



DEPARTMENT OF ECONOMIC DEVELOPMENT  
GAUTENG PROVINCIAL GOVERNMENT, SOUTH AFRICA

**PROJECT TITLE**

**ESTABLISHMENT OF A MONITORING SYSTEM FOR  
SURFACE WATER AND GROUNDWATER  
IN THE CRADLE OF HUMANKIND  
WORLD HERITAGE SITE**

**REPORT TITLE**

**THE KOELENHOF FARM FISH MORTALITY EVENT  
OF MID-JANUARY 2011**

**DATE**

**JANUARY 2011**

**PROJECT**

**BIQ005/2008**



Report prepared for  
**Management Authority**  
**Cradle of Humankind World Heritage Site & Dinokeng**  
**Department of Economic Development**  
**Gauteng Provincial Government**

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Report prepared by  
**Council for Scientific and Industrial Research [CSIR]**  
**CSIR Natural Resources & the Environment**  
**PO Box 395, Pretoria, 0001, South Africa**

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Authors  
**P.J. Hobbs [CSIR]**  
**P.J. Mills [Management Authority]**

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## EXECUTIVE 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. A fish mortality event that occurred on Koelenhof Farm *ca.* mid-January 2011 toward the end of this project generated wide coverage in both the print and broadcast media following its ‘discovery’ on the morning of 13/01/2011. As could be expected, the coverage focused on acid mine drainage (AMD) as the cause of the event. This report aims to piece together the circumstances surrounding the event based on various sources of information and data obtained both before and shortly after the event. The reconstruction hopefully provides a factual narrative that objectively informs the unfortunate situation.

Flood conditions were experienced in the Tweelopie Spruit, the lower Riet Spruit and the Bloubank Spruit following high rainfall experienced in the region in mid-December 2010. The flood event disrupted flow into the A-furrow that serves properties on the right bank of the Bloubank Spruit downstream of the Zwartkrans Spring. This furrow feeds numerous off-channel dams that store primarily irrigation water, but are also stocked with fish. Flow into this furrow from out of the Bloubank Spruit was only restored *ca.* 10/01/2011, when concern was expressed for the yellow appearance of the water and its suitability for various uses including stock watering and irrigation. Both the mid-December 2010 and mid-January 2011 circumstances precipitated a series of field water chemistry variable measurements at ‘key’ locations along the effected drainages.

The Koelenhof Farm fish mortality event was precipitated by a combination of factors. The first of these, identified as the disruption of flow into the A-furrow feeding the off-channel storage dam that hosted the event, occurred almost a month prior to the event. The second factor is identified as the recent partial restoration of flow from the Bloubank Spruit into the A-furrow, and from there into the Koelenhof Farm dam after almost a month of being cut off. Thereafter, a combination of causative factors including

- the resuspension of anoxic sediments as a result of river floods,
- the presence of oxidizable organic matter represented by a high bacteriological load most likely originating in municipal wastewater (sewage) effluent discharges,
- suspended material in the water,
- high water temperatures in the dam, and
- the presence of a significant (albeit diluted) ferric iron-bearing mine water component in the oxygenated surface discharge,

contributed to reducing dissolved oxygen concentrations to sub-lethal and lethal levels for the resident carp population. Together with the precipitation of iron hydroxides, it is probable that these factors resulted in severe irritation causing the carp to secrete mucus as a protective skin cover and to provide protection against toxins, amongst others ammonia and heavy metals, in the water. Such mucus was especially evident in the gills of a specimen studied at Onderstepoort, indicating that the specimen had suffocated. These circumstances explain the observed fish mortalities in this impoundment.

An assessment of the fitness of the water for irrigation and livestock watering uses is severely constrained by the single sample nature and the limited number of variables that characterize the chemical analysis. Nevertheless, the chemical composition of the surface water sample collected at 13h15 on 12/01/2011 at station BB@M in the Bloubank Spruit is equally unsuited for irrigation use and livestock watering use in the medium- to long-term. Although this might not apply to short-term use provided that other factors remain unchanged, it is advised that caution be exercised and, if necessary, the relevant advisory expertise be sought.



