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 2013 TO MARCH 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 fourth such report. It expands on the third status report, which covers the mid-term period April to September 2013, by covering the full-term monitoring period April 2013 to March 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 re-commencement of uncontrolled mine water discharge from the mine area in 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 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 third highest in the ~40-year record for this station.

- The re-commencement of uncontrolled mine water discharge from the mine area in mid-February 2014 followed a period of ~20 months since mid-2012 during which effective control and management of mine water was effected by the refurbished and upgraded high density sludge (HDS) mine water treatment plant in terms of capacity and operational efficiency.

- Synoptic discharge measurements at two stations in the lower reach of the Riet Spruit confirmed earlier results regarding losses of mine water impacted surface water to the karst aquifer of the Zwartkrans Compartment. Representing allogenic recharge of the karst aquifer, the impact of the poorer quality water on the natural dolomitic groundwater is being manifested much more slowly.

- 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 influenced by the re-occurrence of raw mine water discharge from the mine area as a consequence of decant in excess of the installed treatment capacity provided by the HDS plant.

- The water level of the Main Lake in Sterkfontein Caves reflects minor fluctuations (<0.5 m) around a mean elevation of ~1 438.5 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 AMD 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 ~14% and ~3%, respectively, over the October 2013 values of 92 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.

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 ~1 750 mg SO_4/L will definitely impact on the potability of groundwater-based water supplies in the area effected. Although the most recent (March 2014) monitoring results suggest a reduction in SO_4 levels in the effected area, the impact that the recommencement of uncontrolled mine water discharge in February 2014 will have on this trend remains to be established.

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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)
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 area (**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). This document represents the fourth such report, which expands on the mid-term monitoring report for the period April to September 2013 (Hobbs, 2013b) by covering the full-term period April 2013 to March 2014.

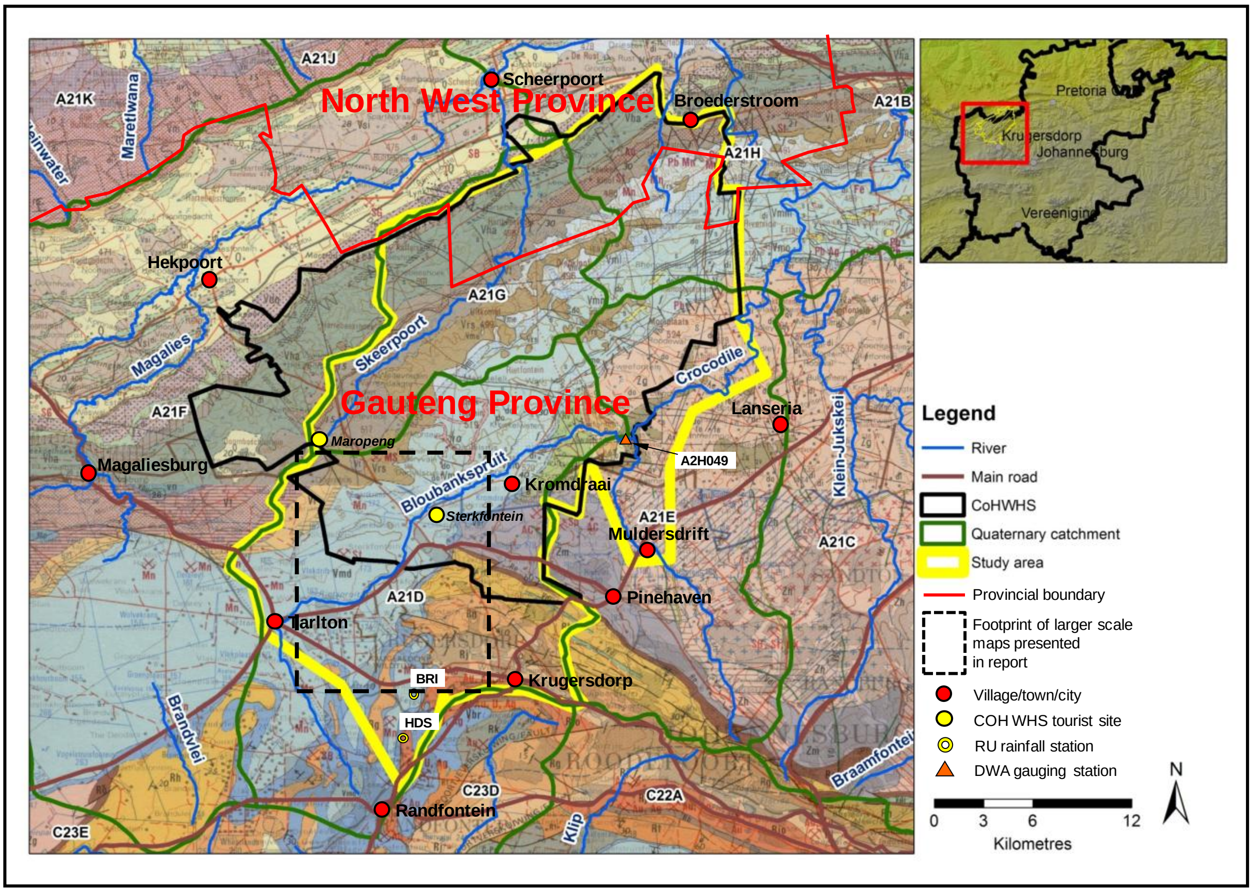

Figure 1 Definition of the study area in regard to the regional geology, surface water drainages, quaternary catchments and other geographic locations for orientation

2 TIMELINE OF KEY EVENTS

It is 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 resumption of uncontrolled mine water decant in February 2014. This is directly attributable to the exceptional rainfall experienced in the region in February and March 2014 (**Section 3**). It follows a period of ~20 months of successful curtailment of raw mine discharge to the environment following the upgrade, expansion and commissioning of the refurbished HDS mine water treatment plant in June 2012 (**Figure 2**).

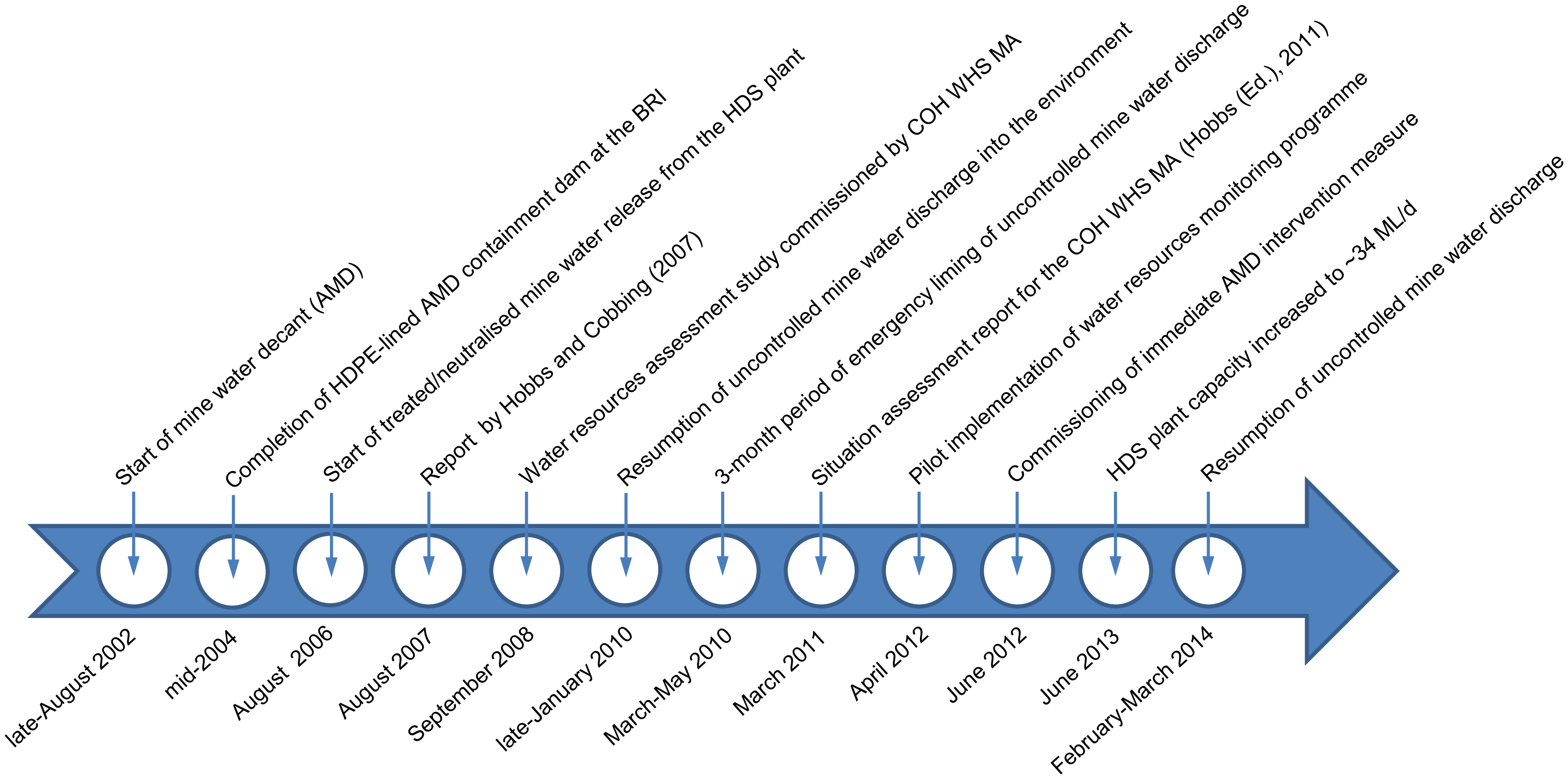

Figure 2 Updated timeline of events relevant to this report

3 RAINFALL

The monthly precipitation record for the period October 2008 to March 2014 of the Rand Uranium/Gold 1 (RU/G1) 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 the observation (Hobbs, 2013b) that monthly rainfall to the north of the continental divide (e.g. at Sterkfontein Caves) is generally ~12% 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 by the DWA. Data for the period June 2010 to March 2014 were provided by the DWA. An analysis of the common monthly rainfall record (n = 46) for the HDS and Sterkfontein Caves stations indicates a good correlation ($R^2 = 0.91$) (**Figure 5**).

Of particular significance is the similarity reflected by the 2010–'11 and 2013–'14 wet season records (**Figure 4**). Some 55% (396 mm) of the 2013–'14 summer rainfall at Sterkfontein Caves (721 mm) occurred in February and March. These circumstances explain the re-commencement of uncontrolled mine water discharge from the mine area in 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**) was insufficient to contain and treat the volume of mine water issuing from the flooded underground mine workings following recharge.

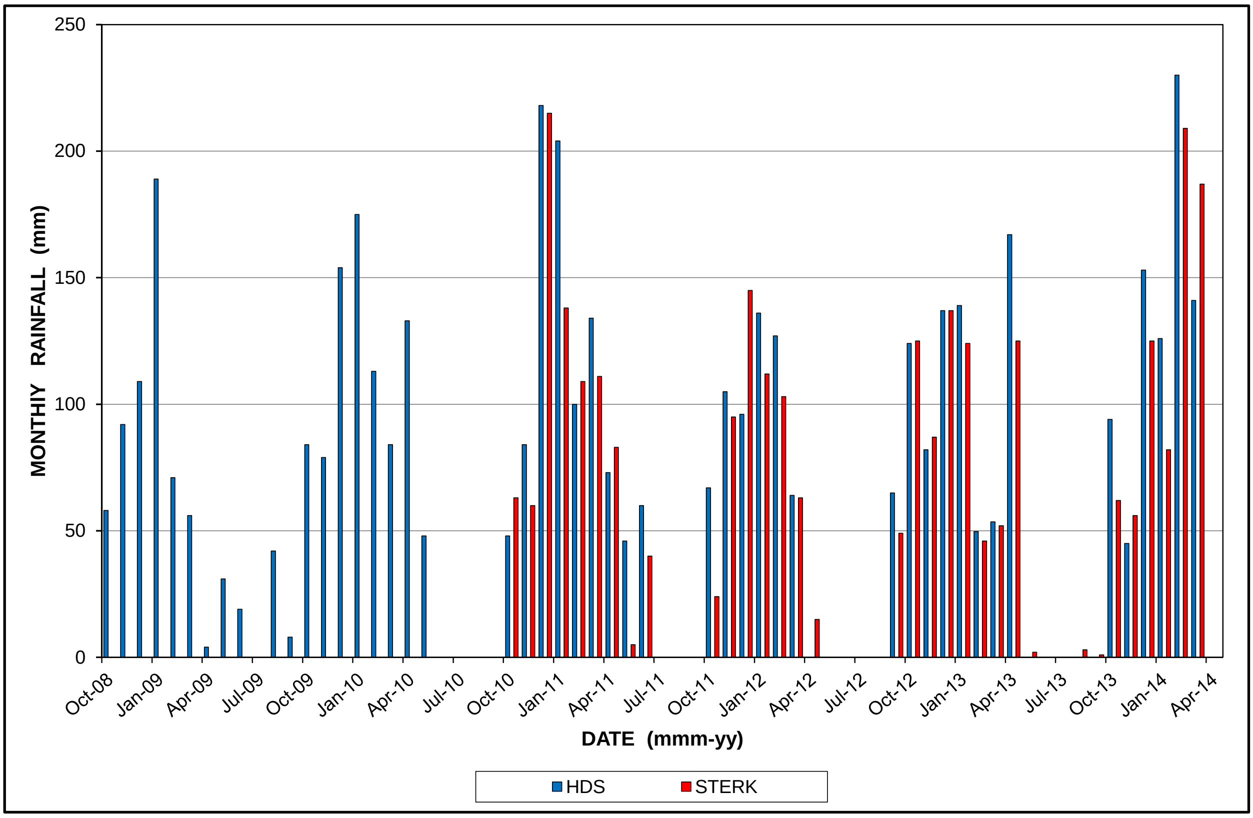

Figure 3 Monthly precipitation at the RU/G1 rainfall monitoring station HDS in the period October 2008 to March 2014, also showing the available record for the Sterkfontein Caves station

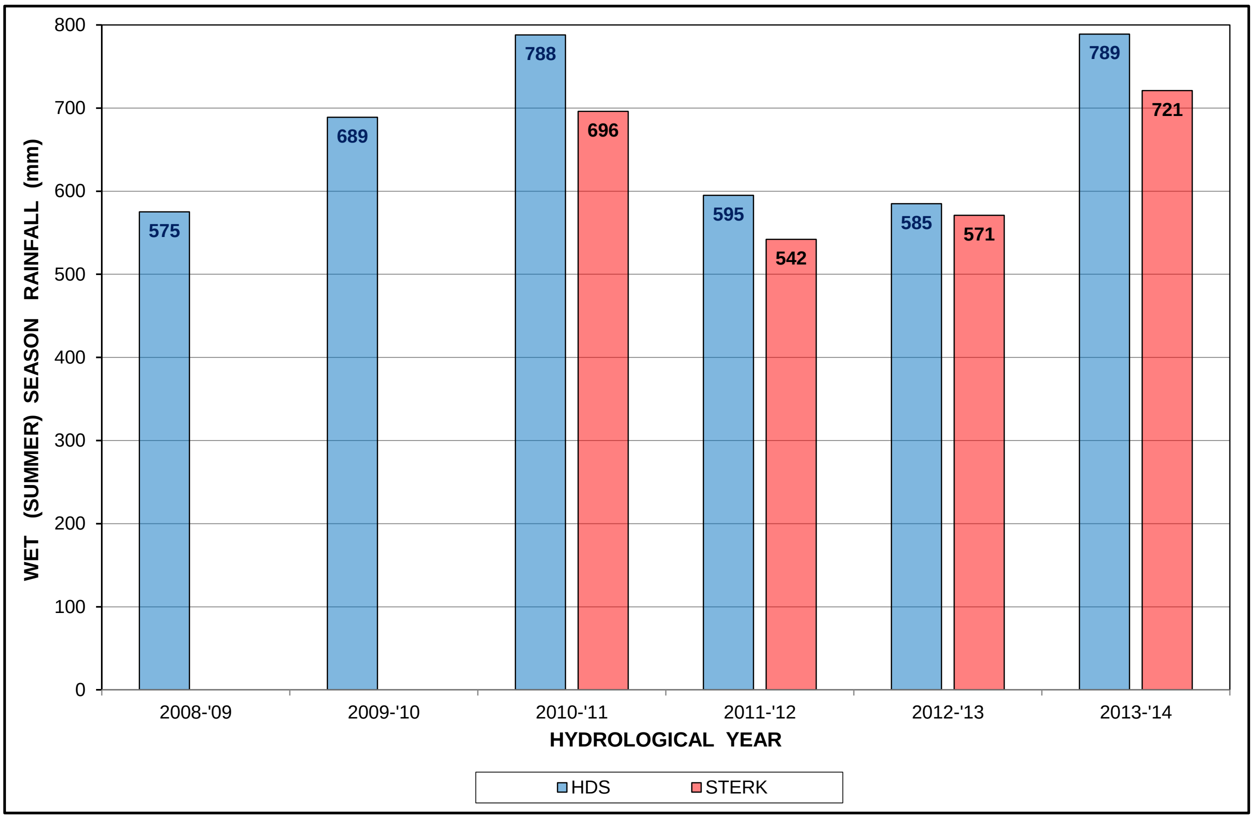

Figure 4 Total wet season (summer) rainfall at the HDS facility in the past six hydrological years, also showing the comparison with that for the available Sterkfontein Caves record

