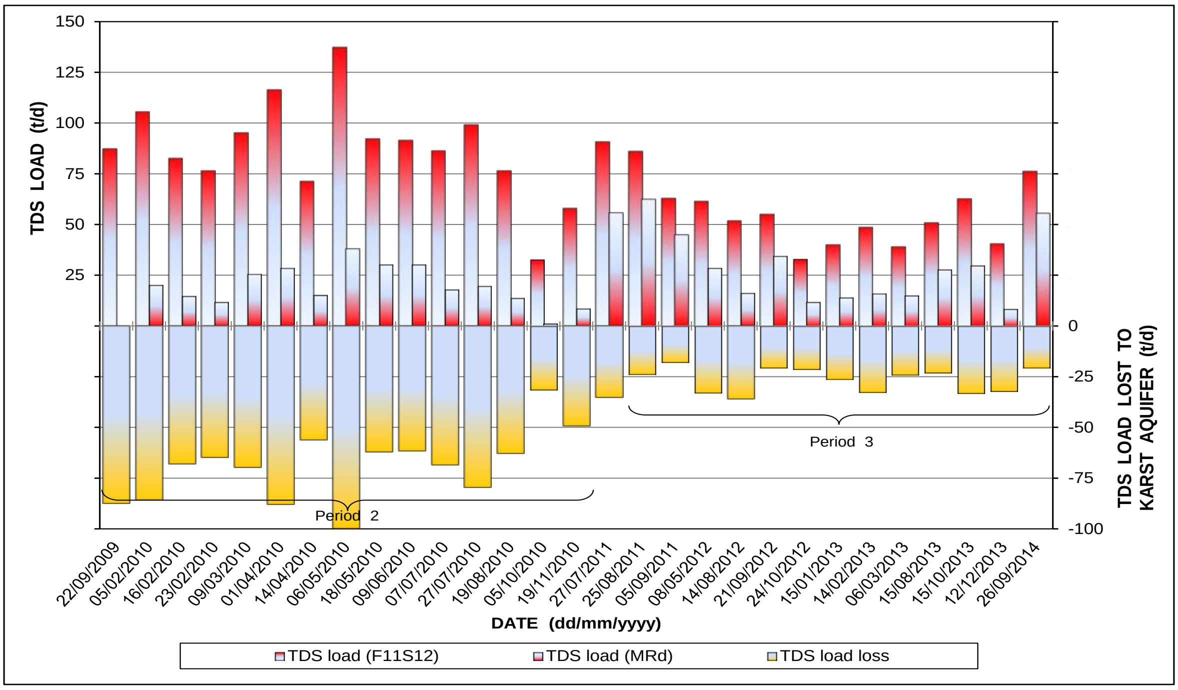


Figure 23 Graph of surface water TDS load lost to groundwater in the lower reach of the Riet Spruit

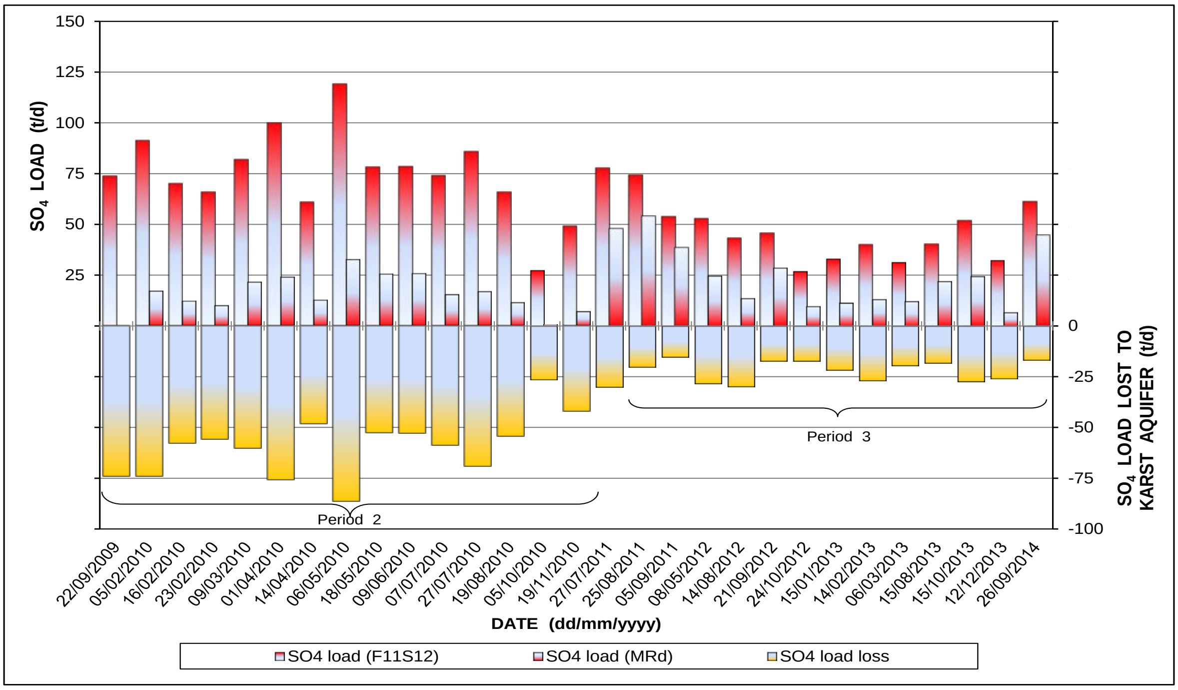


Figure 24 Graph of surface water SO_4 load lost to groundwater in the lower reach of the Riet Spruit

The concern previously expressed for the quality of the water entering the karst aquifer of the Zwartkrans Compartment is echoed in the respective median TDS and SO_4 loads associated with this allogenic recharge. These loads amounted 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. The 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 salt load pattern and trend passing station A2H049. Such re-assessment is shown for TDS in **Figure 25**, and for SO_4 in **Figure 26**. The ratio of SO_4 to TDS illustrated in **Figure 27** and **Figure 28** 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 25**) indicates an increasing TDS load (as indicated by the visually inserted arrows) since early-2007. The text box in **Figure 25** 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 26**) mimics the TDS load pattern (**Figure 25**) in the period since early-2007. This is understandable under circumstances where SO_4 comprises ~62% of the major ion concentration in mine water.

A further analysis of the potential impact of mine water 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 27** for the long-term record, and in **Figure 28** for the period since the start of decant.

The closer inspection in **Figure 29** of the SO_4 data recorded at station A2H049 indicates an approximate doubling of the SO_4 concentration (from ~100 mg/L to ~200 mg/L) between mid-2010 and early-2014. This is also reflected in the SO_4**:**TDS ratio, which increases from ~20% to ~35% in this timeframe (**Figure 28**).

An inspection of **Figure 25** reveals that the most recent TDS load passing station A2H049 represents the highest in the historical record, surpassing the January 2011 value by >1 000 t/m. By comparison, **Figure 26** reveals that the recent (ca. May 2014) SO_4 load passing this station 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 recent (ca. March 2014) discharge at A2H049 exceeds that in January 2011 by ~50%, it is evident that the mine water chemical influence at A2H049 in regard to the TDS load is primarily informed by the discharge component, and that in regard to the sulphate load by the SO_4 concentration. This is reflected in **Figure 29**, which shows that the most recent SO_4 concentrations recorded at A2H049 are the highest on record since the start of mine water decant. The obvious and immediate cause-and-effect evident in the response of surface water chemistry (hydrochemistry) to mine water impacts reflected in **Figure 25** to **Figure 29**, remains obtuse and delayed in regard to the response of groundwater chemistry (hydrogeochemistry) to similar impacts (**Section 5.2**).

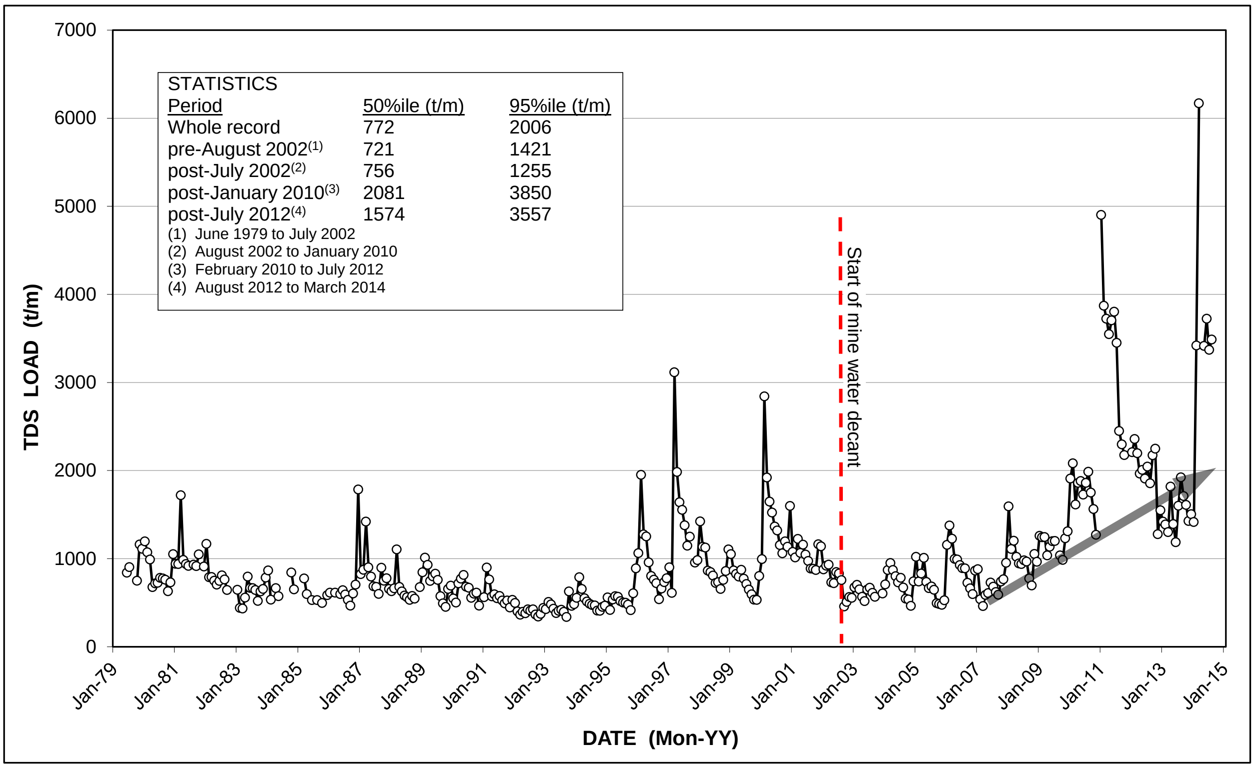


Figure 25 Long-term (June 1979 to August 2014) monthly TDS load pattern and trend in the Bloubank Spruit at DWS station A2H049