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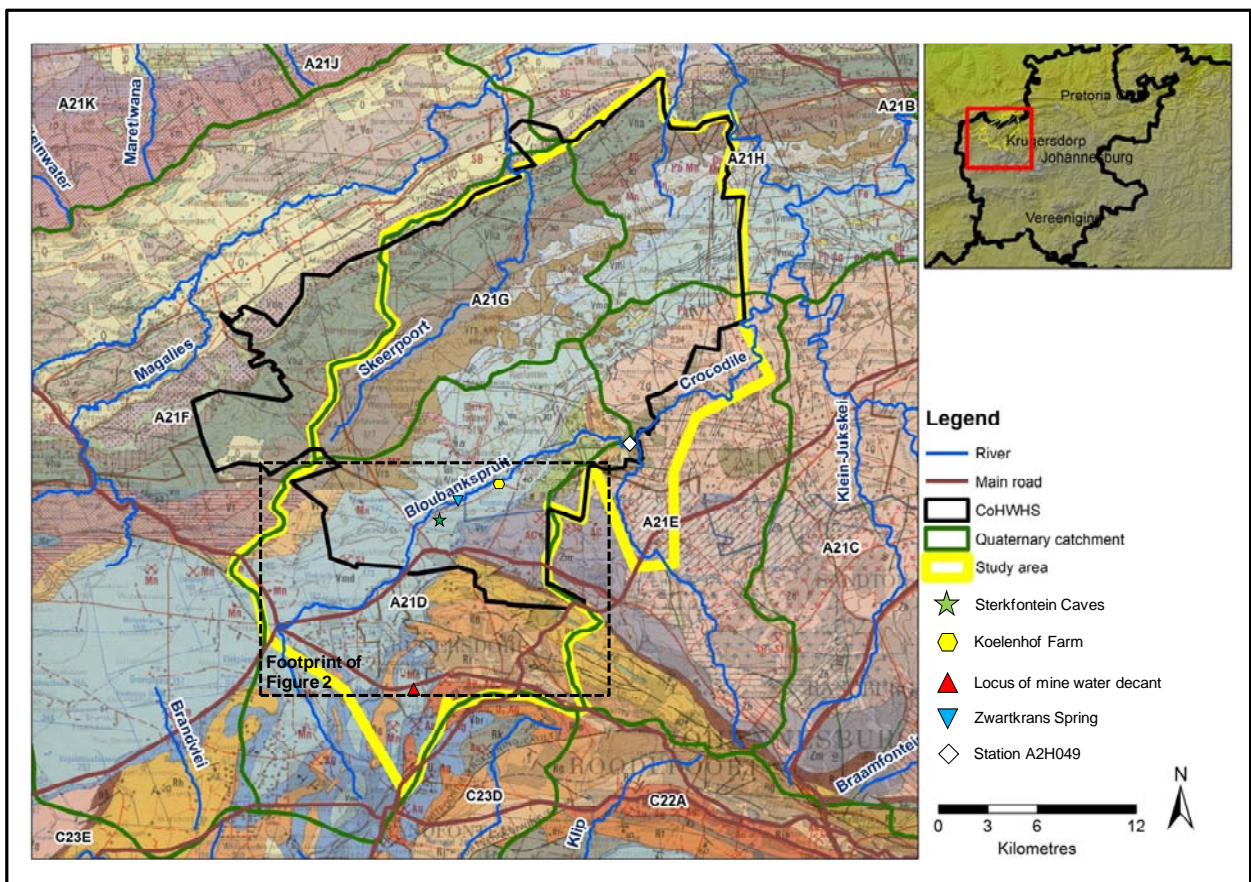
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## DEFINITION OF SYMBOLS, ACRONYMS AND ABBREVIATIONS

~	approximately
>	greater than
%	per cent (parts per hundred)
%ile	percentile
°C	degree(s) Centigrade
Al	aluminium
AMD	acid mine drainage
<i>ca.</i>	<i>circa</i> (about)
Ca	calcium
COH WHS	Cradle of Humankind World Heritage Site
Cl	chloride
CN	cyanide
CTR	corrosion tendency ratio
DWA	Department of Water Affairs (formerly DWAF; Department of Water Affairs and Forestry)
EC	electrical conductivity
Fe	iron
HCO <sub>3</sub>	bicarbonate
HDS	high density sludge
K	potassium
L/s	litre(s) per second
m	metre(s)
MA	Management Authority
MAV	minimum allowable value
meq/l	milliequivalent(s) per litre
Mg	magnesium
mg/L	milligram(s) per litre
mm	millimetre(s)
Mn	manganese
mS/m	milliSiemens per metre
mV	milliVolt
N	nitrogen
Na	sodium
NH <sub>3</sub>	ammonia nitrogen in the un-ionized (free) form
NH <sub>4</sub>	ammonia nitrogen in the ionized form as the ammonium ion
Ni	nickel
n.m.	not measured
NO <sub>2</sub>	nitrite nitrogen
NO <sub>3</sub>	nitrate nitrogen
PO <sub>4</sub>	phosphate
pp.	pages
SAR	sodium adsorption ratio
SO <sub>4</sub>	sulphate
TWQR	target water quality range
WWTW	wastewater treatment works

# 1 INTRODUCTION AND BACKGROUND

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). A fish mortality event occurred on Koelenhof Farm on 11/01/2011 (B. Govender, fax communication) toward the end of this project. The event generated wide coverage in both the print and broadcast media following its ‘discovery’ on the morning of 13/01/2011. As could be expected, the coverage focussed on acid mine drainage (AMD) as the cause of the event (Tempelhoff, 2011a; 2011b). This report aims to piece together the circumstances surrounding the event based on various sources of information and data obtained both before and shortly after the event. The reconstruction therefore attempts to provide a factual narrative that objectively informs the unfortunate situation.



**Figure 1. Definition of the study area in regard to the regional geology, surface water drainages and quaternary catchments, and specific locations of relevance to this report.**

## 2 PRE-EVENT CIRCUMSTANCES

Flood conditions were experienced in the Tweeploep Spruit, the lower Riet Spruit and the Bloubaan Spruit following the high rainfall experienced in mid-December 2010. Various sources in the area reported precipitation in the order of 130 to 140 mm in a period of ~24 hours *ca.* 16/12/2010. The rainfall gauging station operated by Rand Uranium at the Black Reef Incline in the locus of decant in the upper reaches of the Tweeploep Spruit recorded ~90 mm (B. van der Walt, personal communication) between 07h00 on 16/12/2010 and 07h00 on 17/12/2010. The aftermath of the flood event was still visible on 18/12/2010 (Plate 1), when a series of surface water field chemistry measurements were made at ‘key’ locations (refer Figure 2) along the effected drainages. The results are presented in Table 1.