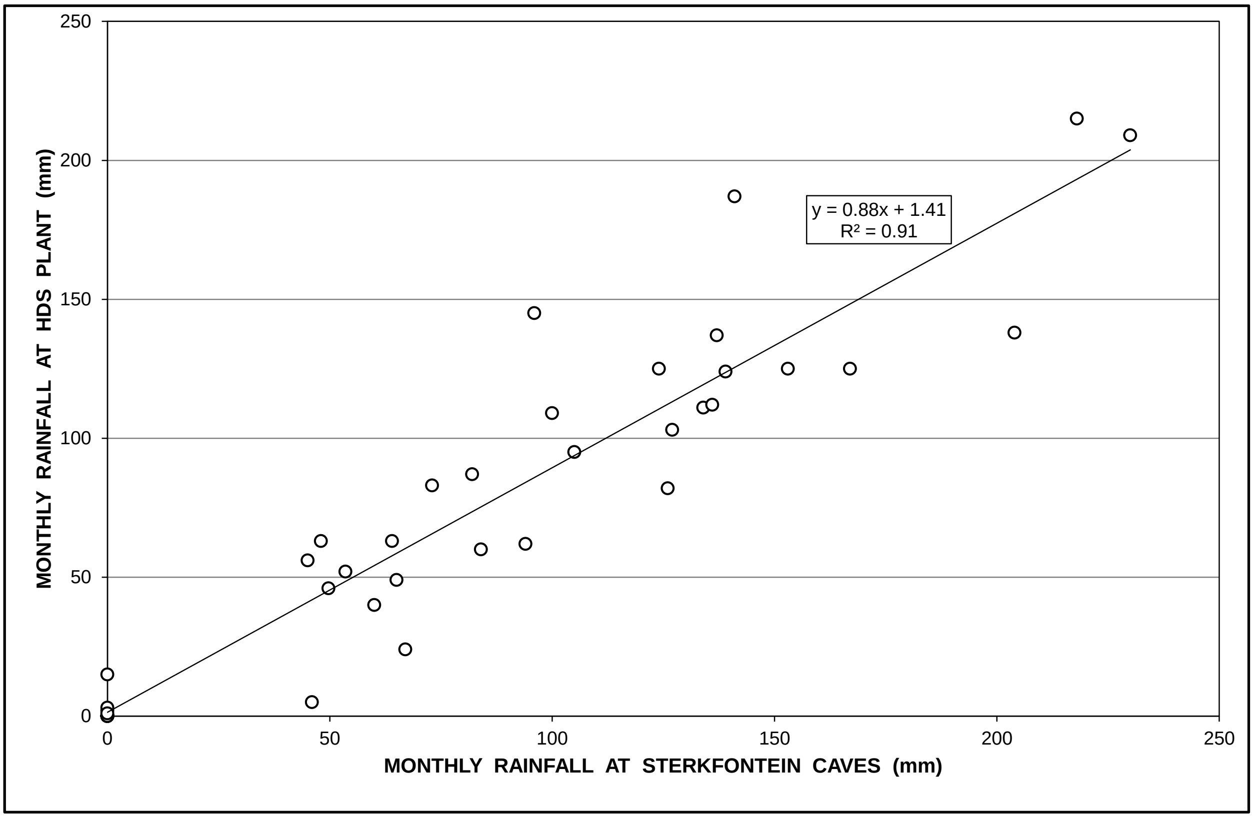

Figure 5 Correlation of monthly rainfall at Sterkfontein Caves with that at the HDS facility in the mine area

4 SURFACE WATER HYDROLOGY

4.1 Physical Hydrology

4.1.1 Surface Water Discharge

The discharge of the Bloubank Spruit system is gauged by the DWA 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 March 2014

Variable	**Month**											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Count (n)	40	40	41	41	42	42	41	40	41	41	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	1.176	0.974	0.948	0.954	0.910	0.798
Mean	1.809	1.810	2.223	2.680	2.647	2.964	2.313	2.185	2.004	1.972	1.850	1.726
Median	1.546	1.710	1.884	2.409	1.949	2.461	1.920	1.799	1.696	1.637	1.555	1.386
95%ile	3.882	2.872	4.539	5.460	6.472	8.265	4.625	4.931	3.642	3.696	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	1.245	1.173	0.943	0.894	0.821	0.857
CoV (%)	50.5	43.3	49.8	73.9	74.1	75.6	53.8	53.7	47.0	45.3	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) shown in **Figure 6** indicates that the three prior to last complete hydrological years witnessed the 2nd, 3rd and 4th highest runoff (59.1, 50.0 and 44.9 Mm^3 after the 66.9 Mm^3 of the 1977–'78 hydrological year) in the historical record of this catchment. By comparison, the most recent complete hydrological year (2012–'13) reflects a modest discharge of only ~33.5 Mm^3 commensurate with the modest contemporaneous summer rainfall of ~580 mm (**Figure 4**).

The instantaneous monthly flow pattern at station A2H049 for the complete record October 1972 to March 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 data record generated at station A2H049 (**Figure 7**) reveals the exceptionally high discharge experienced in February and March 2014. The latter is the third highest in the historical record for this station, and reflects the abnormally wet 2013–'14 summer (**Figure 4**) experienced in the region. These circumstances are also reflected in the re-commencement of uncontrolled mine water discharge from the mine area in February 2014.

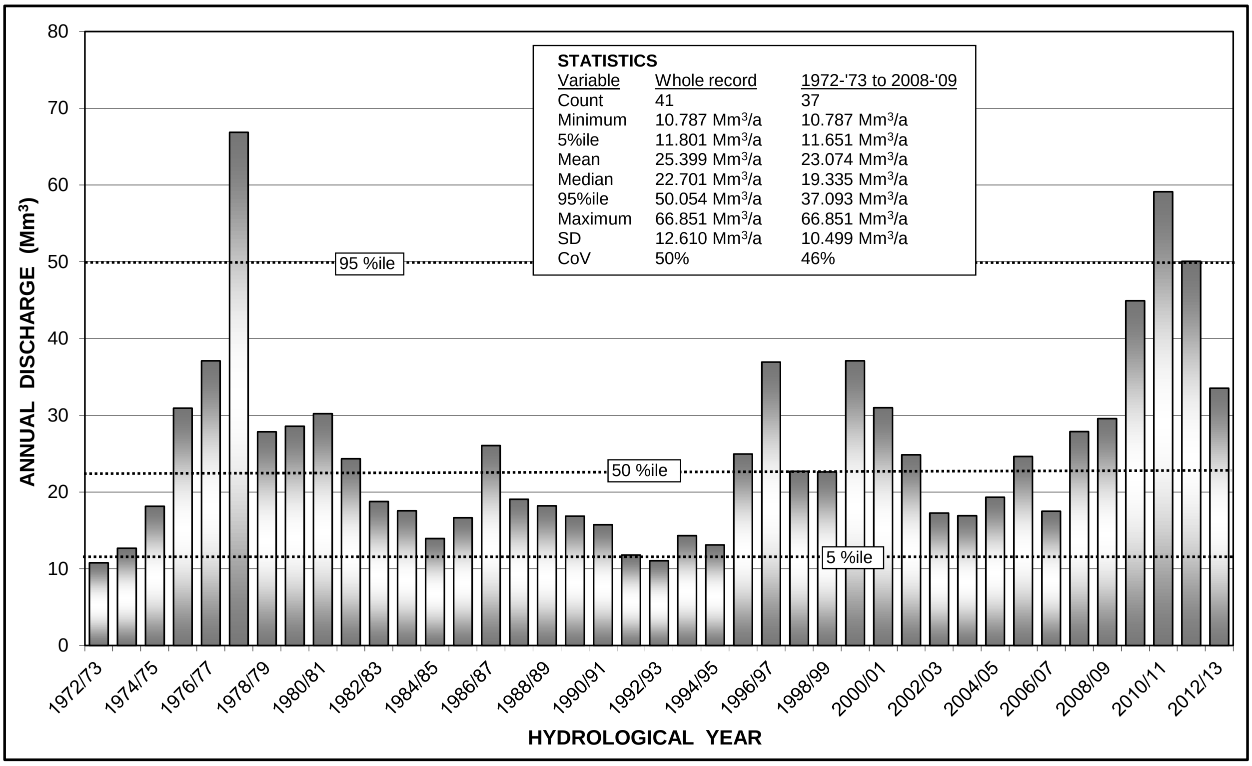

Figure 6 Graph of Bloubank Spruit annual (a_h) discharge gauged at station A2H049 in the period October 1972 to September 2013

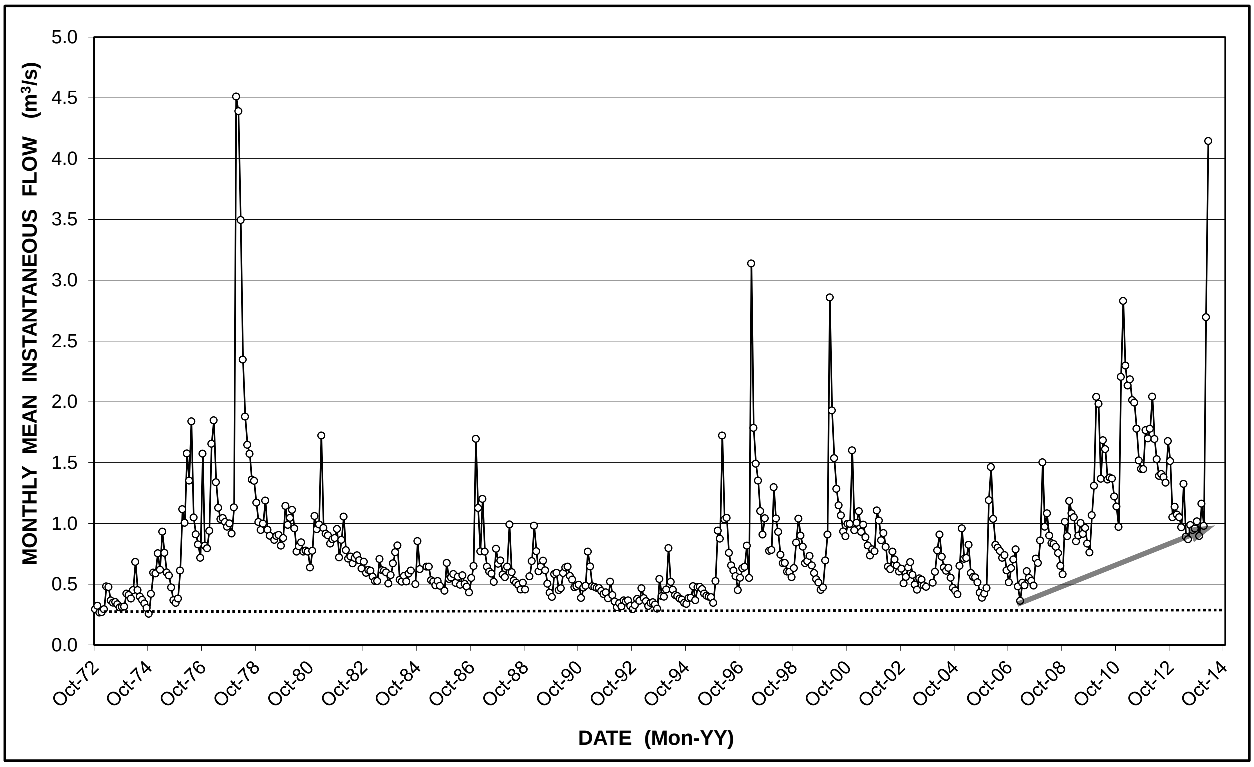

Figure 7 Long-term monthly hydrograph of the Bloubank Spruit at station A2H049 for the period October 1972 to March 2014

4.1.2 Surface Water Fluxes

In-stream synoptic discharge measurements (SDMs) made on 31 occasions (**Table 2**) at stations F11S12 and MRd (**Figure 8**) quantify and elucidate the magnitude of surface water loss to the karst aquifer. The results of the SDMs are illustrated in **Figure 9**. Prior to the 2009–'10 summer, station MRd witnessed surface flow only under exceptional discharge conditions[1], when under 'normal' circumstances all of the discharge entering the Riet Spruit via the Tweelopie Spruit was lost primarily to recharge of the karst aquifer before reaching this location. This is exemplified in the measurements recorded on 09 and 22 September 2009 respectively (**Table 2** and **Figure 9**).

Table 2 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
Count	31	31	31	16	13
Minimum	11.9	0.0	6.6	35.3	19.6
Mean	26.4	8.5	17.9	66.0	34.2
Median	25.8	7.3	15.7	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

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[1] Caused by excessive and uncontrolled mine water discharge from the mine area together with excess surface runoff associated with very high rainfall events.

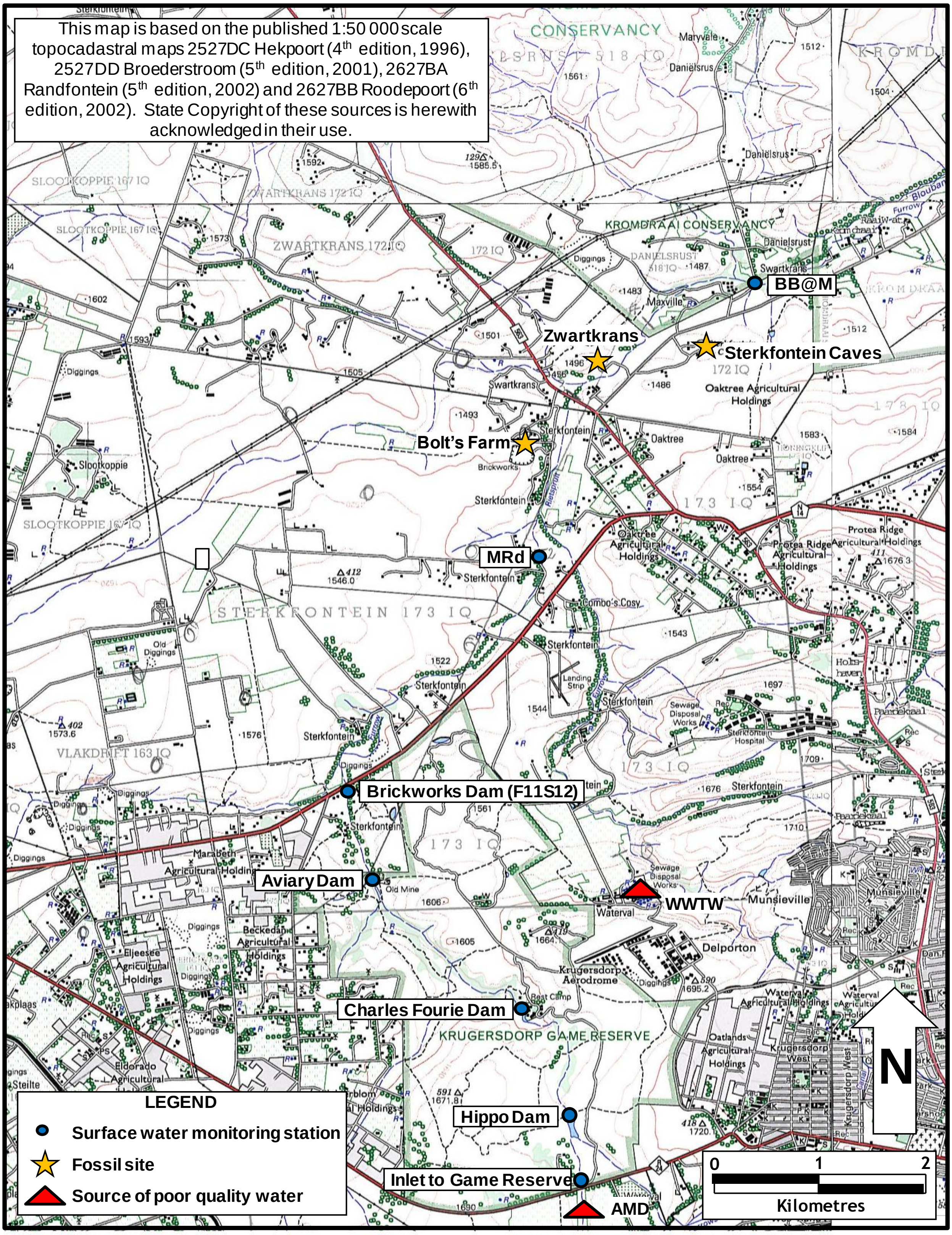


Figure 8 Locality map of surface water quantity and quality monitoring stations

The updated graphs of SDM results presented in **Table 2** and **Figure 9** confirm previous measurements that indicate an ingress value of ~14 ML/d representing a linear absorptive capacity of ~41 L/s/km of stream reach.

