

THE ORIGIN OF GROUNDWATER SALINITY IN THE SANDSPRIUT CATCHMENT, BERG RIVER BASIN (SOUTH AFRICA)

M. Demlie¹, N. Jovanovic² and S. Naicker¹

¹School of Geological Sciences, University of KwaZulu-Natal, Durban, KwaZulu-Natal, South Africa.

E-mail: demliem@ukzn.ac.za

²Center for Scientific and Industrial Research, Stellenbosch, Western Cape, South Africa.

E-mail: NJovanovic@csir.co.za

Abstract

The occurrence of saline groundwater (TDS up to 10900 mg/l and EC 21400 $\mu\text{S}/\text{cm}$) within the Sandspruit catchment, Berg River basin, South Africa has been documented. To understand the origin, occurrence and dynamics of this saline groundwater, a coupled analysis of major ion hydrochemistry and environmental isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$ and ^3H) data have been undertaken. These data were collected in three different field sampling campaigns across the study catchment. These spatial and multi-temporal hydrochemical and environmental isotope data shed light on the origin, dynamics and spatial evolution of the groundwater salinity. These data show that the saline groundwater within the catchment is attributed to the combined effects of the depositional history of the aquifer material, groundwater flow and local and regional groundwater recharge effects. Areas with distinct fresh water bodies were identified, and the salinity of groundwater tends to vary seasonally and evolves in the direction of groundwater flow. The stable isotope data plotted along the local meteoric water line indicating that it is meteoric in origin. These stable environmental isotope signatures further indicate two possible mechanisms of recharge; namely, (1) a slow diffuse type modern recharge through a relatively low permeability material as explained by heavy isotope signal and (2) a relatively quick recharge prior to evaporation from a distant high altitude source as explained by the relatively lighter isotopic signal and sub-modern to old tritium signal.

Keywords: Groundwater salinity, hydrochemistry, environmental isotopes, Sandspruit catchment, South Africa.

1. INTRODUCTION

A groundwater hydrochemical investigation undertaken within the Sandspruit catchment, a tributary of the Berg River located in the Western Cape Province of South Africa indicated the occurrence of saline groundwater (in some instance with TDS up to 10900 ppm and EC $\sim 21400 \mu\text{S}/\text{cm}$). The occurrence of this high TDS groundwater is widespread in the catchment forcing the local farmers to use the groundwater only for livestock watering. This salinity is also documented in seasonal streams that drain within the catchment. Despite the occurrence of these high TDS groundwater and surface water, areas that are characterized by fresh groundwaters have also been documented.

The occurrence of a relatively saline groundwater in an arid to semi-arid regions of the world is a common phenomenon due to limited recharge and higher evapotranspiration. This condition is also exacerbated when the underlying lithology is characterized by minerals and salts that easily dissolve when it comes in contact with water that infiltrates occasionally and when the area is located in proximity to the ocean where the contribution of salts from wind-borne oceanic aerosols is significant. What is striking for this particular catchment is the existence of both fresh and saline groundwater within a limited geographic area? Thus, the main objective of the study was to understand the occurrence, origin and dynamics of groundwater salinity in the catchment using hydrogeological, hydrochemical and environmental isotope data.

General Overview of the Study Catchment Location

The Sandspruit catchment (Figure 1) comprises some 155 km² and is a tributary of the Berg River located in the Western Cape. It represents part of the quaternary catchment G10J, and the towns of Moorreesburg and Riebeek-West situated northeast and south of the catchment respectively.

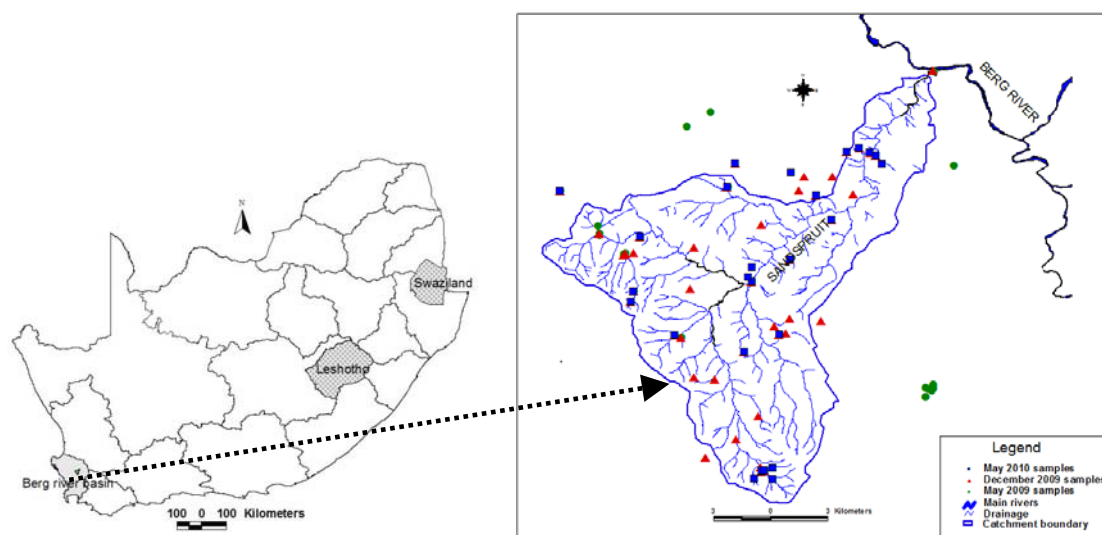


Figure 1. Location map of the study catchment along with water sampling points.