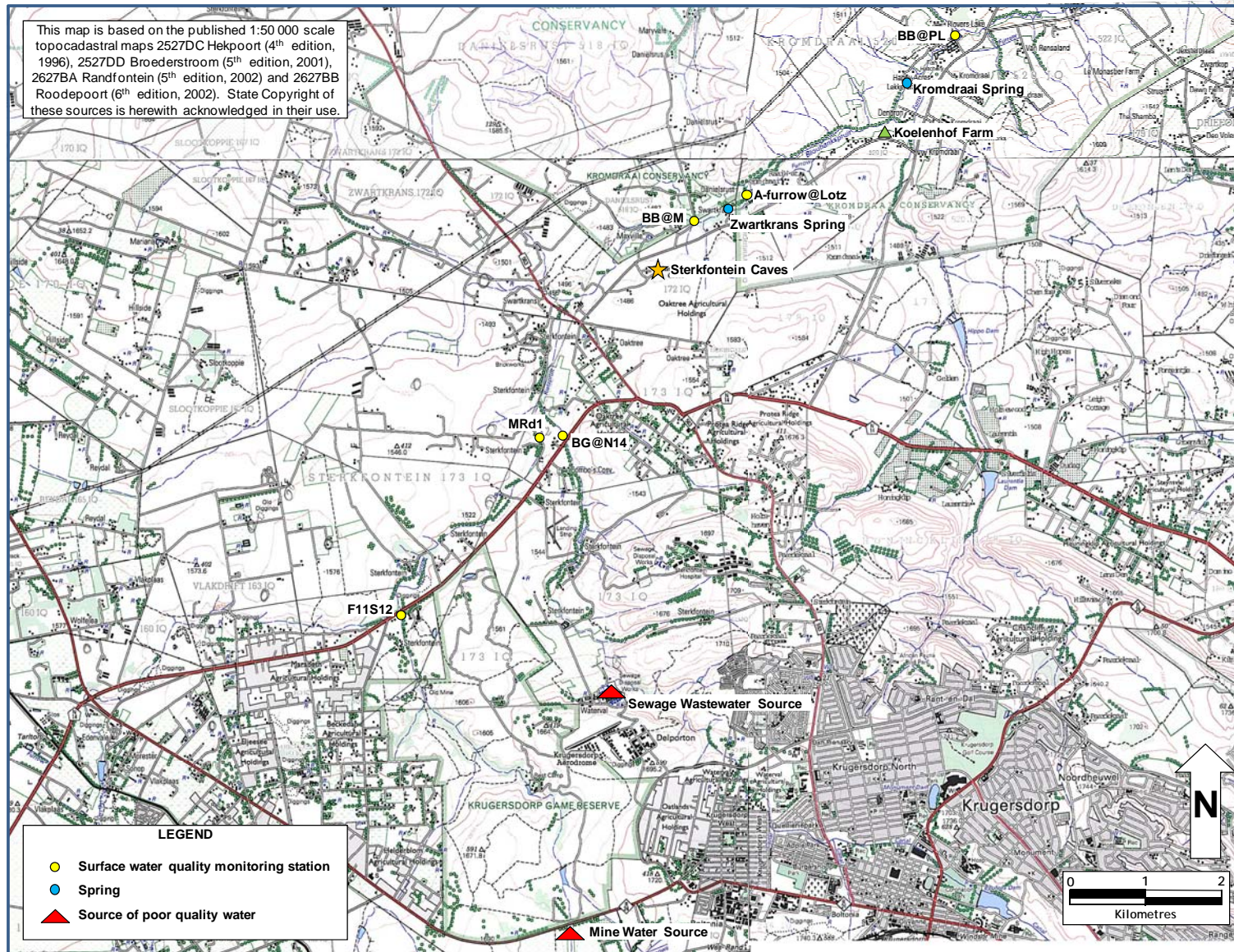


Figure 2. Location of water quality monitoring stations and other relevant sites referred to in this report.



**Plate 1. View of station BB@M on 18/12/2010 showing inundation of the causeway following the flood conditions precipitated by high rainfall experienced in the region *ca.* 16/12/2010. Similar flow conditions again prevailed on 14/01/2011. (Photo: Phil Hobbs).**

Perhaps the most significant impact was the disruption of flow into the A-furrow (Plate 2) that serves properties on the right bank of the Bloubank Spruit downstream of the Zwartkrans Spring (Figure 2).



**Plate 2. View from downstream of the sluice gate at the entrance to the A-furrow downstream of the Zwartkrans Spring following the high discharge conditions experienced in the Bloubank Spruit in mid-December 2010; note the disruption of flow into the furrow and the sediment deposition on the left bank (right foreground). (Photo: Phil Hobbs).**

The A-furrow feeds numerous off-channel dams that store primarily irrigation water, but are also stocked with fish. Flow into this furrow from out of the Bloubank Spruit was only restored, albeit partially, on 10/01/2011 (M. Gomes, personal communication), i.e. a day before the fish mortality event. Concern was expressed for the yellow appearance of the furrow water and its suitability for various uses including stock watering and irrigation. Unaware of the fish mortality event, this communication precipitated another round of field water quality monitoring on 12/01/2011, the results of which are also reported in Table 1. Further, a surface water sample was collected at station BB@M for more complete laboratory chemical analysis. The result of this analysis is presented in Annexure A.

