Monitoring the effect of irrigation with gypsiferous mine wastewater on crop production potential as affected by soil water and salt balance

by N.Z. Jovanovic*, J.G. Annandale*,
A.M. van der Westhuizen*, and J.M. Steyn*

Synopsis

Irrigation of agricultural crops may be a cost-effective option for the utilization of gypsiferous minewater as it may also create an opportunity to produce crops during the dry winter season on farms in South Africa, such as in Mpumalanga. In this study, intensive field monitoring systems were developed and implemented to assess the feasibility and sustainability of irrigation with gypsiferous mine water.

Soil water and salt balance components, as well as crop yields, were monitored in field trials carried out at Kleinkopjé and New Vaal Collieries (Anglo Coal), and at Syferfontein (Sasol). Field measurements indicated that high crop and pasture yields can be obtained, provided fertilization and irrigation water management are appropriate. Soil water and salt balances indicated that considerable amounts of minewater can be used and considerable masses of salts can be removed through precipitation of gypsum in the soil profile. With appropriate management, water and salt runoff and salt leaching can be intercepted, thereby minimizing the impact on groundwater.

The SWB model is being validated through on-going monitoring. This will allow the use of the SWB model at other sites to predict the long-term impact of irrigation with mine water on soil and groundwater, as well as to run scenario simulations in order to recommend sustainable management of irrigation with minewater.

Introduction

In the mining of mineral resources, large volumes of minewater are generated with adverse effects on the already scarce water resources[1]. The type of wastewater emanating from mines depends largely on the geological properties of the coal, gold ore and other geological material with which waters come into contact[2]. In many cases the minewater is gypsiferous, especially when acid mine drainage (AMD) is generated through the oxidation of pyritic components of the ore, which may then need to be neutralized by liming prior to release to the environment[3].

The use of gypsiferous minewater for irrigation of agricultural crops could turn this problem into an opportunity. This has been evaluated in South Africa by Du Plessis[4], using a steady-state chemical equilibrium model[5] to predict the amount of leached salts that could contaminate groundwater.

Irrigation with gypsiferous minewater could also assist in stabilizing dry land crop production and allow dry season production in Mpumalanga, South Africa, whilst at the same time presenting a potentially profitable use of mine drainage compared to the significant cost of alternative effluent treatment strategies. By irrigating with this water, a large fraction of the salts can be removed from the water system through precipitation of gypsum in the soil profile as the soil solution gets concentrated by root water uptake, evaporation, etc.

The use of gypsiferous minewater for irrigation was investigated in a previous Water Research Commission (WRC) project, where a wide range of crop and pasture species was screened for tolerance to irrigation with lime-treated AMD at Landau Colliery (Anglo Coal, Witbank, Mpumalanga Province) from 1993 to 1996[6,7]. The results of the screening trial indicated that:

- Higher crop yields can be obtained under irrigation with minewater compared to dry land production
- No foliar injury was observed due to sprinkle irrigation with gypsiferous mine water
- Possible nutritional problems, for example deficiencies in K, Mg and NO_3, occurring due to Ca and SO_4 dominating the system, can be addressed through fertilization
- Soil salinity increased compared to the beginning of the trial, but the values of soil saturated electrical conductivity fluctuated around 200 mS m^{-1}, which is typical for a saturated gypsum solution and acceptable for crop production.

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* *Department Plant Production and Soil Science, University of Pretoria, Pretoria, South Africa.*

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In a follow-up WRC project, commercial production of several crops irrigated with gypsiferous minewater was tested in a field trial at Kleinkopjé Colliery (Anglo Coal, Witbank) from 1997 to 2000[8]. Data collected in the field trial at Kleinkopjé were used to validate the Soil Water Balance (SWB) model[9] to be used for long-term predictions of the impact of irrigation with gypsiferous minewater on soil and groundwater resources. The results of this project indicated that:

- Crops such as sugarbeans, wheat and maize can be commercially produced under irrigation with gypsiferous minewater
- Land preparation and fertilization management are critical for successful crop production, especially on rehabilitated soil
- The SWB model was validated for the sites where the field trial was carried out
- The use of gypsiferous minewater for irrigation proved to be sustainable in the short term (three years) with negligible impact on the groundwater
- The system is flexible and can be managed depending on the objectives that one wants to achieve, be it maximum crop production, water use, job creation, economic return or maximum gypsum precipitation and minimum salt leaching.

