Regional Description of the Groundwater Chemistry of the Kruger National Park

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1. Introdution

The Kruger National Park (KNP) has adopted a Strategic Adaptive Management (SAM) program with clear ecosystem management goals based on environmental indicators and their thresholds of potential concern (TPC). TPCs are a set of operational goals that together define the spatiotemporal conditions for which the Kruger ecosystem is managed. TPCs are essentially upper and lower limits along a continuum of change in selected environmental indicators. When the upper or lower TPC levels are reached, or when modeling predicts that they will soon be reached, this prompts an assessment of the cause of the extent of change. This assessment provides the basis for deciding whether management action is needed to moderate the change or whether the TPC should be recalibrated in the light of new knowledge and/or understanding.

Groundwater has been recognized as one of the environmental indicators that needs to be monitored and for which TPCs will have to be developed in the park. Two aspects of groundwater that need TPCs and associated monitoring programs have been identified, namely (i) groundwater quantity and (ii) groundwater quality. The Department of Water Affairs and Forestry (DWAF) assists the KNP with the groundwater quantity TPCs. A short 5 month project led by the University of Pretoria assists the KNP to develop a strategic groundwater quality monitoring network and to set the TPC levels correctly and for an appropriate suite of constituents. In order to achieve this goal the project team used the readily available data from the National Groundwater Archive/Database (maintained by DWAF) to provide a regional characterization of the groundwater chemistry in the KNP. Incorporating land use practices outside the park as well as geological maps potential groundwater problem hotspots were identified and sampled. The outputs from the above are used to propose a groundwater monitoring program for the KNP.

2. Geological setting

The Kruger National Park contains rocks that represent the earliest parts of South Africa's geological history as well as relatively young lithologies (Fig. 3). Archaean rocks present in the KNP include both Archaean granitoid intrusions and Archaean greenstone belt fragments. Archaean granitoid intrusions cover small areas within the western central and western northern parts of the Park containing the following (Robb et al., 2006):

- The Makhutswi Gneiss: a complexly folded light grey migmatitic gneissic unit that consists predominantly of plagioclase, quartz, microcline and biotite.
- The Goudplaats Gneiss: a unit that consists of a wide variety of gneissic rocks.

The Archaean Greenstone Belt lithologies within the KNP form part of the Barberton Greenstone Belt, Murchison Greenstone Belt and Giyani Greenstone Belt. The Onverwacht group is the lowermost unit of the Barberton Greenstone Belt and covers parts of the southern border of the KNP. This group consists of basalt, komatiite, intrusive tonalitic gneiss and minor banded iron formations and felsic lavas (Brandl et al., 2006). The Gravelotte group of the Murchison Greenstone Belt includes numerous domains that consist of schists, gneisses, mafic intrusions, felsic lavas and volcanic breccias. These domains are deformed to various degrees (Brandl et al., 2006). The Gravelotte Group covers small parts of the central west of the KNP. In the NW parts of the Park ultramafic and mafic rocks and minor iron formations, felsic schists, and metasediments characterise the Giyani Group of the Giyani Greenstone Belt (Brandl et al., 2006). A small part of Bulai Gneiss (Central zone of Limpopo Belt) is present along the western border in the North of the KNP. The rocks present in this unit are generally intrusive, porphyritic granitic to charnockitic rocks (Kramers et al., 2006).

The entire SW part of the KNP is underlain by rocks belonging to the Nelspruit Suite. The rocks of this batholith have an age of 3303±6 Ma and mostly consist of coarse-grained porphyritic granodiorites. These rocks are grey to pink and are composed of quartz, plagioclase, microcline and biotite (Robb et al., 2006). The Nelspruit Suite also contains lesser occurrences of gneiss and porphyritic granite (Robb, 1978, 1979, 1994; Robb et al., 1983, in Robb et al, 2006:66). Of similar age to the Nelspruit Suite but situated in the western central parts of the KNP is the Baderouke granite. This unit consists of grey coarse-grained granite (Robb et al., 2006).

No major lithologies of Vaalian age occur within the KNP boundaries and after the Archaean rocks the next youngest geological sequence present is the Mokolian-aged Soutpansberg Group. Lithologies belonging to this group cover the majority of the northern western parts of the Park. The Soutpansberg Group lithologies occurring within the KNP are the (Barker et al., 2006):

- Tshifhefhe Formation: epidotised shale, greywacke and conglomerate.
- Sibasa Formation: basalts with intercalated clastic sediments.
- Fundudzi Formation: arenaceous and argillaceous rocks (intercalated with basalt in the upper parts).
- Wyllie’s Poort Formation: pink quartzitic sandstone with minor pebble washes.
- Nzhelele Formation: red argillaceous and arenaceous sedimentary rocks with thick pyroclastic rock layers.

Minor Phalaborwa syenite dykes occur within the central parts of the KNP. These dykes are associated with a series of alkaline complexes that intruded into the Kaapvaal Craton between 2100 and 1200 Ma (Verwoerd & du Toit, 2006). Another relatively young intrusive unit within the park is the 1106-1112 Ma Timbavati Gabbro, which occurs as numerous thin intrusions across the Park and covers a large part of the western southern part of the park. As the name suggests this unit consists mainly of gabbro and forms part of the Umkondo Igneous Province (Hanson et al., 2004 in Anhaeusser, 2006:124).

Almost the entire eastern half of the KNP as well as a large area in the western central parts of the Park is underlain by rocks of the Karoo Supergroup. These rocks can be correlated with those in the Tshipise Basin and include the following sedimentary units (Johnson et al., 2006):

- Madzaringwe Formation: alternating sandstone, siltstone and shale.
- Red Rocks Member, Clarens Formation: very fine- and fine-grained light red argillaceous sandstone.
- Tshipise Member, Clarens Formation: fine-grained cream coloured sandstones.

Following the deposition of the above-mentioned sedimentary units the Lebombo Group was lain down. This group forms part of the Karoo Igneous Province and within the Park consists of the following units (Duncan & Marsh, 2006):

- Letaba Formation: olivine rich lavas
- Jozini Formation: silicic volcanic rocks

The Jozini Formation is more resistant to weathering than the mafic rocks of the Letaba Formation and so forms Lebombo Mountains (Duncan & Marsh, 2006). Numerous small occurrences of dolerite/diabase are seen across the Park within different lithologies and these represent feeder dykes to the Lebombo Group.