The climate of the catchment belongs to the winter rainfall region, and the mean annual rainfall is about 400 mm. The Sandspruit stream only flows during the winter season between May and October. Maximum temperature ranges from 24–31°C and minimum temperature ranges from 8–11°C. The average annual evaporation is approximately 2200 mm, exceeding the average precipitation. The catchment has a gentle hilly topography, with the Table Mountain Group sandstone reaching an altitude of 700m (Figure 2). The rest of the catchment has an altitude between 100–200 m. About 61% of the catchment has slope gradients between 0 and 4 degrees and 27% of the areas have slopes between 4 and 7 degrees. Much of the natural has been replaced by agriculture. Roughly 90% of the catchment is used for small grain, 4% for grapes, and the remainder represents reserves and mountain veld. Surface-water as well as groundwater is primarily utilized for agriculture

2. METHODS AND MATERIALS

Groundwater samples were collected in a north-south and east-west transect across the catchment in three field campaigns (May 2009, December 2009 and May 2010) from private farm boreholes and boreholes drilled within the framework of this research. All of the boreholes were purged for about ten minutes or an equivalent of three well volumes. Surface water samples were also collected at few sampling points. All the hydrochemical samples were filtered through a 0.45µm membrane filter, after which major cation samples were acidified to pH 2 with ultra pure nitric acid (HNO₃) immediately after sampling. Major ions were analyzed using an ICS-1000 Ion Chromatograph in the laboratory of Chemistry and trace elements were analyzed using an ICP-MS system in the Geological Sciences laboratory, University of KwaZulu-Natal, Durban, South Africa. Measurements of electrical conductivity (EC), Total Dissolved solids (TDS), Eh, pH and temperature were made in the field using an HI 9828 HANNA multiparameter instrument by calibrating the electrodes every morning. Total alkalinity, bicarbonate and carbonate were determined on site through titration a 100 ml of water sample using Phenolphthalein (when the pH is greater than 8.3) and bromocresol indicators (for all samples) and a 0.02 M HCl solution. Environmental Isotope samples were collected in plastic bottles (1L for ³H, and 50 ml for ¹⁸O and ²H) and analyzed following standard procedures at the iThemba Environmental Isotope Laboratory in Gauteng, South Africa. Long-term isotopic data of rainfall (from 1961–2002 for δ¹⁸O and δ²H, and 1961–1997 for tritium with interruption of measurements in between) are available at Cape Town GNIP (Global Network of Isotopes in Precipitation) station from the International Atomic Energy Agency (IAEA) database (IAEA/WMO 2004).

Depth to water level was measured using a Solinst TLC meter. The new data collected were complemented by additional groundwater borehole yield, water level and chemistry data from the National Groundwater Archive (NGA). All these data were processed and analyzed along with geology of the area using software such as Arc GIS, Surfer and Aquachem.

3. GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The regional geology of the area is generally composed of low-grade, metamorphosed volcanic-sedimentary succession, intruded by syn- to post-orogenic granitoids (Gresse et al. (2006). The area falls within Von Veh's (1983) Swartland and Tygerberg "Terranes" of the Malmesbury Group rocks (Swartland Subgroup and Tygerberg Formation). The following geological information is an extracted and summarized from Gases et al. (2006).

Amesbury Group

Metasediments of this group covers approximately 90% of the catchment area. The Malmesbury Group is divided into various terranes, of which the Central/Swartland is located within the research area. The Precambrian Malmesbury Shale is deeply weathered and was flooded by the sea till the late tertiary (Verwoerd, 1974). It is composed of the Berg River, Klipplaat and Moorreesburg Formations, which together constitute the Swartland Subgroup (Gresse et al. 2006). The Berg River Formation is composed of chlorite schist, greywacke with impure limestone lenses and quartz schist towards the top. The contact with the overlying Klipplaat Formation is placed just above a strongly deformed, ferruginous, cherty quartzite or the uppermost limestone layer. The Klipplaat Formation is essentially quartz schist, consisting of quartz, Sericite and chlorite. Lenses of phyllite, chlorite schist and limestone may occur. The Moorreesburg Formation consists of interlayered greywacke and phyllite. The lower, most deformed part of the formation contains arenitic layers near the contact with the Klipplaat quartz schists. The metavolcanic Bridgetown Formation comprises a complex of "greenstone" bodies, dolomite, chert and graphitic schists, intruded by numerous altered dykes (Gresse et al., 2006).

The Cape Granite Suit

The Cape Granite suit is late Precambrian to early Cambrian in age and have a composition ranging from low silica (50% SiO₂) to high Silica (77% SiO₂) values. It covers approximately 1% of the catchment area and intruded into metavolcanic rocks of Neoproterozoic age, mainly the Malmesbury Group.

The Table Mountain Group

The Table Mountain Group (TMG) covers approximately 4% of the study area. The lowermost unit of the TMG, the Piekenierskloof Formation, consists of conglomerate, quartz arenite and minor mudrock that are confined to the west coast (Rust, 1967). It unconformably overlies phyllites and quartzites of the Malmesbury Group. The Graafwater Formation is characterised by purple, thin-bedded, ripple-marked and mudcracked sandstone, siltstone and shale beds. The Peninsula Formation comprises a succession of coarse-grained, white quartz arenite with scattered small pebbles and discrete thin beds of small-pebble, matrix supported conglomerate (der Beer, 2002).

Recent Sediments

The Cenozoic (recent) deposits cover approximately 6% of the catchment area. These recent sediments are; the Springfontyn Formation consisting of reddish to grey, unconsolidated quartzose aeolian sands, which are muddy and peaty in places (Rogers, 1980), alluvium and silcrete/ ferricrete deposits.

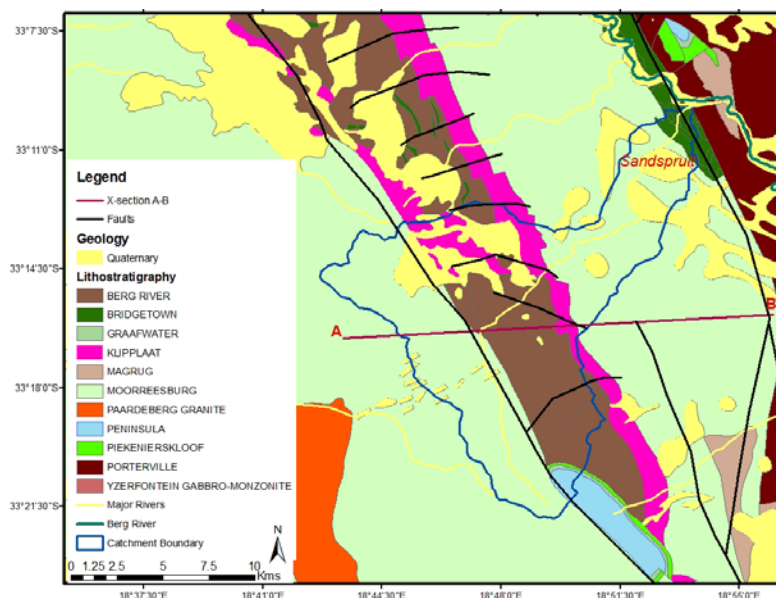


Figure 2. Simplified Geological Map of the study area (modified from DWAF, 2009).