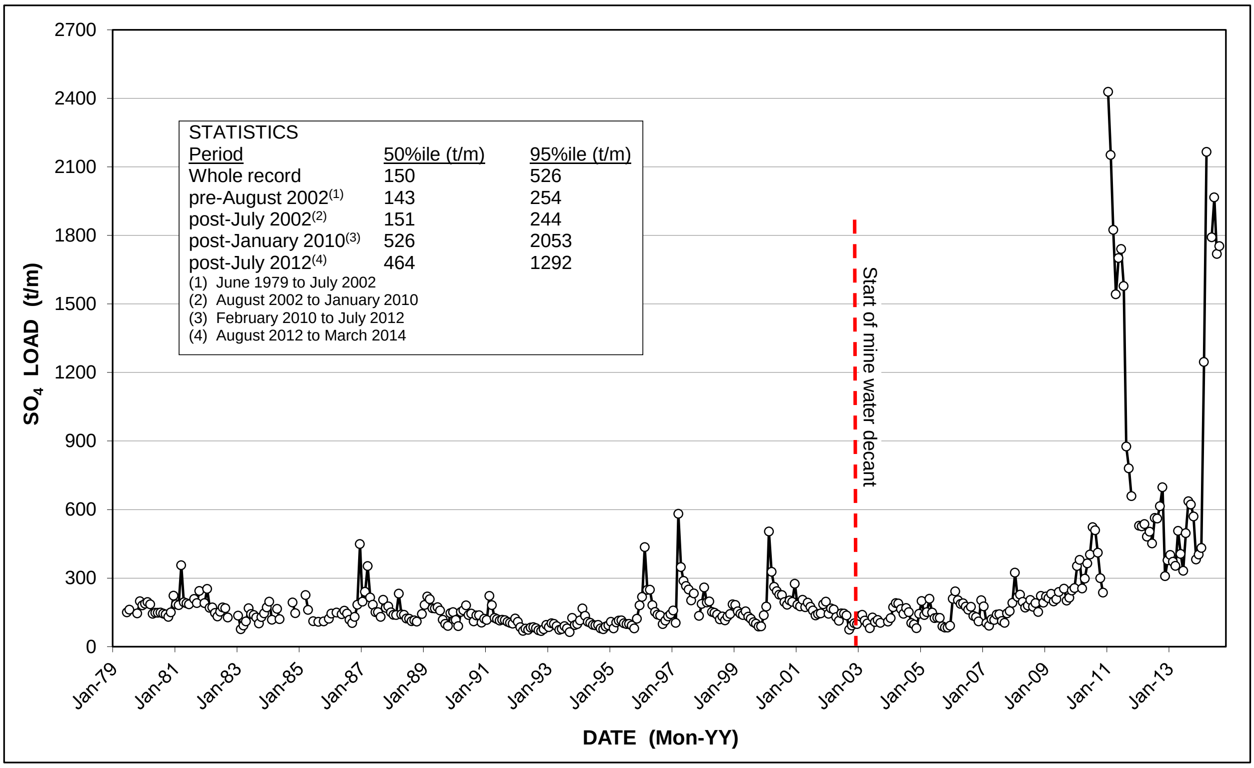


Figure 26 Long-term (June 1979 to August 2014) monthly SO_4 load pattern and trend in the Bloubank Spruit at DWS station A2H049

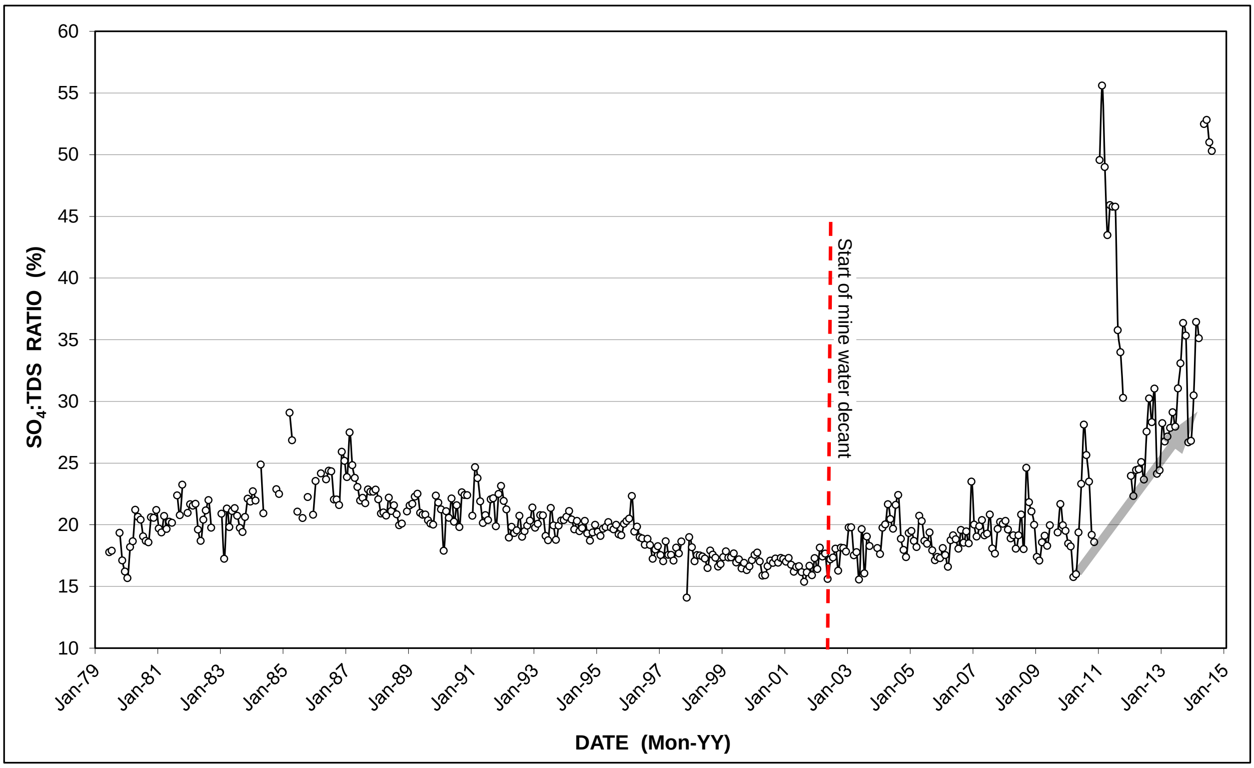


Figure 27 Long-term (June 1979 to August 2014) trend in the SO_4:TDS ratio at station A2H049

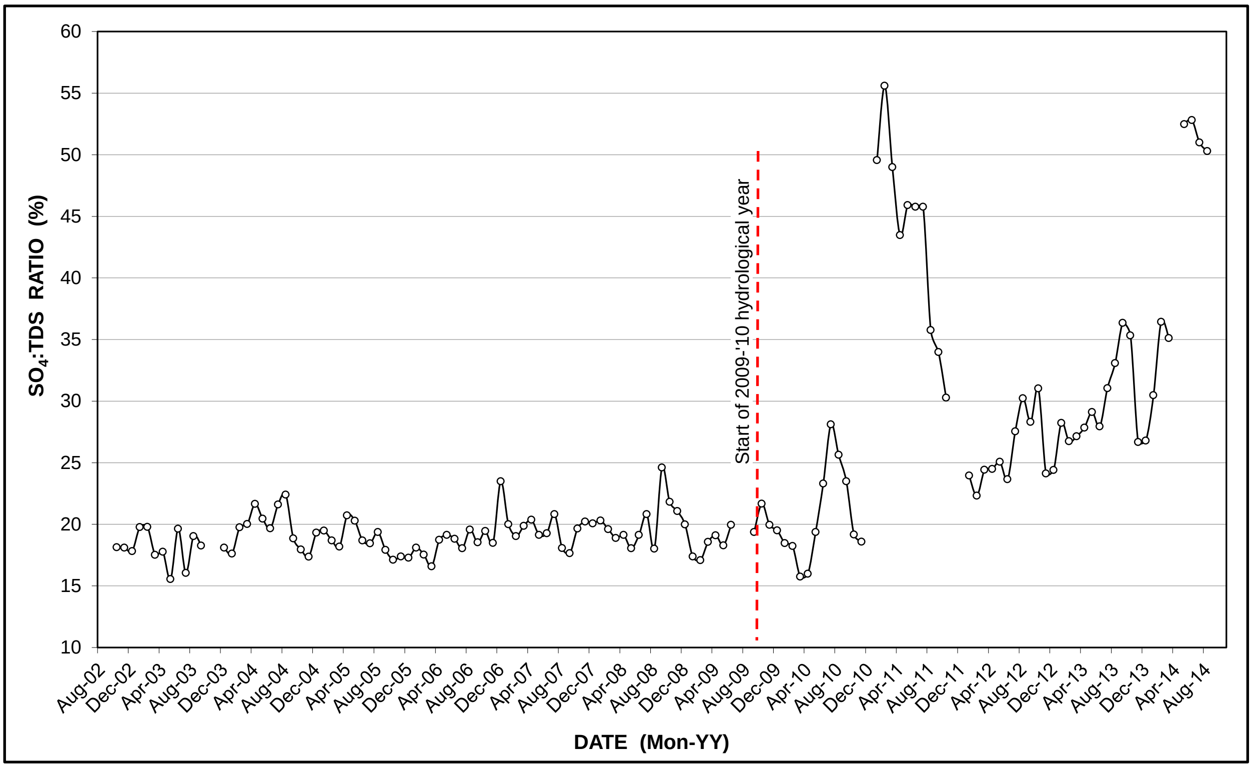


Figure 28 Pattern and trend in the SO_4:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin

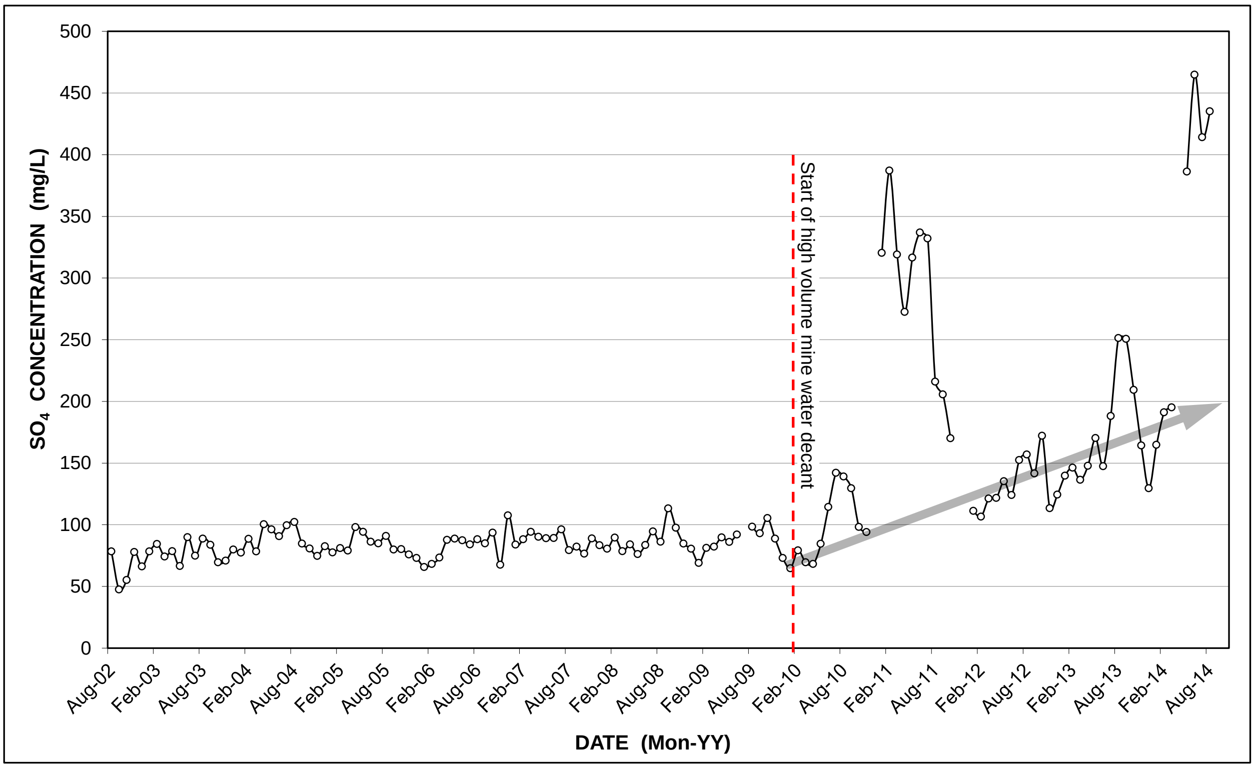


Figure 29 Pattern and trend in the SO_4 concentration at station A2H049 since the start of mine water decant in the Western Basin

The SO_4 concentration in the surface water passing station A2H049 (**Figure 29**) shows a gradually rising trend since the start of the 2009–'10 hydrological year. Superimposed on this trend are excursions in mid-2012 and again in mid-2014. The excursions reflect the impact of large and uncontrolled AMD discharges associated with raw mine water on the chemical composition of surface water leaving the Bloubank Spruit system. The most recent excursion had not yet returned to the gradually rising limb of the graph by August 2014.

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**. A graphical representation of the information is shown in **Figure 30**. An analysis of the %ile Δh data yields a 25%ile value of 3.86 m, a mean value of 5.35 m, a median value of 4.93 m, and a 75%ile value of 6.98 m. Most of these graphs are compared in **Figure 31**.