2.1. Regional groundwater chemistry

The description of the regional groundwater chemistry is based on data retrieved from the National Groundwater Archive / Database (NGDB/NGA, maintained by the Department of Water Affairs and Forestry, DWAF) for the KNP. The most comprehensive sampling campaign of groundwater chemistry in the KNP was performed by DWAF in 1991 and hence used for the assessment of the regional water quality. A total of 355 water analyses, mostly from shallow boreholes within the KNP, were interpreted with regard to their dominant anion and cation (i.e. water-facies). The spatial distribution of the water facies was related to the underlying geology (assuming groundwater is in long-term equilibrium with the aquifer material) to arrive at a water type distribution map (Fig. 1). For the sake of simplicity the water types were named according to the dominant geological units, the water facies itself are given as labels in Fig. 1. Several water types represent essentially the same (short) water facies and are distinguished based on the underlying geology responsible for the mineralization (e.g. sedimentary vs. igneous rocks). Such a distinction is from a geochemical point of view necessary and will also play an important role in the assessment of the water quantity (different geological units have different recharge rates, storage capacities and permeabilities), i.e. it will assist the KNP in future assessments.

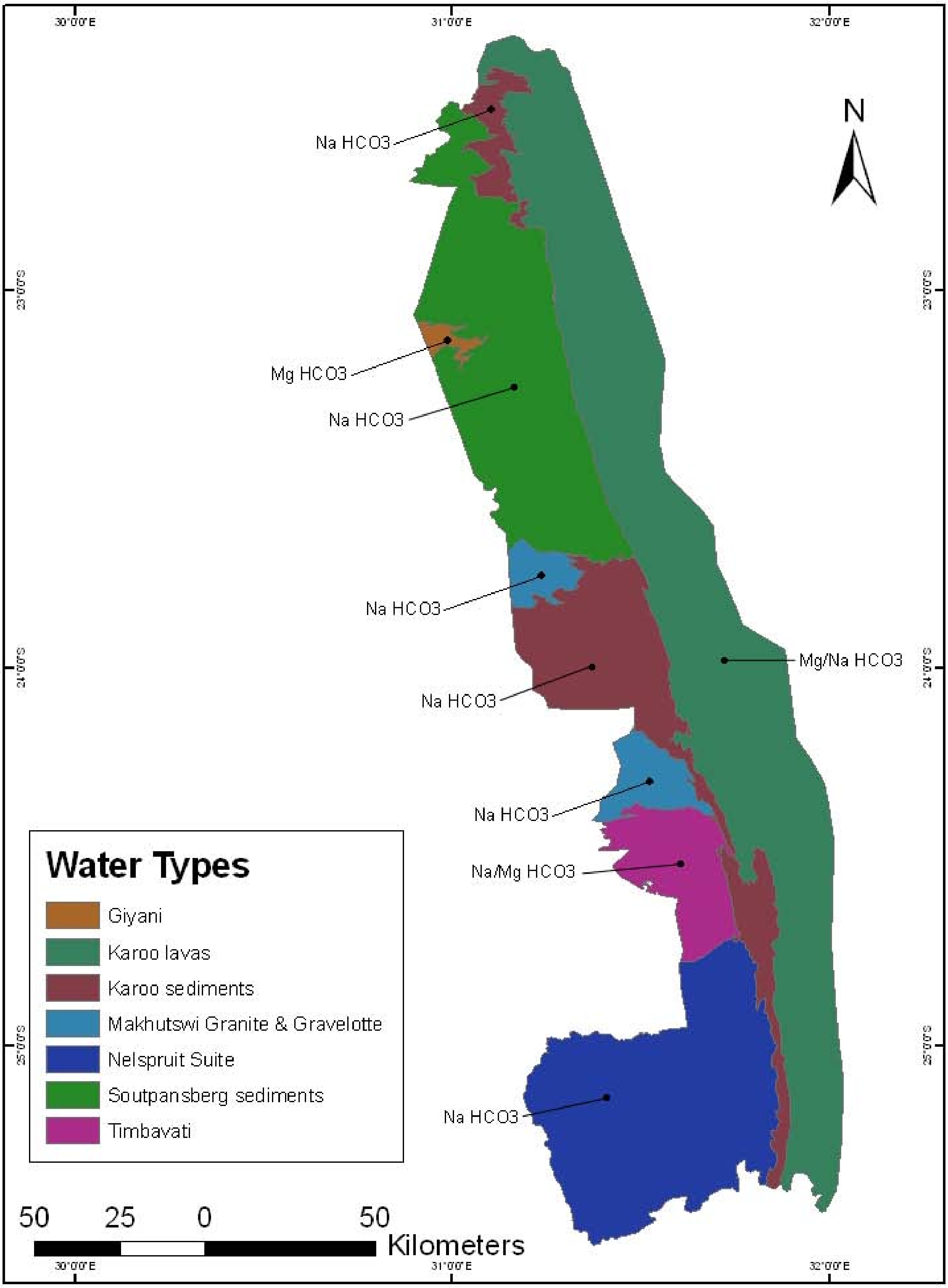

Fig. 1: Regional groundwater types and facies in the KNP (data source: NGA / DWAF).

Two of the water types are based on only a small number of samples and predominantly on geological considerations. The first is the Giyani water type, which is a $Mg\text{-}HCO_3$ facies (represented in the NGA by only 3 samples) related to the basic metamorphic rocks (ultramafic schists, iron formation, felsic schists) of the Giyani

Greenstone belt. The second type is the Makhutswi Granite & Gravelotte water type, whose Na-HCO_3 facies (represented in the NGA by only 9 borehole samples) is a result of the acidic metamorphic rocks of the Makhutswi Gneisses and the Gravelotte Group (schists, gneisses, felsic lavas and volcanic breccias). The more dominant water types in the KNP are generally derived from a large number of samples and therefore more confirmed.

The Nelspruit Suite water type (69 samples) is characterised by a Na-HCO_3 water facies as a result of the underlying acidic igneous rocks (porphyritic granodiorites). Localised areas are underlain by the Timbavati Gabbro and the facies develops as expected from the mafic gabbros towards a Mg-HCO_3 type. The Soutpansberg Sediments water type (58 samples), a Na-HCO_3 water facies is influenced by calcium/magnesium poor silicate rich sedimentary rocks (shale, greywacke, conglomerates, sandstones). Within the outlined area the water type develops in drainage channels (fluvial deposits) and in areas underlain by localised basic igneous rock occurrences towards a Mg-HCO_3 water facies. The Nelspruit Suite water samples as well as the Timbavati and Karoo lavas groundwater samples show frequently elevated F concentrations (Fig. 2), which render the waters unsuitable for human consumption ($F > 1.5$ mg/l).

The Timbavati water type (22 samples), a Na/Mg-HCO_3 water facies, is generally found in gabbros. It shows unexpected higher Na contributions to the mineralisation, which might be due to infiltration of evaporated surface waters. The Karoo sediments water type (49 samples) is found in the central part of the KNP as well as bordering the Karoo lavas on the E side of the KNP. As expected from the silica rich and Ca/Mg poor sedimentary rocks (sandstones, shale and siltstone) a Na-HCO_3 water facies is predominant. Localized basic igneous rock inliers (Timbavati gabbros) cause a change towards a Mg-HCO_3 water facies. The Karoo Lavas water type (152 samples), a Na/Mg-HCO_3 water facies, is found in the Karoo lavas (magnesium/olivine rich lavas of the Letaba Formation and silicic volcanic rocks of the Jozini Formation with higher sodium predominance) on the E side of the KNP. Due to evaporative concentration of shallow groundwater along alluvial deposits and drainage channels the water type develops locally towards a Na HCO_3 or Na-Cl water facies.