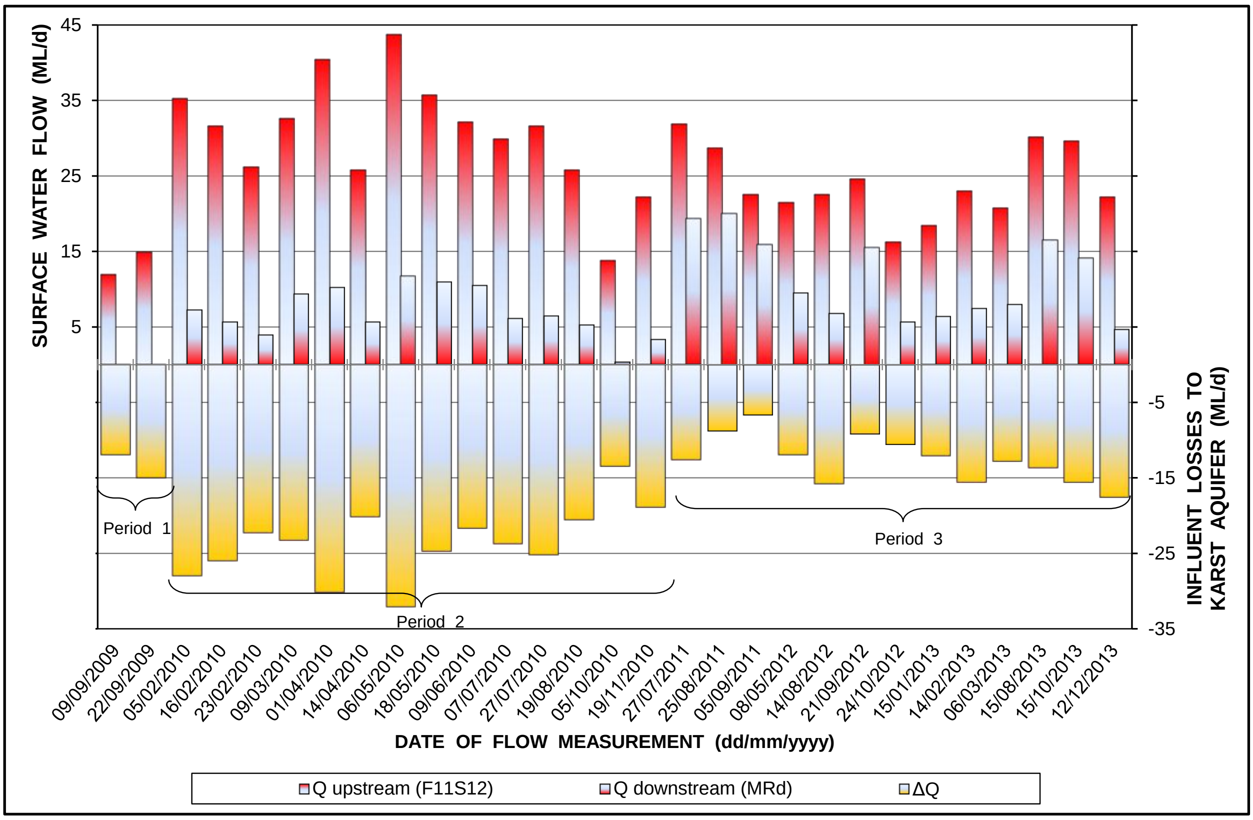


Figure 9 Graph of stream flow and losses to the karst aquifer in the lower Riet Spruit valley

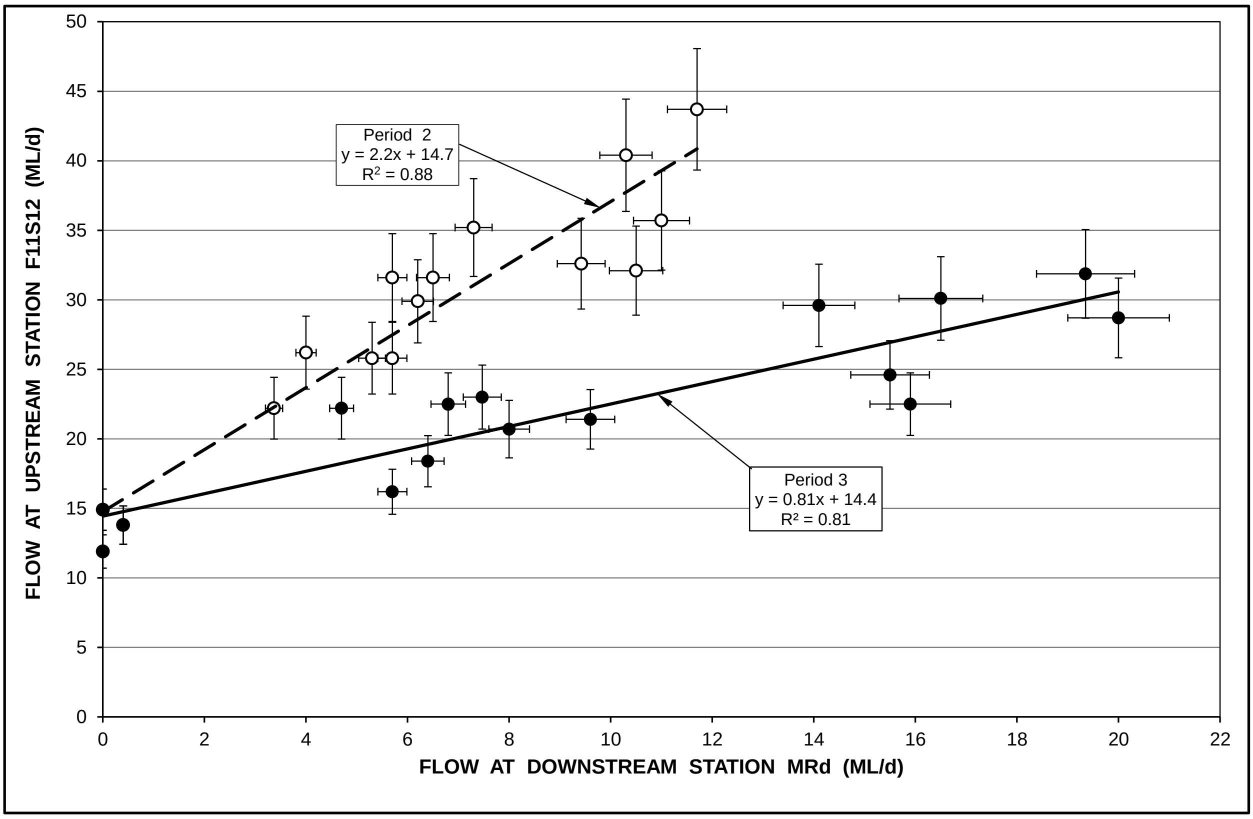


Figure 10 Correlation of stream flow at stations F11S12 and MRd in the Riet Spruit valley (respective regression lines explained in text and **Figure 9**), with error bars denoting ±10% at F11S12 (vertical) and ±5% at MRd (horizontal)

4.2 Chemical Hydrology

4.2.1 Tweelopie Spruit and Riet Spruit

The salinity, 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 **Table 3** are graphed in **Figure 11** (EC), **Figure 12** (pH) and **Figure 13** (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 13** reflects the elevated contemporaneous SO_4 levels (>2 000 mg/L) in this water. The improvement since mid-2012 is equally evident.

Table 3 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 ($-\log_{10}[H^+]$)**	**EC (mS/m)**	**$SO_4^{(1)}$ (mg/L)**	**$TDS^{(2)}$ (mg/L)**	**pH ($-\log_{10}[H^+]$)**
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
Count	30	30	30	30	29	29	29	29
Minimum	219	1 329	1 686	2.6	219	1 329	1 686	2.5
Mean	336	2 190	2 584	4.5	336	2 190	2 584	4.2
Median	349	2 285	2 684	4.1	353	2 320	2 72	3.9
Maximum	40816	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

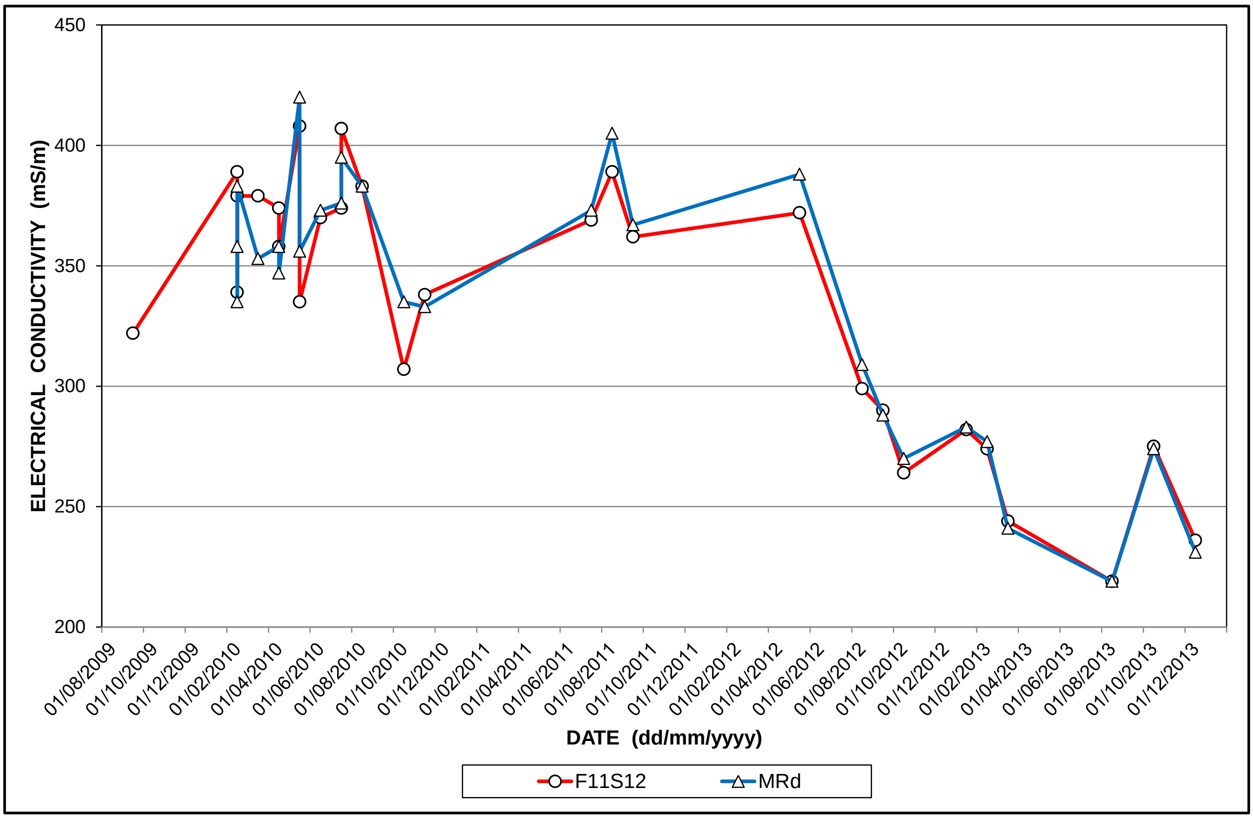


Figure 11 Pattern and trend of electrical conductivity of surface water at stations F11S12 and MRd on occasion of the SDMs reported in **Table 3**

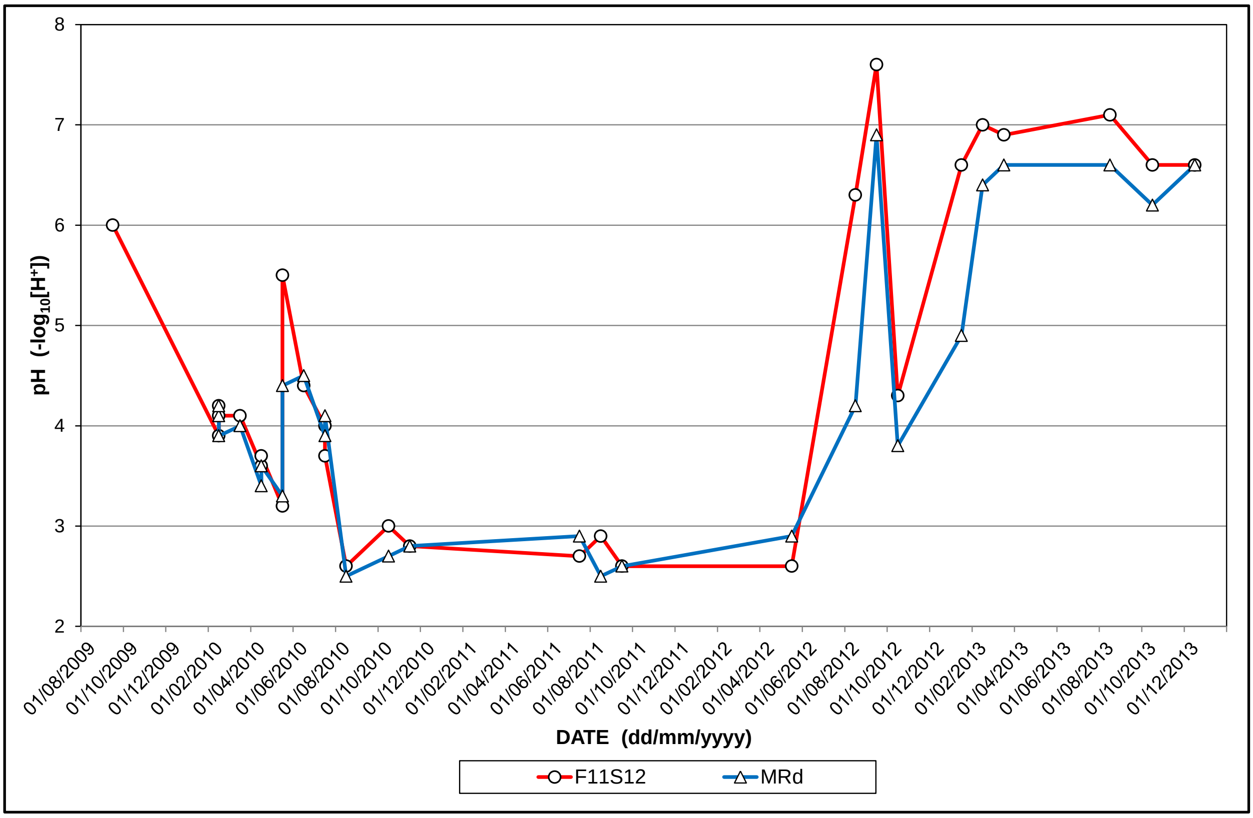


Figure 12 Pattern and trend of pH of surface water at stations F11S12 and MRd on occasion of the SDMs reported in **Table 3**

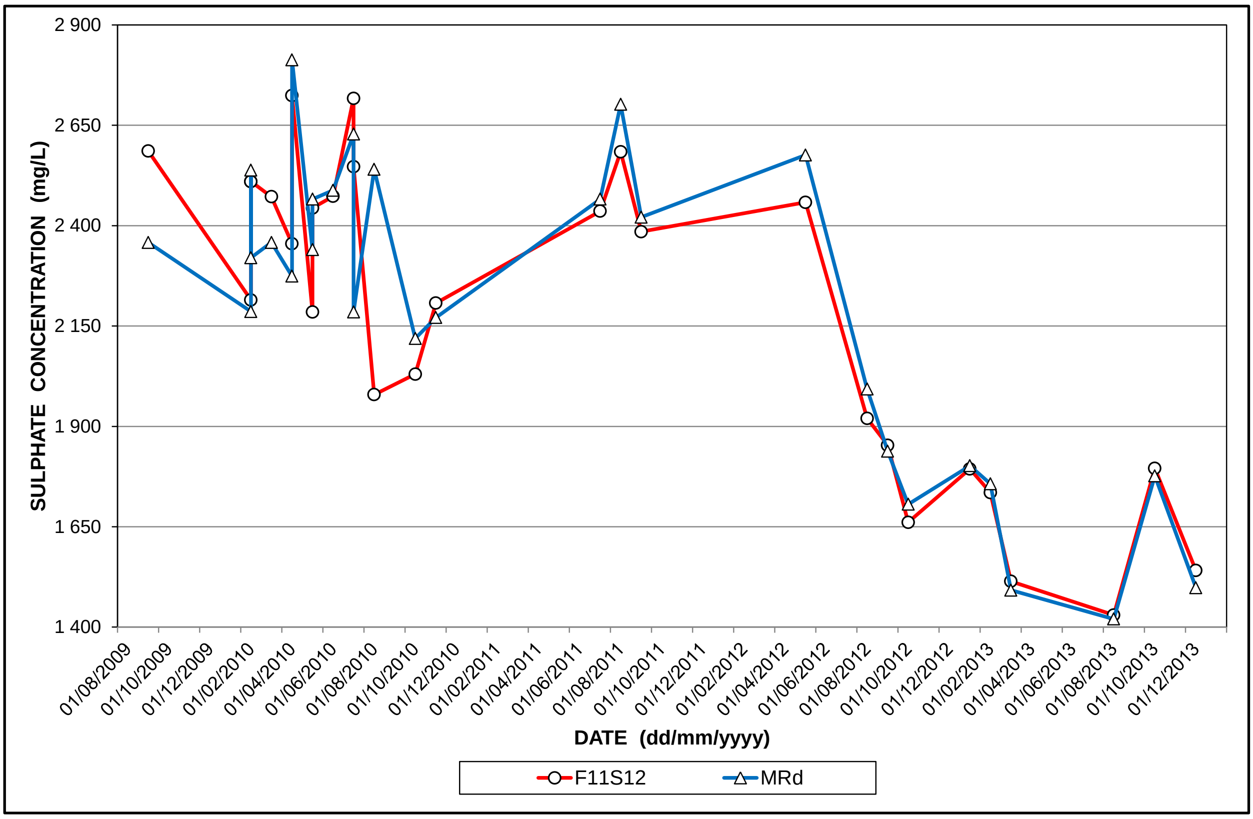


Figure 13 Pattern and trend of SO_4 in surface water at stations F11S12 and MRd on occasion of the SDMs reported in **Table 3**

4.2.2 Bloubank Spruit

A summary of the statistics that characterise the surface water chemistry recorded by the DWA at flow gauging station A2H049 at the lower end of the Bloubank Spruit system is presented in **Table 4**.