**Table 1. Surface water field chemistry variables sourced on 18/12/2010 and 12/01/2011.**

Station	Field Chemical Variable							
	pH		EC (mS/m)		Eh (mV)		Temp. (°C)	
	18/12/2010	12/01/2011	18/12/2010	12/01/2011	18/12/2010	12/01/2011	18/12/2010	12/01/2011
F11S12	2.7	2.5	416	397	230	243	21.3	21.1
MRd1	3.0	2.3	276	410	217	254	24.1	25.0
BG@N14	n.m.	8.2	n.m.	53	n.m.	-65	n.m.	26.1
BB@M	6.1	2.9	158	155	51	221	24.8	23.9
BB@PL	n.m.	6.8	n.m.	94	n.m.	12	n.m.	21.3
A2H049	n.m.	7.7	n.m.	87	n.m.	-37	n.m.	22.3

The salinity (EC) values of 158 and 155 mS/m recorded at station BB@M are the highest recorded at this station in the year-long course of the main study, and the pH values of 6.1 and 2.9 similarly the lowest observed. These circumstances reflect the dominant contribution of raw mine water discharge to the chemistry of surface water at this locality on this occasion. Of specific relevance to the fish mortality event is the very low pH value of 2.9 observed on 12/01/2011. A further inspection of the 12/01/2011 data (Table 1) reveals the following hydrochemical characteristics:

- The very low pH values and elevated salinity values of ~400 mS/m at the uppermost two stations F11S12 and MRd1 indicating a strong mine water signature at these localities (Plate 3).
- The generally good inorganic quality associated with the Percy Stewart WWTW discharge via the Blougat Spruit (station BG@N14) into the Bloubank Spruit system as shown by the high pH value and low salinity (EC) value; note that this does not imply an acceptable bacteriological quality.
- The very low pH and elevated salinity of the surface water at station BB@M, again indicative of a mine water impact on the quality of the surface water at this locality. Whereas the pH value represents the most extreme value observed at this station in the project period, the EC value is only exceeded by that observed on 18/12/2010 (Table 1). Significantly, the Eh value of 221 mV (indicative of an oxidizing environment) approximates those observed at the upstream stations F11S12 and MRd1.
- The improvement in quality at the downstream station BB@PL, as reflected in a higher pH and lower EC compared to that at station BB@M, is attributed to the mitigatory influence contributed by the ~307 L/s Kromdraai Spring.

- The still quite ‘acceptable’ pH and EC values at station A2H049 at the bottom end of the Bloubank Spruit system (Figure 1) at Glenburn Lodge near Zwartkop, although the pH value approaches the long-term 5%ile value of 7.4, and the EC value exceeds the long-term 95%ile value of 66 mS/m recorded at this DWA flow gauging and water quality monitoring station. In fact, the observed EC value of 87 mS/m exceeds the maximum value of ~75 mS/m recorded in the 29-year period May 1979 to May 2008 that represents the historical record of water chemistry data available for this station from the DWA.



**Plate 3. Discharge in the Riet Spruit at its intersection with the Malmani Road (station MRd1) on 12/01/2011; note the red colouration of the water indicative of a strong acid mine water character (refer Table 1 for supportive field chemistry variable values). Downstream of this position, this water merges with sewage wastewater delivered by the Blougat Spruit. (Photo: Phil Hobbs).**

In regard to the surface water sample collected for laboratory analysis, it was observed that the oxidation of dissolved iron in the water sample resulted in the precipitation of an iron oxide in the sample bottle during transport and laboratory storage. This was not observed in the acidified sample bottle. This observation finds support in the iron concentration of 44 mg/L reported in Annexure A. Further inspection of the laboratory report results (Annexure A) reveals the following characteristics:

- The indicator variables pH, EC, Ca, SO<sub>4</sub>, Fe and Mn that reflect the presence of mine water in the surface water.
- The indicator variables Cl, NO<sub>3</sub> and NH<sub>4</sub> that reflect the presence of sewage wastewater in the surface water.
- The metals Al and Ni are considered to reflect the presence of both mine water and sewage wastewater sources, although the respective contribution of these sources to the observed concentrations is not readily established.

### 3 POST-EVENT CIRCUMSTANCES

The first author was notified on 13/01/2011 that fish mortalities had been ‘discovered’ on Koelenhof Farm upstream of the Kromdraai Store T-junction (M. Liefferink, personal communication). The mortalities occurred in an off-channel irrigation water storage dam fed by the A-furrow, and not in the natural stream course of the Bloubank Spruit (G. Krige, personal communication). It is therefore probable that the partially restored flow of Bloubank Spruit water into the A-furrow (refer section 2), and shortly thereafter also into the Koelenhof Farm off-channel storage dam, resulted in the observed fish mortalities for the following reasons.