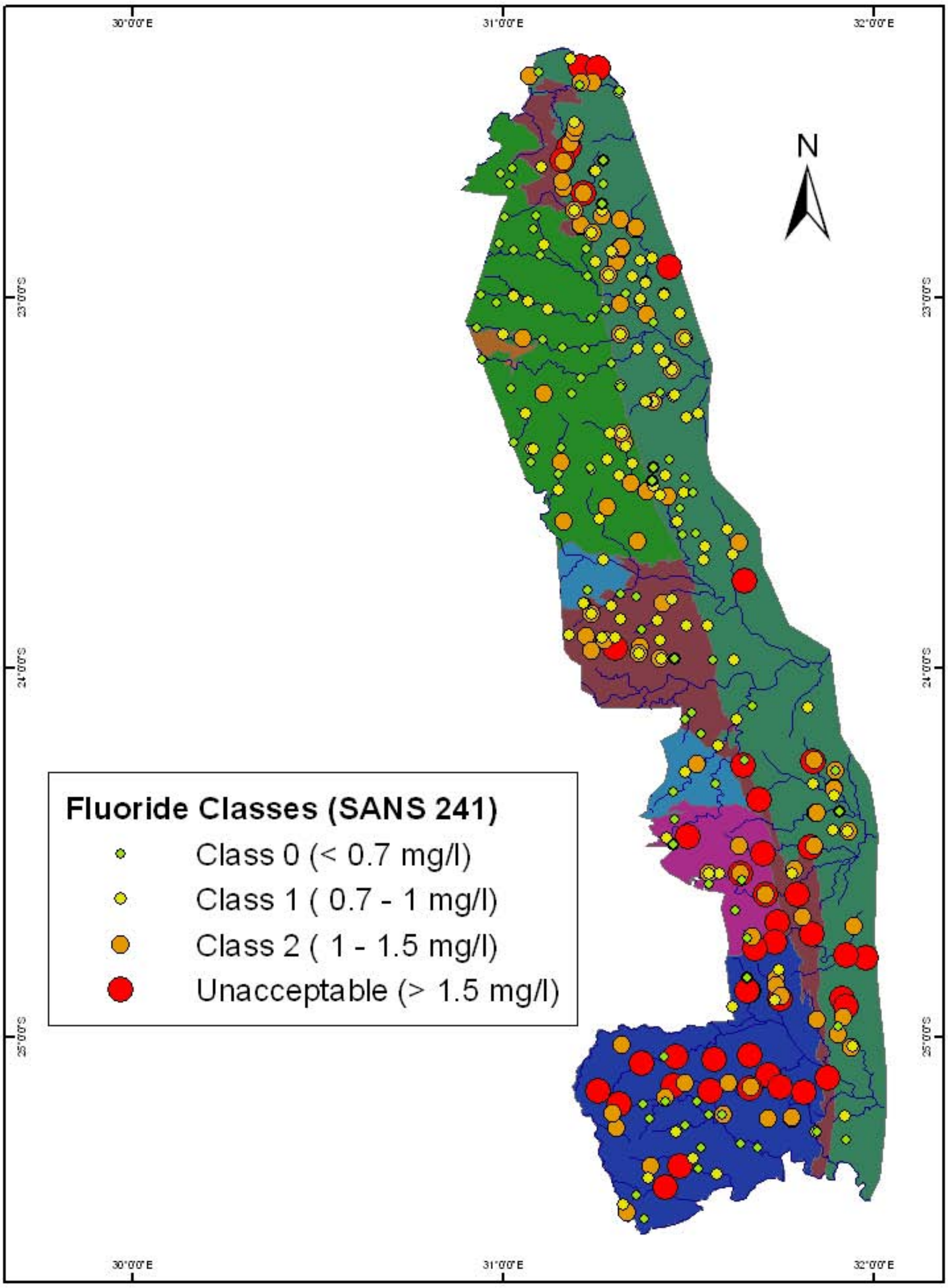

Fig. 2: Regional distribution of fluoride concentrations in the KNP (data source: NGA / DWAF, 1991 data).

3. UP sampling campaign

Based on available DWAF water quality data within the KNP a number of representative boreholes and rivers throughout the KNP were selected for sampling.