The comparison indicates two distinct groupings, namely Group A occupying an elevation of >1 530 m amsl, and Group B occupying an elevation <1 490 m amsl. The elevation difference of >40 m reflects the location of these groupings in two separate subcompartments of the Zwartkrans Compartment. These groupings are produced separately in **Figure 32** (Group A) and **Figure 33** (Group B).

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	274	–59.95	–54.55	–54.32	–51.01	11.13	8.94	05/1985–09/2014
A2N0582	210	–42.91	–40.11	–40.15	–35.77	8.53	7.14	05/1985–12/2010
A2N0583	234	–45.54	–44.95	–44.90	–44.40	1.84	1.14	05/1985–10/2014
A2N0584	268	–28.09	–25.52	–26.26	–21.28	8.19	6.81	05/1985–09/2014
A2N0586	289	–28.67	–26.23	–27.14	–21.34	8.54	7.33	05/1985–10/2014
A2N0589	169	–29.90	–28.89	–28.97	–27.92	3.85	1.98	05/1985–06/2010
A2N0590	188	–36.46	–34.62	–35.14	–31.50	6.11	4.96	05/1985–10/2014
A2N0592	278	–78.53	–76.92	–77.33	–73.62	6.33	4.91	06/1985–10/2014
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	208	–25.38	–23.92	–24.39	–21.22	5.07	4.16	04/1989–10/2014
A2N0602	233	–55.95	–54.30	–54.85	–51.02	6.44	4.93	06/1987–10/2014
A2N0605	202	–63.65	–62.49	–62.74	–60.18	4.16	3.47	04/1989–09/2014
A2N0606	72	–69.51	–67.07	–67.06	–64.83	5.11	4.68	08/1989–10/2014
A2N0607	169	–70.68	–67.00	–66.97	–64.20	7.95	6.48	10/1993–10/2014

(1) From month of first measurement to month of most recent available measurement as at November 2014 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

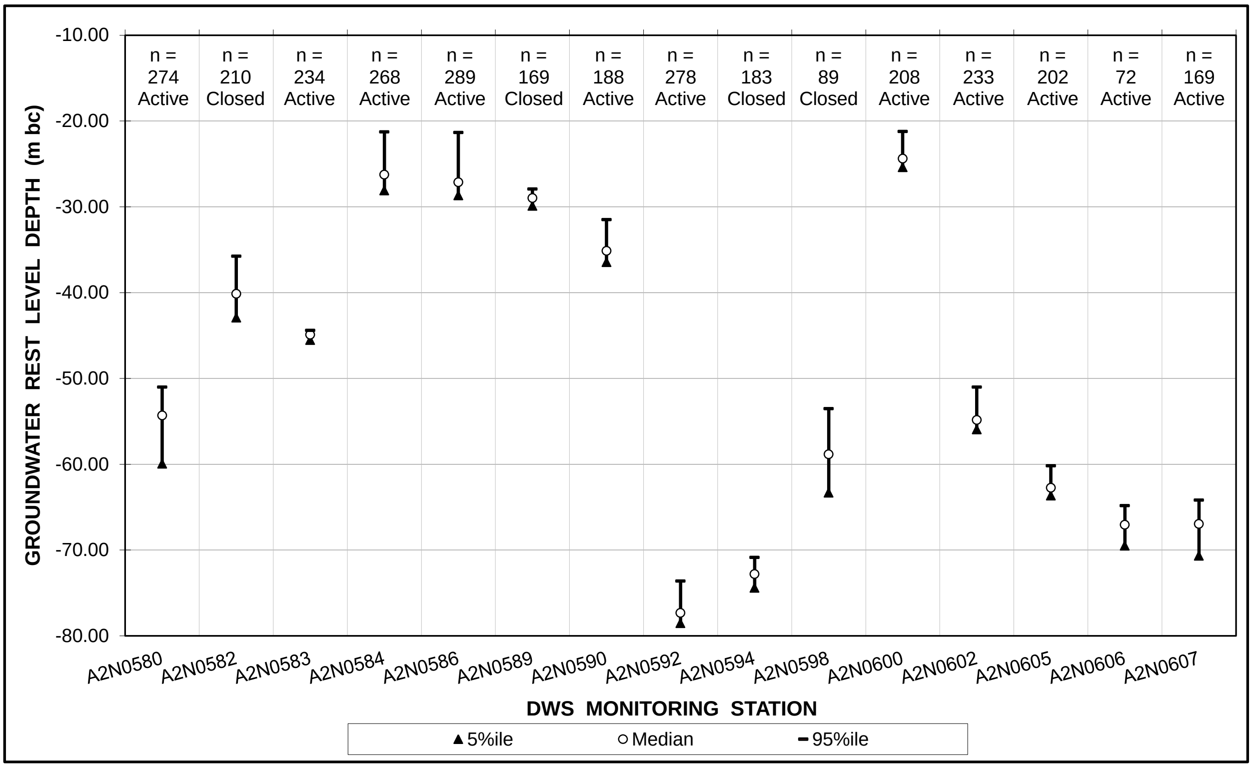


Figure 30 Graphic comparison of the statistical hydrographic response observed in DWS groundwater level monitoring stations in the period 1985 to 2014 (data from **Table 5**)

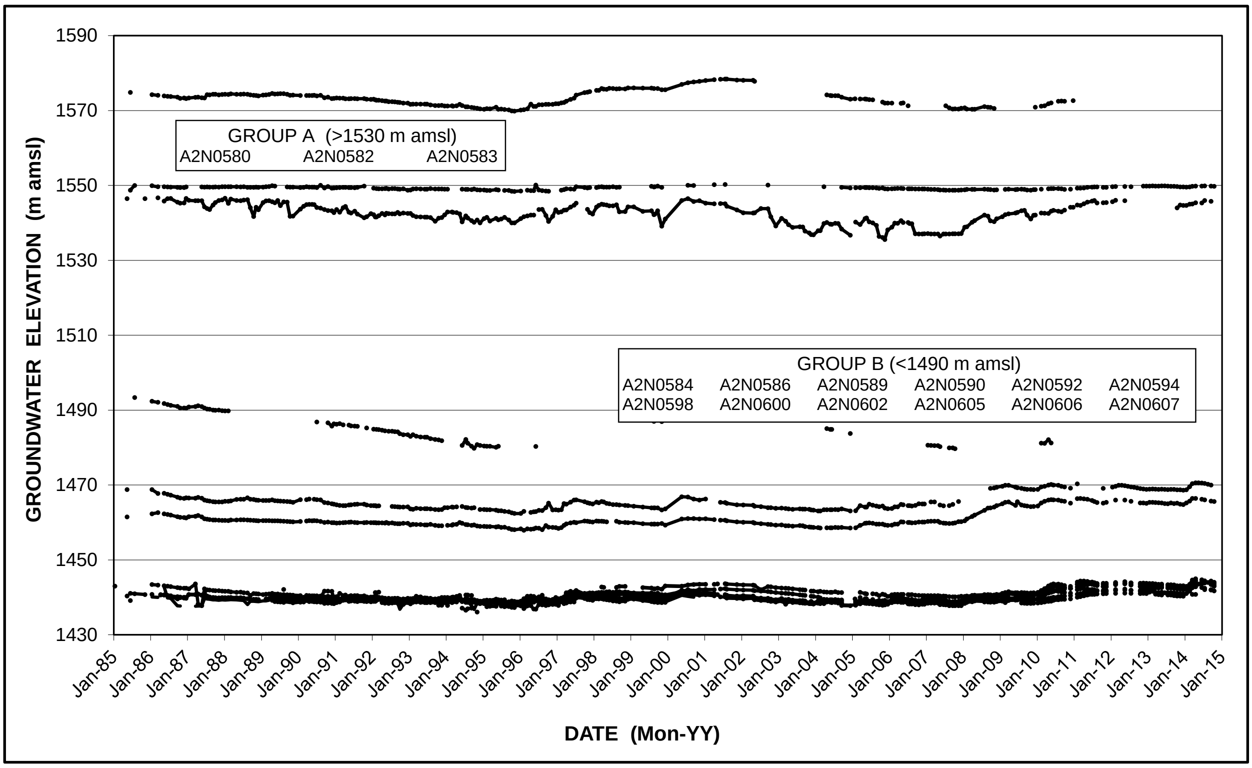


Figure 31 Long-term groundwater level response pattern in DWS monitoring boreholes

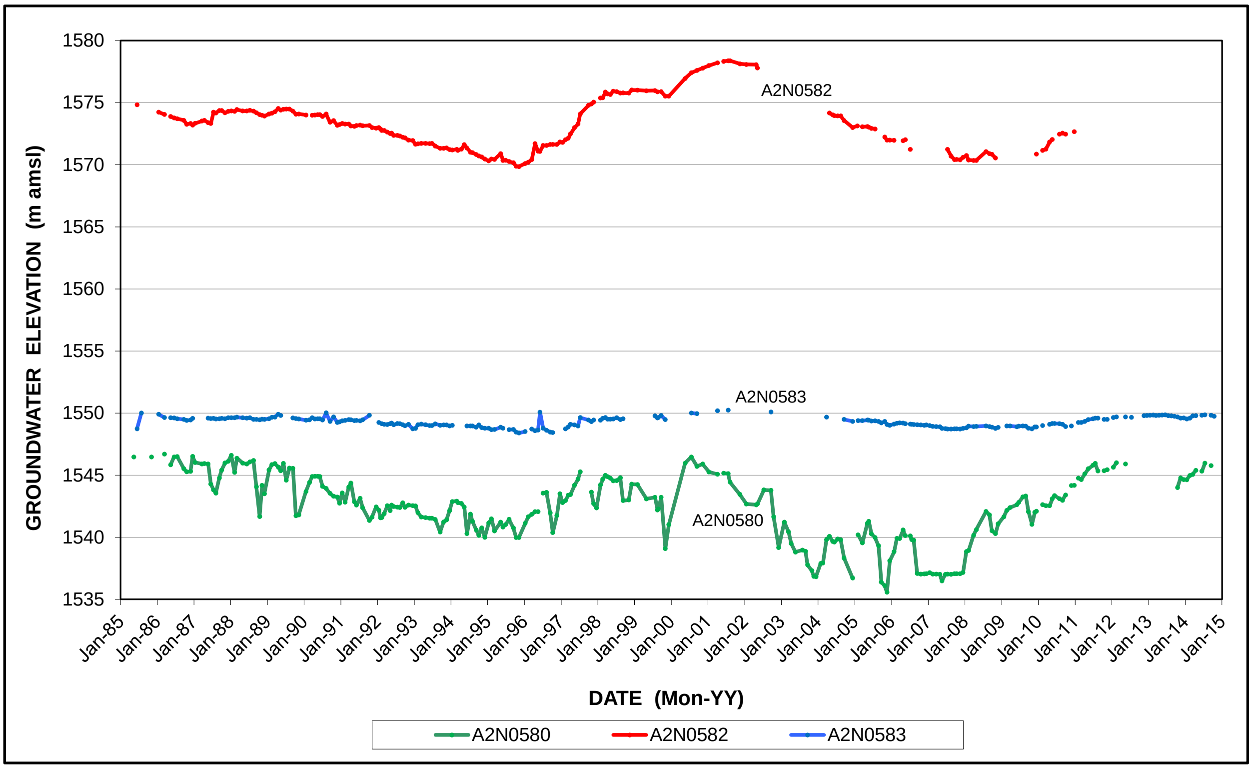


Figure 32 Long-term groundwater level response pattern in Group A boreholes from **Figure 31**