Firstly, consider that the Koelenhof Dam had experienced a lack of inflow since disruption of the A-furrow flow *ca.* 16/12/2010. When inflow from this source resumed on 10/01/2011, the field water chemistry variable values reported in Table 1 at station BB@M on 12/01/2011 indicate the significant presence of mine water in the surface water discharge at this location. This finds support in the more complete chemical analysis reported in Annexure A. It is therefore reasonable to presume that subsequent replenishment of the Koelenhof Farm dam with turbid Bloubank Spruit water via the A-furrow resulted in the depletion of oxygen associated with the precipitation of iron hydroxides in this low energy impounding environment. It is probable that these factors resulted in severe irritation causing the carp to secrete mucus as a protective skin cover and to provide protection against toxins (note the presence of ammonia<sup>1</sup> in the water as reflected in Annexure A). Such mucus was especially evident in the gills of a specimen studied at Onderstepoort (Dr. J. Myburgh, email communication), indicating that the specimen had suffocated. These circumstances explain the observed fish mortalities in this impoundment, and are also likely to have similar consequences for crustaceans, invertebrates and other aquatic organisms resident in the dam.

Enquiries by the first author on 13/01/2011 also established that abnormally high fish mortalities had recently been experienced at the Brookwood Trout Farm located downstream of station BB@PL (Table 1) (H. Carpenter, personal communication). It is probable that similar activities such as at Kloofzicht Lodge might also have experienced this impact. However, the better quality of the surface water in the lower reaches of the Bloubank Spruit (section 2) is certain to have lessened the magnitude of any negative impact on aquatic life in off-channel storage dams in this part of the study area.

The Koelenhof Farm fish mortality event precipitated further field studies on 14/01/2011 by the authors. The nature of the event that prompted these studies necessitated the measurement of dissolved oxygen (DO) as an additional field water chemistry variable. The results are presented in Table 2 and discussed in greater detail hereunder.

**Table 2. Surface and groundwater field chemistry variables sourced on 14/01/2011.**

Station	Field Chemical Variable				
	pH	EC (mS/m)	Eh (mV)	DO (%)	Temp. (°C)
Bloubank Spruit at Makiti (BB@M)	6.0	21.9	48	106	21.1
Zwartkrans Spring (ZWSp)	7.3	73.6	-19	66	19.1
A-furrow @ Lotz (upstream of KFD)	6.2	24.0	44	101	21.1
Koelenhof Farm dam (KFD)	3.6	128.7	178	60	24.0
Koelenhof Farm furrow downstream of KFD	5.6	126.8	72.2	103	21.5
Sterkfontein Caves lake	7.8	55.8	-49	66	16.7

<sup>1</sup> At the field pH values of 2.9 on 12/01/2011 at the station BB@M (Table 1) and 3.6 on 14/01/2011 at the station Koelenhof Farm dam (Table 2), this is almost certainly ammonium (NH<sub>4</sub>) rather than free ammonia (NH<sub>3</sub>).

An inspection of the data presented in Table 2 reveals the following hydrochemical characteristics:

- In regard to the station BB@M;
  - the low pH value that is indicative of, amongst other sources, a combination of very low pH mine water and low pH rain water runoff in the discharge at this position in the Bloubank Spruit,
  - the very low EC value of ~22 mS/m compared to the value of 155 mS/m measured two days earlier on 12/01/2011 (Table 1), which similarly reflects the significant contribution of fresh water in the river on 14/01/2011,
  - the high level of oxygen saturation reflected by the DO value of 106%, which is readily explained by the degree of turbulence in the strong-flowing river and natural diffusion of gaseous oxygen (O<sub>2</sub>) from the atmosphere into the water (DWAF, 1996a); the super-saturated oxygen state is possibly indicative of eutrophication (Annexure C) associated with a high nutrient load attributable to the presence of sewage wastewater effluent.
- The similar variable values observed at the station A-furrow @ Lotz as were observed at station BB@M, which establishes the direct hydraulic link between the Bloubank Spruit surface water and that flowing in the A-furrow.
- The very low pH and DO<sup>2</sup> values, and the elevated EC and temperature<sup>3</sup> values of the Koelenhof Farm dam water, which likely represent an artefact of the water quality conditions that gave rise to the fish mortality event.
- The saturated oxygen content of the furrow water downstream of the Koelenhof Farm dam compared to the 60% DO concentration of the dam water.
- The similar variable values (except for temperature) associated with the Zwartkrans Spring and Sterkfontein Caves lake water, which establishes the hydraulic connection between these two groundwater sources. [Note: The cave water level has risen by 0.66 m between 09/06/2010 and 14/01/2011, an average rate of rise of ~0.09 m per month.] Whereas the Zwartkrans Spring salinity of ~74 mS/m is similar to its more recent ‘historical’ value, the cave water salinity of ~56 mS/m is slightly lower than the typical 59 to 62 mS/m range that characterizes this cave water quality variable. The fresher nature of the cave water is attributed to the influence of considerably fresher rain water directly infiltrating the cave environment from above. For comparison, the DWA reports a salinity value of 74 mS/m in April 2001.

#### **4 FITNESS OF WATER FOR USE**

The concern for the suitability of the A-furrow water quality for uses such as irrigation and stock watering is mentioned in section 2. The more complete chemical analysis reported in Annexure A provides some information to address this concern, although the veracity of the assessment must be qualified as follows.