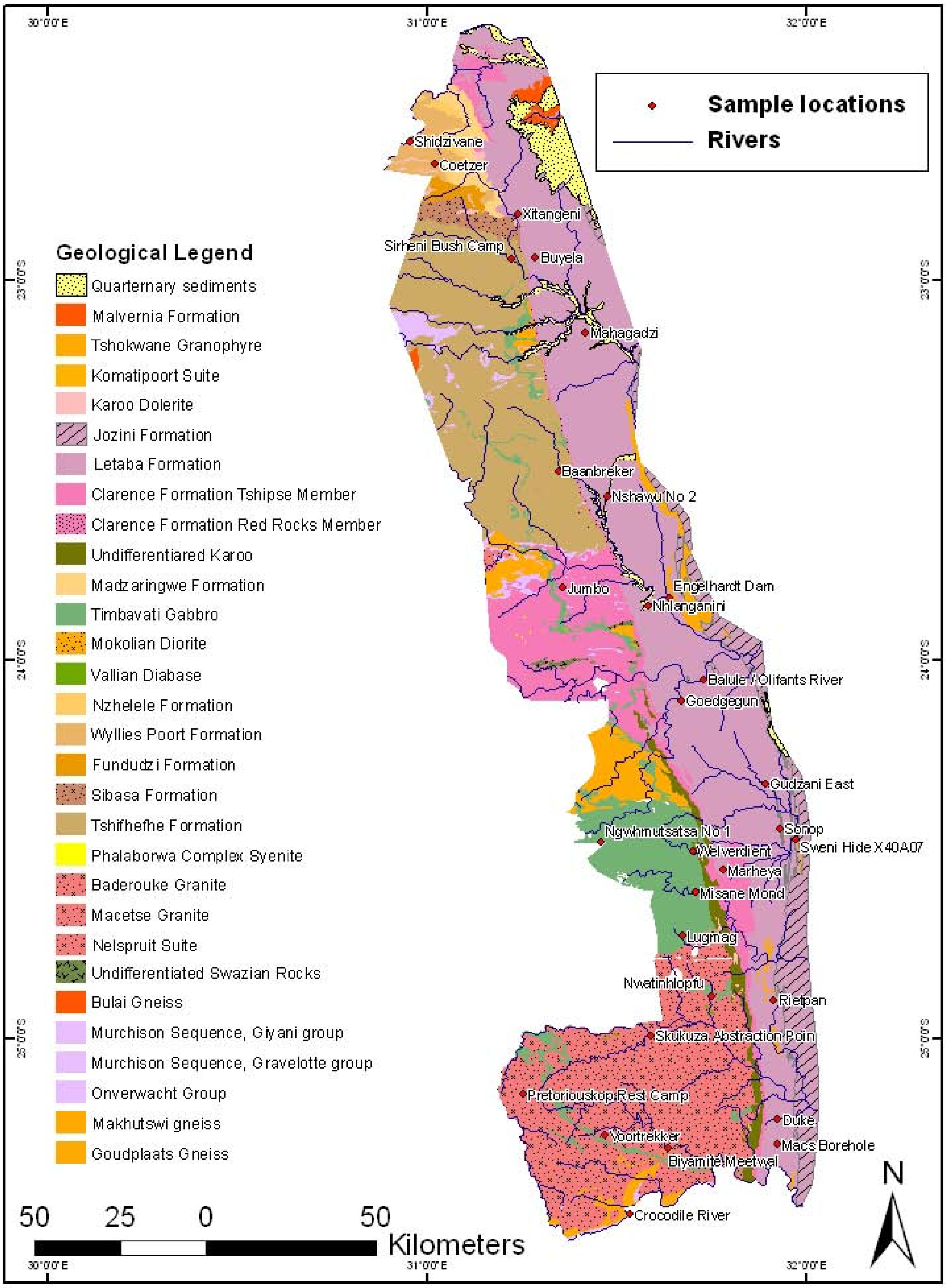

Fig. 3: Regional geology and UP sample locations.

The sampling campaign commenced on the 11/06/2007 (with a lecture and field training of SanPark personal) and ended on the 21/06/2007. A total of 29 surface and groundwater samples were taken (Tab. 1) and analyzed for major and trace elements, microbiological parameter as well as water isotopes (^{2}H, ^{18}O). The results of the chemical, microbiological and isotope analysis (^2H and ^{18}O, tritium outstanding) are given in APPENDIX A.

Tab. 1: UP sample location and field measurements (colour code: rivers – blue, reservoirs – yellow).

#	KNP name	date	longitude	latitude	elev [masl]	description	pump rate [l/sec]	water temp	colour	smell	pH	EC [mS/cm]	redox [mV]
1	Nwatinhlopfu	2007/06/11	31.749920	-24.886890	260	bh	0.11	24.4		fresh	7.46	0.695	-227
2	Skukuza Abstraction Point	2007/06/11	31.589940	-24.990310		sabie river		20.5	clear	fresh	7.94	0.275	120
3	Pretoriouskop Rest Camp	2007/06/12	31.252220	-25.145360	606	bh	0.12	23.1	slightly brown	fresh	6.80	0.420	32
4	Voortrekker	2007/06/12	31.467490	-25.252230	351	reservoir		20.8			7.00	1.320	120
5	Biyamite Meetwal	2007/06/12	31.635770	-25.285230	256			26.3	clear	fresh	6.80	1.700	-160
6	Crocodile River	2007/06/12	31.534750	-25.460610		crocodile river		18.3			8.90	0.363	88
7	Duke	2007/06/13	31.924140	-25.210560	210	bh	0.03	27.0	clear	little metallic	7.20	1.861	-190
8	Macs Borehole	2007/06/13	31.925170	-25.277440		bh	0.13	25.3	clear	fresh	6.80	1.714	-107
9	Lugmag	2007/06/14	31.672580	-24.728670		bh	0.05	25.0	dirty brownish	sulfatic	7.30	1.737	-208
10	Misane Mond	2007/06/14	31.710140	-24.613580	308	bh	0.31	23.4	clear	fresh	7.20	5.400	32
11	Rietpan	2007/06/14	31.914280	-24.896830	289	bh	0.19	26.2	clear	metallic	6.70	3.640	-50
12	Welverdient	2007/06/15	31.700890	-24.505220	308	reservoir		22.7	clear	fresh	7.60	3.000	56
13	Marheya	2007/06/15	31.781000	-24.554720	302	bh	0.18	25.9	clear	fresh	6.90	2.100	55
14	Sonop	2007/06/16	31.929780	-24.444580	191	bh	0.17	22.1	clear		7.96	1.203	123
15	Sweni Hide X40A07	2007/06/16	31.972690	-24.473610	166	bh	0.07	26.1	slightly grey	metall + sulfate	7.30	2.900	-207
16	Gudzani East	2007/06/16	31.894330	-24.327970	201	bh							
17	Nhlanganini	2007/06/17	31.583940	-23.858390	222	bh	0.28	26.1	clear	fresh	7.02	1.802	-139
18	Balule / Olifants River	2007/06/17	31.729890	-24.052750	179	olifants river		20.7	clear	fresh	8.65	0.578	92
19	Goedgegun	2007/06/17	31.670920	-24.109830	226	bh	0.08	27.1	clear	fresh	7.36	1.319	143
20	Ngwhmutsatsa No 1	2007/06/18	31.459390	-24.479170	409	bh	0.19	24.6	milky whitish	iron	6.40	1.296	-106
21	Engelhardt Dam	2007/06/18	31.639360	-23.837970	204	letaba river		19.5	slightly dirty	fresh	7.94	0.598	103
22	Buyela	2007/06/18	31.286000	-22.941080	304	reservoir		23.8	clear	fresh	7.33	1.359	128
23	Nshawu No 2	2007/06/18	31.474500	-23.571500	298	bh	0.18	26.3			7.54	1.140	143
24	Mahagadzi	2007/06/19	31.418610	-23.140280	294	reservoir		24.3	clear	fresh	7.30	1.102	188
25	Coetzer	2007/06/19	31.021560	-22.697500	450	bh	0.15	25.8	clear	fresh	6.90	2.280	-182
26	Sirheni Bush Camp	2007/06/20	31.222120	-22.946600		dwaf bh	0.18	26.1	slightly grey	none	6.73	8.020	-123
27	Shidzivane	2007/06/20	30.954360	-22.637330	355	levuvu river		19.7	clear	fresh	8.05	0.166	133
28	Xitangeni	2007/06/20	31.240110	-22.828190	352	bh	0.03	24.0	greyish	slightly metallic	7.36	6.470	-219
29	Baanbreker	2007/06/21	31.347170	-23.504750	327	bh	0.11	26.1	clear		6.95	1.479	53
30	Jumbo	2007/06/21	31.358940	-23.811470	315	bh	0.13	26.4	greyish	fresh	6.98	1.143	50

3.1. Water chemistry of sampled waters

The major ionic composition of the water samples (in %-meq/l) is visualized using a Piper plot (**Fig. 4**). A general trend from a Mg/Ca-HCO_3 towards a Na-Cl water facies is apparent in the plot. Especially the highly mineralized (TDS = 3710 mg/l) Xitangeni sample shows a very distinct and pronounced Na-Cl facies, though no evaporative concentration effect is confirmed by its isotopic composition (**Fig. 5**). The isotopic composition of the sample shows the opposite effect, a highly depleted ^{18}O signature typical for arid inland vapor source of high latitudes or altitudes. While the increased Na concentrations can be assigned to the Karoo lavas, the elevated chloride concentrations in excess of sodium (Na/Cl molar ratio of 0.91) can't be explained at this stage. Other parameters of concern for the Xitangeni sample are highly elevated F (11.9 mg/l), K (20.1 mg/l) as well as slightly elevated Al (0.18 mg/l) concentrations. While the Karoo Lavas water type (Letaba Formation) shows generally elevated F and Al (maximum of 1.06 mg/l in the Ngwhmutsatsa sample) concentrations in the northern part of the KNP, the elevated K concentrations were only found in this sample. With no surface water influence apparent and due to the unusual mineralization as well as isotopic signature an influence of deeper, old groundwater emanating along a geological structure is suspected.

