Collection, treatment and re-use of mine water in the Olifants River Catchment

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Synopsis

Mine water in the Upper Olifants River Catchment in Mpumalanga (upstream of Loskop Dam) is at times discharged into local streams, resulting in local acidification and regional salination of surface water resources. Pollution of surface water can be prevented by collecting and treating mine water to a quality where it could be re-used without restriction (Cleanwater 2020 Initiative). Mine water in the Olifants River Catchment currently amounts to only 4,6% of the total water usage, but contributes 78,4% of the sulphate load.

Limestone and lime treatment is the most cost-effective technology for neutralization and partial sulphate removal of acidic/sulphate-rich water to sulphate levels of less than 1500 mg/l due to precipitation of magnesium and removal of the associated sulphate fraction (through gypsum crystallization). Neutralized mine water of this quality may be suitable for irrigation. A number of alternative desalination treatment technologies were investigated (subsequent to gypsum crystallization pre-treatment) where treated mine water must meet more stringent quality requirements (e.g. less than 200 mg/l SO_4). The capital cost of these processes varied between R4 million/(Ml/d) and R10 million/(Ml/d) and the running cost between R2/m^3 and R5/m^3.

Water usage in the Upper Olifants River Catchment currently amounts to 947 Ml/d (including the power stations), and will increase to an estimated 1385 Ml/d by 2020. The additional water demand by 2020 (438 Ml/d) will have to be supplied by importation from neighbouring catchments, and more efficient utilization of the local water resources, including excess mine water. Various levels of treatment are required to make mine water suitable for the following potential applications (acceptable treated water sulphate concentration shown in brackets): irrigation (2000 mg/l), coal processing plant (1000 mg/l), general industrial use (500 mg/l), discharge to public streams (500 mg/l), potable use (200 mg/l) and cooling water in power stations (20 to 40 mg/l). The following two options, or a combination thereof, can be considered for management of excess mine water in the Upper Olifants River Catchment:

➤ Collection and treatment of excess mine water to a quality suitable for selected urban and industrial applications (Option A)

➤ Collection and treatment of mine water to a quality suitable for irrigation (Option B).

The estimated capital and running cost for Option A amounts to R528.5 million and R55.7 million/year, respectively, compared with R68,2 million and R11,9 million/year for Option B. It is recommended that Option B be investigated for implementation in the short to medium-term. Option B was selected due to cost benefits and the initial favourable results obtained by a joint Water Research Commission and Coal Industry initiative where mine water is used for irrigation. Option A may become feasible in the long-term to ensure maximum environmental protection and reduced treatment cost as a result of anticipated technological improvements over the next 5 to 10 years.

Introduction

The South African coal industry initiated a research initiative in 1998 (COALTECH 2020) with the vision to promote collaboration between the industry, researchers, the state and labour and to promote research initiatives that would benefit them and other stakeholders. Another initiative came about almost at the same time when the Olifants River Forum formulated the Cleanwater 2020 project. The project aims: '*To establish a profitable public-private partnership that will collect and treat water arising from mining, industrial and other economic activities in the Witbank-Highveld coalfield (100 km east of Johannesburg) and make it available to users in the area*'. Funds were obtained from COALTECH 2020 in 1999 to finance this study conceived by the Cleanwater 2020 initiative.

The Witbank-Highveld coalfield is located 100 km east of Johannesburg. The region is a summer rainfall area and receives 750 mm on average annually. Day temperatures vary between 15 and 30°C.

Mine water in the Upper Olifants River Catchment in Mpumalanga Province (upstream of Loskop Dam) is at times discharged into local streams, resulting in local acidification and regional salination of surface water resources. The natural groundwater resources are also impacted by dewatering around mining operations and migration of polluted subsurface plumes from mine workings. So, for instance, 120-160 mg/l sulphate is routinely measured in the Witbank Dam and Middelburg Dam mainly as a result of coal mining and related activities. It is estimated

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that, in the absence of any coal mining and related activities, the sulphate concentration would have been as low as 20-40 mg/ℓ. High salinity in surface water limits the use of water, and introduces indirect costs in the use of the water further downstream. Pollution of surface water can be prevented by collecting and treating excess mine water to a quality where it could be re-used without restriction (Cleanwater 2020 Initiative). Successful implementation of the Cleanwater 2020 Initiative will offer the following benefits.