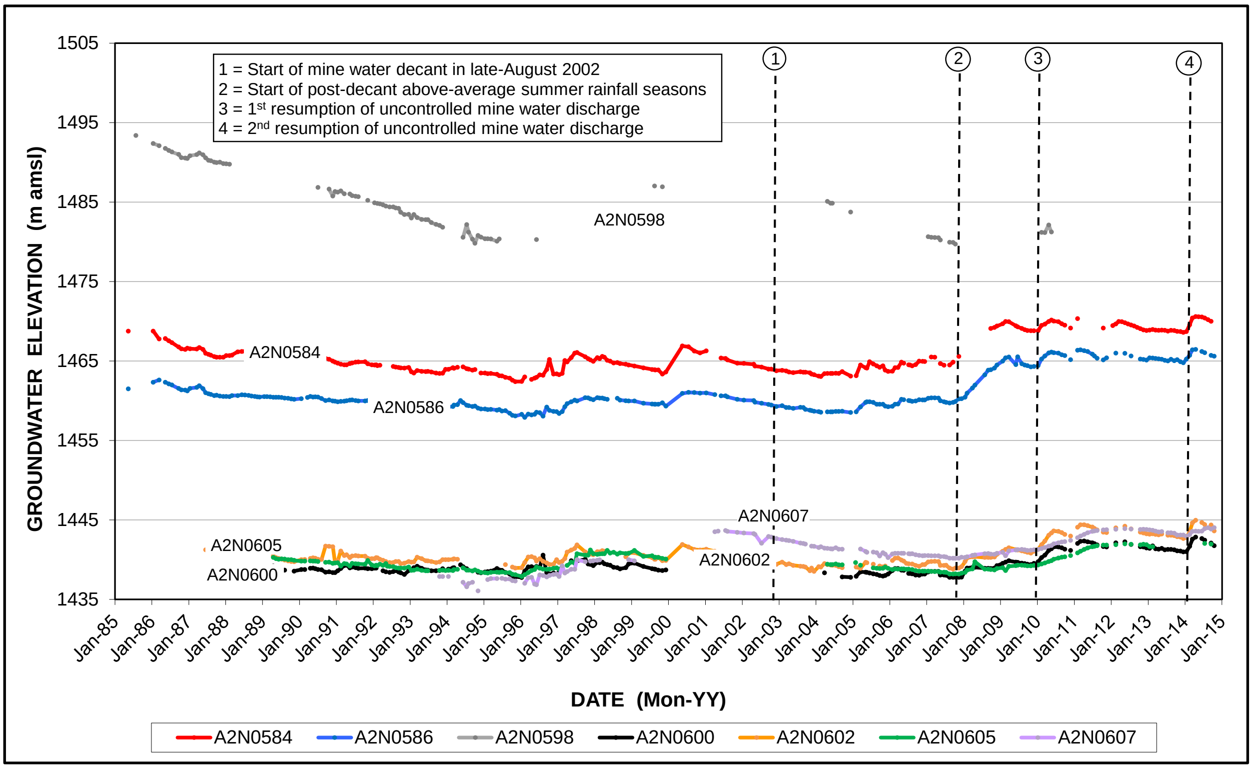


Figure 33 Long-term groundwater level response pattern in Group B boreholes from **Figure 31**

The unprecedented rise in the groundwater level observed in stations A2N0584 and A2N0586 since late-2007 (**Figure 33**) reflects the impact of exceptional recharge associated with raw and/or treated mine water being lost from the lower reach of the Riet Spruit (**Section 4.1.2**). Both these stations are located in proximity to the Riet Spruit (**Figure 34**). 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 artificial flow in this drainage to >60 ML/d.

An inspection of the more recent potentiometric response in DWS monitoring boreholes located downstream of the mine area is presented in **Figure 34.** The boreholes are grouped into a southern, a central and a northern segment to distinguish between their near- to far-field location in the receiving hydrogeologic environment downstream of the mine area. 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. The hydrographs indicate only very slight temporal variations that echo the decimetre scale of recent cave water level changes observed since mid-2010 (**Section 5.1.2**).

The long-term hydrographs presented in **Figure 33**, in particular those of stations A2N0584, A2N0586 and A2N0600, indicate that groundwater elevations in the last few years are the highest in the 25 to 30-year record of measurements. The most recent levels are, in fact, the highest on record. 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 anticipated to be in the order of 15–20% (2.9–3.9 Mm^3/a).

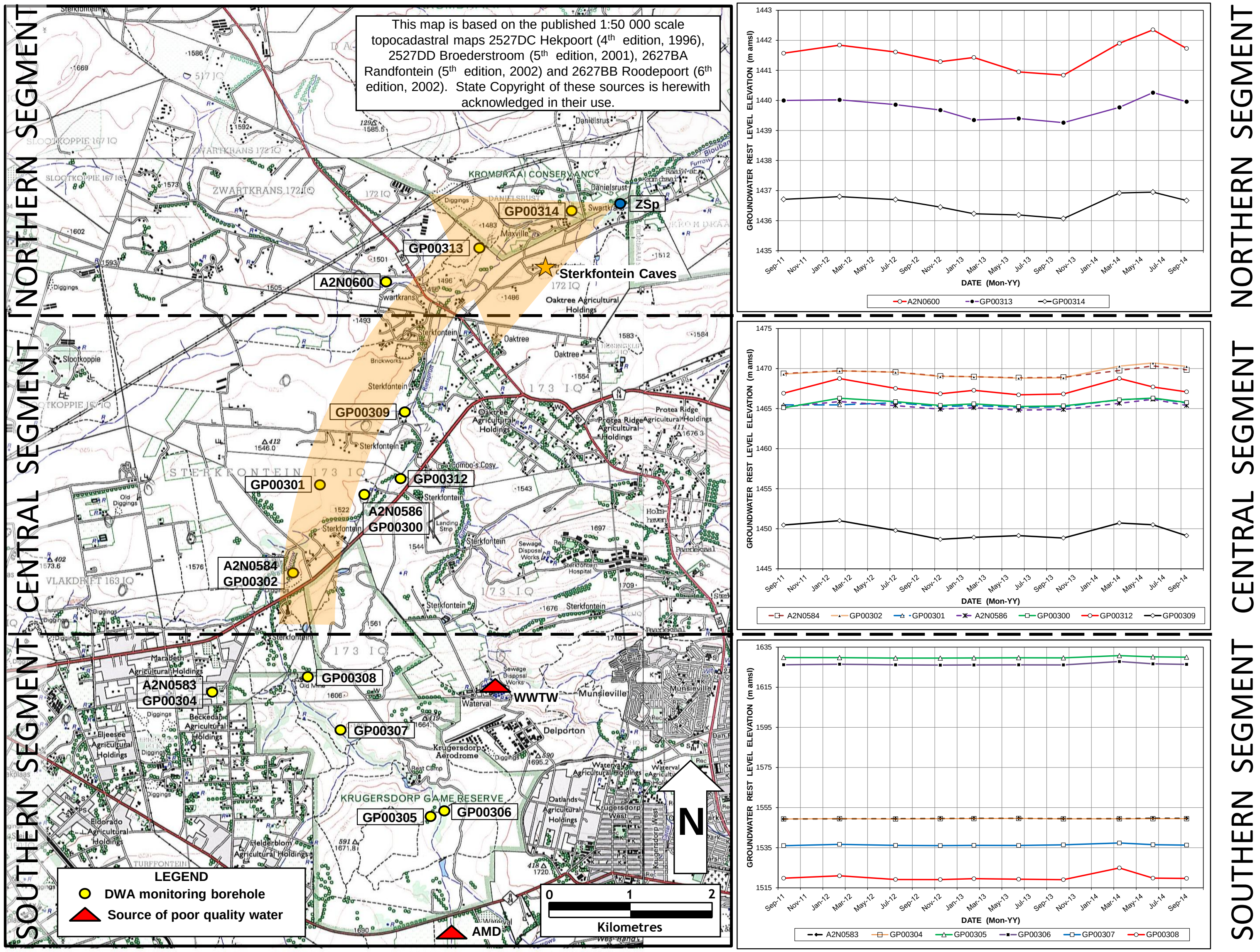


Figure 34 Distribution of DWS monitoring boreholes with groundwater hydrographs (right); arrow denotes principal direction of groundwater flow

5.1.2 Sterkfontein Caves Water Level

The international significance of Sterkfontein Caves as the flagship fossil site in the COH focuses attention on any perceived impact on this site. It is common cause that a recent substantial rise in the cave water level has 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 on three occasions since early-2010. 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 35**, and suggests that the cave lake water level might have started rising in mid-2009. Although the more recent trend (since mid-2012) reflects a decline in the Main Lake water level, the very high rainfall in February and March 2014 and its broader impacts in the form of natural (autogenic) and mine water (allogenic) recharge, is manifested as a rapid rise of ~1 m that is mirrored in a number of the monitoring borehole hydrographs (**Figure 33**). The most recent water level rise reflects the influence of the wet 2013-’14 summer rainfall season (**Figure 4**), and indicates stabilisation of the Lake level at an elevation of ~1 439.5 m amsl. Representing a quite rapid rise of ~1 m in less than six months, the rate of ~0.16 m per month is similar to the 0.15 m per month reflected in the earlier rise between the February 2010 and January 2011 measurements (**Figure 35**). This demonstrates the rapidity of positive potentiometric response rates in the karst and cave environment. The groundwater recession rates similarly reflect a consistent value of −0.03 m per month.

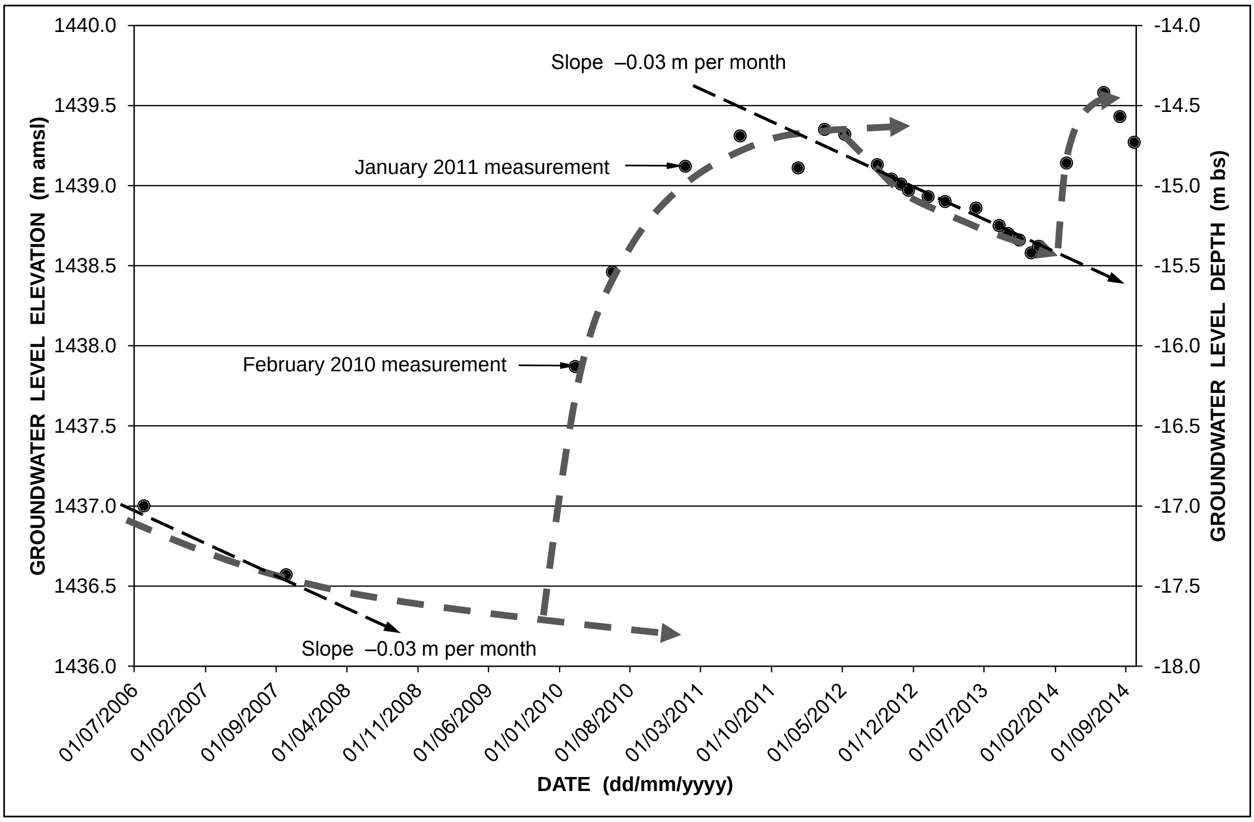


Figure 35 Recent groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the Main Lake water level in Sterkfontein Caves

The ‘maximum’ elevation of ~1 439.5 m amsl (**Figure 35**) approaches the elevation assigned to the Bloubank Spruit channel to the north of the caves. This suggests that the cave water level reaches equilibrium at an elevation of just below 1 440 m amsl (equivalent to a depth of ~14.5 m below surface in/at borehole SF1) when the karst water table intersects the stream channel of the Bloubank Spruit located to the north. If so, then the maximum possible rise of ~3 m agrees well with the zone of 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 Main 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 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 mine water 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 study area was substantially expanded with the establishment of an additional 13 monitoring boreholes in late-2010. These stations (identified by the alpha-numeric code GP003##) supplement the four stations (identified by the alpha-numeric code A2N0###) that are the legacy of the mid-1980 DWA study (Bredenkamp et al., 1986) in the region. The distribution of this monitoring network is shown in **Figure 36** and **Figure 37**. 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 product of this monitoring that forms the basis for evaluating the impact on the mine water receiving karst environment of the Zwartkrans Compartment (**Section 5.2.2**). It is also important to recognise that the ~9 800 ha Zwartkrans Compartment, as focal area in this regard, represents ~19% of the COH footprint (~52 000 ha) and ~36% of the karst footprint (~26 860 ha) in the property.