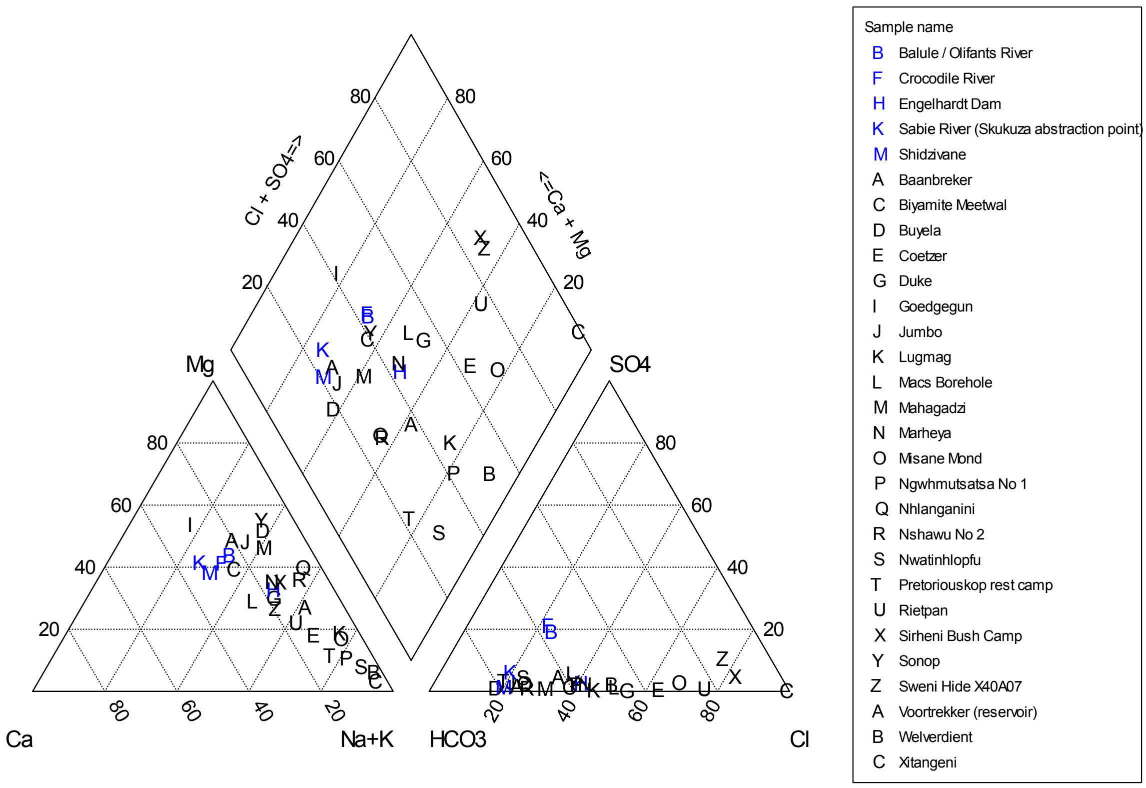

Fig. 4: Piper plot of KNP water samples (surface water samples in blue).

The highly mineralized (TDS = 3230 mg/l) Misane Mond groundwater sample, which was taken in close vicinity to the Nwasnitsontso River, is also characterized as a Na-Cl facies and shows several peculiarities, which point towards anthropogenic influences by surface-groundwater interaction. Despite not yet exceeding the South African standards for drinking water (except for Se), the sample shows elevated SO_4 (70.7 mg/l), Se (0.07 mg/l) and Zn (0.43 mg/l) concentrations. Without a proposed screening of the Nwasnitsontso River quality, a comprehensive assessment of potential sources is not possible.

Two other groundwater samples show also elevated SO_4 concentrations, the Sirheni Bush Camp (173 mg/l, also elevated total coliform bacteria) and the Sweni Hide (131 mg/l) sample. While generally elevated concentrations are expected due to strong evaporative signals (Fig. 5) with subsequent concentrating of ions, the SO_4 source is yet unknown. The highly mineralized (TDS = 5806 mg/l) Sirheni Bushcamp sample exceeds for a number of parameters acceptable drinking water limits and should not be used as a drinking water resource without treatment. A close-by borehole is currently used for drinking water supply and should be analysed as soon as possible (at the time of the sampling campaign the equipped borehole could not be sampled).

A number of otherwise unsuspicious groundwater samples show unexpectedly elevated, though still acceptable, NO_3 concentrations (Baanbreker: 25.8 mg/l, Goedegun: 32.7 mg/l, Jumbo: 18.4 mg/l, Mahagadzi: 25 mg/l, Marheya: 22.3 mg/l, Nshawu: 26.5 mg/l). Since it is unlikely that the NO_3 concentrations are related to farming activities prior the demarcation of the KNP or to atmospheric deposition (see remainder samples in APPENDIX A), a potential source might be increased urination/defaecation of animals in the vicinity of water holes. The hypothesis is supported by elevated total coliform bacteria counts (APPENDIX B) of these samples, but needs obviously further proof (especially with regard to the thickness of the unsaturated zone as well as the predominant soil type and vegetation around these boreholes).