- Convert a pollution threat to the water resources into an augmentation of the local water resources.
- Preserve the local water resources and increase the reliable yield.
- Reduce the need for importation of fresh water to the Olifants River Catchment from neighbouring catchments.
- Assist in the creation of job opportunities through the construction, operation and maintenance of water-related projects.
- Enhance best utilization of local water resources, both of natural and mining origin.

The aims of this project were to:

- Determine the location, quantity and quality of excess mine water
- Identify a promising regional collection and treatment scheme
- Identify potential users for treated mine water
- Recommend promising mine water management options for the short-term and the long-term
- Provide a cost estimate of various management options to guide future decision making.

The interests of the following stakeholders were valued as important due to their direct interests:

- Coal mining industry, who has to carry the cost of treating excess mine water
- Downstream water users, who have to carry the costs associated with poor quality raw water
- Authorities, who are responsible for the supply of potable water and control of pollution through legislation and law enforcement
- Technology suppliers, who have made investments in technology development that could be used for treatment of excess mine water.

Quantity and quality of mine water

Mine water discharged in the Upper Olifants River Catchment currently amounts to approximately 44 Mℓ/d (Table I) during an average hydrological year and is expected to increase to an estimated 131 Mℓ/d by 2020. The quality of mine water is generally poor with a sulphate concentration between 800 and 3000 mg/ℓ. It is not acceptable to discharge such poor quality mine water into high quality surface water. The current background sulphate load of water in the Upper Olifants River Catchment is estimated at 28,4 t/d (as SO_4) (947 Mℓ/d @ 30 mg/ℓ SO_4), which is small compared to the estimated 102,9 t/d sulphate load associated with excess mine water (2337 mg/ℓ SO_4 @ 44 Mℓ/d). The above-mentioned figures show that a relatively small volume of excess mine water is responsible for a major contribution of salinity. Excess mine water in the Olifants River Catchment currently amounts, volume wise, to only 4,6% of the total water usage, but contributes 78,4% of the sulphate load (Table II and Figure 1).

Table I

Estimated volumes of mine water in the Upper Olifants River Catchment (based on an average hydrological year)

Power station/Colliery	Volume (Mℓ/d)	Quality		
		pH	Sulphate (mg/ℓ) 95%	Magnesium (mg/ℓ) 95%
Middelburg Dam catchment	14,55		1524	88
1. Arnot	4,4	8,5	2832	77
2. Eikeboom	0,46	8,6	75	41
3. Woestalleen	0,19	8,1	2069	280
4. Optimum	9,5	7,8	977	91
Witbank Dam catchment	10,74		2498	287
5. Douglas	0,66	7,8	1645	250
6. Goedehoop	0,56		2500	250
7. Greenside	0,65	8,7	3050	292
8. Kleinkopje and Landau	4,08	8,9	2604	304
9. Kroonfontein	0,09	8,5	1361	99
10. Middelburg South	0,02	7,6	2018	303
11. Middelburg North	0,58	3,8	2805	308
12. Rietspruit	1,41	8,5	2626	380
13. Tavistock	0,49	7,1	1520	148
14. Khutala	2,2		2500	250
Kriel/Matla complex	9,12		563	47
15. Kriel	1,99	8,4	729	99
16. Matla	5,67	8,9	485	32
17. Syferfontein	1,46	8,8	637	37
Klipspruit catchment	9,62		5071	217
18. South Witbank	2,47	2,8	4986	160
19. Middelburg Stream	0,61		2600	50
20. Old Tavistock	0,08		2600	50
21. Brugspruit High TDS	2,7	4,0	8203	435
22. Brugspruit Low TDS	2,5	3,3	3701	170
Total	44,03			

* Note: The sulphate concentration has a confidence level of 95% to be lower than the given value (i.e. 95 per cent of the periodic samples taken has sulphate concentrations lower than the given value).