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<sup>2</sup> The Target Water Quality Range (TWQR) for the DO level in aquatic ecosystems brackets the range 80 to 120% of saturation, and a DO level below the Minimum Allowable Value (MAV) defined by a 7-day mean minimum value of >60% (sub-lethal) in combination with a 1-day minimum value of >40% (lethal), is likely to cause acute toxic effects on aquatic biota (DWAF, 1996).

<sup>3</sup> High water temperatures combined with low DO levels can compound stress effects on aquatic organisms (DWAF, 1996).

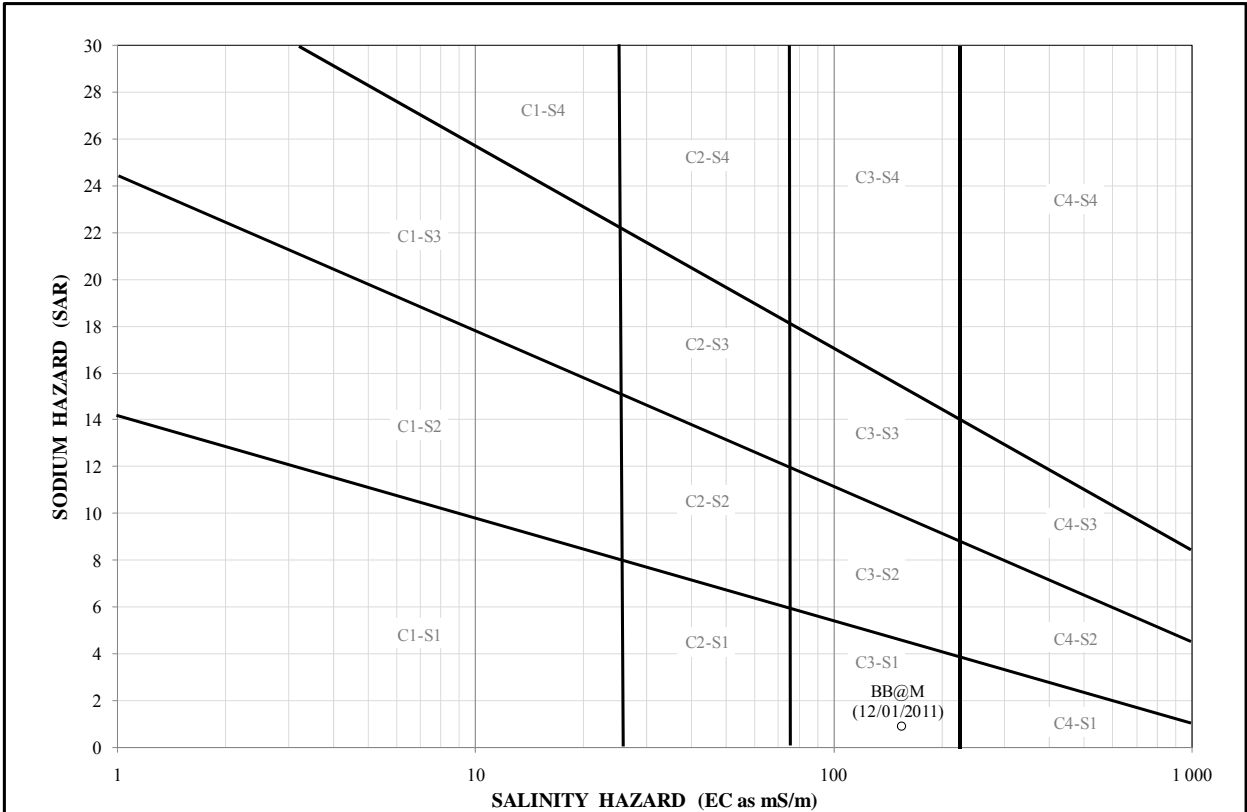
The analysis represents the quality at the time of sampling, namely at 13h15 on 12/01/2011. The field variable values associated with the 12/01/2011 (Table 1) and 14/01/2011 (Table 2) measurements at the sampling locality BB@M indicate how much the water quality/chemistry may vary over a short space of time. Further, the bacteriological quality of the water was not determined, although the presence of ammonia (NH<sub>4</sub>) suggests that elevated bacteria levels (total coliform, faecal coliform and *E. coli*) were most likely also present in the water on 12/01/2011. The assessment is therefore valid only for the sample analysis and the variables reported in Annexure A. Nevertheless, the following discussion attempts to describe the fitness of the water for irrigation and stock watering uses within the framework of these limitations.

**4.1 Irrigation**

The fitness of water for irrigational use is assessed on the basis of the sodium adsorption ratio (SAR) and salinity (expressed as electrical conductivity) of the water. The SAR is calculated as the ratio between the Na concentration and the combined Ca and Mg concentrations using the formula

$$SAR = Na / [(Ca + Mg)/2]^{1/2} \quad (\text{variable concentrations as meq/L})$$

to derive the sodium hazard (designated S) associated with the water. This value is graphed against the electrical conductivity value, which represents the salinity hazard (designated C), to derive an alpha-numeric classification (e.g. C#-S#) defined by the Wilcox diagram (Figure 3), and where the numeric component ranks from 1 = **low** through 2 = **medium** and 3 = **high** to 4 = **very high**. The C3-S1 classification (Figure 3 and Annexure B) is in keeping with that typically observed in the Blougat Spruit and the Riet Spruit (Hobbs, 2011), and clearly identifies salinity (EC) as the limiting variable.