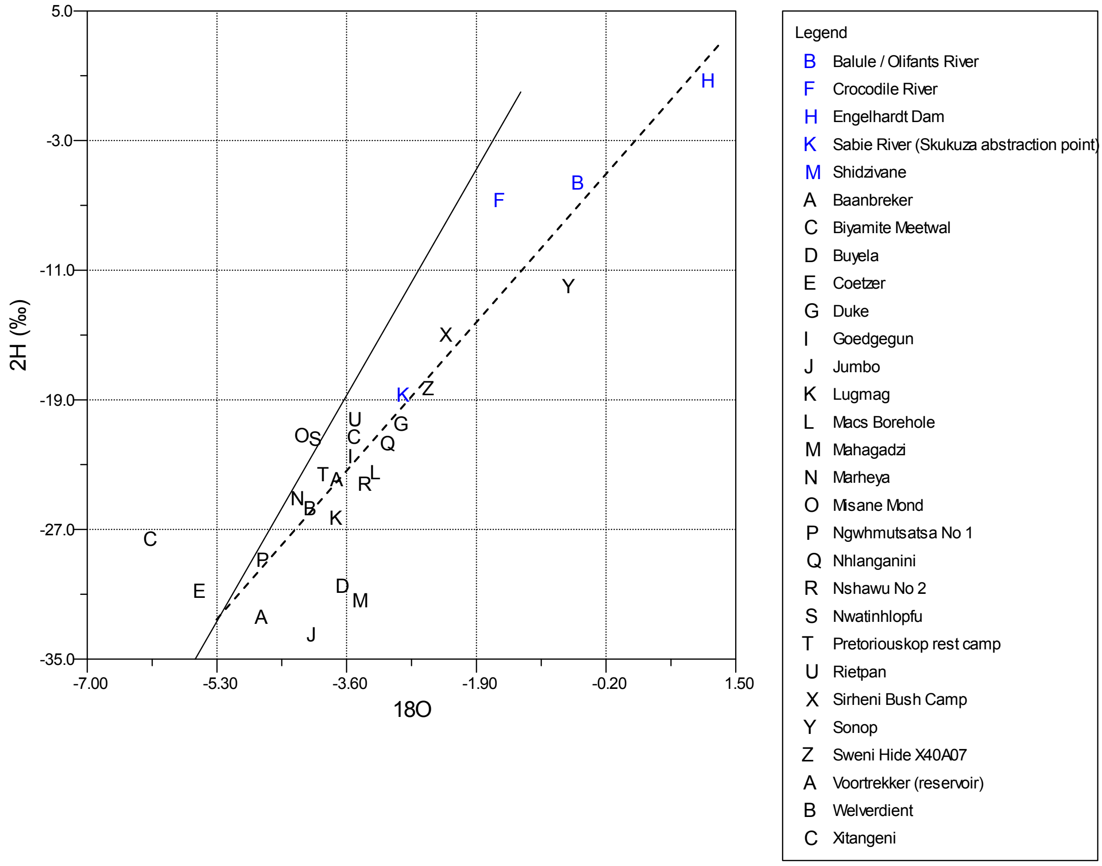

Fig. 5: Isotopic composition of KNP samples including global meteoric waterline ($^2H = 8.2\ ^{18}O + 10.2$, solid line) and tentatively drawn local evaporation line (dashed line).

Evaporative effects are apparent for a few groundwater samples (Sonop, Sirheni Bush Camp and Sweni Hide). While the Sirheni Bush Camp as well as the Sweni Hide sample shows a Na-Cl facies, expected for groundwater samples affected by surface –groundwater interaction (evaporation) in the vicinity of streams, the Sonop sample maintained its Mg-HCO_3 signature from the Karoo lavas. The geological signature is generally apparent for most of the groundwater samples, which confirm the regional groundwater types derived from the NGA data.

All sampled surface waters are characterized as Mg-HCO_3 facies, despite evaporative effects apparent in their isotopic composition (**Fig. 5**). It must be emphasized that the sampled rivers (Crocodile, Letaba/Engelhardt dam, Olifants, Sabie, Shidzivane) are of a general acceptable quality (except elevated total coliform bacteria in the Crocodile river, APPENDIX B), despite abundant townships, intensive farming as well as mining activities in the catchments upstream of the KNP. However, the focus of the sampling campaign was on groundwater and the surface water quality of rivers flowing into or bordering the KNP (especially Shingwedzi, Letaba and Crocodile, **Fig. 6**) is a major concern and should be monitored continuously.

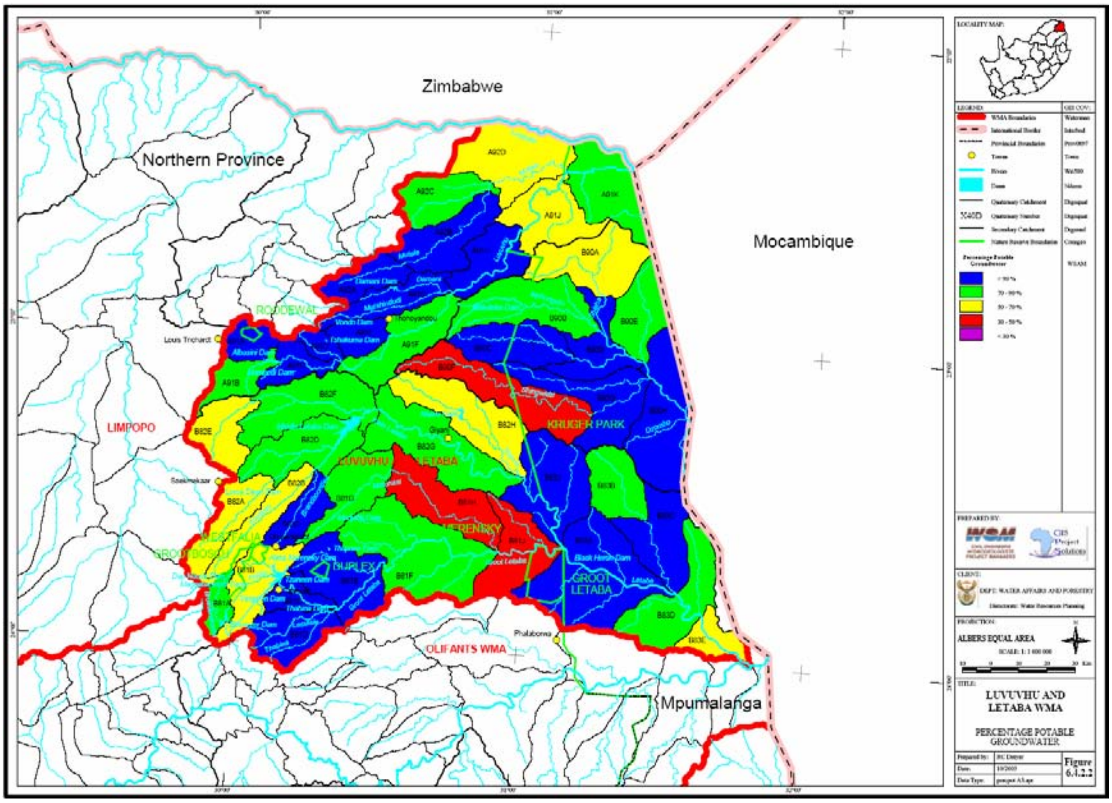

Fig. 6: Percent potable groundwater in quaternary catchments (DWAF 2003).