Table II

Comparison between water volumes and sulphate load of fresh water usage and excess mine water discharges in the Upper Olifants River Catchment

Parameter	Fresh water	Mine water	Total	Fresh water	Mine water
	Mℓ/d	Mℓ/d	Mℓ/d	%	%
Volume (Mℓ/d)	947	44,0	991	95,6	4,4
Sulphate concentration (mg/ℓ)	30	2337			
Sulphate load (t/d)	28,4	102,9	131,3	21,6	78,4

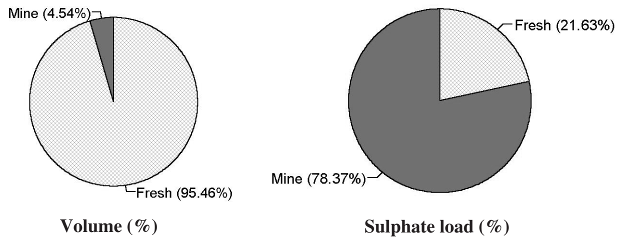

Figure 1—Comparison of water volumes and sulphate load of fresh water usage and mine water in the Upper Olifants River Catchment

Cost associated with treatment, collection and distribution

Limestone treatment is the most cost-effective technology for neutralization of acid water and partial sulphate removal to levels of approximately 2000 mg/ℓ SO_4 (Table III). With high lime treatment to pH >11, sulphate can be further reduced to 1400 mg/ℓ due to precipitation of magnesium and removal of the sulphate fraction (through gypsum crystallization) associated with magnesium. Neutralized mine water of this quality may be suitable for irrigation.

A number of alternative desalination treatment technologies were considered (subsequent to gypsum crystallization pre-treatment) when treated mine water must meet more stringent quality requirements for industrial re-use, discharge to a public stream, drinking or power station cooling water, including Aqua K, Barium, Biological sulphate removal, EDR, Electrolytic, GYPCIX, RO or Savmin. The cost of such technologies is expected to decrease over the next 10 years through further technological progress.

Table III shows the capital and running cost associated with the treatment of mine water with various treatment processes. For mine water to be re-used for any application, except for irrigation (which could be utilized at the source), a collection system will have to be installed for transportation of the untreated mine water to a central treatment plant, as well as a distribution system for transportation of the treated water to the users. The cost of collection systems for the catchment is estimated at R192,9 million (Table IV) and that of a distribution system at R65,1 million (Table V). The annual running cost for the collection and distribution systems is estimated at R3,1 million and R2,2 million respectively (Tables IV and V).

Re-use options for treated mine water

Water usage in the Upper Olifants River Catchment currently amounts to 947 Mℓ/d (including the power stations), and will increase to an estimated 1385 Mℓ/d by 2020 (Table VI). The additional water demand by 2020 (438 Mℓ/d) will have to be supplied by water importation from neighbouring catchments, and more efficient utilization of the local water resources, including water stored or discharged by mines.

Different levels of treatment are required to make excess mine water suitable for the following potential applications (acceptable sulphate concentration of treated water shown in brackets):

- irrigation (2000 mg/ℓ)
- coal processing plant (1000 mg/ℓ)
- general industrial use (500 mg/ℓ)
- discharge to public streams (500 mg/ℓ)
- potable use (200 mg/ℓ)
- cooling water in power stations (20 to 40 mg/ℓ).