Hydrogeological Background

Groundwater occurs in both confined and unconfined conditions in the study area. The groundwater flow direction is generally the same as the surface water drainage, following the topographic gradient. General borehole yields are low to moderate depending on from which aquifer the wells are sited. The boreholes that tap the Malmesbury phyllites and greywacke yield between 0.9-2 l/s. Groundwater exploitation in the Malmesbury Group is often problematic due to the largely argillaceous nature of the lithological units.

The often fractured arenaceous TMG is largely anisotropic, and thus does not display uniform aquifer characteristics. An intricate network of fissures, joints, fractures and even cavities govern the infiltration, storage and transmission of groundwater within the brittle TMG rocks. The TMG remains the most productive aquifer in the region, with yields reaching an average of 2.25 l/s, increased mean yields of up to 4 l/s are located at major discontinuities.

Groundwater in the Cape Granite rocks occur both within the weathered and jointed zones, which implies that it is a fractured and intergranular aquifer. Reported mean borehole yields are as low as 0.38 l/s. Intergranular aquifers of recent age that include Springfontyn Formation, alluvial sediments and ferricrete/silcrete deposits do exist, and borehole yield within the alluvial deposits vary between 0.1 and 20 l/s. Table 1 presents borehole yield variation within the main geological units in the study area.

Table 1. Reported borehole yield information for the main geological units.

	Shale (n = 12)	Sandstone (n = 12)	Granite (n = 11)	Remark
Minimum	0.02	0.01	0.01	Since the number of boreholes yield data (n) within each unit is small, the mean yields reported should be considered as indicate values.
Maximum	3.38	17.07	1.6	
Mean	0.83	2.28	0.38	
Standard deviation	0.94	4.47	0.45	

4. RESULTS AND DISCUSSION

Hydrochemistry

Results of onsite measurements and laboratory chemical analysis of water samples collected within and in the vicinity of the study catchment are presented in Tables 2, and 3. Figures 3, 4, and 5 are illustrations of the hydrochemical data presented in the tables. These data sets show variable groundwater chemistry across the catchment (TDS ranging from 340 to more than 10000 mg/l). The general groundwater chemistry is brackish, dominated by sodium and chloride ions. The data further revealed the occurrence of pockets of fresh and saline groundwater within the catchment, indicating a very strong compartmentalization of the groundwater system.

A general increase in salinity of the groundwater along the groundwater flow direction (Figure 3) is observed, which is similar to the direction of surface water drainage in the catchment. Because of the occurrence of fresh, brackish, saline and a widespread Na-Cl facies of groundwater in the area, a clear hydrogeochemical evolution trend is lacking.

Table 2. Groundwater physical parameters measured onsite within the study catchment.

Station ID	Sampling Date	Sample location		Water source	Altitude (m. amsl)	DTW (m. bgl)	WL (m. amsl)	EC ($\mu\text{s/cm}$)	TDS (ppm)	Temp ($^{\circ}\text{C}$)	pH	DO (ppm)	Eh (mv)	Salinity	TAL (mg/l)
SDC 66	22/05/10	-33.21682	18.7198	GW	205			2775	1387	21.97	6.77	7.72	12.3	1.44	
SDC 67	23/05/10	-33.20024	18.8681	GW	61			21050	10520	21.36	6.81	4.36	15.1	12.65	427
SDC 68	23/05/10	-33.20432	18.8709	GW	73	5.21	67.79	12290	6142	22.4	6.69	1.12	24.9	7.04	356
SDC 69	23/05/10	-33.19875	18.8653	GW	69	1.2	67.8	19280	9623	22.92	6.74	2.7	13.8	11.52	216
SDC 70	23/05/10	-33.19681	18.8604	GW	60	14.02	45.98	2868	1435	22.11	7.64	3.75	-23.2	1.5	68
SDC 71	23/05/10	-33.19852	18.8544	GW	118	44.45	73.55	424	212	25	6.67	5.15	-5	0.2	22
SDC 72	24/05/10	-33.25959	18.8098	GW	99	5.08	93.92	2072	1035	21.28	7.9	2.09	-41	1.06	147
SDC 73	24/05/10	-33.25753	18.8081	GW	116	11.08	104.92	6650	3316	21.79	6.73	5.01	19.8	3.63	178
SDC 75	24/05/10	-33.24908	18.8278	GW	107			2825	1413	23.11	7.4	0.11	-14.3	1.47	219
SDC 76	24/05/10	-33.21485	18.7985	GW	135	5.29	129.71	2286	1144	21.17	6.77	6.23	16.9	1.18	97
SDC 77	24/05/10	-33.20367	18.8022	GW	127	12.93	114.07	2772	1393	22.73	7.32	6.86	-14.9	1.43	227
SDC 78	24/05/10	-33.20818	18.8284	GW	99			3806	1903	21.08	6.78	7.53	-4	2.02	112
SDC 79	24/05/10	-33.21879	18.8402	GW	131	42.38	88.62	881	440	22.18	6.38	6.41	39.1	0.43	18.5
SDC 80	24/05/10	-33.23057	18.8475	GW	95			2475	1237	21.9	8.02	6.17	-43.7	1.28	148
SDC 81	24/05/10	-33.29257	18.8064	GW	155			9803	4900	20.46	7.26	6.35	-27.5	5.53	203
SDC 83	25/05/10	-33.34907	18.8146	GW	271	3.73	267.27	2331	1167	20.59	6.8	3.91	15.3	1.2	
SDC 84*	25/05/10	-33.34877	18.8146	SW	265			1402	700	13.91	8.22	6.57	-53.4	0.71	208
SDC 86	25/05/10	-33.34739	18.8198	GW	308	11.54	296.46	1792	895	20.67	7.38	5.08	-13.9	0.91	192
SDC 87	25/05/10	-33.34847	18.8158	GW	271	5.37	265.63	682	341	19.93	6.8	5.3	45.2	0.33	
SDC 88	25/05/10	-33.34852	18.8158	GW	273	8.01	264.99	901	450	20.79	7.63	3.09	-30.9	0.44	177
SDC 89	25/05/10	-33.28473	18.7738	GW	156	0.57	155.43	4487	2243	22.45	6.67	4.6	20.3	2.4	
SDC 90	25/05/10	-33.28469	18.7738	GW	141	0	141	3412	1704	22.1	7.97	3.83	-41.8	1.79	185
SDC 91	25/05/10	-33.26415	18.7543	GW	224	17.15	206.85	3140	1565	19.38	7.06	6.09	-2.1	1.64	323
SDC 92	25/05/10	-33.26887	18.75312	GW				5780	2893	20.79	7.32	8.27	2.5	3.15	395
SDC 93	25/05/10	-33.23831	18.7575	GW	169			7692	3848	17.79	6.94	5.12	6.9	4.28	281
SDC 94	26/05/10	-33.35284	18.8196	GW	295	11.82	283.18	1546	775	18.92	6.06	5.43	-7.2	0.79	124
SDC 95	26/05/10	-33.35284	18.8197	GW	299	5.8	293.2	2159	1080	20.62	6.28	5.13	45.4	1.11	75
SDC 96	26/05/10	-33.28449	18.8229	GW	145			717	359	22.56	6.14	4.9	66	0.35	10