4. Groundwater monitoring programme / Recommendations

Based on the analysis of the sampled boreholes, land use practices outside the park boundaries and general hydrochemical considerations the following groundwater monitoring programme is proposed:

- Once-off screening (major and trace elements) of all inlet and outlet pipes of service reservoirs/treatment or disinfection plants supplying drinking water to camps and staff villages. The analysis should include microbiological parameters and a screening for hydrocarbons if the camps have a petrol station. Routine analysis of drinking water supplied to all camps in the KNP should be (if not already ongoing) implemented thereafter. Parameters should be selected based on legal requirements for a water supplier (SANS 241) as well as on problematic parameters identified in the once-off screening. Inorganic parameters of concern are for example F, As and Se with unacceptable F concentrations measured in a borehole at the Pretoriuskop rest camp. Drinking water TPCs / standards and sampling frequency (suggested monthly sampling for a served population less than 2500 in the absence of a formally established sampling programme, SANS 241) are set out in SANS 241 and SANS 5667-5. The maximum consumption period for class II water (SANS 241) must be considered for water supply to staff villages.
- A continuous monitoring of river water quality for rivers entering or bordering (e.g. Crocodile) the KNP. Beyond major constituents the analysis should include trace elements (indicator for mine effluents or waste disposal leachate) as well as microbiological parameters (indicator for faecal contamination). It is understood that such monitoring can form part of the river health program by DWAF.
- A number of boreholes show highly elevated F concentrations (see above and APPENDIX A), which render the groundwater samples unsuitable for human consumption. While potential effects on animal health are not the focus of the report, further investigations in this regard might be merited to set suitable TPCs.
- Unexpectedly elevated NO_3 concentrations and increased total coliform bacteria counts were observed in a number of boreholes in otherwise pristine areas. The influence of increased animal densities around water holes on the groundwater quality (with subsequent deterioration thereof) might form an interesting research project.

Any future water analyses (drinking, surface or groundwater) should be captured in a dedicated KNP water database, which should be submitted regularly to DWAF for inclusion in their databases. If boreholes are sampled, their accurate coordinates, accessibility and status (e.g. closed, equipped, sample outlet etc.) should be captured.

5. Acknowledgements

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7. Appendices

APPENDIX A: Results of the chemical analysis KNP samples (all concentrations in mg/l, colour coding according to SANS 241, drinking water).

Sample Name	X	Y	Sample date	TDS	EC	Eh [mV]	pH	Ca	Mg	K	Na	Mn	Fe
Baanbreker	31.347170	-23.504750	2007/06/21	872	1.479	53	7.0	32.3	49.8	4.7	216	0.05	0.05
Balule / Olifants River	31.729890	-24.052750	2007/06/17	342	0.578	92	8.7	28	32	3.7	43.8	0.05	0.05
Biyamite Meetwal	31.635770	-25.285230	2007/06/12	1016	1.700	-160	6.8	90.4	87.5	2.8	152	0.25	0.05
Buyela	31.286000	-22.941080	2007/06/18	870	1.359	128	7.3	32.4	98.2	2.2	136	0.05	0.05
Coetzer	31.021560	-22.697500	2007/06/19	1284	2.280	-182	6.9	57.9	49.1	0.6	362	0.17	0.05
Crocodile River	31.534750	-25.460610	2007/06/12	230	0.363	88	8.9	20.5	19.3	1.6	27.9	0.05	0.05
Duke	31.924140	-25.210560	2007/06/13	1036	1.861	-190	7.2	68.8	68.2	1.6	224	0.2	0.05
Engelhardt Dam	31.639360	-23.837970	2007/06/18	322	0.598	103	7.9	20.6	24.1	5	67.9	0.05	0.06
Goedgegun	31.670920	-24.109830	2007/06/17	906	1.319	143	7.4	77	88.8	0.5	57.9	0.05	0.05
Jumbo	31.358940	-23.811470	2007/06/21	744	1.143	50	7.0	42.3	75.5	5.2	103	0.05	0.05
Lugmag	31.672580	-24.728670	2007/06/14	940	1.737	-208	7.3	18.1	39.4	5.9	302	0.14	0.05
Macs Borehole	31.925170	-25.277440	2007/06/13	970	1.714	-107	6.8	82.5	60.4	0.5	187	0.07	0.05
Mahagadzi	31.418610	-23.140280	2007/06/19	692	1.102	188	7.3	33	69.7	1	116	0.05	0.05
Marheya	31.781000	-24.554720	2007/06/15	1220	2.100	55	6.9	70.3	93.9	5	244	0.05	0.05
Misane Mond	31.710140	-24.613580	2007/06/14	3230	5.400	32	7.2	70.8	120	2.6	1040	0.05	0.05
Ngwhmutsatsa No 1	31.459390	-24.479170	2007/06/18	832	1.296	-106	6.4	22.2	17.8	1.4	260	0.4	1.47
Nhlanganini	31.583940	-23.858390	2007/06/17	1104	1.802	-139	7.0	24	98	0.8	255	0.25	0.05
Nshawu No 2	31.474500	-23.571500	2007/06/18	708	1.140	143	7.5	20.7	55.5	0.5	165	0.05	0.05
Nwatinhlopfu	31.749920	-24.886890	2007/06/11	444	0.695	-227	7.5	7	6.6	0.6	140	0.05	0.76
Pretoriouskop rest camp	31.252220	-25.145360	2007/06/12	290	0.420	32	6.8	10.1	6.3	0.8	81.6	0.05	0.05
Rietpan	31.914280	-24.896830	2007/06/14	2342	3.640	-50	6.7	115	94.8	0.5	505	0.05	0.05
Sabie River (Skukuza)	31.589940	-24.990310	2007/06/11	82	0.275	120	7.9	9.7	7.4	0.9	8.3	0.05	0.05
Shidzivane	30.954360	-22.637330	2007/06/20	110	0.166	133	8.1	10.8	7.7	1.3	10.6	0.05	0.06
Sirheni Bush Camp	31.222120	-22.946600	2007/06/20	5806	8.020	-123	6.7	235	352	1.9	971	1.29	0.05
Sonop	31.929780	-24.444580	2007/06/16	774	1.203	123	8.0	22.2	86	0.5	108	0.05	0.05
Sweni Hide X40A07	31.972690	-24.473610	2007/06/16	2018	2.900	-207	7.3	100	86.8	1.6	341	0.35	0.06
Voortrekker (reservoir)	31.467490	-25.252230	2007/06/12	840	1.320	120	7.0	62.2	90.8	2.7	110	0.05	0.05
Welverdient	31.700890	-24.505220	2007/06/15	1818	3.000	56	7.6	11.4	22.3	1.2	646	0.05	0.05
Xitangeni	31.240110	-22.828190	2007/06/20	3710	6.470	-219	7.4	38.6	22.3	20.1	1270	0.38	0.05