Irrigation

Mine water which is partially treated for removal of free acidity, metals, magnesium and sulphate (to less than 2000 mg/ℓ) can be used for irrigation. This option is currently being investigated and would appear to be attractive. The

Table III

Capital and running cost of various treatment processes (treatment module of 15 Mℓ/d)

Treatment process	SO_4 level in treated water	Capital cost (R million / (Mℓ/d))	Running cost (R/m^3)
Limestone neutralization (incl. iron(II) oxidation)	2500	0,50	0,59
Lime neutralization (pH 8)	1500	0,53	1,36
Limestone/lime treatment (pH 11) & gypsum crystallization	1100	0,88	1,02
Lime treatment (pH 11.5) & gypsum crystallization	1100	0,57	1,61
Advanced sulphate removal (including neutralization pre-treatment)	200	4,0 to 10,0	2,0 to 5,0

Table IV

Cost of collection systems

Sub-catchment	Capital cost (R)	Running cost (R/year)
Middelburg Dam	32 000 000	410 000
Witbank Dam	52 400 000	745 000
Matla/Kriel/Syferfontein	90 900 000	1 525 000
Brugspruit	17 600 000	400 000
Total	192 900 000	3 080 000

Table V

Cost of distribution systems

Sub-catchment	Capital cost (R)	Running cost (R/year)
Middelburg Dam	30 134 974	691 236
Witbank Dam	17 442 583	627 774
Matla/Kriel/Syferfontein	5 239 648	236 232
Brugspruit	12 258 531	601 989
Total	65 075 736	2 156 231

Table VI

Current and projected water usage in the Upper Olifants River Catchment

User	Water demand/supply (Mℓ/d)		
	Current	2020	Change
Demand			
Irrigation	211	211	0
Stock watering	16	19	3
Urban and industrial	173	504	331
Mining	68	27	-41
Power stations*	479	625	146
Total (excluding power stations)	468	761	237
Total (including power stations)	947	1 385	483
Supply			
Mine water decant	44	131	87

further investigation addresses the following aspects.

- *Cost effectiveness*. Should irrigation be applied near the source of partially treated mine water, the costs would be relatively low as no collection and distribution system, other than that needed for irrigation, will be required. Such costs could be carried from income generated by the irrigation scheme.
- *Long-term effects on soil and groundwater*. It is known that sodium-rich water is not suitable for long-term irrigation purposes due to soil degradation effects. The mine water in the Upper Olifants Catchment is low in sodium and thus the only question that remains is whether gypsum-rich water is suitable for irrigation in the long-term. No negative effects were observed from irrigation with gypsum-rich water in the following cases: a three year WRC demonstration project (Annandale[2000]), Israeli experience (Tanner[1999]) and even from 100 year modelling (Annandale[2000]).
- *Water availability*. Due to limited water resources, the current policy of the Department of Water Affairs and Forestry requires that water can only be allocated for new applications (e.g. new irrigation schemes) should sufficient quantities of water be available. Currently, 211 M*l*/d of fresh water is used for irrigation of 9097 ha in the Upper Olifants River Catchment. If mine water (current volume is estimated at 44 M*l*/d and it is estimated to increase to 131 M*l*/d in 2020) is used to replace fresh water in existing irrigation schemes, it will fall within the current policy. Although existing irrigation schemes are not situated in the vicinity of excess mine water, the likelihood of finding suitable sites are quite high. (Figure 2).

Other uses

Treated mine water to a sulphate level in the range of 50 to 500 mg/*l* can also be used for other uses such as stock-watering, urban and industrial and potentially power stations (Table VI). The following aspects must however be addressed to allow the concept of regional collection and treatment of excess mine water for use by selected users.

- Legal aspects associated with the collection and re-use of treated mine water (e.g. water transfer policy, water price policy, licence system).
- Institutional aspects related to the type and form of organization needed for the implementation of the project.

Management options

The following two options, or a combination thereof, can be considered to assist in the management of mine water in the Upper Olifants River Catchment.