Table 3. Major ion hydrochemical data of boreholes measured within the study area in units of mg/l.

Sample ID	Sampling date	Sample location		EC ($\mu\text{S/cm}$)	TDS (ppm)	pH	TAL	Na	K	Ca	Mg	Cl	F	HCO ₃	SO ₄	NO ₃	NO ₂
SDC-67	23/05/10	-33.20024	18.8681	21050	10520	6.8	427.0	3840.0	22.5	236.5	589.7	14700	0.9	520.7	420		0.0
SDC-68	23/05/10	-33.20432	18.8709	12290	6142	6.7	356.0	1951.0	13.7	130.0	324.5	8500	0.5	434.1	85	0.3	0.0
SDC-69	23/05/10	-33.19875	18.8653	19280	9623	6.7	215.5	2661.7	17.2	67.1	900.9	12900	0.2	262.8	888	0.2	0.0
SDC-70	23/05/10	-33.19681	18.8604	2868	1435	7.6	68.0	377.8	5.4	67.1	75.5	1150	0.2	82.9	41	0.4	0.0
SDC-71	23/05/10	-33.19852	18.8544	424	212	6.7	22.0	48.7	5.9	1.3	8.3	140	0.0	26.8	21	10.6	0.1
SDC-72	24/05/10	-33.25959	18.8098	2072	1035	7.9	146.5	262.4	5.3	50.2	45.9	600	0.1	178.6	49	0.3	0.0
SDC-73	24/05/10	-33.25753	18.8081	665	3316	6.7	178.0	1088.4	22.0	88.5	162.4	3500	0.0	217.1	223	59.3	0.0
SDC-76	24/05/10	-33.21485	18.7985	2286	1144	6.8	97.0	371.5	8.3	22.9	47.3	850	0.3	118.3	40	8.5	0.0
SDC-77	24/05/10	-33.20367	18.8022	2772	1393	7.3	227.0	438.0	10.5	38.3	47.3	1250	0.8	276.8	82		0.0
SDC-79	24/05/10	-33.21879	18.8402	881	440	6.4	18.5	116.8	21.6	10.7	18.7	275	0.8	22.6	21	37.8	0.0
SDC-80	24/05/10	-33.23057	18.8475	2475	1237	8.0	148.0	506.9	7.8	6.9	20.5	1050	1.2	180.5	92	1.0	0.0
SDC-81	24/05/10	-33.29257	18.8064	9803	4900	7.3	203.0	1711.4	35.0	83.1	238.5	5900	1.2	247.5	404	18.7	0.0
SDC-86	25/05/10	-33.34739	18.8198	1792	895	7.4	192.0	158.1	2.6	112.5	62.1	250	0.3	234.1	359	0.4	0.0
SDC-88	25/05/10	-33.34852	18.8158	901	450	7.6	177.0	83.1	1.4	35.9	25.1	30	0.2	215.8		0.2	0.0
SDC-90	25/05/10	-33.28469	18.7738	3412	1704	8.0	185.0	505.1	6.3	57.1	70.8	1750	1.8	225.6	100	0.3	0.0
SDC-91	25/05/10	-33.26415	18.7543	3140	1565	7.1	323.0	410.5	3.8	109.9	99.5	1350	0.5	393.9	262	1.4	0.0
SDC-93	25/05/10	-33.23831	18.7575	7692	3848	6.9	281.0	1291.5	21.6	82.6	150.5	4700	1.3	342.7	326	59.3	0.2
SDC-94	26/05/10	-33.35284	18.8196	1546	775	6.1	124.0	170.2	2.1	51.6	49.3	600	0.3	151.2	54	1.1	0.6
SDC-96	26/05/10	-33.28449	18.8229	717	359	6.1	10.0	101.7	4.8	12.1	12.0	385	0.0	12.2	20	40.0	0.0

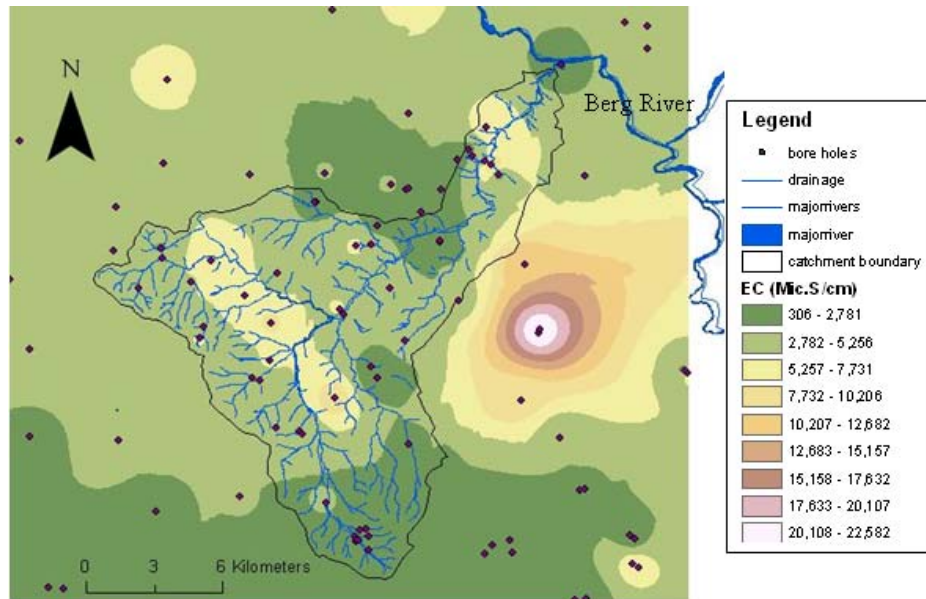


Figure 3. Electrical conductivity distribution within the study catchment.