5.2.2 Mine Water Receiving Environment

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 property. This is illustrated in **Figure 36** and **Figure 37** with the aid of bar graphs for the chemical variables pH and electrical conductivity (EC) respectively. The bar graphs in **Figure 36** 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 37** similarly reflect the general progressive increase in salinity from south to north within the central segment. In the northern segment, the spatial trend along the flow path is a declining one, even though all of the stations individually reflect an increase in salinity over time. The significant influence exerted by proximity to the Riet Spruit in the central segment is again evident. As in the case of pH (**Figure 36**), 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 into the karst aquifer.

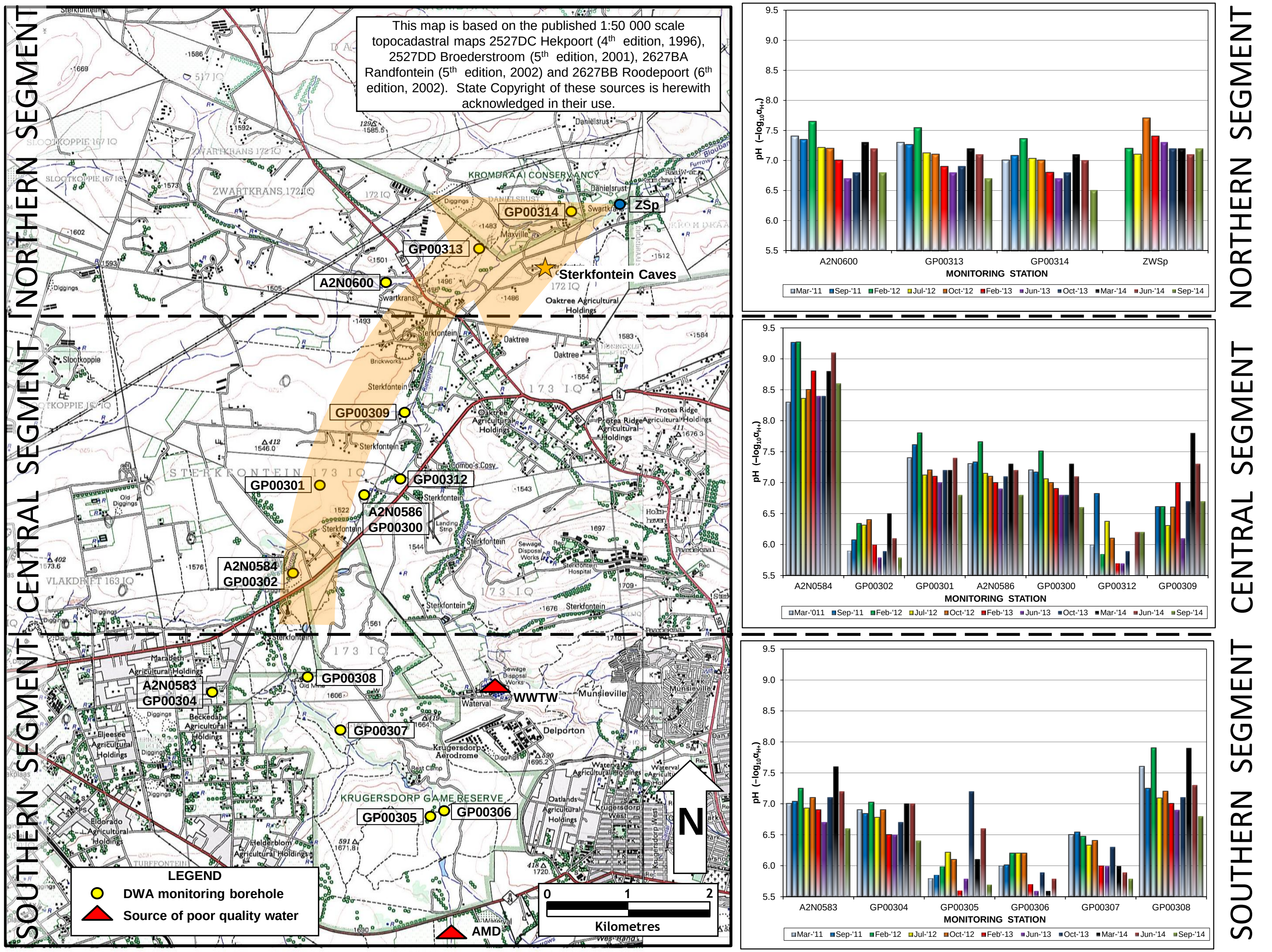
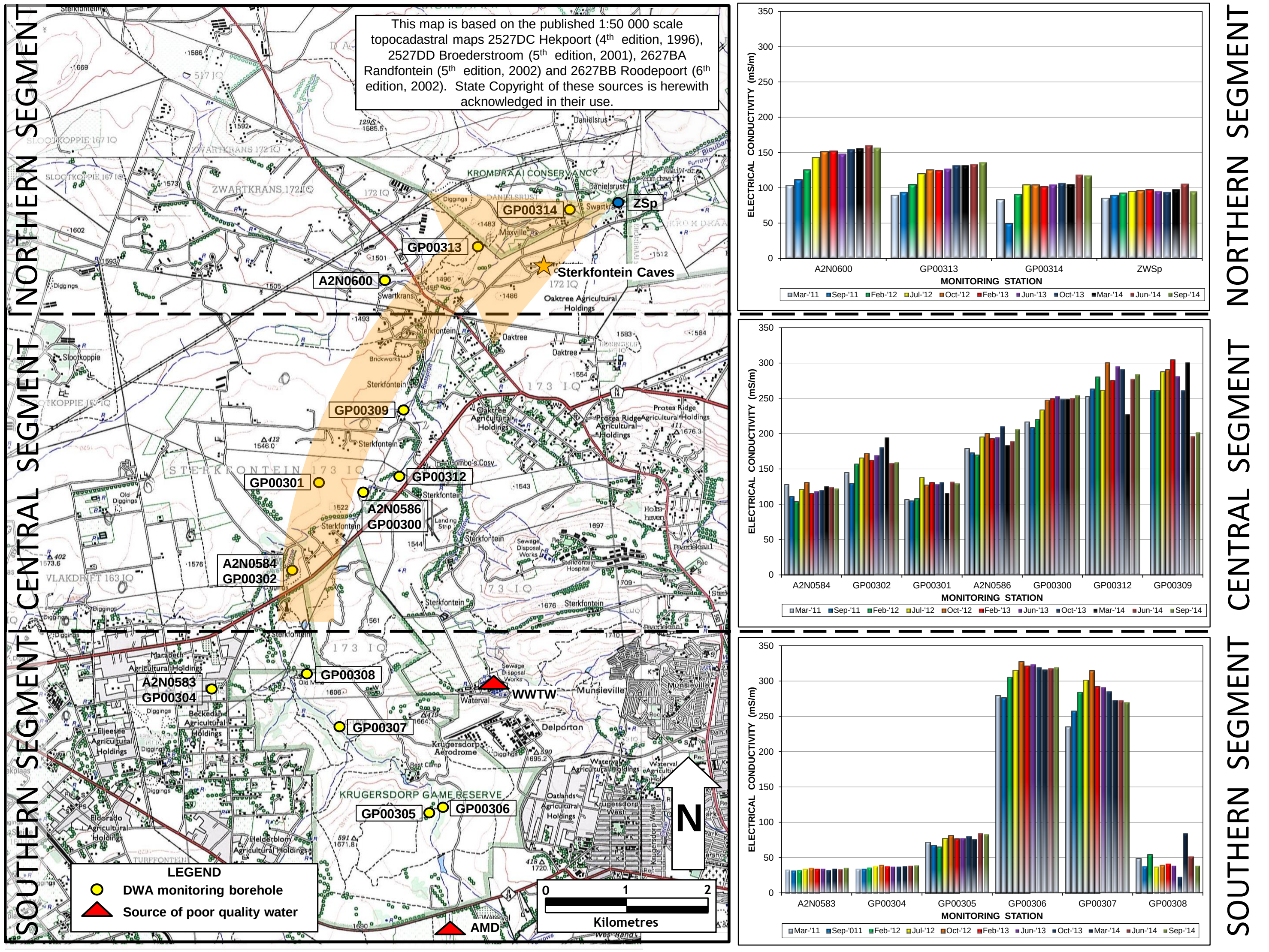


Figure 36 Distribution of DWS monitoring boreholes with pH pattern and trend as bar graphs; arrow denotes principal direction of groundwater flow



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

The historical pattern and trend of groundwater salinity and sulphate concentrations 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 38**, and reveal the pattern and trend of EC and SO_4 levels within the pseudoplume that marks 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 slower travel times in the subsurface. The analyte SO_4 represents a particular concern for its exceedance, in all five instances, of the SANS (2011a) standard health-related limit of 500 mg/L (**Table 3**) for drinking water.