Table 4 Statistical analysis of Bloubank Spruit water chemistry data associated with station A2H049 for the period May 1979 to March 2014

Variable	**Statistical Parameter**							**SANS (2011a)(1)**
	n	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**	
pH (–log$_{10}$[H+])	960	7.4	—	8.2	8.5	0.3	4	5.0–9.7
EC (mS/m)	1 065	51.1	60.1	60.5	68.7	7.2	12	<170
TDS (mg/L)	1 065	355.2	435.9	443.3	487.2	54.3	12	<1 200
Ca (mg/L)	882	42.7	53.5	53.6	61.4	7.9	15	n.s.
Mg (mg/L)	880	25.1	32.3	32.4	37.7	4.6	14	n.s.
Na (mg/L)	874	10.0	21.9	21.8	33.4	7.0	32	<200
K (mg/L)	880	0.7	1.9	1.8	3.5	0.9	47	n.s.
Cl (mg/L)	886	19.9	31.7	32.1	40.7	5.9	19	<300
SO_4 (mg/L)	883	65.1	89.0	83.5	128.8	33.9	38	<500
HCO_3 (mg/L)	877	147.2	191.7	197.3	219.4	24.5	13	n.s.
NO_3+NO_2 (mg N/L)	917	2.996	4.545	4.355	6.352	1.739	38	<11
PO_4 (mg P/L)	956	0.005	0.093	0.054	0.316	0.105	114	n.s.
Si (mg/L)	956	5.08	5.99	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 (%)	834	–1.5	3.6	3.6	9.6	3.9	109	±5

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

The median and mean electrical balance values afford the analytical results a high degree of confidence. The 95%ile value of 9.6% suggests the increasing inaccuracy of analyses at higher SO_4 concentrations. None of the variables recorded in **Table 4** exceed the respective SANS (2011a) health-related limit where specified.

The surface water quality monitoring carried out at the Nedbank Olwazini Estate complex (station NOE in **Figure 14**) 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 Mogale City Local Municipality (MCLMs) Percy Stewart Wastewater Treatment Works (WWTW) and the DWAs water quality data for upstream monitoring stations 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, discounting the ephemeral 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 December 2013 (5 years) are given in **Table 5**. The temporal pattern of the pH and bacterial variables is illustrated in **Figure 15**.

Table 5 Analysis of Bloubank Spruit water nutrient and bacterial content at the NOE property in the period January 2009 to December 2013

Variable / Analyte	**Statistical Parameter**								**SANS (2011a)(1)**	**TWQR(2) TWQR(3)**
	n	**1%ile**	**5%ile**	**Mean**	**Median**	**95%ile**	**SD**	**CoV (%)**		
pH ($-\log_{10}[H^+]$)	56	—	7.5	—	8.0	8.6	0.3	4	5.0–9.7	—
NO_3 (mg N/L)	49	—	3.8	8.0	7.3	**14.9**	3.7	46	<11	—
O-PO_4 (mg P/L)	56	—	0.1	0.4	0.3	1.0	0.3	84	n.s.	—
COD (mg/L)	41	—	9.0	58.8	49.0	174.0	51.3	87	n.s.	—
N:P (ratio)(4)	48	—	7.3	30.4	24.2	69.6	21.7	71	—	—
Faecal coliforms (cfu/100 mL)	56	**38**	**55**	**640**	**304**	**2 310**	1 194	171	≤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 5**). The association of higher faecal coliform concentrations with rainfall is evident in **Figure 15**. This observation suggests that significant municipal wastewater impacts on surface water bacteriological quality are driven by rainfall. The mean and median faecal coliform values of 640 and 304 cfu/100 mL respectively (**Table 5**), 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 located further upstream (**Figure 14**). The lower NOE values fit the decreasing pattern 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 at the NOE position in the Bloubank Spruit system. This situation undoubtedly worsens progressively with distance upstream.

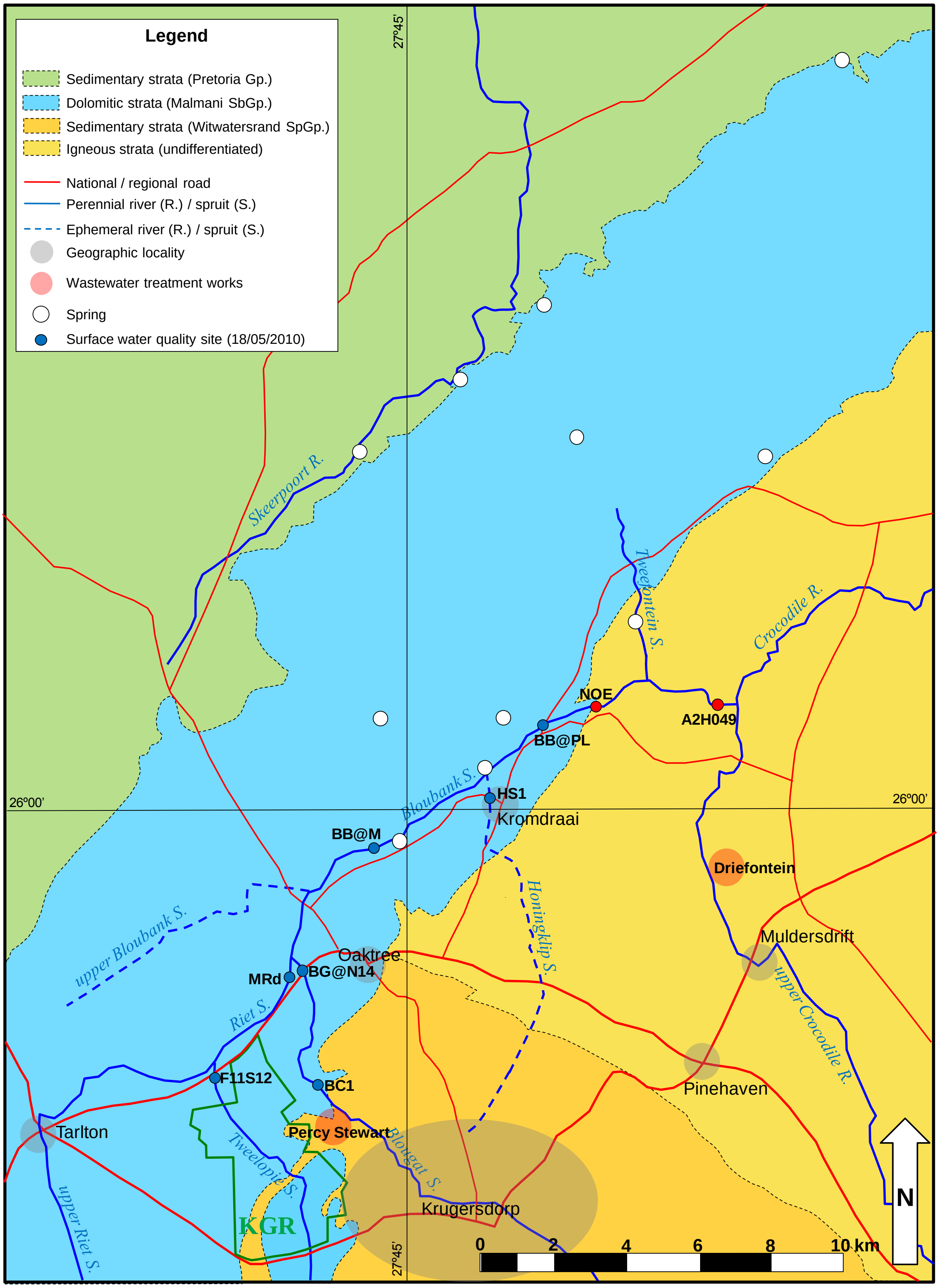


Figure 14 Surface water quality sampling sites in the study area

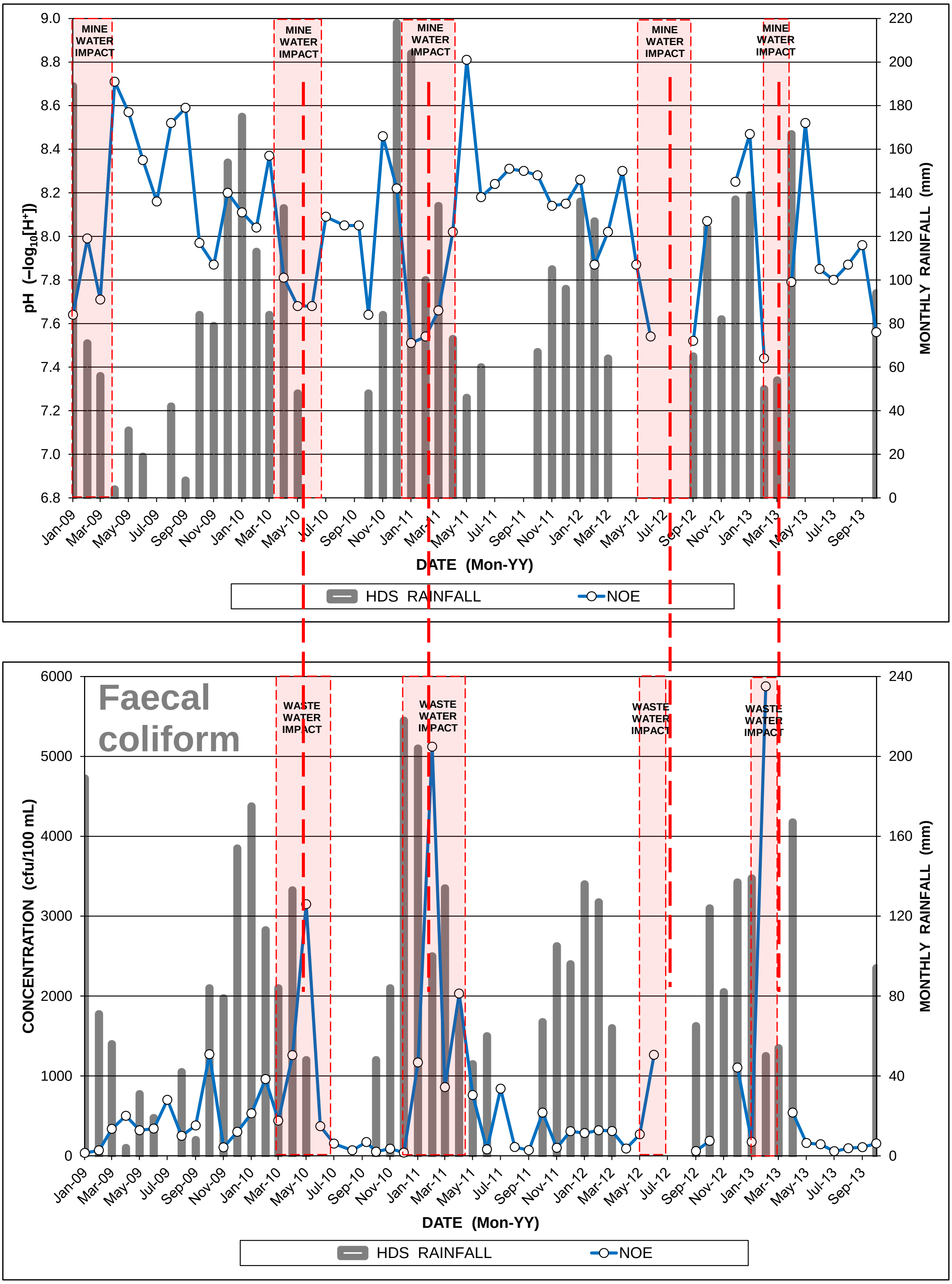


Figure 15 Correlation of pH (top) and faecal coliform bacteria (bottom) levels in the Bloubank Spruit at the NOE property with rainfall in the headwaters of the catchment

4.3 Salt Load

4.3.1 Riet Spruit

The combination of quantified stream flow losses (**Table 2**) and associated TDS levels and sulphate concentrations (**Table 3**) between stations F11S12 and MRd, allows for the derivation of the TDS and SO4 loads lost to the karst aquifer as illustrated in **Figure 16** and **Figure 17**, respectively.

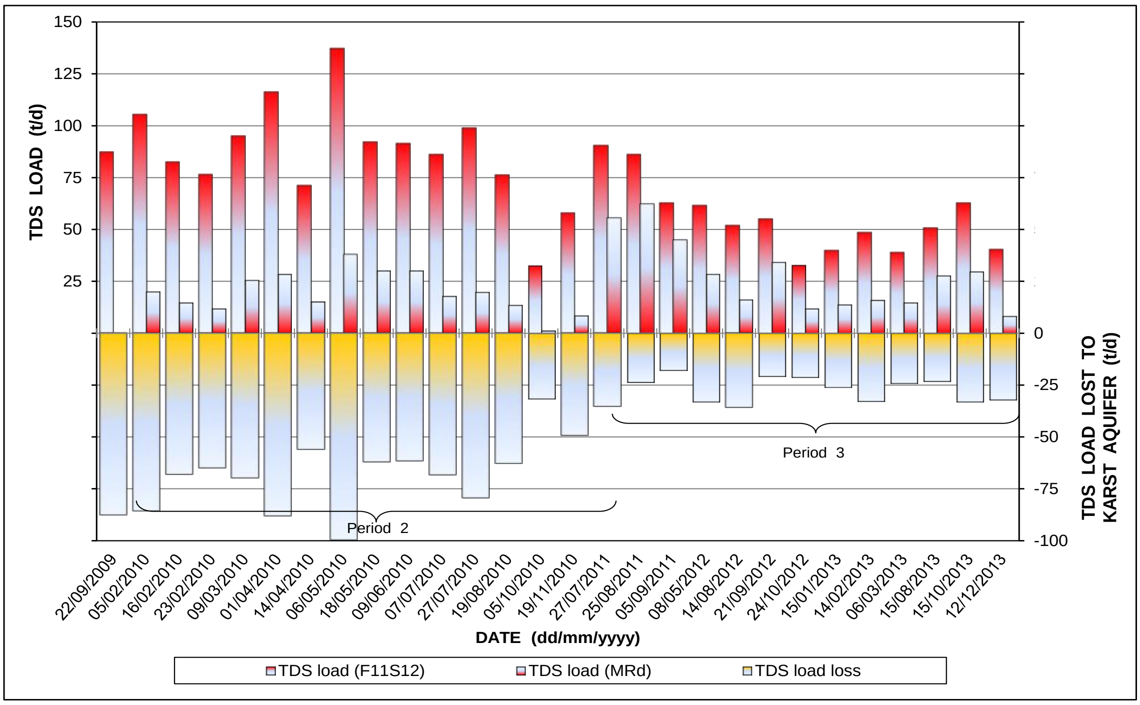


Figure 16 Graph of surface water TDS load lost to groundwater in the lower reach of the Riet Spruit

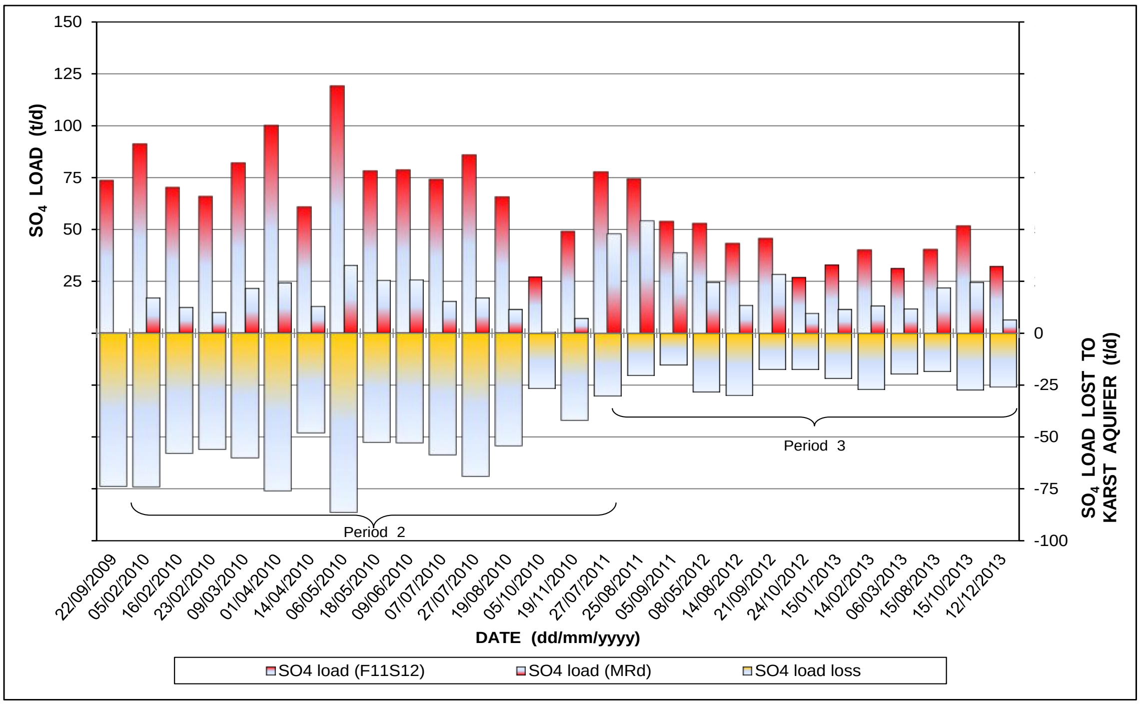


Figure 17 Graph of surface water SO_4 load lost to groundwater in the lower reach of the Riet Spruit

The concern previously expressed for the quality of the water entering the karst aquifer 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 ~26 t TDS/d and ~22 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 salt load pattern and trend manifested at station A2H049. Such re-assessment is shown for total dissolved solids (TDS) in **Figure 18**, and for sulphate (SO_4) in **Figure 19**. The ratio of SO_4 to TDS illustrated in **Figure 20** 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.