- Collection and treatment of excess mine water to a quality suitable for selected urban and industrial applications (Option A). The benefit of this option is that mine water (4.5% by volume) will be treated to a quality comparable with that of unpolluted surface water.
- Collection and treatment of mine water to a quality suitable for irrigation (Option B). The benefit of this option is that the large volume of good quality surface water (95.5%) will not be affected through mixing with a small volume (4.5%) of saline mine water.

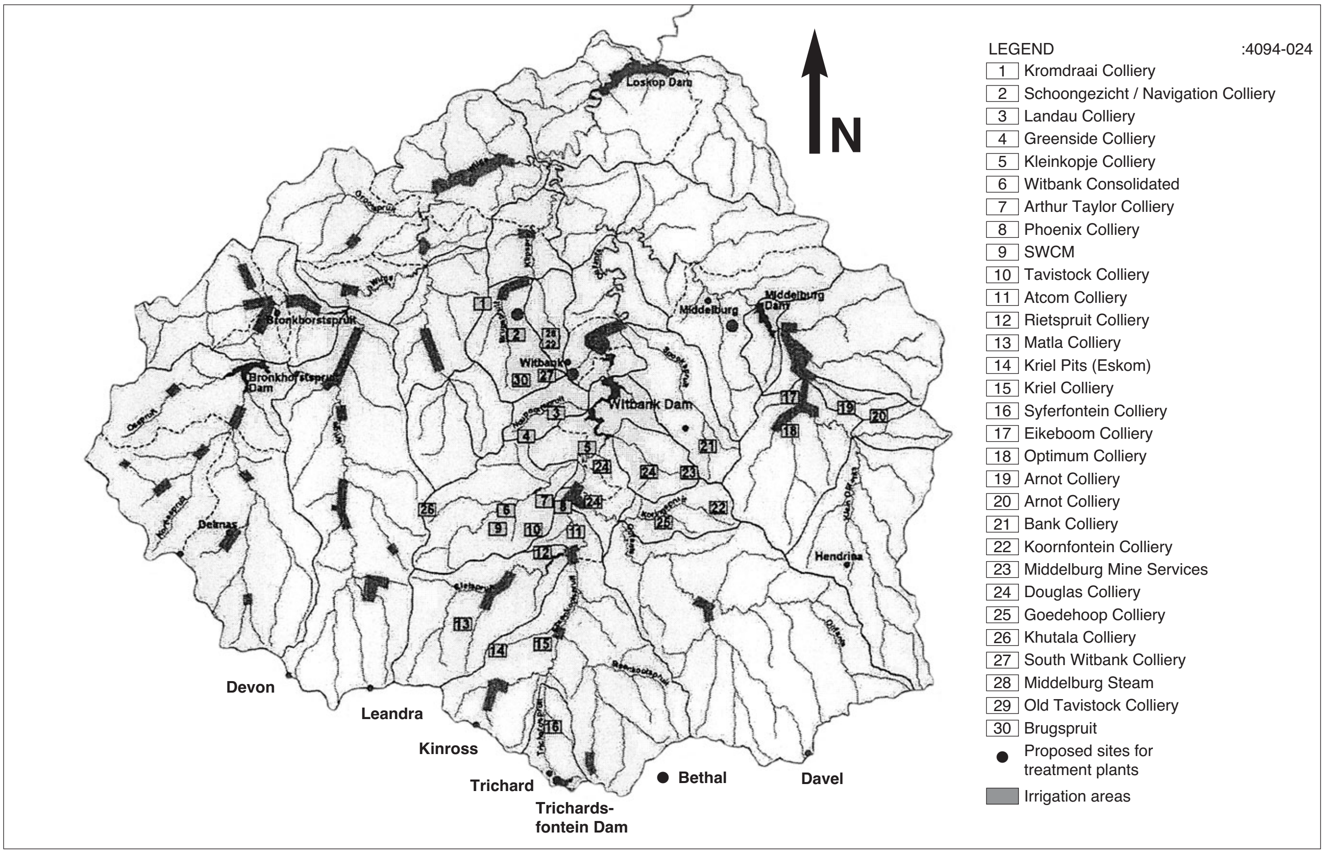

Figure 2—Map of existing irrigation areas and existing mining operations

Table VII

Comparison between Option A (complete treatment and Option B (pre-treatment/irrigation combination) for the Upper Olifants river catchment