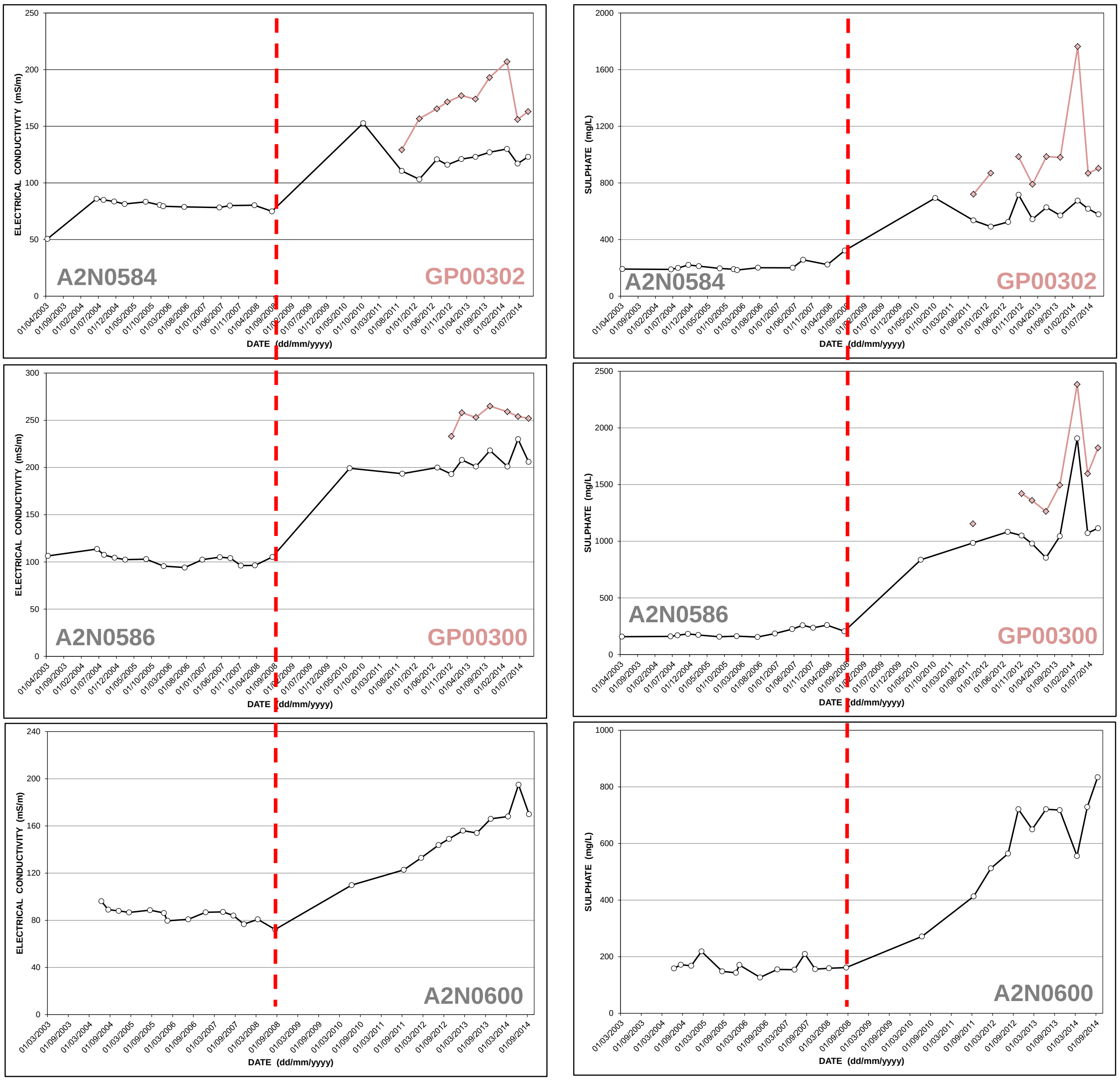


Figure 38 Long-term pattern and trend of electrical conductivity (left) and sulphate (right) in karst groundwater from paired DWS monitoring stations A2N0584 / GP00302 and A2N0586 / GP00300, and station A2N0600; note common time scales and postulated commencement of rise in concentrations (vertical pecked line)

It would also appear from **Figure 38** that recent sulphate levels along the Riet Spruit exhibit a “spike” after the levelling off observed in 2013, whereas the SO_4 level at the downstream station A2N0600 exhibits a decrease. The “spike” is unequivocally attributable to the most recent and current discharge of raw and treated mine water from the mine area. It is notable that the SO_4 peaks evident in the paired monitoring stations ca. March 2014, is manifested some six months (ca. September 2014) at station A2N0600. This observation also applies to the preceding decline in SO_4 levels evident in the graphs.

The distribution of SO_4 concentrations associated with the stations represented in the central and northern segments of **Figure 36** and **Figure 37**, is shown in **Figure 39**. This provides an indication of the conceptualised footprint of this impact. The impact is described as a pseudoplume (after Ewers, 2012) discussed in greater detail later in this section. The pseudoplume shown in **Figure 39** encompasses ~1 030 ha. This represents ~11% of the Zwartkrans Compartment, and only ~4% of the entire karst footprint in the COH.

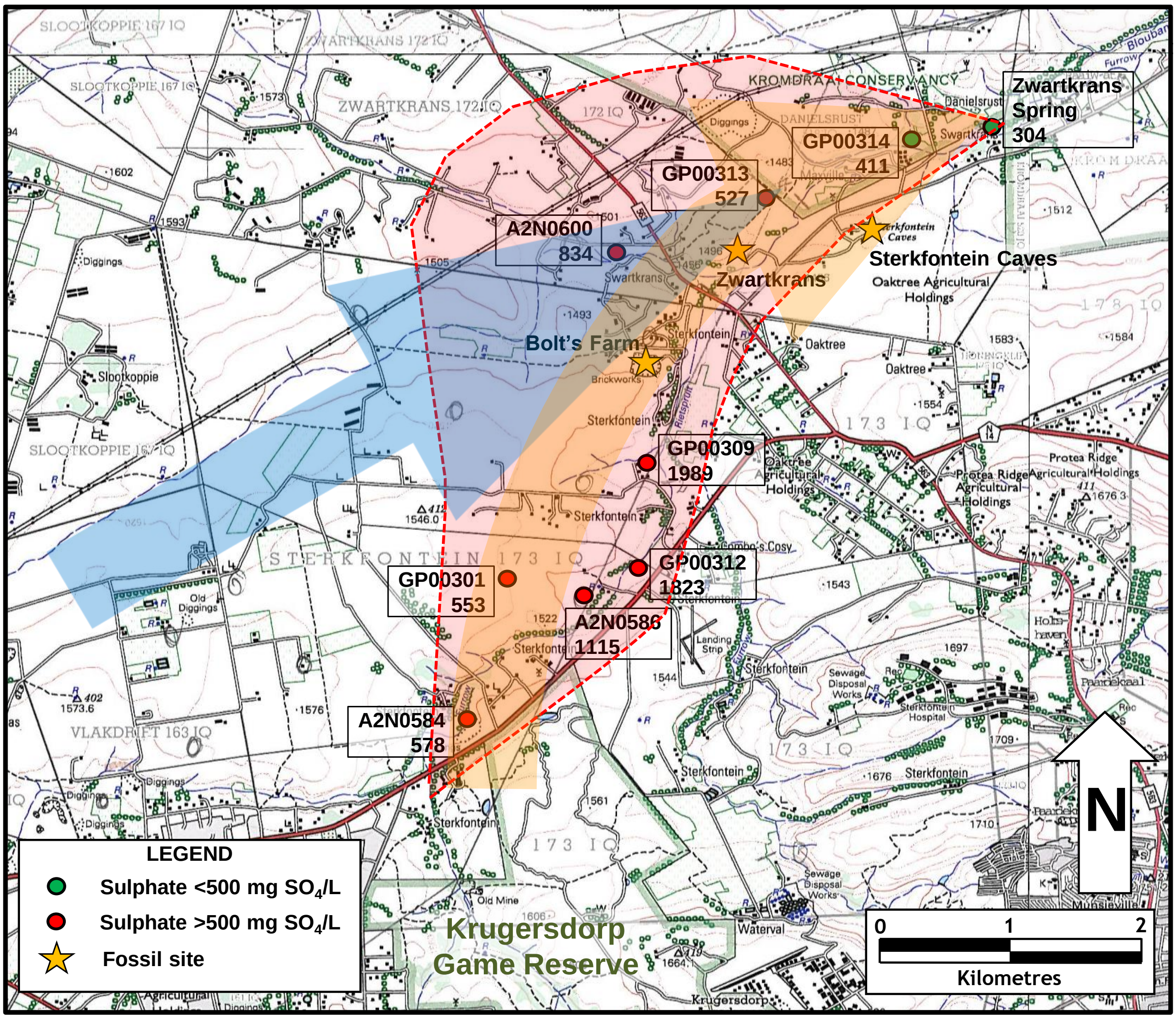


Figure 39 Distribution of SO_4 concentrations in groundwater of the Zwartkrans Compartment in September 2014, also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow) and the postulated footprint (shaded area) of a mine water impact in the karst aquifer

An assessment of the groundwater chemistry data for the karst hydrosystem shared by the caves provides the information presented in **Figure 40** and **Figure 41**.

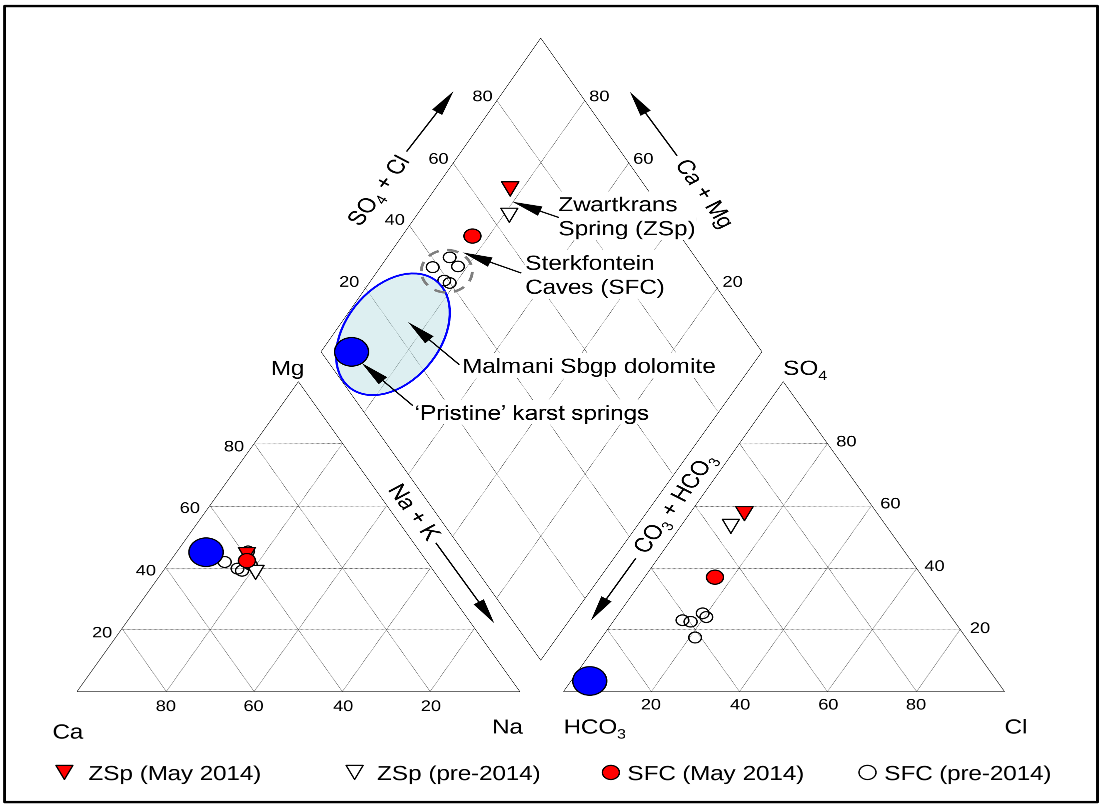
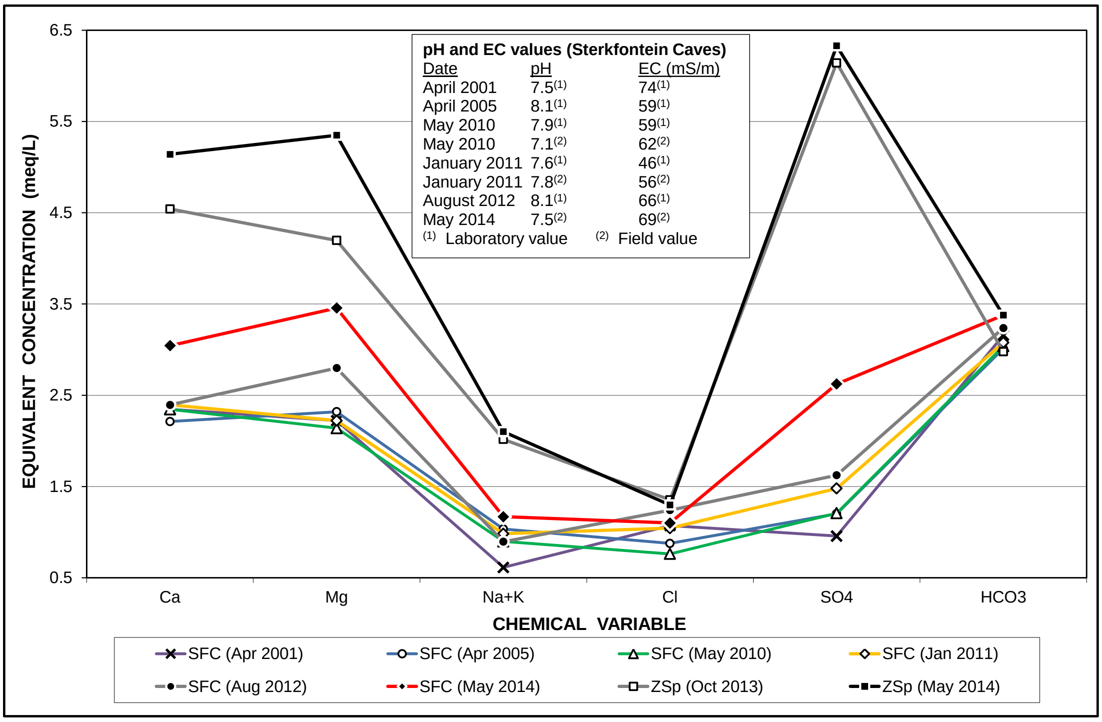