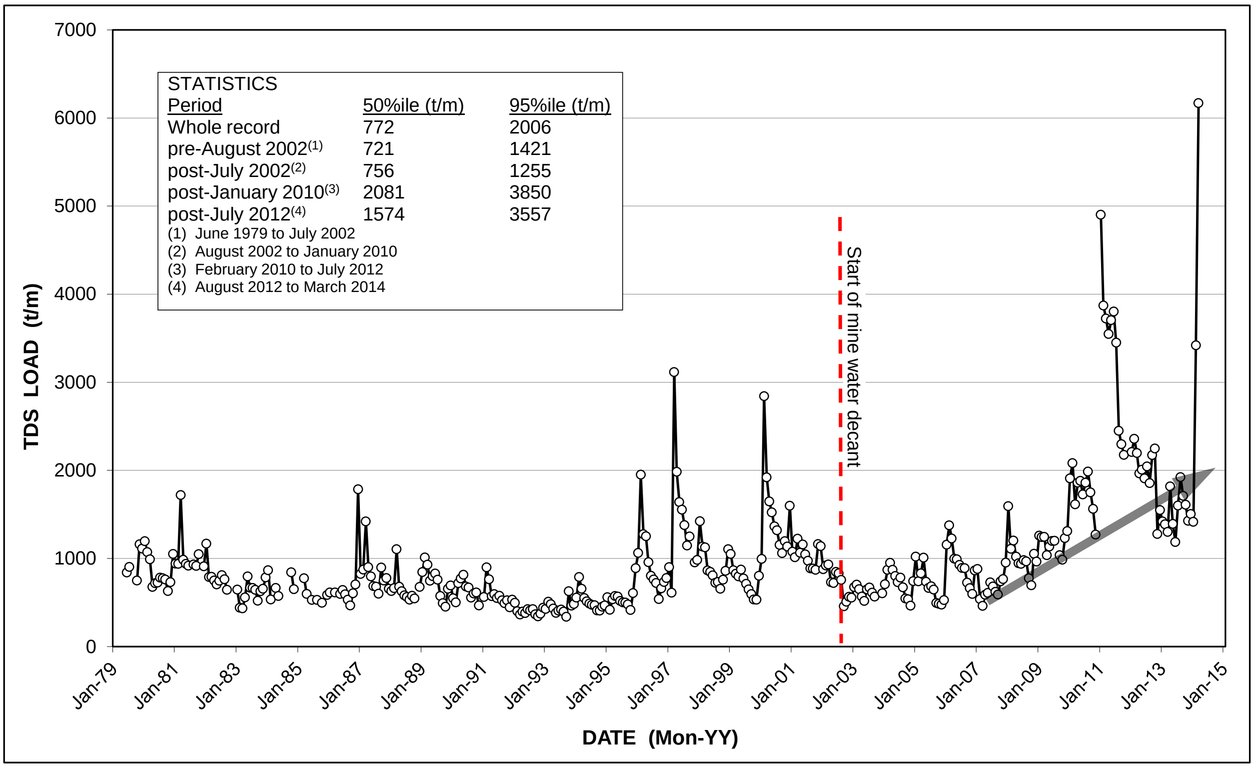
The long-term monthly trend in the TDS load delivered by the Bloubank Spruit (**Figure 18**) indicates an increasing TDS load (as indicated by the visually inserted arrows) since early-2007. The text box in **Figure 18** lists the median and 95%ile values associated with different periods of record. 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 19**) mimics the TDS load pattern (**Figure 18**) 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 20** for the long-term record, and in **Figure 21** for the period since the start of decant.

The closer inspection in **Figure 22** 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 mid-2014. This is also reflected in the SO_4**:**TDS ratio, which increases from ~20% to ~35% in this timeframe (**Figure 21**).

An inspection of **Figure 18** 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 19** reveals that the most recent 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 most recent discharge at A2H049 exceeds that in January 2011 by ~50%, it is evident that the most recent mine water chemical influence is substantially mitigated at A2H049 compared to that experienced in 2010–'11. This is also reflected in **Figure 22**, which shows that the most recent SO_4 concentrations recorded 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 (hydrochemistry) to mine water impacts reflected in **Figure 18** to **Figure 22**, remains obtuse and delayed in regard to the response of groundwater chemistry (hydrogeochemistry) to similar impacts (**Section 5.2**).

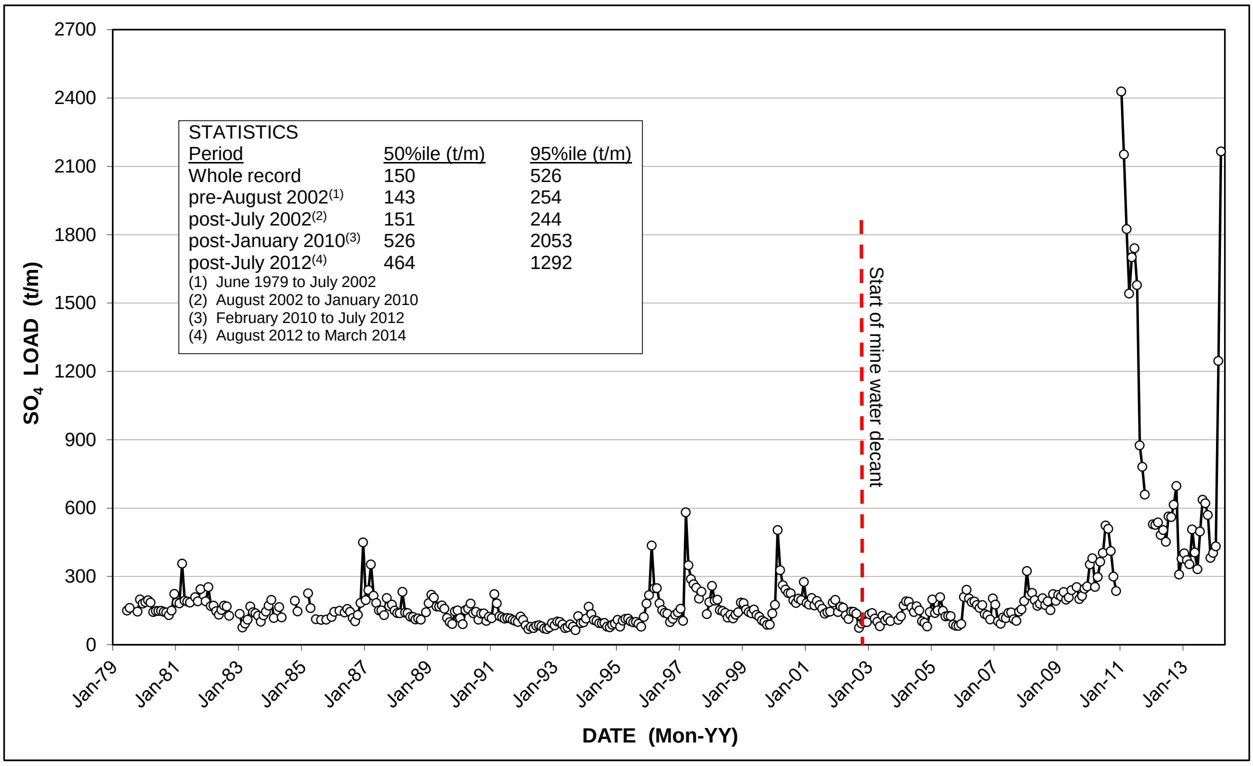


STATISTICS

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$^{(4)}$	1574	3557

(1) June 1979 to July 2002
(2) August 2002 to January 2010
(3) February 2010 to July 2012
(4) August 2012 to March 2014

Figure 18 Long-term (June 1979 to March 2014) monthly TDS load pattern and trend in the Bloubank Spruit at DWA 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$^{(4)}$	464	1292

(1) June 1979 to July 2002
(2) August 2002 to January 2010
(3) February 2010 to July 2012
(4) August 2012 to March 2014

Figure 19 Long-term (June 1979 to March 2014) monthly SO_4 load pattern and trend in the Bloubank Spruit at DWA station A2H049

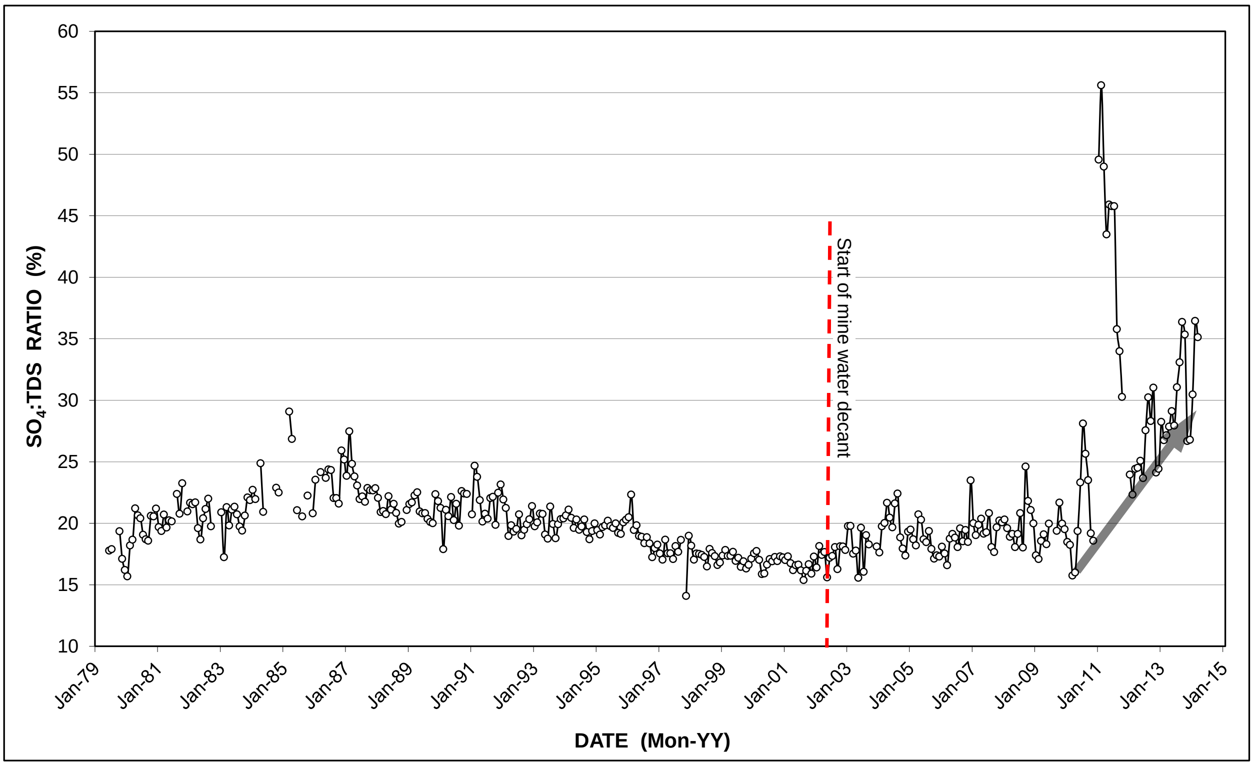


Figure 20 Long-term (June 1979 to March 2014) trend in the SO_4:TDS ratio at station A2H049

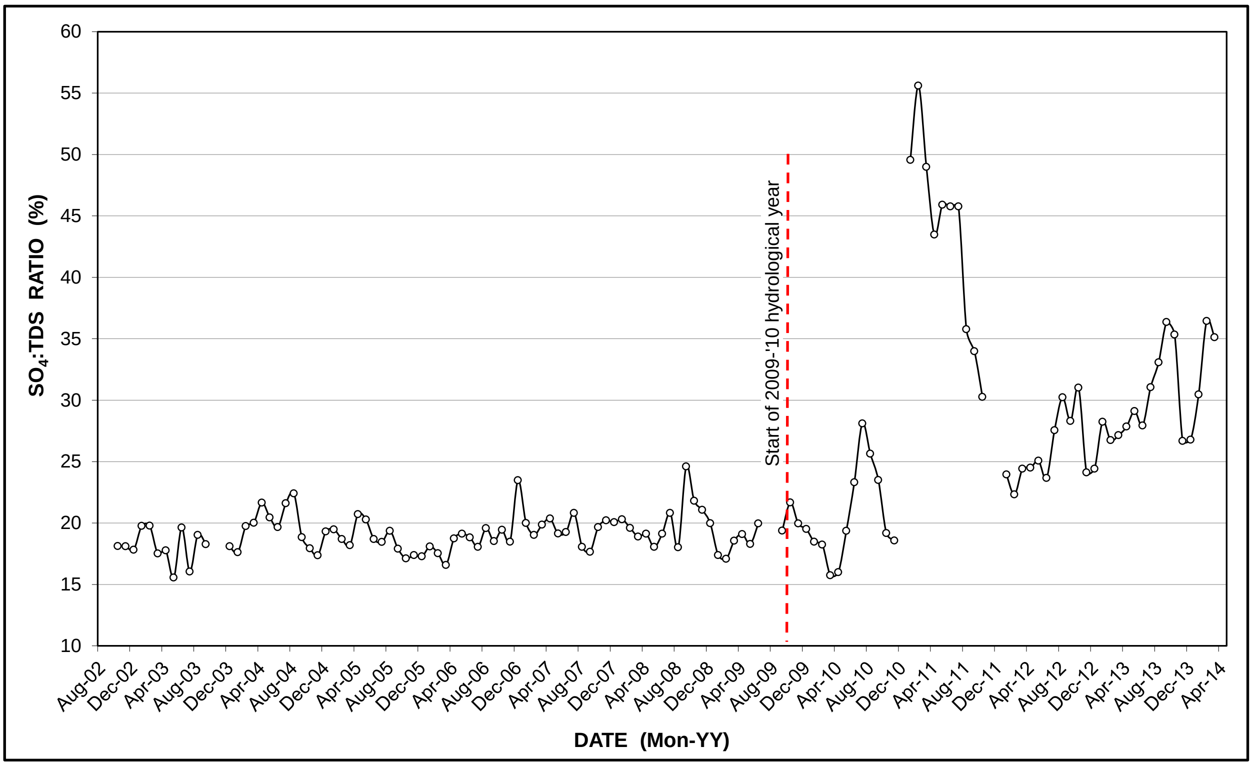


Figure 21 Pattern and trend in the SO_4:TDS ratio at station A2H049 since the start of mine water decant in the Western Basin

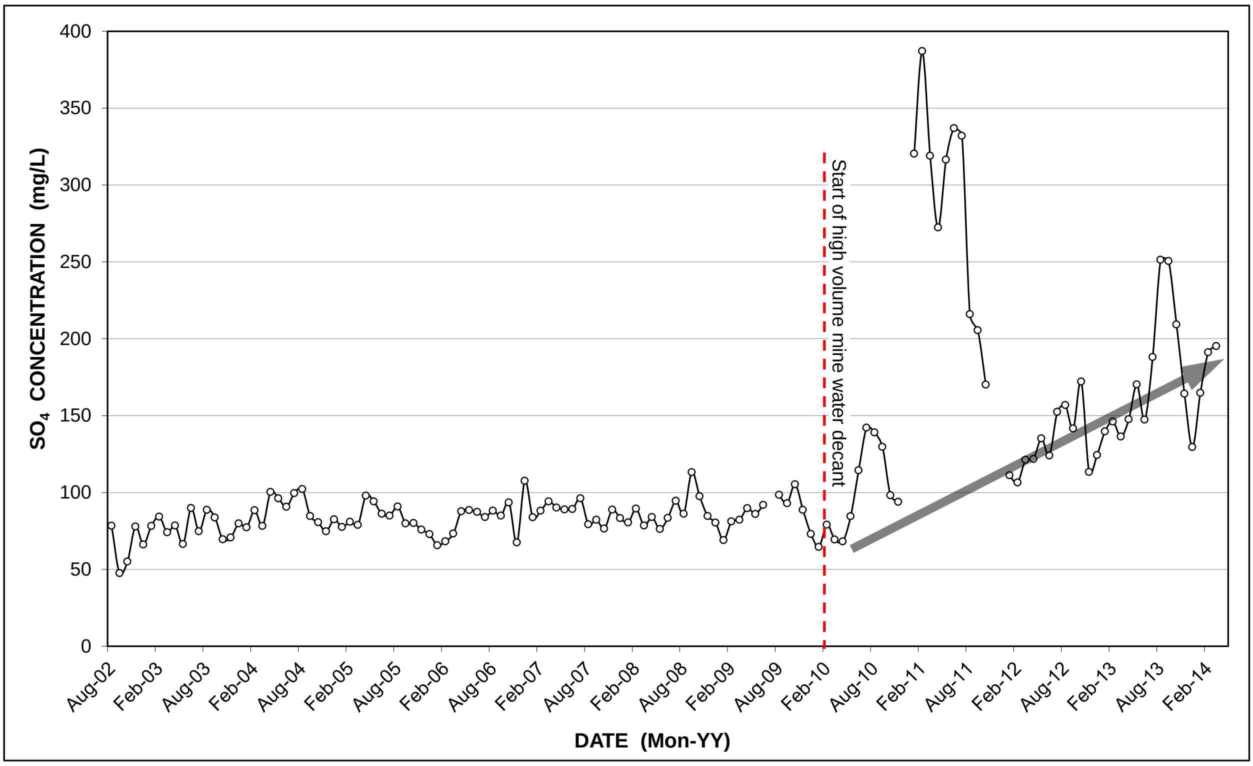


Figure 22 Pattern and trend in the SO$_4$ concentration at station A2H049 since the start of mine water decant in the Western Basin

The SO$_4$ concentration in the surface water passing station A2H049 (**Figure 22**) shows a return to the recent gradually rising trend since the start of 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. This impact had dissipated by early-2012 with a return to 'normal' values, as confirmed by salinity values of <100 mS/m measured in the upper reach of the Bloubank Spruit near Sterkfontein Caves since May 2012.