Name	Volume Ml/d	Quality				Cost								Irrigation land (ha)	Irrigation Capital R/ha	CaO dosage kg/m³
						Option A: (pre-treatment/SO₄ removed to 200 mg/l)				Option B: (pre-treatment/SO₄ removed to 1500 mg/l)						
		pH	Sulphate	Magnesium 95%	Acidity	Capital (R)		Running (R/a)		Capital (R)		Running (R/a)				
						Pre-tmt	SO₄	Pre-tmt	SO₄	Irrigation	Lime/Crys	Irrigation	Lime/Crys			
Treatment technologies																
MiddelburgDam	14,55	8,6	**1524**	**88**		8377283	73484937	2589111	13276875	2293235	3759225	160000	765010	188,94	12137	0,35
catchment										376611	828005	16790	73579	19,75	19066	0,26
1. Arnot	4,4	8,6	2832	77						185648	457878	6935	47824	8,16	22754	0,82
2. Eikeboom	0,46	8,1	75	41						4244879	6295928	346750	1702699	407,94	10406	0,38
3. Woestalleen	0,19	7,8	2069	280												
4. Optimum	0,5		977	91												
						6835304	59995808	2733563	9800250							
Witbank Dam	**10,74**		**2498**	**287**												
catchment	0,66		1645	250												
5. Douglas	0,56	7,8	2500	250						502715	1054580	24090	158536	28,34	17738	0,75
6. Goedehoop	0,65		3050	292						440795	944650	20440	134516	24,05	18331	0,75
7. Greenside	4,08	8,7	2604	304						496612	1043847	23725	166547	27,91	17792	0,85
8. Kleinkopje & Landau	0,09	8,9	1361	99						2158811	3573776	148920	1064167	175,20	12322	0,88
9. Koornfontein	0,02	8,5	2018	303						102113	277541	3285	16410	3,86	26422	0,40
10. Middelburg South	0,58	7,6	2805	308						30656	101315	730	5213	0,86	35695	0,88
11. Middelburg North	1,41	3,8	2626	380						453345	967123	21170	152212	24,91	18202	0,89
12. Rietspruit	0,49	8,5	1520	148						922702	1753726	51465	408941	60,55	15239	1,05
13. Tavistock	2,2	7,1	2500	250						396135	863806	17885	98565	21,04	18827	0,51
14. Khutala						6126064	53737401	1482394	8322000	1317118	2362698	80300	528454	94,47	13942	0,75
	9,12		**563**	**47**												
Kriel/Matla	1,99	8,4	729	99												
15. Kriel	5,67	8,9	485	32						1215539	2209106	72635	362848	85,45	14225	0,40
16. Matla	1,46	8,8	637	37						2809007	4445389	206955	888251	243,48	11537	0,24
17. Syferfontein						6349101	55693873	3517889	8778250	948787	1795153	53290	231295	62,69	15134	0,25
	9,62		**5071**	**217**												
Klipspruit catchment	1,26		2600	50	1500											
18. Kromdraai	2,47	2,8	4986	160	1500					843301	1626422	45990	379923	54,11	15586	1,12
19. South Witbank	0,61		2600	50	1500					1444921	2553242	90155	848994	106,06	13623	1,38
20. Middelburg Stream	0,08		2600	50	1500					472009	1000359	22265	183931	26,19	18020	1,12
21. Old Tavistock	2,7	4	8203	435	1500					92931	256481	2920	24122	3,44	27052	1,12
22. Brugspruit High	2,5	3,3	3701	170	1500					1551592	2710183	98550	1212510	115,94	13383	2,02
TDS										1458943	2573978	91250	868408	107,35	13590	1,40
23. Brugspruit Low TDS	**44,03**					**27687752**	**242875019**	**10322956**	**40177375**	**24758402**	**43464410**	**1607095**	**10322956**	**1890,70**		
Total																
Total treatment cost						**27700000**	**242900000**	**10300000**	**40200000**	**24800000**	**43500000**	**1600000**	**10300000**			
Cost ratio							**270562771**		**50500000**		**68222812**		11930000			
							1,00		1,00		0,25		0,24			
Collection systems:																
Middelburg Dam							32000000		410000		0		0			
Witbank Dam							52400000		745000		0		0			
Matla/Kriel/Syferfontein							90900000		1525000		0		0			
Brugspruit							17600000		400000		0		0			
Distribution systems:																
Middelburg Dam							30134974		691236		0		0			
Witbank Dam							17442583		627774		0		0			
Matla/Kriel/Syferfontein							5239648		235232		0		0			
Brugspruit							12225831		601989		0		0			
Total capital cost (R)							**528 506 000**				**68 223 000**					
Capital cost ratio							**1,00**		**1,00**		**0,13**		**0,21**			
Total running cost (R/a)									**55 700 000**				**11 930 000**			