Figure 40 Characterisation of recent Sterkfontein Caves (SFC) and Zwartkrans Spring (ZSp) groundwater chemistry in relation to historical and regional groundwater chemistry



pH and EC values (Sterkfontein Caves)

Date	pH	EC (mS/m)
April 2001	7.5(1)	74(1)
April 2005	8.1(1)	59(1)
May 2010	7.9(1)	59(1)
May 2010	7.1(2)	62(2)
January 2011	7.6(1)	46(1)
January 2011	7.8(2)	56(2)
August 2012	8.1(1)	66(1)
May 2014	7.5(2)	69(2)

(1) Laboratory value (2) Field value

Figure 41 Graphical comparison of recent Sterkfontein Caves (SFC) and Zwartkrans Spring (ZSp) groundwater chemistry with historical cave water chemistry

The Piper diagram (**Figure 40**) shows the shift of the May 2014 composition away from the historical composition toward that of the Zwartkrans Spring groundwater. The Schoeller diagram (**Figure 41**) provides a quantitative measure of both the shift in recent cave and springwater chemistry and the muted impact reflected in the cave water composition. Despite the compositional shift in cave water chemistry described above, it is evident from **Figure 41** that the cave water maintains its MgCa–HCO_3 character typical of karst groundwater. The sharp contrast of the cave water chemistry with the Ca-SO_4 composition of the Zwartkrans Spring water is equally evident. The May 2014 springwater composition itself shows a shift toward a 'stronger' Ca–SO_4 character (**Figure 40**), reflecting the mine water impact on the groundwater leaving the Zwartkrans Compartment via this feature. This pattern and trend is explored in greater detail in **Figure 42**, which illustrates the compositional change of the water passing through the Zwartkrans Spring over time.

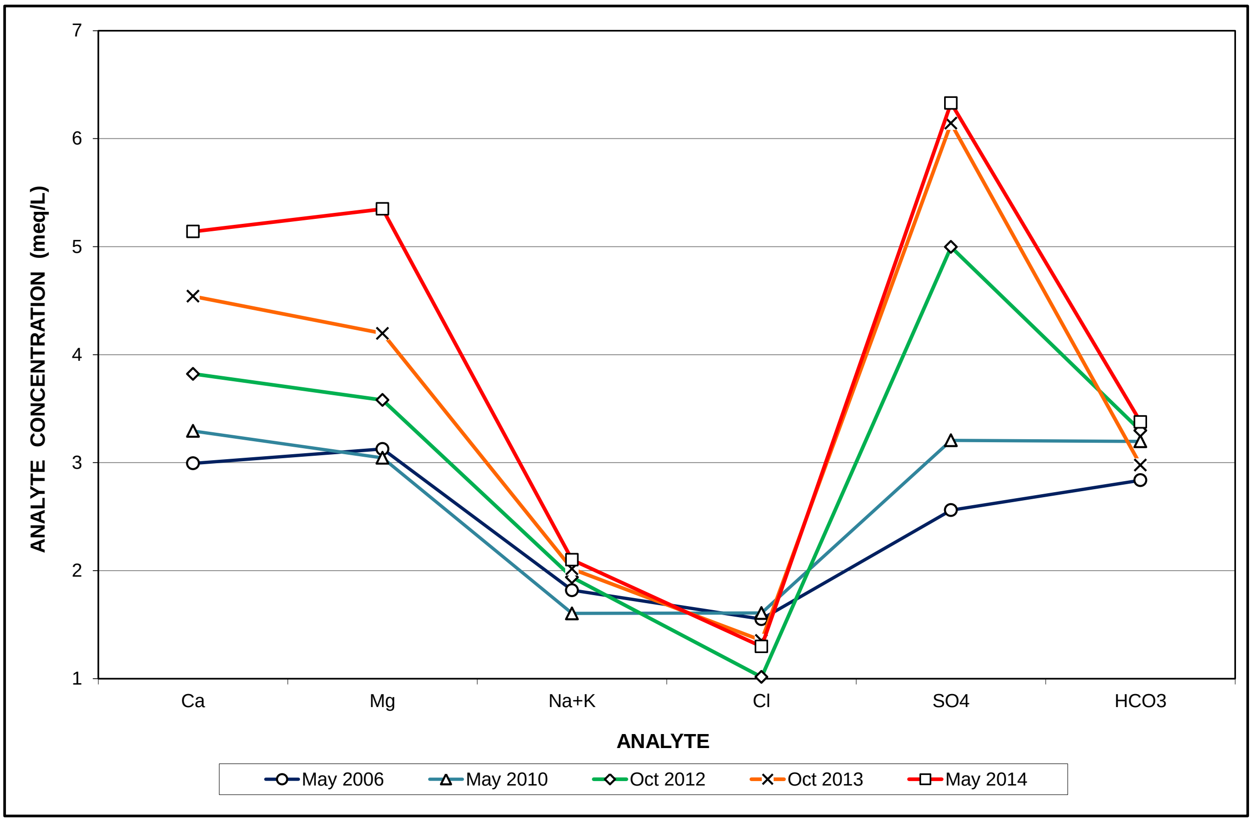


Figure 42 Temporal trend of Zwartkrans Spring water chemistry

The electrical conductivity of 69 mS/m of the cave water in May 2014 similarly exhibits a small (~5%) increase over the August 2012 value of 66 mS/m (text box, **Figure 41**). By comparison, the EC of 105 mS/m of the Zwartkrans Spring water reflects an increase of ~9% over the October 2012 value of 96 mS/m. The most recent SO_4 concentration in the cave water (126 mg/L) reflects an increase of ~62% over the August 2012 value of 78 mg/L. The current SO_4 level of 304 mg/L in the Zwartkrans Spring water, on the other hand, reflects an increase of ~21% over the October 2012 value of 240 mg/L.

The salinity record of the Zwartkrans Spring water recorded by the data logger installed at the spring is presented in **Figure 43**. The record period dates back to July 2013, and reveals a gradual increase through to March 2014, followed by a declining trend to May 2014 and, after a 2 to 3-month period of stable salinity, a resumption of the gradual increase to the end of record ca. September 2014.

The rate of increase amounts to 0.8 mS/m per month, and is matched by a similar rate of decrease (0.7 mS/m per month) for the declining limb of the graph. The peak ca. March 2014 is interpreted to reflect the passage of the poorer quality plume of groundwater in the Zwartkrans Compartment triggered by the 2009–'10 and 2010–'11 mine water impact through the spring. Hobbs (2013b) predicted this 'event' would occur in December 2013. The most recent rising salinity trend is interpreted to reflect the most recent (March to July 2014) mine water impact on the karst groundwater triggering a second flush of poorer (more saline) water through the aquifer toward the spring. The 'anomalies' evident in the salinity record (**Figure 43**) are associated with two flood events (on 31/01/2014 and 03/02/2014, respectively), on which occasions the Zwartkrans Spring was submerged beneath ~2 m of fresher (lowest EC of 17 mS/m) surface water.

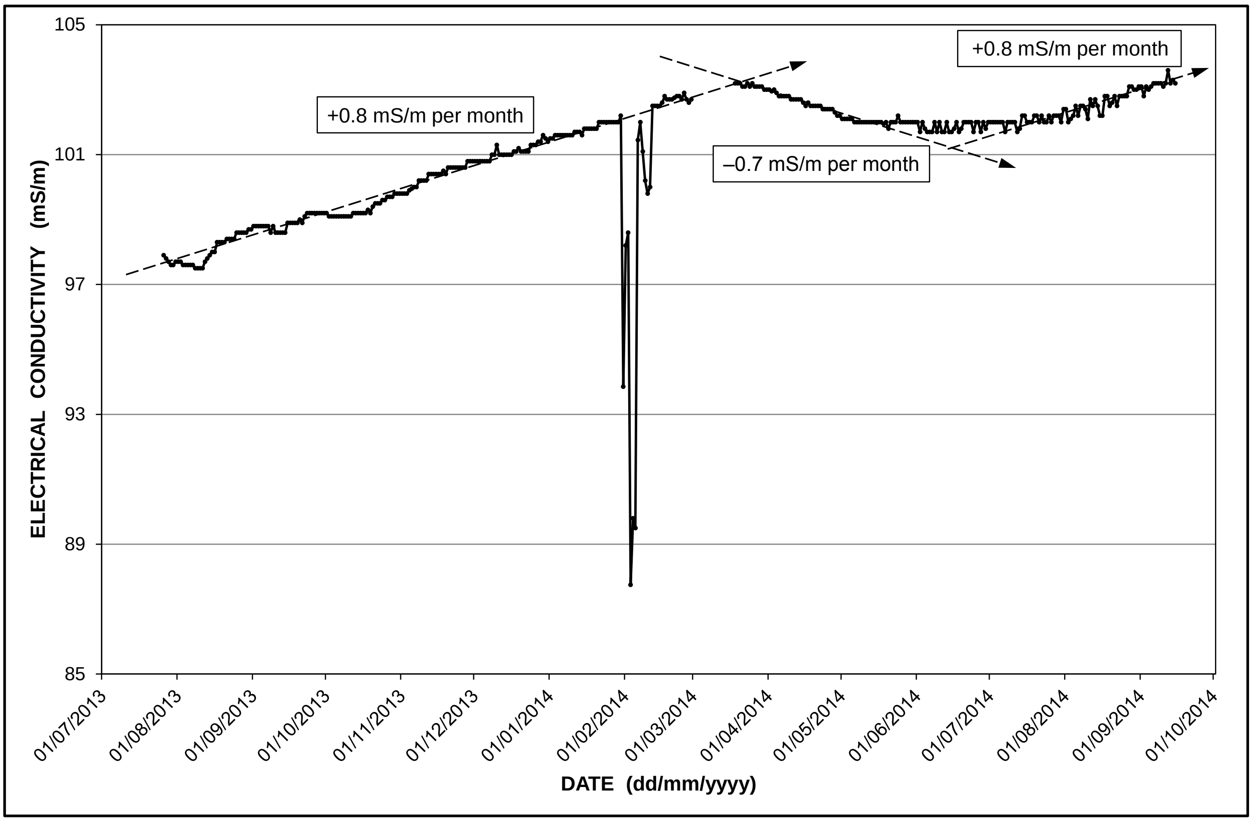


Figure 43 Pattern and trend of Zwartkrans Spring water salinity since mid-2013

It has been reported (Hobbs, 2011) that SO_4 comprises ~62% of the TDS concentration associated with Western Basin mine water, ~19% of the TDS typical of surface water in the receiving downstream environment, and <2% in the case of pristine karst groundwater. The SO_4:TDS ratio value therefore serves as an indicator of a mine water presence in receiving water resources. An evaluation of this ratio for the most recent cave water chemistry returns a value of 24%, and is therefore interpreted to reflect the influence of poorer quality surface water on the cave water chemistry. The marginal location of Sterkfontein Caves in the karst hydrosystem remains the most plausible explanation for the muted impact exhibited by the cave water chemistry compared to that of the springwater. Exploration borehole information suggests that the main flowpath (thalweg) of groundwater discharge through the Zwartkrans Compartment toward the spring coincides with the Bloubank Spruit drainage and the Riet Spruit tributary. This flowpath lies ~600 to 700 m to the north-west of the caves. It is postulated, therefore, that the location of the cave system on the south-eastern periphery of the main flowpath offers an explanation for the muted mine water impact on the Lake water chemistry.