**Figure 3. Wilcox diagram illustrating the classification of the Bloubank Spruit surface water chemistry on 12/01/2011 for irrigation purposes**

Other aspects of the water chemistry that have relevance to the irrigational use of the water are the N/P ratio and the corrosion tendency ratio (CTR) values. The N/P ratio value of 34:1 (Annexure B) is only slightly smaller than the 41:1 ratio that characterizes the long-term median value at station A2H049 (Hobbs, 2011). It still falls within the >25 to 40:1 range that typically characterizes unimpacted systems<sup>4</sup>. The CTR value of 338, together with the low pH value of ~3, indicates the water is extremely corrosive. However, corrosion of pipelines and fittings is only likely to manifest as a problem through continued and medium- to long-term use of water with this chemical composition. This is unlikely to be the case.

Annexure B shows that 8 out of the 13 reported variables for which TWQR values for irrigation use are specified, exceed this limit. Although this might appear harsh, it should be considered that the listed TWQR values represent the strictest (most conservative) limit, and that higher limits define successively relaxed ranges with associated increasingly negative impacts.

## **4.2 Livestock Watering**

Annexure B shows the metals iron and manganese to be the only variables that exceed the listed TWQR values for the 10 reported variables for which limits are set. It should again be considered that the listed TWQR values represent the strictest (most conservative) limit, and that higher limits define successively relaxed ranges with associated increasingly negative impacts. It is probable that the combination of high Fe and Mn concentrations and low pH value might impart a bitterness to the water that would make it less palatable to livestock. However, adverse chronic effects such as liver and pancreas damage may occur, but are unlikely if feed concentrations are normal and exposure is short-term (DWAF, 1996c).

## **5 CONCLUSIONS**

The Koelenhof Farm fish mortality event was precipitated by a combination of factors. The first of these, identified as the disruption of flow into the A-furrow feeding the off-channel storage dam that hosted the event, occurred almost a month prior to the event. The second factor is identified as the recent partial restoration of flow from the Bloubank Spruit into the A-furrow, and from there into the Koelenhof Farm dam after almost a month of being cut off. Thereafter, a combination of causative factors including (a) the resuspension of anoxic sediments as a result of river floods, (b) the presence of oxidizable organic matter represented by a high bacteriological load most likely originating in municipal wastewater (sewage) effluent discharges, (c) suspended material in the water, (d) high water temperatures in the dam, and (e) the presence of a significant (albeit diluted) iron-bearing mine water component in the oxygenated surface discharge, contributed to reducing dissolved oxygen concentrations in the Koelenhof Farm dam water to sub-lethal and lethal levels for the resident carp population.

An assessment of the fitness of the water for irrigation and livestock watering uses is severely constrained by the single sample nature and the limited number of variables that characterize the chemical analysis. Nevertheless, the chemical composition of the surface water sample collected at 13h15 on 12/01/2011 at station BB@M in the Bloubank Spruit is equally unsuited for irrigation use and livestock watering use in the medium- to long-term. Although this might not apply to short-term use provided that other factors remain unchanged, it is advised that caution be exercised and, if necessary, the relevant advisory expertise be sought.

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<sup>4</sup> Most impacted (eutrophic or hypertrophic) systems are characterized by an N/P ratio of less than 10:1 (DWAF, 1996a).

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## ANNEXURE A

### Chemical analysis laboratory report for surface water sample collected at station BB@M on 12/01/2011.

Variable	Value	Source Indicator Variable		Drinking Water TWQR (SANS 241: 2006)
		Mine water	Sewage wastewater	
Laboratory	CSIR (Pretoria)	—	—	—
Laboratory report no.	9156	—	—	—
Laboratory sample no.	82235	—	—	—
Report date (dd/mm/yyyy)	19/01/2011	—	—	—
Sample date (dd/mm/yyyy)	12/01/2011	—	—	—
pH (field value)	<b>2.9</b>			5.0 – 9.5
pH (lab value)	<b>3.2</b>			5.0 – 9.5
EC (mS/m) (field value)	<b>155</b>			<150
EC (mS/m) (lab value @ 25°C)	122			<150
Ca (mg/L)	149			<150
Mg (mg/L)	49			<70
Na (mg/L)	50			<200
K (mg/L)	9			<50
Cl (mg/L)	40			<200
SO <sub>4</sub> (mg/L)	<b>758</b>			<400
HCO <sub>3</sub> (mg/L)	<6			not specified
NO <sub>2</sub> + NO <sub>3</sub> (mg N/L)	4.8			<10
NH <sub>3</sub> + NH <sub>4</sub> (mg N/L)	2			
PO <sub>4</sub> (mg P/L)	<0.2			not specified
Fe (mg/L)	<b>44</b>			<0.2
Mn (mg/L)	<b>16</b>			<0.1
Al (mg/L)	<b>0.78</b>			<0.3
Ni (mg/L)	<b>0.35</b>			<0.15
CN (mg/L)	<0.01			
Electrical balance (%)	-3.0 <sup>(1)</sup>			±5
Chemical character	CaSO <sub>4</sub>			
<p>(1) Includes Fe and Mn in the calculation. Value reduces to -10% without inclusion of these cations.  Notes: Bold and larger font values denote exceedance of SANS 241 (2006) guideline value for a Class 1 drinking water.  Shaded cells denote dominant source water indicator variable.</p>				