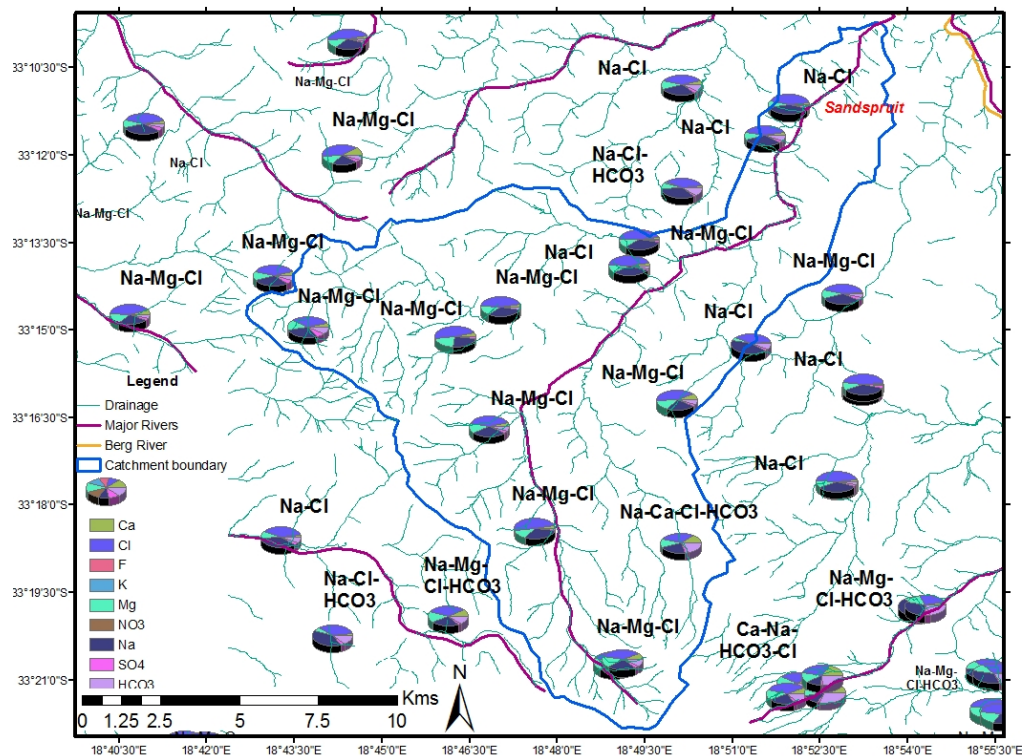


Figure 4. Groundwater major ion and hydrochemical facies distribution in the study area.

However, the Piper and Ludwig Lungelie plots of Figure 5 indicate that some sort of groundwater evolution from Na-Mg-HCO₃ and Na-Ca-Mg-SO₄ type groundwater (upstream Samples) to a Na-Cl type groundwater in the middle and lower reaches of the catchment is occurring. This evolution is supported by the existence of measurable amounts of tritium in the upstream borehole samples, while the middle and downstream areas have practically zero tritium signals.