Sample Name	F	Cl	SO4	HCO_3	PO4	Si	NO3	Al	As	B	Ba	Cu	Li	Ni	Se	Sr	U	V	Zn
Baanbreker	5.9	154.3	27	480.90	<0.80	45.40	25.80			0.234	0.028	0.017	0.034			0.382	0.002	0.059	0.042
Balule / Olifants River	0.2	49.7	51.3	193.60	<0.80	5.70	<0.30	0.09		0.034	0.056	0.003	0.002			0.163	0.001	0.007	
Biyamite Meetwal	0.4	227.7	9.5	615.30	<0.80	43.40	2.40	0.03		0.13	0.06	0.01	0.03		0.058		0.01		
Buyela	7.6	81.7	4.8	630.00	<0.80	55.60	5.00			0.249	0.1	0.006	0.002			1.343	0.002	0.117	0.047
Coetzer	2.8	473.7	3.7	457.50	<0.80	39.30	<0.30			0.161	0.5	0.01	0.032	0.006		0.45	0.001	0.001	0.794
Crocodile River	0.1	28.2	34.7	118.10	<0.80	6.10	1.90	0.06		0.02	0.01				0.007		0.01		
Duke	0.5	347.2	0.3	492.50	<0.80	23.60	<0.30			0.21	0.02				0.032				
Engelhardt Dam	2	79.6	6.2	188.90	<0.80	6.80	0.80	0.119		0.074	0.092	0.003	0.001			0.208	6E-04	0.005	
Goedgegun	0.3	138.9	28.1	364.30	<0.80	46.10	32.70			0.095	0.013	0.002	0.001	0.006		1.23	2E-04	0.105	0.042
Jumbo	2.6	79.6	13.1	466.90	<0.80	50.00	18.40			0.169	0.038	0.005	0.054			0.275	0.003	0.049	0.014
Lugmag	0.3	261.5	1	526.30	1.00	11.30	<0.30	0.074	0.001	0.346	0.062		0.016			0.744	3E-04	0.001	0.026
Macs Borehole	0.4	299.6	9	474.50	<0.80	34.00	<0.30			0.21					0.046		0.02		
Mahagadzi	5.4	110.8	3.3	411.80	<0.80	47.10	25.00	0.01		0.142	0.017	0.017				0.964	5E-04	0.162	0.052
Marheya	0.6	299.3	19.1	676.40	<0.80	47.00	22.30			0.319	0.064	0.006	0.006	0.007		1.063	0.001	0.048	0.036
Misane Mond	1.1	1327	70.7	983.90	<0.80	40.70	5.80		0.014	0.788	0.1	0.032	0.067		0.072	1.315	0.021	0.059	0.432
Ngwhmutsatsa No 1	3.5	179.3	11.9	455.40	1.40	28.60	0.40	1.062		0.283	0.049	0.043	0.019			0.177	0.005	0.022	0.661
Nhlanganini	0.6	158.2	19.2	807.70	<0.80	35.80	<0.30			0.344	0.123	0.009	0.009	0.006		1.099	0.006	0.068	0.062
Nshawu No 2	4.6	95.3	4.1	442.00	<0.80	40.20	26.50			0.229	0.063	0.003				0.683	7E-04	0.249	0.024
Nwatinhlopfu	1.1	51.7	12.4	266.90	<0.80	20.00	<0.30			0.16	0.02	0.08	0.02		0.029		0.01		
Pretoriouskop rest camp	3.6	24.6	5.1	161.90	<0.80	26.50	8.10	0.09		0.12	0.01		0.01		0.036		0.01		
Rietpan	1	897.8	11.3	477.00	<0.80	34.00	<0.3	0.144	0.018	0.401	0.241	0.012	0.02	0.01		1.29	0.005	0.008	0.041
Sabie River (Skukuza)	0.1	8.8	3.6	56.50	1.80	5.20	0.70	0.05	0.01		0.02				0.006				
Shidzivane	0.7	10	0.8	69.20	<0.80	5.80	<0.30	0.042		0.014	0.057	0.005				0.064	1E-04	0.002	
Sirheni Bush Camp	1.3	2347	172.9	637.70	<0.80	23.40	<0.30		0.077	1.061	0.135	0.033	0.073	0.025		3.3	0.06	0.007	0.004
Sonop	0.4	151.7	13.8	386.80	<0.80	41.00	19.60			0.161	0.006	0.005	0.006			0.136	2E-04	0.073	0.013
Sweni Hide X40A07	0.3	722.3	131.3	199.70	<0.80	28.00	<0.30	0.081	0.013	0.438	0.039	0.014	0.047	0.009		1.953			0.028
Voortrekker (reservoir)	0.4	100.3	8.7	533.60	<0.80	41.70	0.70			0.08	0.05		0.02		0.053		0.03		
Welverdient	2.1	497.9	27	819.20	<0.80	40.20	1.50			0.663	0.025	0.015	0.037		0.01	0.218	0.01	0.08	0.006
Xitangeni	11.9	2159	1.7	25.80	<0.80	7.70	<0.30	0.178		0.126	0.084	0.068	0.003	0.008		4.481	1E-04	0.01	0.044

Colour formatting according to SABS 241 water classification

Class 0 - Ideal | **Class I - Acceptable** | **Class II - Max. allowable** | **Unacceptable** | **No limts defined**

APPENDIX B: Results of the microbiological analysis KNP samples (colour coding according to SANS 241, drinking water).

StationID	SampleDate	Heterotrophic plate count	Total coliform bacteria	Total faecal coliform	
Baanbreker	2007/06/21	3127	900	300	
Balule / Olifants River	2007/06/17	288	0	0	
Biyamite Geetwal	2007/06/12	740	5300	0	
Buyela	2007/06/18	2987	100	0	
Coetzer	2007/06/19	1400	100	100	
Crocodile River	2007/06/12	112	600	0	
Duke	2007/06/13	5720	11900	0	
Engelhardt Dam (Letaba River 1-E)	2007/06/18	419	500	200	
Goedgegun	2007/06/17	3287	1300	1200	
Jumbo	2007/06/21	3291	500	200	
Lugmag	2007/06/14	784	0	0	
Macs Borehole	2007/06/13	910	2100	0	
Mahagadzi	2007/06/19	3127	0	0	
Marheya	2007/06/15	1904	0	0	
Misane Mond	2007/06/14	504	0	0	
Ngwhmutsatsa No 1	2007/06/18	1120	600	100	
Nhlanganini	2007/06/17	3017	0	0	
Nshawu No 2	2007/06/18	3098	200	100	
Nwatinhlopfu	2007/06/11	2960	5600	0	
Pretoriouskop rest camp	2007/06/12	2160	300	0	
Rietpan	2007/06/14	3136	0	0	
Sabie River (Skukuza abstraction point)	2007/06/11	316	0	0	
Shidzivane (Levnun River)	2007/06/20	212	100	0	
Sirheni Bush Camp	2007/06/20	290	1300	0	
Sonop	2007/06/16	281	0	0	
Sweni Hide X40A07	2007/06/16	1568	0	0	
Voortrekker (reservoir)	2007/06/12	3970	1700	0	
Welverdient	2007/06/15	276	0	0	
Xitangeni	2007/06/20	3091	2700	0	
		95% of sample: Min	4% of sample	1% sample: Max	Unacceptable