A further WRC project was subsequently initiated in 2001, as a new phase of development of this technology. The research was extended to new soils, waters and crops with the following objectives:

- To determine the impact of irrigation with several gypsiferous water/soil combinations on soil conditions and groundwater quality
- To further develop and refine the SWB model that can be used to predict gypsum precipitation, crop response, water quality and balance, under irrigation with gypsiferous water
- To predict the likely long-term impact of irrigation with gypsiferous water on the groundwater system
- To determine whether these waters can be used to produce crops on a commercial basis; and
- To utilize the information gained to predict the sustainability of irrigation with gypsiferous water.

The issue of excess minewater was previously discussed in several publications[7,10,11]. However, the detailed description of the monitoring system required to measure and model the various components of the soil water and salt balance was not published. The aim of this paper is to provide a detailed description of the system implemented to monitor the soil water and salt balance of fields irrigated with gypsiferous water at different mines. Examples of data collected in the field are also presented (soil water and salt balance components, as well as crop yields under commercial production). The interpretation of these field measurements serves to determine the feasibility and sustainability of irrigation with gypsiferous water at specific sites.

Approach

Field trials have been established at different mines in order to assess the sustainability of irrigation with gypsiferous minewater for a range of climates, crops, water qualities and soils. These are summarized in Tables I to III.

The field trials are under way at three mines (Kleinkopjé, Syferfontein and New Vaal), where Kleinkopjé mine includes three irrigated fields, namely Major, Tweefontein and Fourth (Table I).

All fields are irrigated with centre pivots. Farming companies operating close to the mine or a representative from the mine took responsibility for cropping the irrigated fields. They were also expected to keep records of farming activities and budgets in order to determine management requirements and profitability of different cropping systems.

The cropping systems were selected depending on the interest of the mines and/or farmers. Cash crops were the selected option at Kleinkopjé and New Vaal, while perennial

Table I

Location, date of beginning of trial, climates and crops grown at the different mines in order to assess the sustainability of irrigation with gypsiferous minewater

Mine	Company	Location	Coordinates and altitude	Beginning of trial	Climate	Field size	Cropping system	Farming company
Kleinkopjé	Anglo Coal	Witbank, Mpumalanga Province	Lat. 22°00' S Long. 28°75' E Alt. 1570 m	December 2000	Summer rainfall: 700 mm a^{-1}	Major: 28.3 ha	Maize/wheat rotation	Smit Bros.
						Tweefontein: 18.1 ha	Maize/wheat rotation	
						Fourth: 28.3 ha	Maize/wheat/ potato	
Syferfontein	Sasol	Secunda, Mpumalanga Province	Lat. 23°64' S Long. 29°20' E Alt. 1610 m	October 2001	Summer rainfall: 700 mm a^{-1}	20.6 ha	Fescue (cv. Iewag); Lucerne-fescue; Fescue (cv. Demeter); Eragrostis-ryegrass	Mine
New Vaal	Anglo Coal	Vereeniging, Gauteng Province	Lat. 26°35' S Long. 27°59' E Alt. 1550 m	November 2001	Summer rainfall: 700 mm a^{-1}	10 ha	Maize/wheat rotation	Soetvelde

pastures were planted at Syferfontein due to the highly saline irrigation water (Table II) and very heavy clay soil (Table III).

Each mine generates different water qualities depending on the geological properties of the site. Typical irrigation water qualities are shown in Table II. Kleinkopjé mine generates two waters of similar qualities rich in $CaSO_4$ and $MgSO_4$ (Jacuzzi and Tweefontein waters). Syferfontein mine generates the most saline water (electrical conductivity EC = 380 mS m^{-1}) with high concentrations of Na^+ and SO_4^{2-}. New Vaal generates water with EC = 110 mS m^{-1}, predominantly rich in $CaSO_4$ with some NaCl. These water qualities are subject to some seasonal variability depending on rainfall.

Soil surveys were completed on all mines before the beginning of the field trials in order to site the irrigation systems to ensure the best chance of success, as site selection for irrigation is crucial. Table III describes the soils on which the field trials are carried out, including average soil depths and textures as well as the average initial soil salinity expressed as the soil saturation paste extract electrical conductivity (ECe).

Soil depths generally range from very shallow (~ 0.5 m) at Syferfontein to very deep (> 2.0 m) at Kleinkopjé (field Fourth). Soil texture ranges from heavy clay at Syferfontein to very sandy at New Vaal.

Soil saturated electrical conductivity gave an indication of the initial soil salinity at the field trial sites. At Kleinkopjé, ECe ranged from 40 to 60 mS m^{-1} as these soils had already been irrigated with minewater for several seasons during the previous WRC project[8]. At Syferfontein, soil salinity was the highest as this soil had been occasionally irrigated before the beginning of the trial and the salinity of the minewater is the highest (Table II). At New Vaal, the initial soil salinity level was the lowest as this soil had not been previously irrigated with minewater.