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 DWA monitoring boreholes in the study area. An assessment of these data returns the statistics presented in **Table 6**. A graphical representation of the information is shown in **Figure 23**. An analysis of the %ile Δh data yields a 25%ile value of 3.7 m, a mean value of 4.9 m, and a 75%ile value of 6.4 m. Most of these graphs are compared in **Figure 24**. The comparison in **Figure 24** indicates two distinct groupings of hydrograph, 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 different compartments/subcompartments. These groupings are produced separately in **Figure 25** (Group A) and **Figure 26** (Group B).

Table 6 Salient statistics for long-term DWA 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	271	–59.96	–54.59	–54.37	–51.01	11.13	8.94	05/1985–04/2014
A2N0582	210	–42.91	–40.11	–40.15	–35.77	8.53	7.14	05/1985–12/2010
A2N0583	230	–45.55	–44.96	–44.91	–44.41	1.84	1.14	05/1985–04/2014
A2N0584	262	–28.09	–25.63	–26.28	–21.57	8.00	6.52	05/1985–04/2014
A2N0586	285	–28.67	–26.30	–27.17	–21.49	8.54	7.18	05/1985–04/2014
A2N0589	169	–29.90	–28.89	–28.97	–27.92	3.85	1.98	05/1985–06/2010
A2N0590	184	–36.46	–34.69	–35.22	–31.66	6.11	4.80	05/1985–04/2014
A2N0592	274	–78.54	–76.97	–77.34	–73.94	6.33	4.59	06/1985–04/2014
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	204	–25.39	–23.97	–24.39	–21.31	5.07	4.08	04/1989–04/2014
A2N0602	229	–55.95	–54.36	–54.85	–51.19	6.44	4.76	06/1987–04/2014
A2N0605	200	–63.65	–62.52	–62.75	–60.33	4.09	3.33	04/1989–02/2013
A2N0606	68	–69.52	–67.09	–67.17	–64.78	5.11	4.73	08/1989–04/2014
A2N0607	165	–70.69	–67.08	–67.07	–64.26	7.82	6.43	10/1993–04/2014

(1) From month of first measurement to month of most recent available measurement as at May 2014 update from DWA; 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

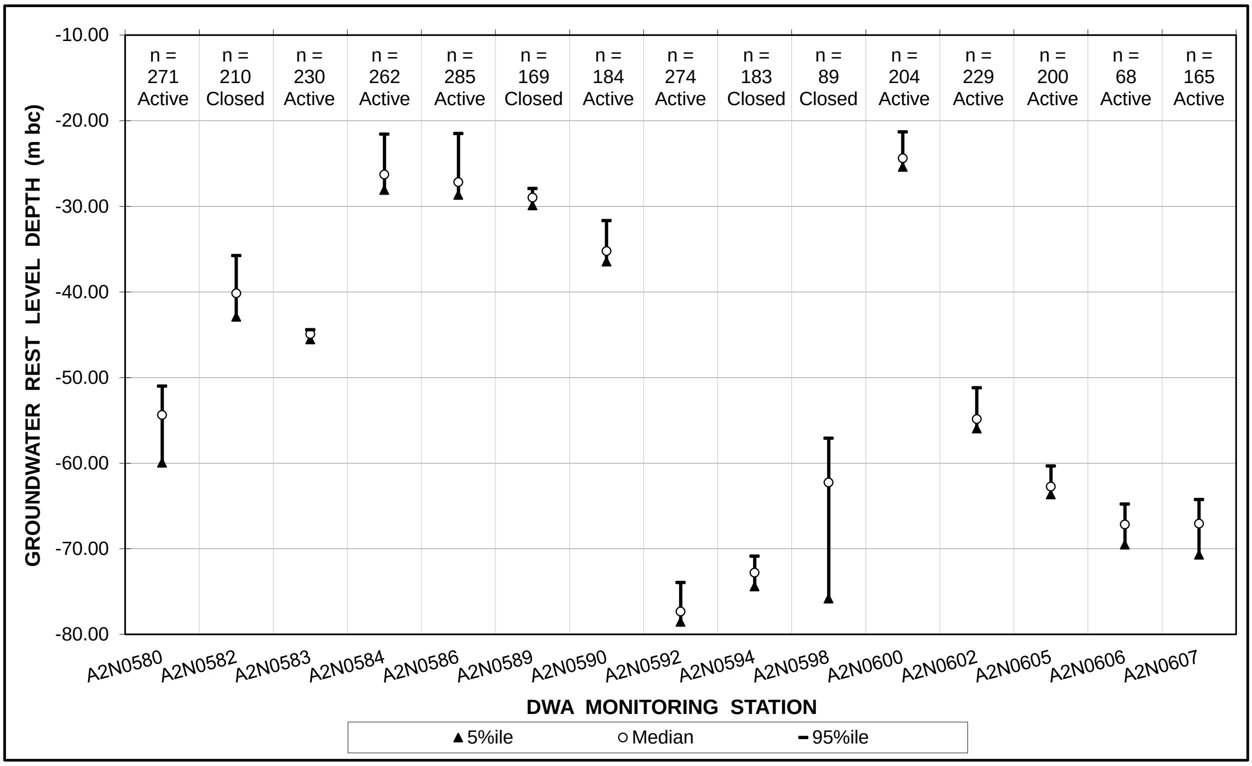


Figure 23 Graphic comparison of the statistical hydrographic response observed in DWA groundwater level monitoring stations in the period 1985 to 2014 (data from **Table 6**)

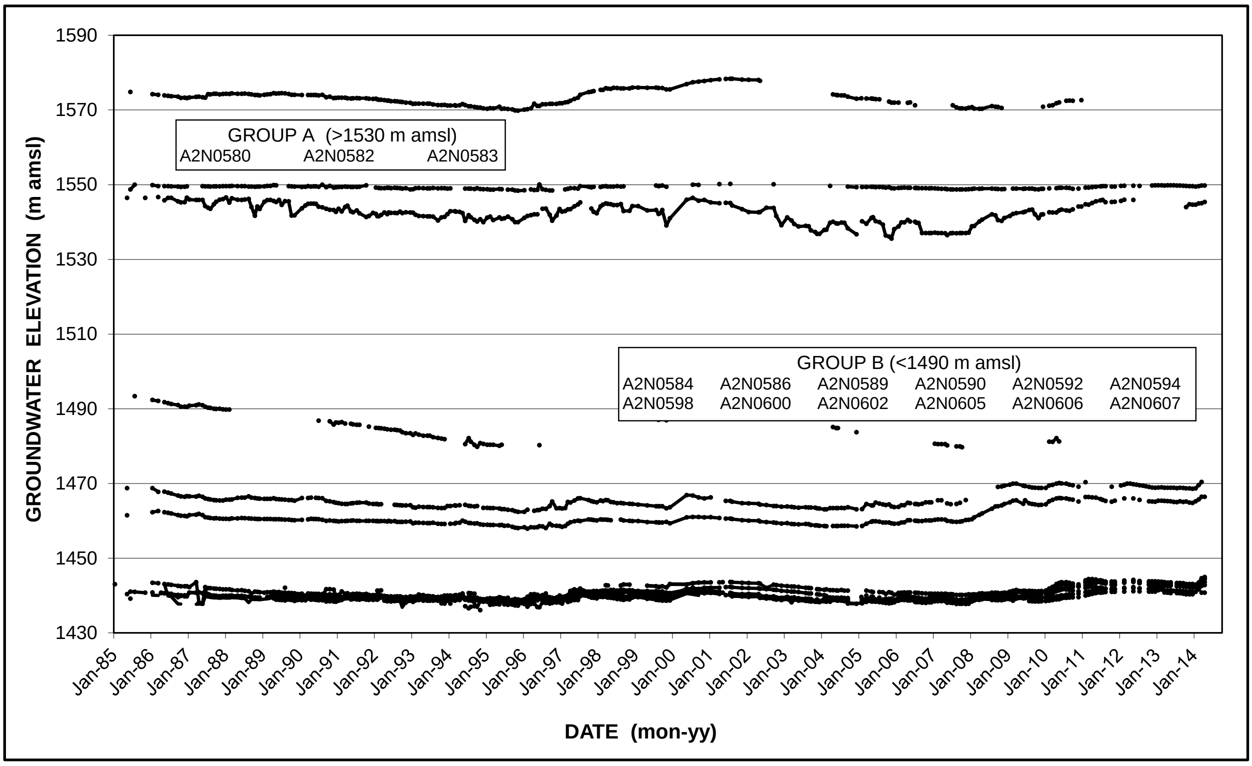


Figure 24 Long-term groundwater level response pattern in DWA monitoring boreholes

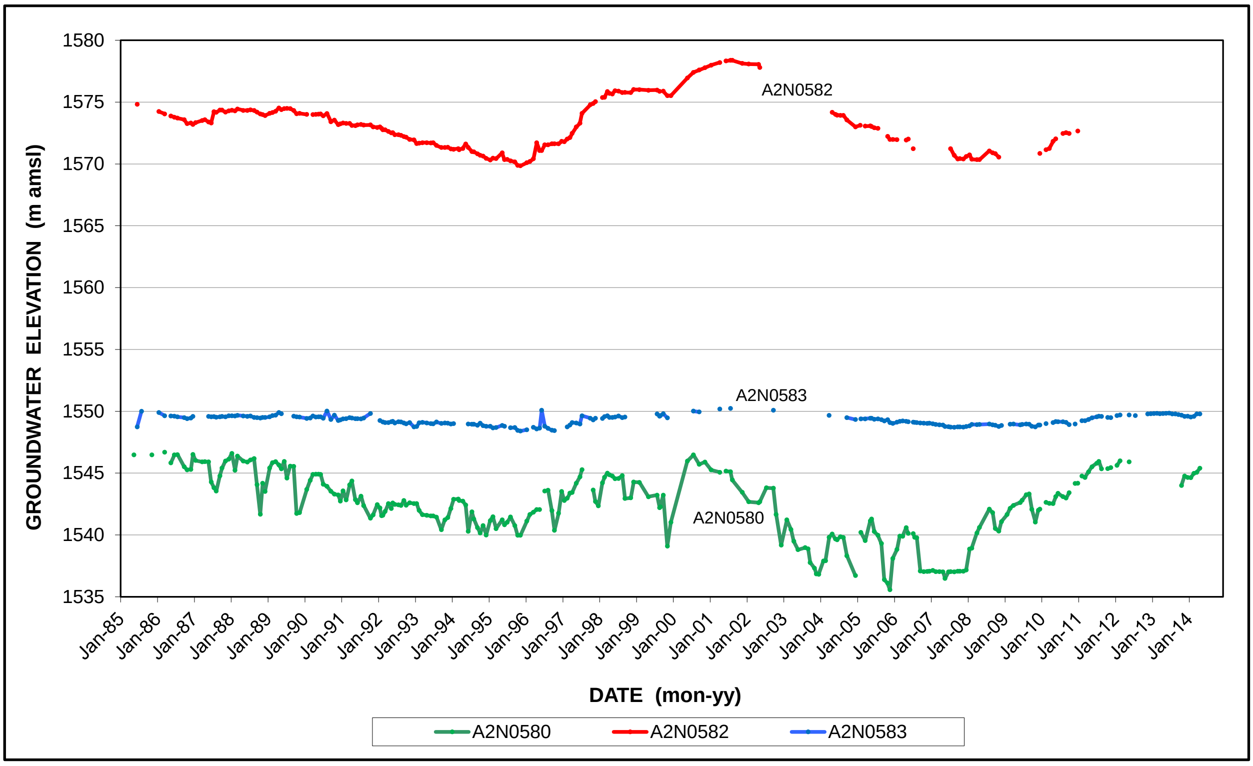


Figure 25 Long-term groundwater level response pattern in Group A boreholes from Figure 24

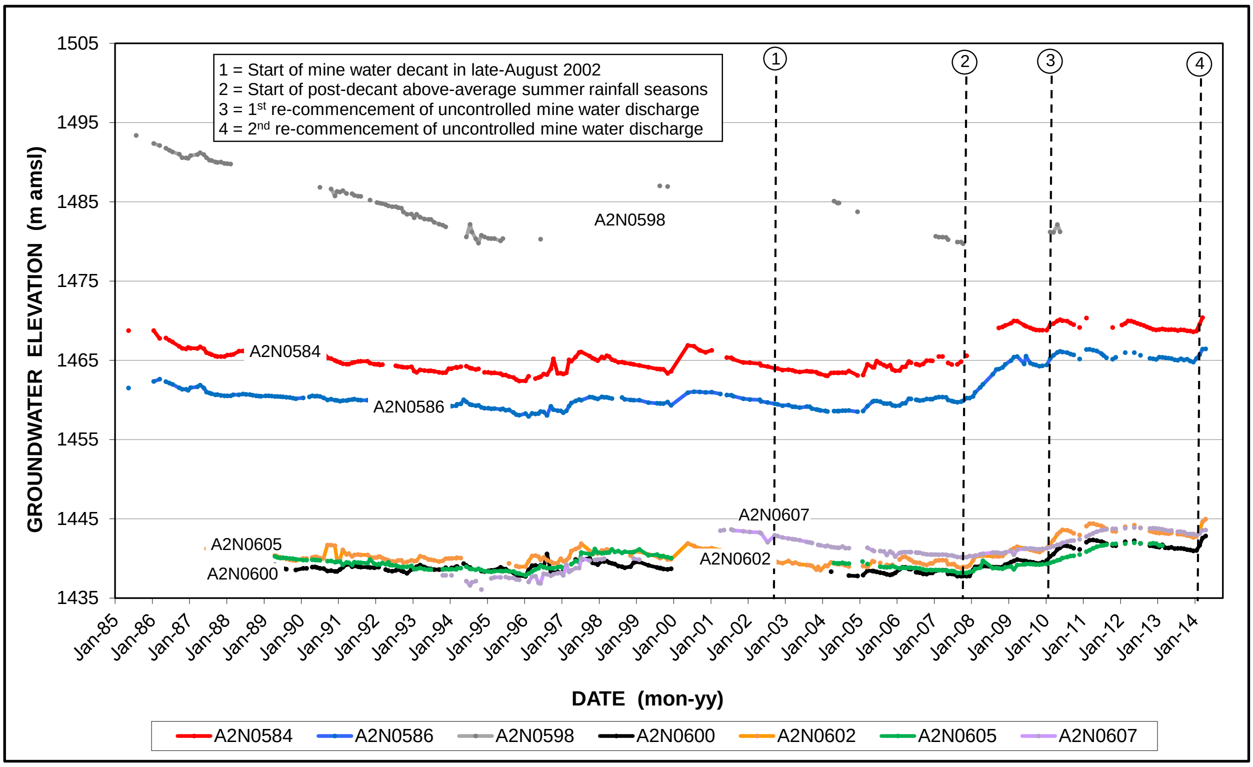


Figure 26 Long-term groundwater level response pattern in Group B boreholes from **Figure 24**

The unprecedented rise in the groundwater level observed in stations A2N0584 and A2N0586 since late-2007 (**Figure 26**) 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 27**). 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 DWA monitoring boreholes located downstream of the mine area is presented in **Figure 27.** 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. 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**, **Figure 28**).

The long-term hydrographs presented in **Figure 26**, 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).

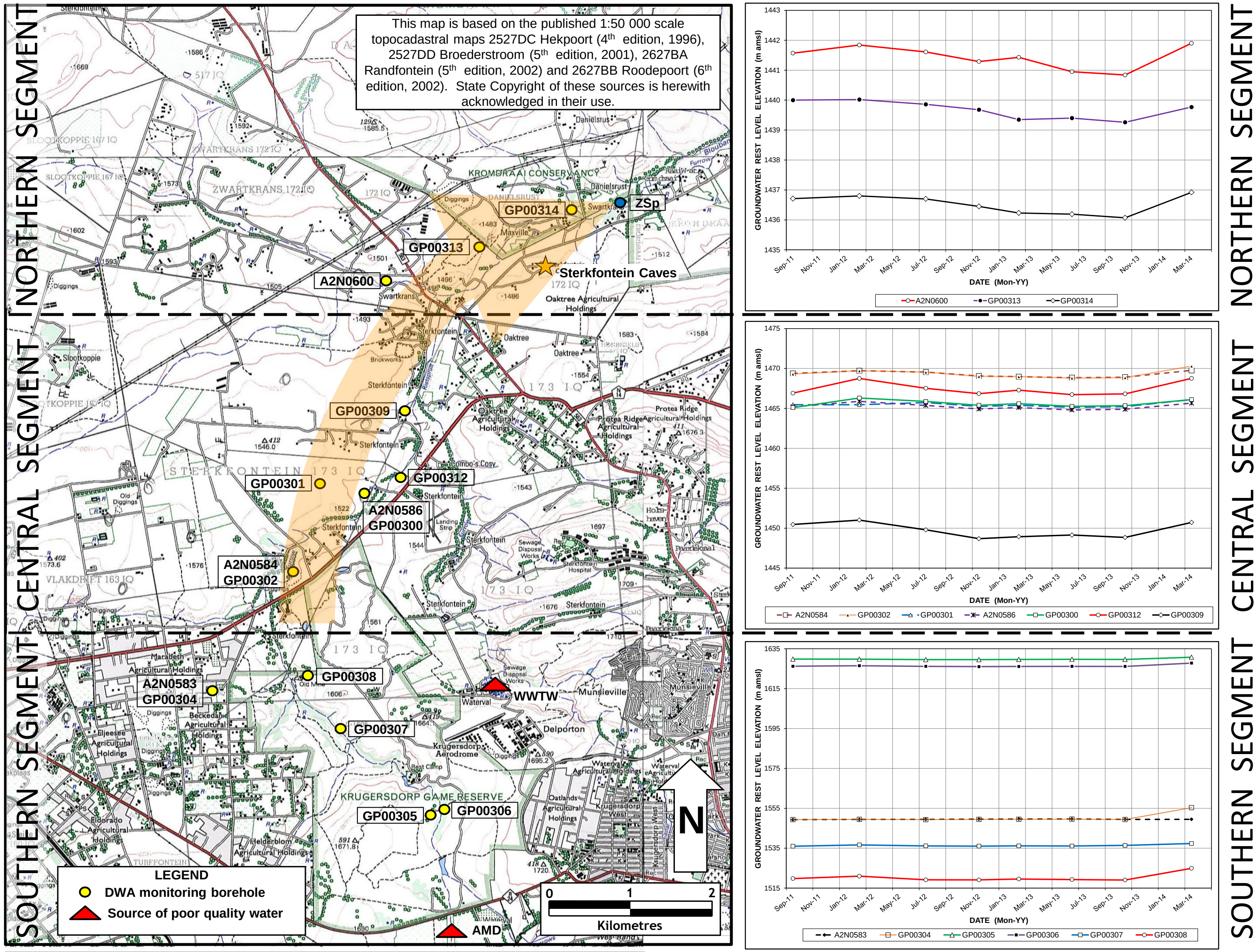


Figure 27 Distribution of DWA monitoring boreholes with groundwater hydrographs (right); arrow denotes principal direction of groundwater flow

5.1.2 Sterkfontein Caves Water Level

The international significance of Sterkfontein Caves as the flagship fossil site in the COH WHS 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. 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 28**, 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 ~0.5 m that is mirrored in a number of the monitoring borehole hydrographs (**Figure 26**).