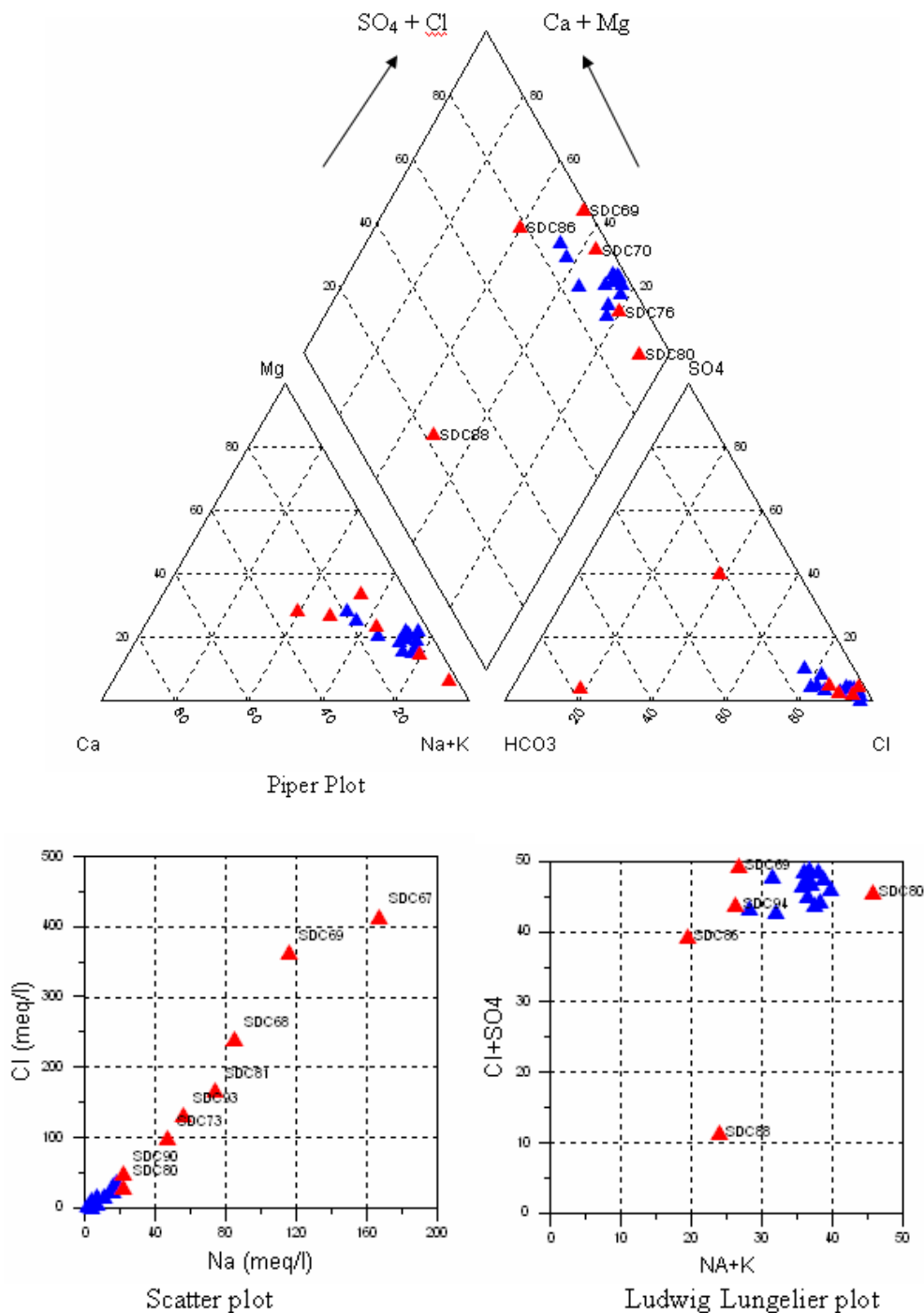


Figure 5. Piper, Scatter and Ludwig Lungelier plots of hydrochemical data.

A very interesting hydrochemical observation is that Mg is dominant over Ca, indicating a typical geologic control as the saturation indices of all the samples with respect to calcite and other common mineral phases except dolomite are negative. Trace element concentrations in all of the groundwater samples are very low except for Sr.

Environmental Isotopes (Deuterium, ¹⁸O and Tritium)

Table 6, figures 6 and 7 present environmental isotope data generated for the study catchment. Considering that the least modified groundwater is similar in terms of isotopic signal to that of the rainfall that has recharged the aquifer, most groundwater samples plot near to the local meteoric water line (LMWL) established for rainfall at the Cape Town (Malan) GNIP station, suggesting that it is meteoric in origin. However, a number of groundwater samples are plotted below the LMWL indicating evaporation processes during recharge.

It was tried to capture the seasonal isotopic variation of groundwater by sampling at three different times (dry season sampling in May, 2009 and wet season sampling in December, 2010 and May 2010), only the May 2010 data are presented due to space limitation space. Even though these are a one go on- project basis sampling, and monitoring for longer number of years should be done to reach to conclusive results, the December samples plot are relatively more enriched compared to the two May samples. All of the December samples plot below the LMWL indicating some evaporation taking place perhaps during and after precipitation.

The tritium values in the catchment groundwater ranges from 0 to 1.1 tritium units (TU). Generally the tritium signals of groundwater in the catchment is zero or nearly zero suggesting that it has been recharged before 1953. Although rapid recharge through preferential flow paths has been recorded, the local modern infiltration process is slow, commensurate with hydrogeological characteristics of the rock units.

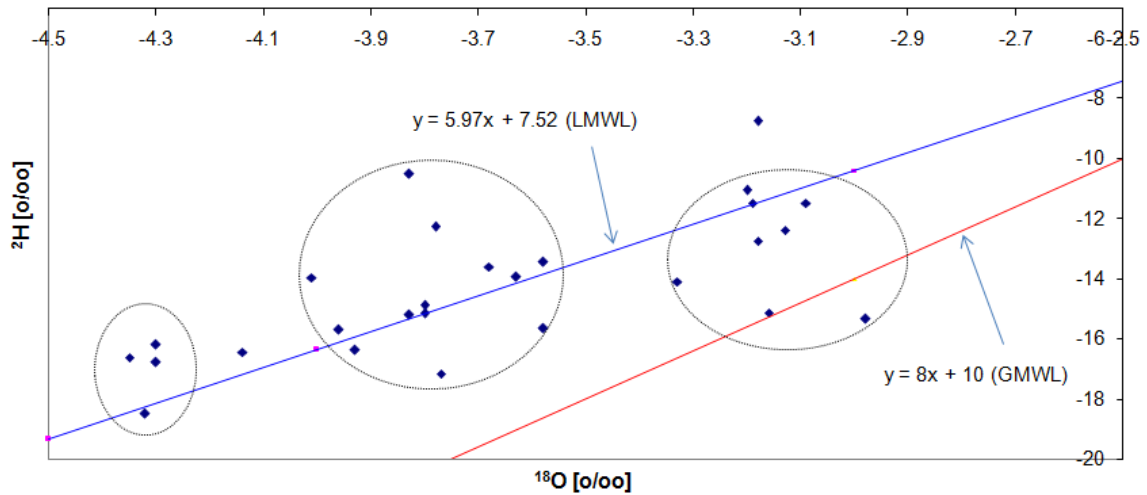


Figure 6. Environmental isotope data plot of groundwater samples collected in May 2010 within the study catchment