The thalweg hypothesis finds support in the “flood induced pseudoplume” described by Ewers et al. (2012), which postulates the intrusion of contaminated groundwater from a flooded major conduit into peripheral porous karst strata during storm/flood events. Although the intruded water returns to the major conduit as groundwater levels recede following passage of the flood, it leaves behind contaminants in various settings in the intruded portion of the karst aquifer. These circumstances are more likely to prevail in the lower (downstream) reaches of a karst basin where conduits are convergent (Ewers et al., 2012), a hydrogeologic setting that suitably describes the location of the caves in the landscape. It is also worth noting that the caves straddle the contact between the chert-poor Oaktree Formation that forms the south-eastern (and oldest) lithostratigraphic margin of the Malmani Subgroup, and the overlying chert-rich strata of the Monte Christo Formation. The latter is generally associated with a more ‘productive’ aquifer, in contrast to the typically more ‘barren’ character of the Oaktree Formation. These circumstances underscore the distal location of the caves relative to a postulated subsurface thalweg. This is illustrated in **Figure 44**, which reflects a combination of the hydrophysical and hydrochemical dynamics that describe the relationship of the cave system hydrogeology with its broader hydro-environment along two transects.

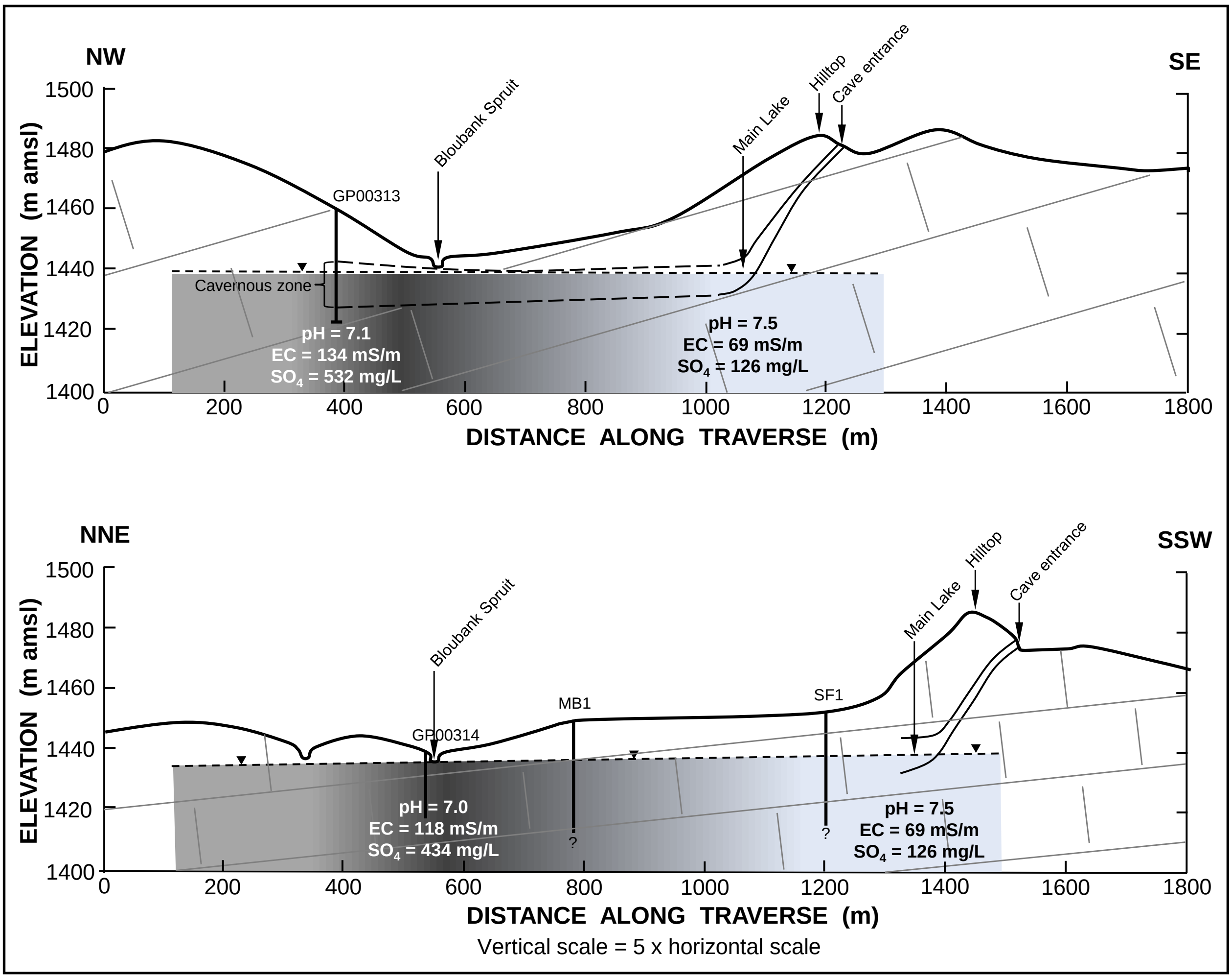


Figure 44 Schematic profiles through the Bloubank Spruit valley and Sterkfontein Caves illustrating the relationship between the water table and Lake elevations and the stream channel; lateral gradational shading reflects relative intensity of mine water impact on karst groundwater as shown by the most recent pH, electrical conductivity and sulphate values; see **Figure 39** for location of boreholes GP00313 and GP00314 in relation to the Caves

5.2.3 Broader Karst Environment

The quality of groundwater in the broader karst 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 45**. Except for the Zwartkrans Spring, which has already been discussed in greater detail in **Section 5.2.2**, the comparisons reveal the similarity of the recent springwater chemistries with the historical compositions as originally reported by Hobbs (2011).

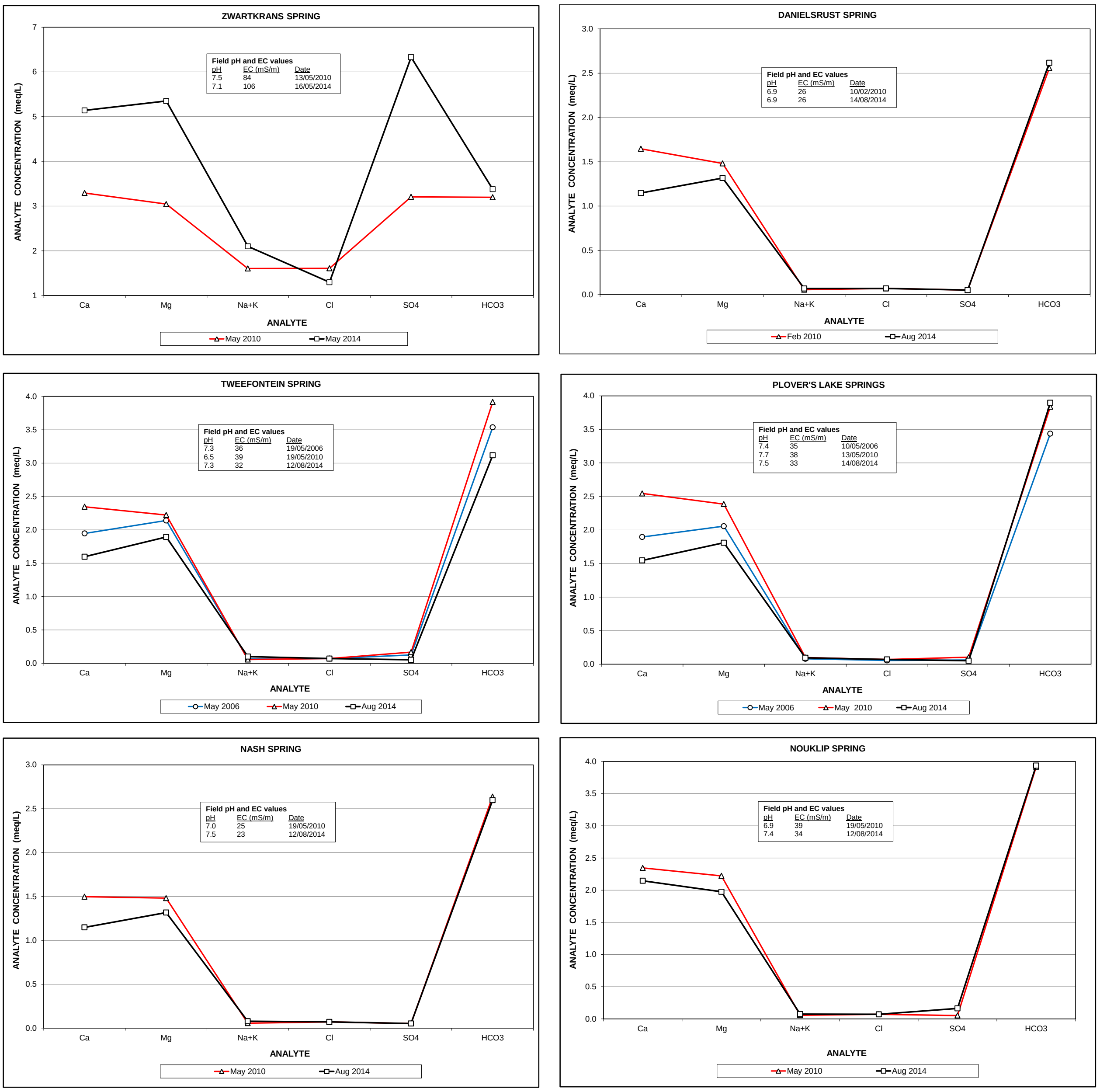


Figure 45 Graphical comparison of recent and historical springwater chemistry in the COH

6 CONCLUSIONS

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

The karst environment of a portion of the Zwartkrans Compartment in the south-western quadrant of the property continues to reflect a significantly poorer groundwater quality attributable to the ingress of mine water from a losing reach of the Riet Spruit. The resumption of uncontrolled mine water discharge in late-February 2014 has reversed the modest improvement generated by the containment of raw mine water discharge in the previous ~20 months since mid-2012. Although contained in late-July 2014, the continued monitoring programme will establish the extent and magnitude of the latest mine water impact particularly on the groundwater resources.

7 ACKNOWLEDGEMENTS

The compilation of this report would not have been possible without the contribution of DWS field personnel Messrs Theo Moolman and Nico de Meillon in the collection of field data. The services of the Georequests, Resource Quality Services and Hydstra Support personnel of the DWS in the provision of water resources monitoring data is also recognised and appreciated. Finally, the goodwill and cooperation of numerous landowners in granting permission to access their properties for the purpose of collecting water resource data, is gratefully acknowledged.

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ANNEXURE A

QUANTIFICATION OF STREAM FLOW LOSS RATE IN THE RIET SPRUIT

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	16	14
Minimum	11.9	0.0	6.6	35.3	19.6
Mean	26.3	8.2	18.1	66.0	34.2
Median	25.8	7.1	17.3	67.3	35.4
Maximum	43.7	20.0	32.0	95.0	46.6

(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 SALINITY 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 (–log10α_{H+})	EC (mS/m)	SO$_4^{(1)}$ (mg/L)	TDS$^{(2)}$ (mg/L)	pH (–log10α_{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	6.3
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	2 166	2 559	4.2
Median	339	2 215	2 610	4.1	350	2 297	2 696	4.0
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	16/05/2014	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	94.8	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	–48.5	–60.0	–61.0	–42.1	–61.5	–61.4	–69.3
ORP	mV	–14.4	–17.1	–20.3	–10.6	–16.9	–20.1	–22.0
Calcium	mg Ca/L	103	23	31	68	32	43	23
Magnesium	mg Mg/L	65	16	22	32	23	24	16
Sodium	mg Na/L	47	1.3	1.9	23	1.6	1.4	1.5
Potassium	mg K/L	2.2	<1	<1	1.9	1.2	<1	<1
Chloride	mg Cl/L	46	<5	<5	29	<5	<5	<5
Sulphate	mg SO_4/L	304	<5	<5	127	<5	7.8	<5
Total alkalinity	mg $CaCO_3$/L	169	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	9.1	0.29	0.3	3.9	7.7	5.6	0.41
Ortho-phosphate	mg PO4/L)	0.49	<0.2	<0.2	<0.2	0.27	0.5	0.27
Silica	mg Si/L	6.2	5.2	5.8	5.7	4.8	4.9	5
Iron (total)	mg Fe/L	0.04	<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