Notes:

Water application (mm/a)					850						
Water application (m³(d.ha))					2328767						
Capital cost:											
Irrigation (R/ha)					12000						
Lime neutralisation/gypsum crystallisation (R/(M□/d))	570000	5000000				570000					
Total sulphate removal (R/(M□/d))	0,67	0,67			0,80						
Scale factor											
Running cost:											
Irrigation (R/m³)							0,10				
Lime neutralisation/gypsum crystallisation (R/m³) (excluding								0,32			
chemicals)			0,32	2,50							
Total sulphate removal (R/m³)											

The estimated capital and running cost for the total Upper Olifants River Catchment for Option A amounts to R528.5 million and R55.7 million/year, respectively, compared with R68,2 million and R11,9 million/year for Option B (Table VII). These cost figures are based on a cost of R75 million for a 15 Ml/d sulphate removal plant (including brine/sludge disposal cost), to a sulphate level of 200 mg/l, and R8.55 million for a 15 Ml/d pre-treatment plant. It is recommended that Option B (pre-treatment/irrigation combination) be investigated for implementation in the short to medium-term for the following reasons.

- Prevent pollution of surface water by not discharging potentially acidic and saline mine water to public streams.
- Treatment cost for irrigation application of the excess mine water is more affordable, as the capital expenditure is only 13% compared with Option A, and the running cost only 21% compared with Option A.
- The land required for irrigation of excess mine water (1891 ha in 2000) amounts to only 21% of what is already used for irrigation (9097 ha in 2000). Research indications are that gypsum-rich water can be

used for irrigation, without affecting the long-term suitability of soil for irrigation.

- The potential exists to more than double the income generated from irrigation compared to dry land farming. In addition, two crops instead of one can be produced annually.
- Irrigation could create job opportunities and stimulate the regional economy.

The long-term environmental impacts of the irrigation use of sulphate-rich mine water should be investigated and resolved to the satisfaction of all stakeholders, before proceeding with the catchment wide implementation of the scheme.

Option A, however, also holds merit, and should be reconsidered over the medium to long-term, along with the following developments.

- Reduction in the cost of advanced sulphate removal technologies. It is foreseen that, due to technological improvements to some of the technologies, cost could be reduced to levels near to that of lime treatment within the next 5–10 years.
- Increased cost of imported fresh water. The cost of fresh water in the Upper Olifants River Catchment will increase over the next decade. This is due to the fact that the future increased demand for water in the catchment will have to be imported from neighbouring catchments at substantial cost.
- The cost of mine water collection may in future be substantially reduced, by utilization of the natural underground drainage paths set up in the underground mine workings.

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