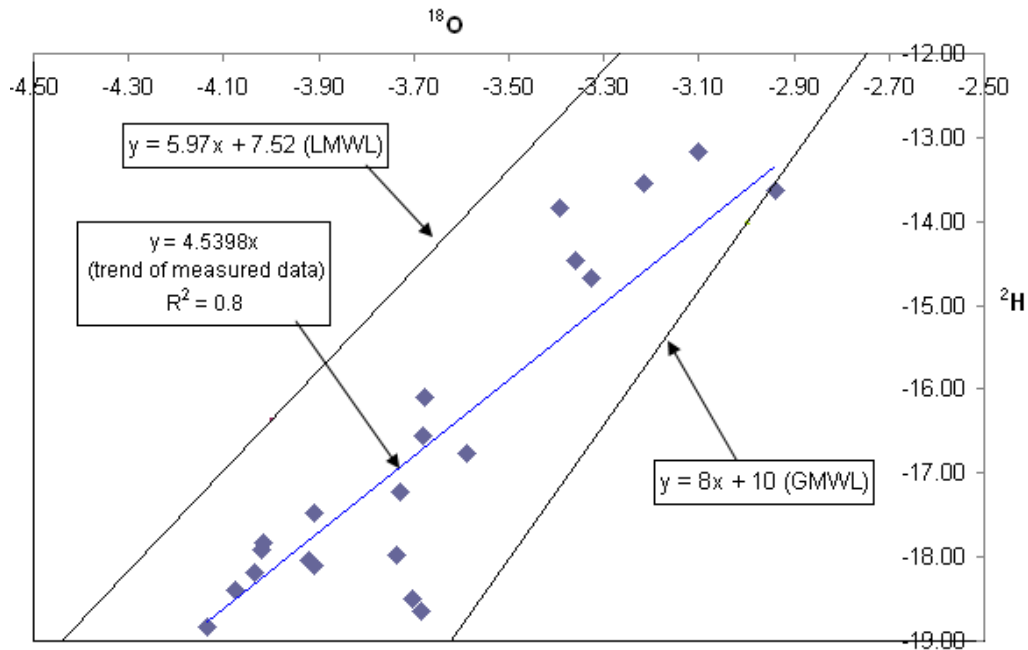


Figure 7. Environmental isotope data plot of groundwater samples collected in December 2010 within the study catchment.

Table 6. Groundwater environmental isotope data within the study catchment.

Sample ID	Sampling date	Sample location Latitude	Sample location Longitude	Water source	Altitude (m a.m.s.l)	DTW (m bgl)	EC ($\mu\text{S}/\text{cm}$)	TDS (ppm)	Temp ($^{\circ}\text{C}$)	pH	$\delta^{18}\text{O}$ ‰	$\delta^2\text{H}$ ‰	D-excess	^3H (TU)
S DC 66	22/05/10	-33.21682	18.71982	GW	205		2775	1387	21.97	6.77	-3.58	-15.64	13	
S DC 67	23/05/10	-33.20024	18.86811	GW	61	artesian	21050	10520	21.36	6.81	-3.16	-15.12	10.16	0 ± 0.2
S DC 68	23/05/10	-33.20432	18.87094	GW	73	5.21	12290	6142	22.4	6.69	-2.98	-15.34	8.5	0 ± 0.2
S DC 69	23/05/10	-33.19875	18.86531	GW	69	1.2	19280	9623	22.92	6.74	-3.19	-11.47	14.05	
S DC 70	23/05/10	-33.19681	18.86040	GW	60	14.02	2868	1435	22.11	7.64	-3.18	-12.74	12.7	0 ± 0.2
S DC 71	23/05/10	-33.19852	18.85443	GW	118	44.45	424	212	25	6.67	-3.8	-14.87	15.53	
S DC 72	24/05/10	-33.25959	18.80982	GW	99	5.08	2072	1035	21.28	7.9	-4.14	-16.44	16.68	0.3 ± 0.2
S DC 73	24/05/10	-33.25753	18.80807	GW	116	11.08	6650	3316	21.79	6.73	-3.33	-14.09	12.55	0.5 ± 0.2
S DC 75	24/05/10	-33.24908	18.82782	GW	107		2825	1413	23.11	7.4	-3.93	-16.37	15.07	
S DC 76	24/05/10	-33.21485	18.79846	GW	135	5.29	2286	1144	21.17	6.77	-3.63	-13.94	15.1	0 ± 0.2
S DC 77	24/05/10	-33.20367	18.80222	GW	127	12.93	2772	1393	22.73	7.32	-4.3	-16.77	17.63	0 ± 0.2
S DC 78	24/05/10	-33.20818	18.82843	GW	99		3806	1903	21.08	6.78	-4.51	-15.4	20.68	
S DC 79	24/05/10	-33.21879	18.84017	GW	131	42.38	881	440	22.18	6.38	-4.01	-13.95	18.13	0.2 ± 0.2
S DC 80	24/05/10	-33.23057	18.84751	GW	95		2475	1237	21.9	8.02	-4.35	-16.62	18.18	
S DC 81	24/05/10	-33.29257	18.80636	GW	155		9803	4900	20.46	7.26	-4.32	-18.49	16.07	0 ± 0.2
S DC 83	25/05/10	-33.34907	18.81464	GW	271	3.73	2331	1167	20.59	6.8	-3.68	-13.59	15.85	
S DC 84*	25/05/10	-33.34877	18.81463	SW	265		1402	700	13.91	8.22	-3.18	-8.76	16.68	
S DC 86	25/05/10	-33.34739	18.81983	GW	308	11.54	1792	895	20.67	7.38	-4.3	-16.19	18.21	0.5 ± 0.2
S DC 87	25/05/10	-33.34847	18.81578	GW	271	5.37	682	341	19.93	6.8	-3.13	-12.38	12.66	
S DC 88	25/05/10	-33.34852	18.81581	GW	273	8.01	901	450	20.79	7.63	-3.09	-11.48	13.24	0.5 ± 0.2
S DC 89	25/05/10	-33.28473	18.77377	GW	156	0.57	4487	2243	22.45	6.67	-3.77	-17.16	13	
S DC 90	25/05/10	-33.28469	18.77378	GW	141	0	3412	1704	22.1	7.97	-3.8	-15.14	15.26	0 ± 0.2
S DC 91	25/05/10	-33.26415	18.75431	GW	224	17.15	3140	1565	19.38	7.06	-3.83	-15.2	15.44	
S DC 92	25/05/10	-33.26887	18.75312	GW	240		5780	2893	20.79	7.32	-3.2	-11.06	14.54	
S DC 93	25/05/10	-33.23831	18.75748	GW	169		7692	3848	17.79	6.94	-3.58	-13.44	15.2	0 ± 0.2
S DC 94	26/05/10	-33.35284	18.81960	GW	295	11.82	1546	775	18.92	6.06	-3.78	-12.25	17.99	
S DC 95	26/05/10	-33.35284	18.81968	GW	299	5.8	2159	1080	20.62	6.28	-3.83	-10.5	20.14	
S DC 96	26/05/10	-33.28449	18.82290	GW	145		717	359	22.56	6.14	-3.96	-15.68	16	0.4 ± 0.2

The Origin of Groundwater Salinity

The groundwater samples analyzed have specific electrical conductivities (EC) ranging from 424 $\mu\text{S}/\text{cm}$ to 21050 $\mu\text{S}/\text{cm}$ and TDS ranging from 212 to 10520 ppm (see the preceding hydrochemical tables), indicating that that most groundwaters in the catchment are brackish and of poor quality except in areas where fresh groundwater occurs associated with cherts and highly fractured rock units which are being targeted by farmers for locating their boreholes. Interestingly, areas that are characterized by fresh groundwater have Na and chloride as the dominant ions giving rise to a Na-Cl type water.