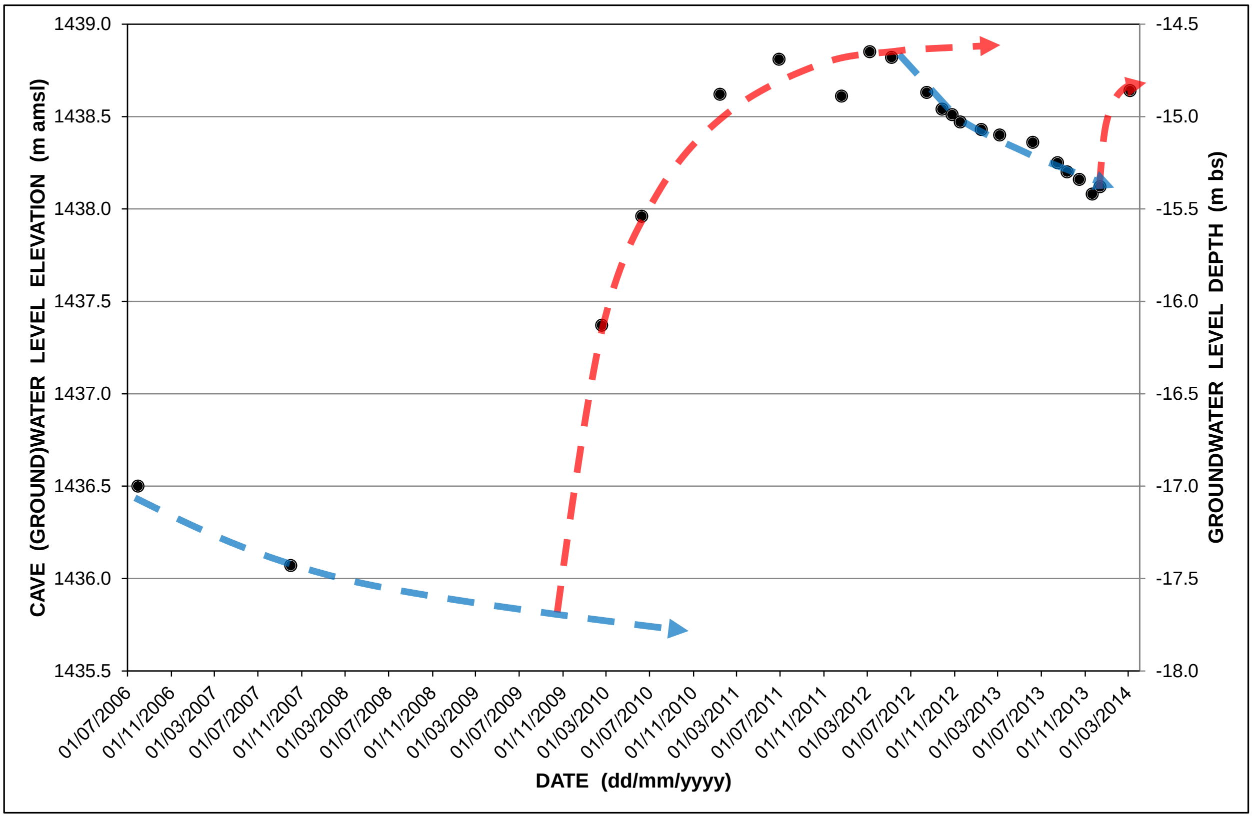


Figure 28 Recent groundwater level response pattern and trend in borehole SF1 that serves as a proxy for the Main Lake water level in Sterkfontein Caves

The 'maximum' elevation of ~1 438.8 m amsl (**Figure 28**) approaches the ~1 439.5 m amsl 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 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 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 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 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

An assessment of the groundwater chemistry data for the karst hydrosystem shared by the caves provides the insight illustrated in **Figure 29** and **Figure 30**. The Piper diagram (**Figure 29**) shows the shift of the May 2014 composition away from the historical composition toward that of the Zwartkrans Spring groundwater. The May 2014 springwater composition itself shows a shift toward a 'stronger' Ca–SO_4 character reflecting the mine water impact on the groundwater leaving the Zwartkrans Compartment via this feature.

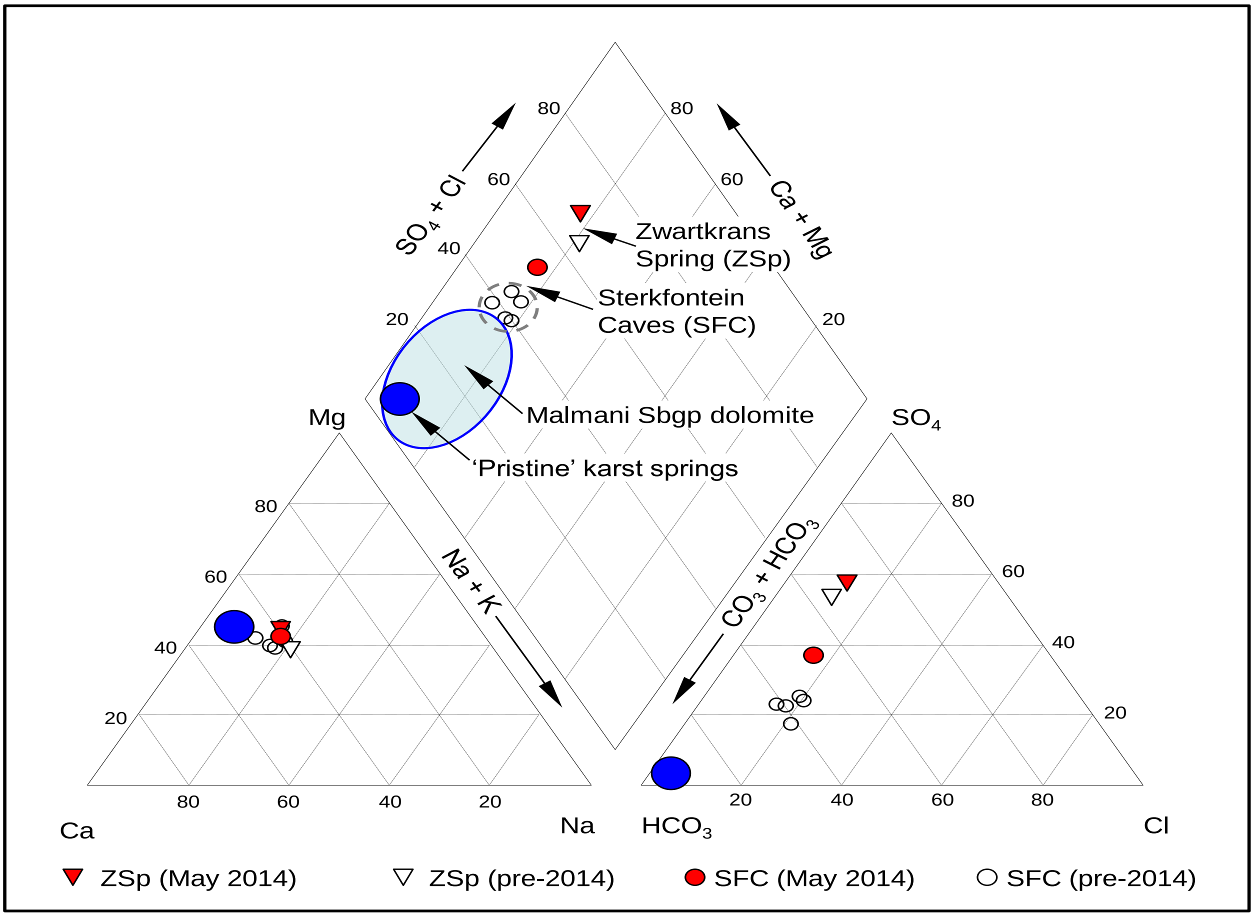
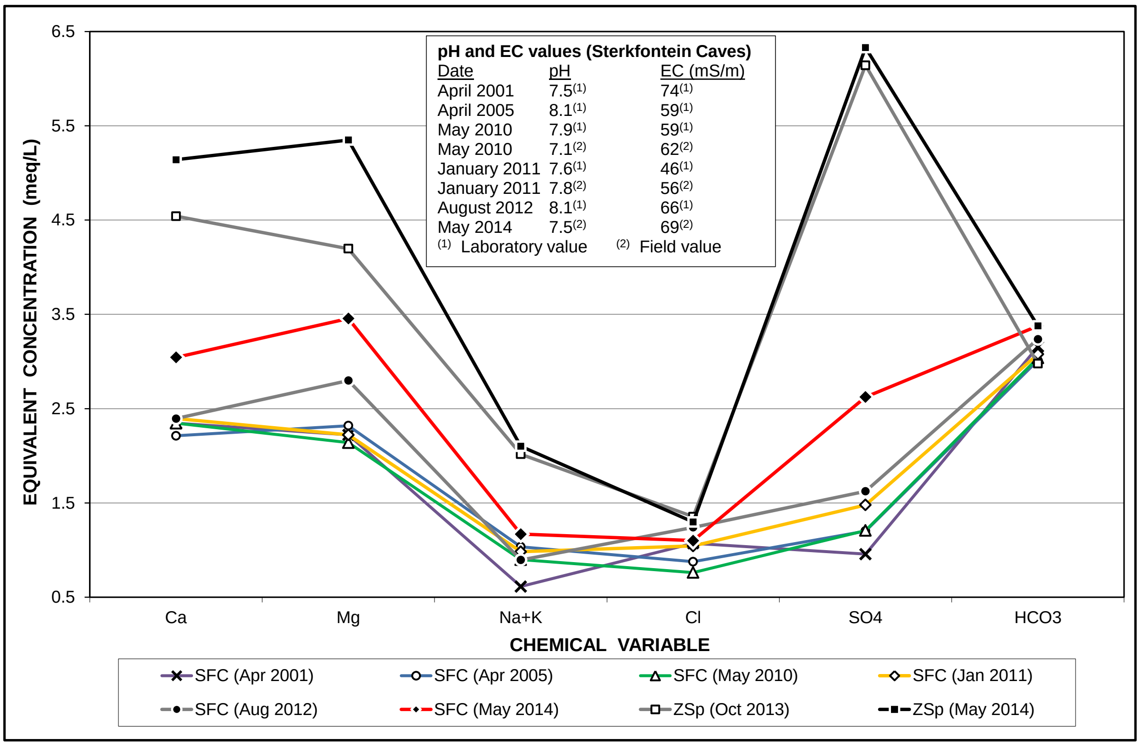


Figure 29 Characterisation of recent Sterkfontein Caves (SFC) and Zwartkrans Spring (ZSp) groundwater chemistry in relation to historical and regional groundwater chemistry



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

The Schoeller diagram (**Figure 30**) 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 30** 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 electrical conductivity (EC = 69 mS/m) of the cave water similarly exhibits a small (~5%) increase over the August 2012 value of 66 mS/m (text box, **Figure 30**). By comparison, the EC (105 mS/m) of the Zwartkrans Spring water reflects an increase of ~14% over the October 2013 value of 92 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 ~3% over the October 2013 value of 295 mS/m.

The salinity record of the Zwartkrans Spring water recorded by the data logger installed at the spring is presented in **Figure 31**. The record period dates back to July 2013, and reveals a gradual increase through to March 2014, followed by a declining trend to the end of record. The rate of increase amounts to 0.75 mS/m per month, and is matched by a similar rate of decrease for the declining limb of the graph. Although the declining trend indicates a gradual and consistent (albeit slight) improvement in the quality of the springwater, it is considered premature to attach too much significance to this observation. It is possible that the “peak” and subsequent improvement reflects 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. It is similarly possible that the most recent mine water impact on the karst groundwater will trigger a second flush of poorer (more saline) water through the aquifer toward the spring.

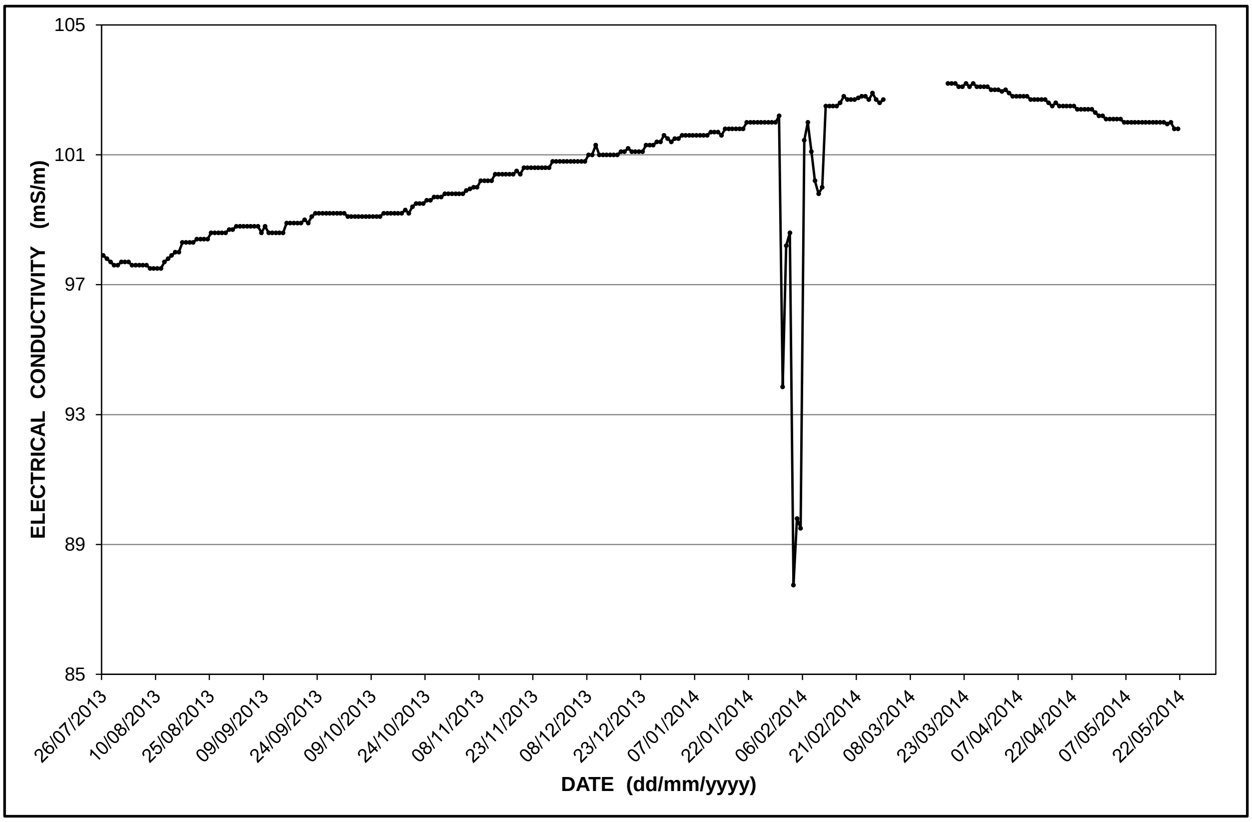


Figure 31 Pattern and trend of Zwartkrans Spring water salinity since mid-2013

The anomalies evident in the salinity record (**Figure 31**) are associated with two flood events (on 31/01/2014 and 03/02/2014, respectively), on which occasions the Zwartkrans Spring was completely inundated with fresher surface water. The depth of submergence of the spring approached 2 m on both occasions.

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 associated with the most recent cave water chemistry returns a value of 24%. This is slightly greater than the ~19% which characterises surface water at the downstream end of the Bloubank Spruit system, and is therefore interpreted to reflect the influence of poorer quality surface water on the cave water chemistry. The marginal location of the 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 preceding evaluation provides a clear indication of a surface water influence on the cave water chemistry. Given the previously demonstrated evidence of a mine water impact on the surface water chemistry of the Bloubank Spruit system (**Section 4.2.2**), the corollary transposes a muted mine water impact also on the cave water chemistry.

5.2.1 Mine Water Impact

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 32** and **Figure 33** with the aid of bar graphs for the chemical variables pH and electrical conductivity (EC) respectively.

The bar graphs in **Figure 32** 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 33** 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 32**), 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 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 34**, 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 slower travel times in the subsurface. The variable of concern is SO_4, which exceeds the SANS (2011a) standard health-related limit of 500 mg/L (**Table 4**) in all five instances.