## ANNEXURE B

### Assessment of fitness for selected agricultural use of surface water sample collected at station BB@M on 12/01/2011.

Variable	Value		Fitness for Use	
			Irrigation TWQR (DWAf, 1996b)	Livestock Watering TWQR (DWAf, 1996c)
Sample date (dd/mm/yyyy)	12/01/2011		—	—
pH (field value)	2.9	6.5 – 8.4		not specified
pH (lab value)	3.2			
EC (mS/m) (field value)	155	≤40		<155
EC (mS/m) (lab value @ 25°C)	122			
Ca (mg/L)	149	not specified		<1000
Mg (mg/L)	49	not specified		not specified
Na (mg/L)	50	≤70		<2000
K (mg/L)	9	not specified		not specified
Cl (mg/L)	40	≤100		<1500
SO <sub>4</sub> (mg/L)	758	not specified		<1000
HCO <sub>3</sub> (mg/L)	<6	not specified		not specified
NO <sub>2</sub> + NO <sub>3</sub> (mg N/L)	4.8	6.8	≤5	22
NH <sub>3</sub> + NH <sub>4</sub> (mg N/L)	2			
PO <sub>4</sub> (mg P/L)	<0.2	not specified		not specified
Fe (mg/L)	44	≤5	≤0.2 <sup>(1)</sup>	<10
Mn (mg/L)	16	≤0.02	≤0.1 <sup>(1)</sup>	<10
Al (mg/L)	0.78	≤5		<5
Ni (mg/L)	0.35	≤0.2		<1
CN (mg/L)	<0.01	not specified		not specified
SO <sub>4</sub> /Cl ratio	14.0	1.9 <sup>(2)</sup>		not applicable
N/P ratio	34:1	41:1 <sup>(2)</sup>		not applicable
Corrosion Tendency Ratio (CTR)	338	not specified		not applicable
Sodium Adsorption Ratio (SAR)	0.91	≤2		not applicable
Wilcox Classification for Irrigation	C3-S1	C1-S1 (ideal)		not applicable
(1) For clogging of irrigation equipment.				
(2) Defined by Hobbs (2011) as the long-term median value for the Bloubank Spruit at station A2H049.				
Note: Shaded cells denote TWQR of variable exceeded in water sample.				

## ANNEXURE C

### Notes on dissolved oxygen and iron occurrence in regard to aquatic ecosystems

The South African Water Quality Guidelines – Aquatic Ecosystems (DWAF, 1996a) identifies several causative factors for the reduction in the dissolved oxygen (DO) levels in water. These are replicated hereunder:

- *Resuspension of anoxic sediments, as a result of river floods or dredging activities.*
- *Turnover or release of anoxic bottom water from a deep lake or reservoir.*
- *The presence of oxidizable organic matter, either of natural origin (detritus) or originating in waste discharges, can lead to reduction in the concentration of dissolved oxygen in surface waters.*
- *The amount of suspended material in the water affects the saturation concentration of dissolved oxygen, either chemically, through the oxygen-scavenging attributes of the suspended particles, or physically through reduction of the volume of water available for solution.*

*Under anoxic conditions (in the absence of free and bound oxygen) in the water column or in sediments, heavy metals such as iron and manganese can appear in solution, as ferrous ( $Fe^{2+}$ ) and manganous ( $Mn^{2+}$ ) species, and toxic sulphides (S) may also be released.*

*High water temperatures combined with low dissolved oxygen levels can compound stress effects on aquatic organisms. The depletion of dissolved oxygen in conjunction with the presence of toxic substances can also lead to a compounded stress response in aquatic organisms. Under such conditions increased toxicity of zinc, lead, copper, cyanide, sulphide and ammonia have been observed.*

*Concentrations <100% saturation indicate that dissolved oxygen has been depleted from the theoretical equilibrium concentration. Results in excess of saturation (super-saturation of oxygen) usually indicate eutrophication in a water body.*

In regard to iron, a common metal in mine water, the DWAF (1996a) reports the prediction that “.....at a low pH, ferrous [ $Fe^{2+}$ ] iron will predominate in the absence of oxygen, whilst ferric [ $Fe^{3+}$ ] iron will predominate in oxygenated water.”

Recognition of the pre-event circumstances described in section 2 of this report indicate that at least three (1<sup>st</sup>, 3<sup>rd</sup> and 4<sup>th</sup>) of the four causative factors listed above could have played a role in the Koelenhof Farm fish mortality event. The resuspension of anoxic sediments is self-evident under the circumstances. The more than likely presence of a high bacteriological load in the Percy Stewart WWTW effluent is equally self-evident. Similarly, the amount of suspended material carried in the furrow following its ‘re-opening’ must be acknowledged. The presence of iron associated with the mine water component in the oxygenated surface water is also recognized and acknowledged.

It is evident from the preceding discussion that the unfortunate fish mortality event experienced in the Koelenhof Farm off-channel storage dam cannot be attributed to acid mine water alone. An objective view must recognize other contributory factors as also playing a role. It remains arguable which of the various factors (or grouping of factors), if any, played the dominant role.