A close study of the distribution of saline groundwater along with the geological map of the area indicates that most saline groundwater is hosted within the Malmesbury Group shale (see figures 2 and 3). It is generally expected that groundwater circulating within weathered shale aquifers to have a relatively poor quality. The question is where does the salt come from? Why do all fresh, brackish and saline groundwaters occurring within the research area are characterized by a Na-Cl type water?

The International atomic energy agency (IAEA, 1983) and Payne (1988) suggest that there are generally three main mechanisms of groundwater salinity in an arid environment like the study catchment. In each case groundwater is expected to have some specific isotopic and chemical composition. These mechanisms and the expected isotopic and chemical signal are the following:

(a) If salinity arises due to mixing with marine water trapped in alluvial sediments the δD and $\delta^{18}\text{O}$ values are together and individually with chloride, linearly correlated along mixing line with sea water as one end-point. This correlation is absent in the area under investigation.

(b) If salinity arises due to concentration of salts by evaporation, the δD and $\delta^{18}\text{O}$ values lie on a line having slope of 4 to 6. The EC or chloride is positively correlated with the isotopic contents. The December 2010 isotope data (figure 7) indicates a good fitting trend line having a slope of about 4.5. However, neither the EC nor Cl of this data set nor the May 2010 isotope and chemical data show any such pattern.

(c) If the cause of salinity is due to the dissolution of salts from soils and rocks, the stable isotopic composition is not changed with the increase in salinity of groundwater, and there is no correlation between isotopic values and chloride concentrations.

Analysis of all the isotopic data, Isotope and chloride plots, isotope and EC plots, EC and depth to water level and the general depth to groundwater information, it appears that the salinity of groundwater in the area is caused by dissolution of salts from the host rock. This is further supported by the fact that the Swartland formation is a typical marine geosynclinal assemblage (Verwoerd, 1974), and hence historical marine salts within the formation is responsible for the salinity of the groundwater. This salinity is exacerbated by the general arid nature of the area (low recharge), relative low permeability of the rock that lead to ponding of water on the surface and slow infiltration which lead to some evaporative enrichment and perhaps contribution from maritime aerosols as reported by Weaver and Talma (2002), Fey and de Clerq (2004) and Fluegel (1995). A preliminary note from this study is that, as a result of a relatively deep depth to groundwater situation (> 5m below ground level), the contribution of groundwater to dryland salinity (i.e. mobilization and redistribution of salts closer to the surface and or into waterways by rising groundwater) is unlikely. This is because of the fact that no unusual enhanced recharge or percolation is observed in the area. It can be suggested that soil and surface water salinity as is the case for the salinity of groundwater in the area is due to the presence of natural salts of geologic and marine origin that are partly mobilized by water moving in the unsaturated zone (interflow) along the drainage system.

5. CONCLUSIONS AND RECOMMENDATIONS

Widespread groundwater salinity in the Sandspruits catchment (Berg River basin) is evident from the measured electrical conductivities (EC) values (reaching 21050 $\mu\text{S}/\text{cm}$ and TDS values (reaching 10520 ppm). However, there are areas where fresh groundwater occurs associated with cherts and highly fractured rock units which are being targeted by farmers for locating their boreholes. Generally the groundwater water is Na-Cl type, including the fresh groundwaters. It was observed that the saline groundwater is hosted within the Malmesbury Group shale

It appears that the salinity of groundwater in the area is caused by dissolution of salts from the aquifer material. This conclusion is supported by the fact that the Swartland Formation is a typical marine geosynclinal assemblage and historical marine salts within the formation is responsible for the salinity of the groundwater. This salinity is exacerbated by the general arid nature of the area (low recharge), relative low permeability of the rock that lead to ponding of water on the surface and slow infiltration which will be subjected to evaporative enrichment before infiltration as evidenced from the stable isotope data and perhaps contribution from maritime aerosols. Further research on the measurement of maritime aerosol deposition and long-term monitoring of environmental isotopes of precipitation and groundwater, groundwater level are recommended.

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7. REFERENCES

Fey, M.V and de Clerq, W.P (2004) Dryland Salinity Impacts on Western Cape Rivers. Water research Commission, WRC Report No. 1342/1/04.

Flugel, W.A (1995) River salinity due to dryland agriculture in the Western Cape Province, Republic of South Africa. *Env. Int.* Vol 21. Pp 679-686.

Fourie, J.M (1976) Mineralization of Western Cape Rivers. PhD dissertation, University of Stellenbosch.

(IAEA/WMO 2004) Global network of isotopes in precipitation. The GNIP database. Accessible at <http://Isohis.iaea.org>.

Gresse, P.G, von Veh, M.W and Frimmel, H.E (200) Namibian (Neoproterozoic) to Early Cambrian Successions. In the geology of South Africa Johnson, M.R., Anhaeusser, C.R and Thomas, R.J.(Edts). The geological Society of South Africa and Council for Geosciences.

Hartley, C.J.H., Newton, A.R. and Theron, J.N. (1974) The stratigraphy and structure of the Malmesbury Group in the South-western Cape. In: Kroener, A. (Ed.). Contributions to the Precambrian Geology of Southern Africa. Bull. Precamb. Res. Unit, Univ. Cape Town, 15, 193-213.

Meyer, P.S (2001) An explanation of the 1:500 000 general hydrogeological map – Cape Town 3317. Department of Water Affairs and Forestry, Republic of South Africa.

Verwoerd, W.J (1974) Geological Map of the Moorreesburg-Wellington Area. University of Stellenbosch. Vol 49. Series 5.

Von Veh, M.W.(1983). Aspects of sedimentation, structure and tectonic evolution in the Tygerberg Terrane, South-western Cape Province. Bull. Precamb. Res. Unit, Univ, Cape Town, 32, 88pp.



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