It would also appear from **Figure 34** 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 undoubtedly attributable to the most recent and current discharge of raw and treated mine water from the mine area. It is postulated that the SO_4 decline at A2N0600 reflects the passage of the 2010–’11 and 2011–’12 contamination peak through the karst aquifer at this location, and that the most recent peak has not yet manifested an impact at this location.

The distribution of SO_4 concentrations associated with the stations represented in the central and northern segments of **Figure 32** and **Figure 33**, is shown in **Figure 35**. This provides an indication of the footprint of this impact.

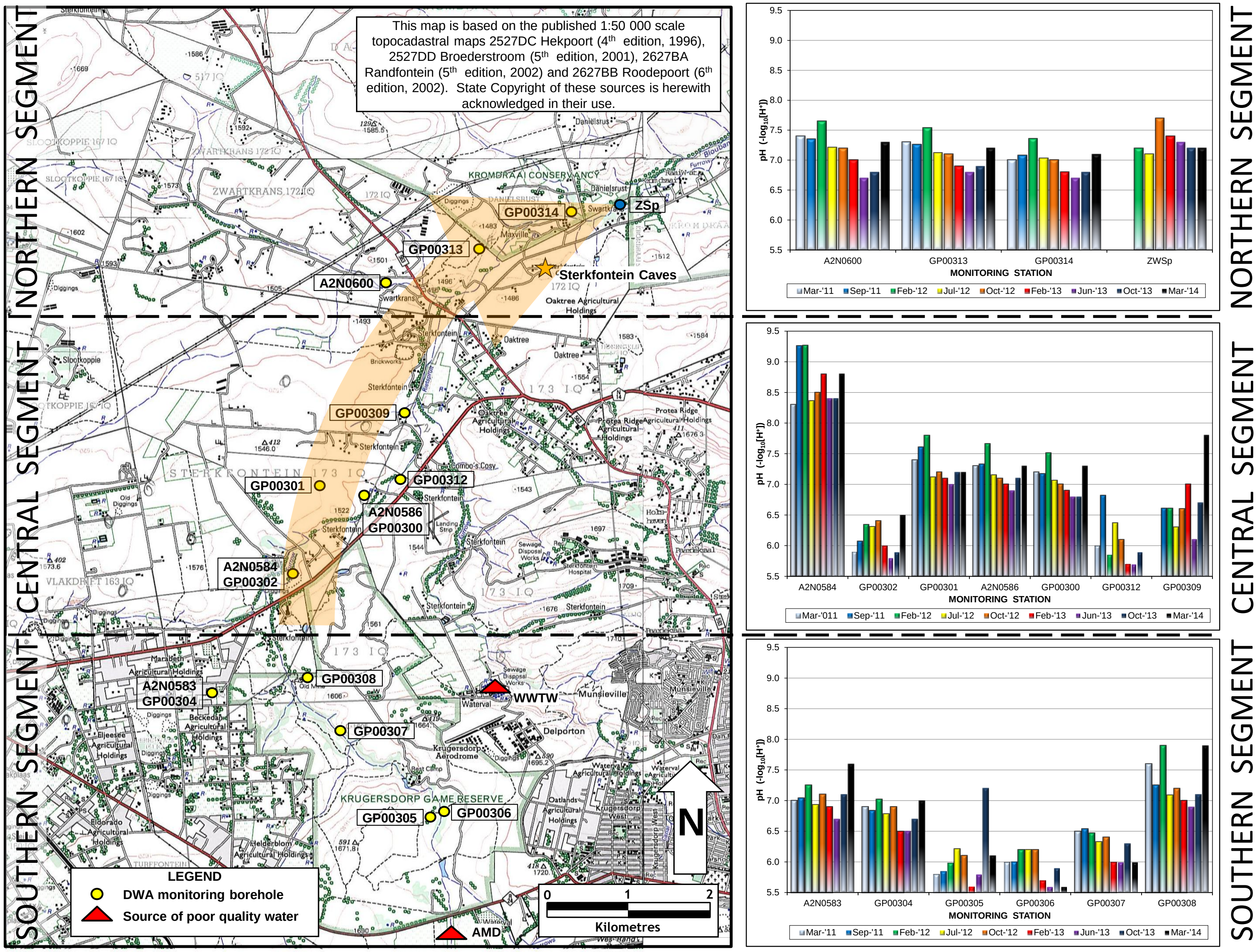
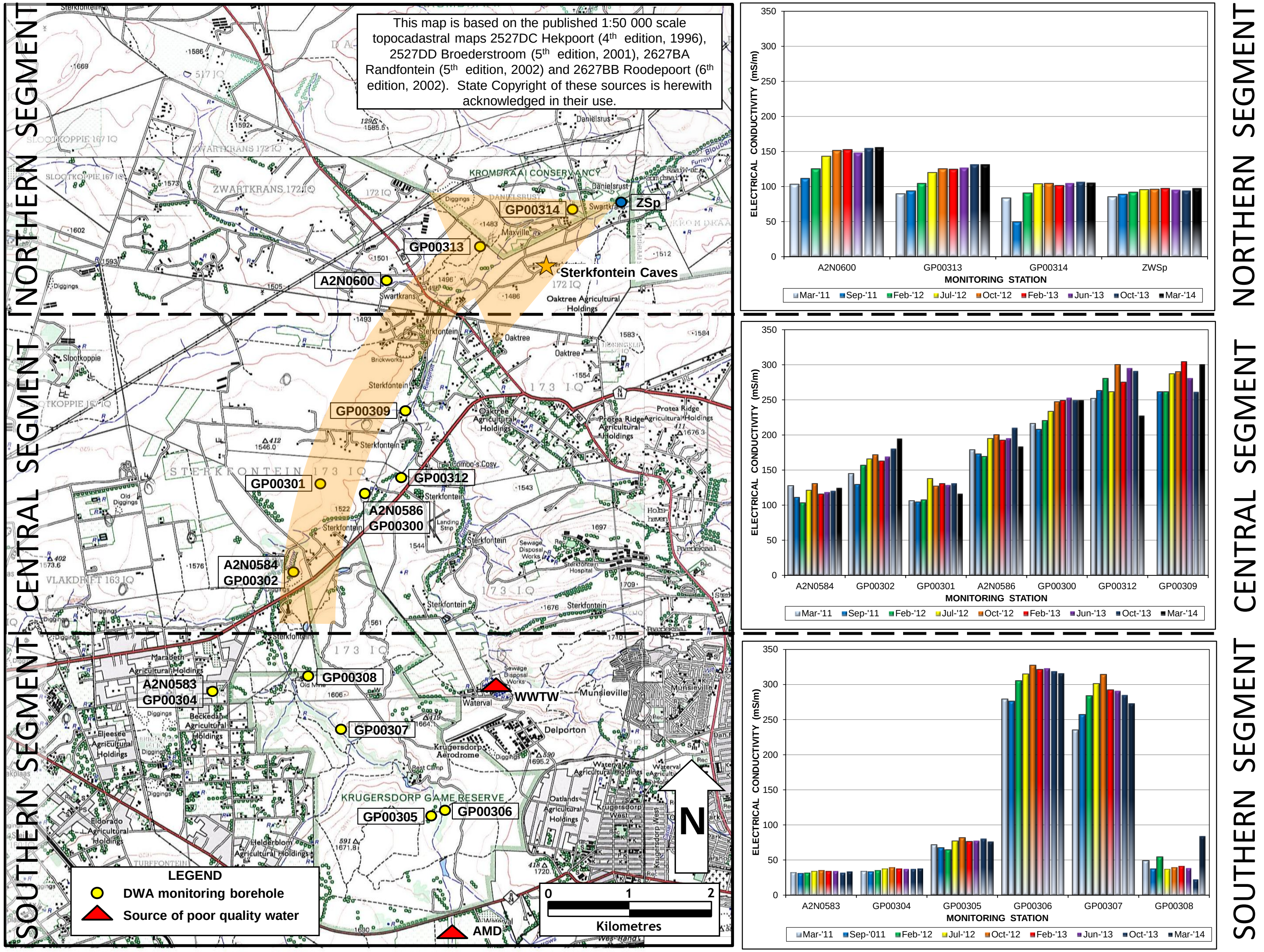


Figure 32 Distribution of DWA monitoring boreholes with pH pattern and trend as bar graphs; arrow denotes principal direction of groundwater flow



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

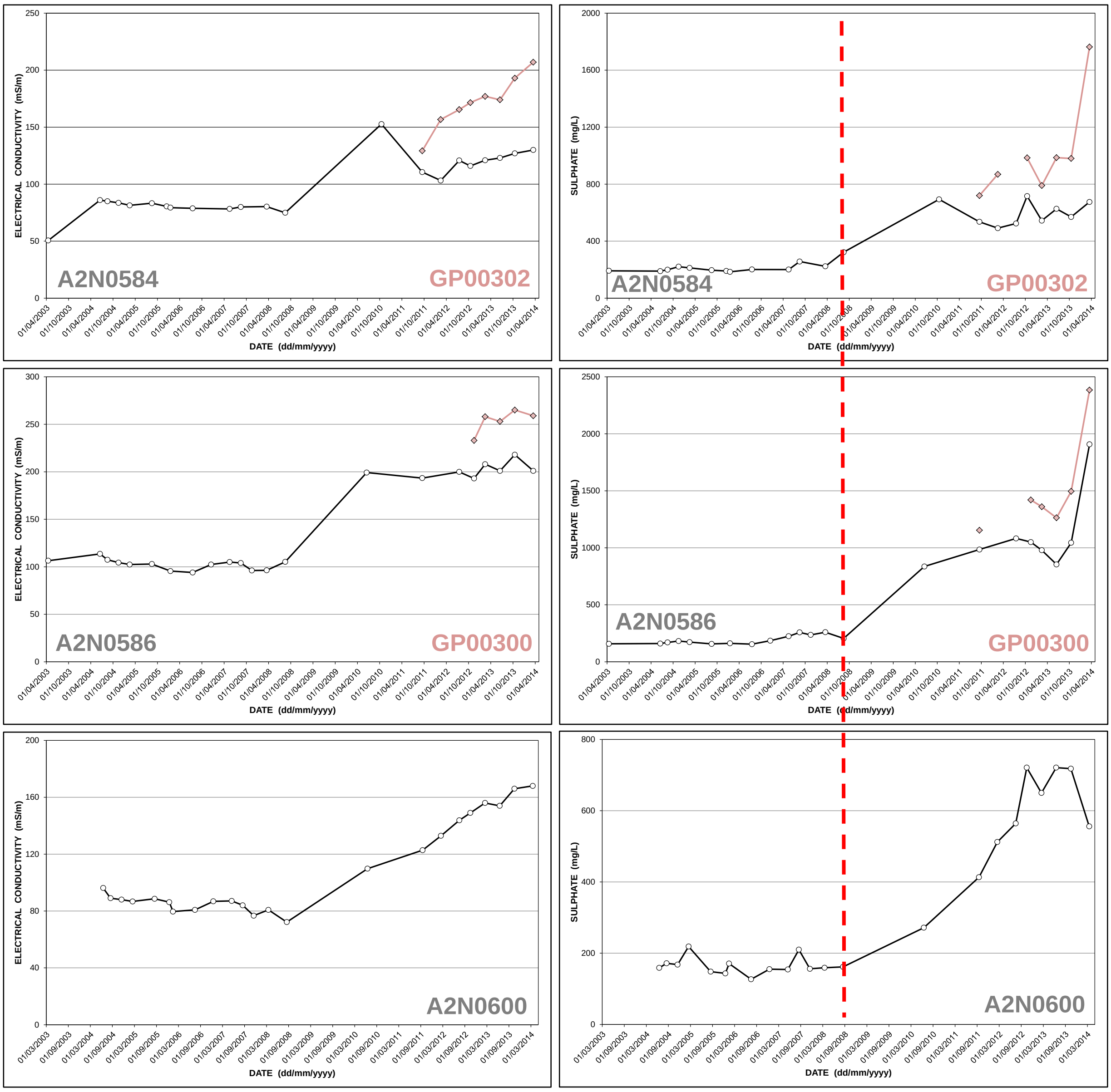


Figure 34 Long-term pattern and trend of electrical conductivity (left) and sulphate (right) in karst groundwater from paired DWA monitoring stations A2N0584 / GP00302 and A2N0586 / GP00300, and station A2N0600; note common time scales and postulated commencement of rise in concentrations (vertical pecked line)

6 CONCLUSIONS

The water resources monitoring results documented in this report largely 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. 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 most recent (March 2014) monitoring results. Unfortunately the recommencement of uncontrolled mine water discharge in February 2014 is likely to reverse the improvement generated by the containment of raw mine water discharge in the previous ~20 months since mid-2012. The continued monitoring programme will establish the extent and magnitude of this impact.

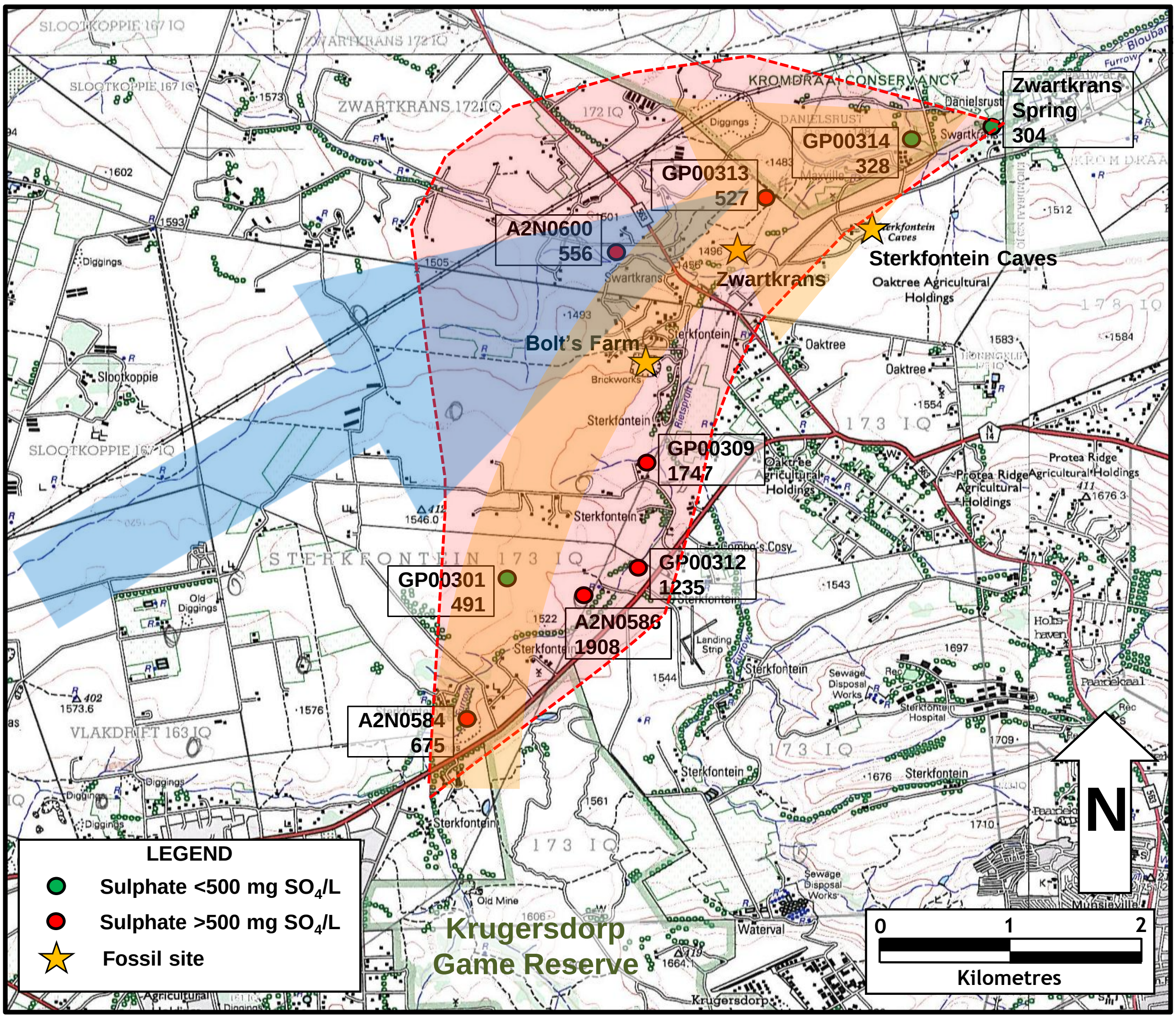


Figure 35 Distribution of SO_4 concentrations in groundwater of the Zwartkrans Compartment in March 2014, also showing the principal vectors of allogenic recharge (brown arrow), autogenic recharge (blue arrow) and the postulated footprint (shaded area) of a mine water impact in the karst aquifer

- Whereas the three prior to last complete hydrological years witnessed the 2nd, 3rd and 4th highest runoff (59.1, 50.0 and 44.9 Mm^3 respectively), after the 66.9 Mm^3 of the 1977–'78 hydrological year, in the 40-year historical gauging record of Bloubank Spruit system, the 2012–'13 hydrological year produced a modest discharge of only ~33.5 Mm^3.

- The re-commencement of uncontrolled raw mine water discharge from the mine area in February 2014 triggered an 18-month period of impact (from mid-2010 to late-2011) on the downstream receiving hydrologic environment before returning to 'more normal' pre-2010 conditions.

- Further abatement of the mine water impact on surface water quality commenced in mid-2012 with the commissioning of the immediate AMD intervention measures that witnessed an upgrade of the capacity and efficiency of the high density sludge (HDS) mine water treatment plant.

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