The detailed data on crops, water qualities and soil properties are available in Annandale *et al.*[12].

Materials and methods

The experimental scheme for each field is shown in Figures 1a and b. Intensive monitoring systems have been established in each field to determine the components of the soil water and salt balance. The monitoring systems include

Table II

Typical irrigation water qualities (pH, electrical conductivity EC and concentrations of dominant ionic species) at the different mines

Mine and field		Typical water analysis	Period
Kleinkopjé	Major (Jacuzzi water)	pH = 6.5 EC = 280 mS m^{-1} Ca^{2+} = 490 mg l^{-1} SO_4^{2-} = 1930 mg l^{-1} Mg^{2+} = 190 mg l^{-1}	1997–1999
	Tweefontein and Fourth (Tweefontein water)	pH = 8.0 EC = 300 mS m^{-1} Ca^{2+} = 420 mg l^{-1} SO_4^{2-} = 1750 mg l^{-1} Mg^{2+} = 240 mg l^{-1}	1997–1999
Syferfontein		pH = 9.1 EC = 380 mS m^{-1} Na^+ = 630 mg l^{-1} SO_4^{2-} = 1660 mg l^{-1} Mg^{2+} = 80 mg l^{-1} Cl^- = 40 mg l^{-1} Ca^{2+} = 30 mg l^{-1}	2001
New Vaal		pH = 7.6 EC = 110 mS m^{-1} Na^+ = 70 mg l^{-1} SO_4^{2-} = 400 mg l^{-1} Mg^{2+} = 40 mg l^{-1} Cl^- = 40 mg l^{-1} Ca^{2+} = 90 mg l^{-1}	1997–2002

Table III

Soil classification, depth, texture and initial soil salinity of the irrigated fields at the different mines

Mine and field		Soil classification	Soil depth (m)	Texture	Initial soil saturated electrical conductivity (mS m^{-1})
Kleinkopjé	Major	Bainsvlei, Clovelly	~ 1.0	Loamy sand	60
	Tweefontein	Witbank (rehabilitated land)	~ 0.9	Sandy loam	40
	Fourth	Hutton	> 2.0	Sandy loam	50
Syferfontein		Arcadia	~ 0.5	Clay	160
New Vaal		Clovelly, Dundee, Oakleaf	> 1.4	Sand	10

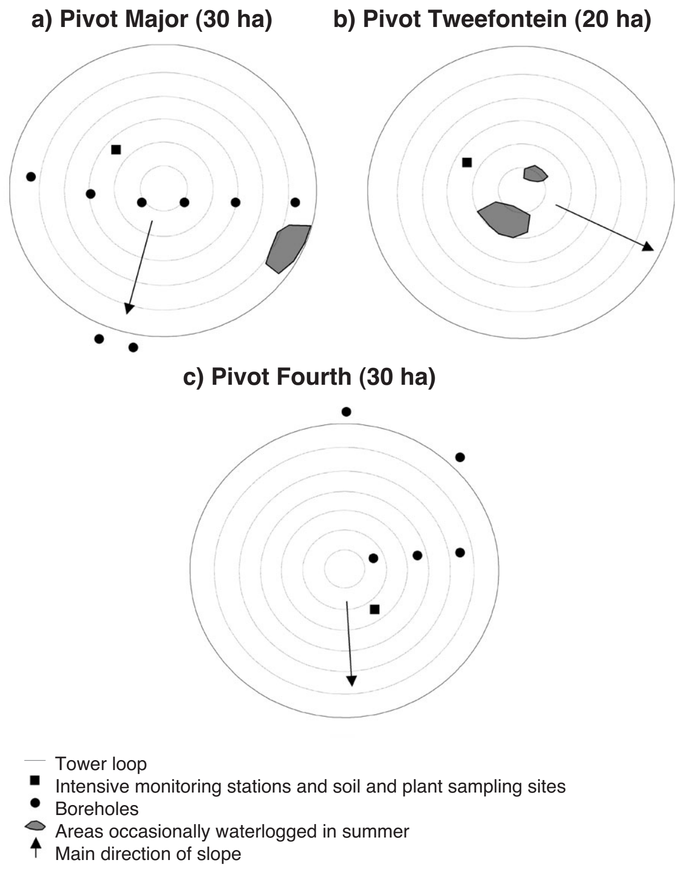

Figure 1a—Experimental scheme of the irrigated fields at Kleinjkopjé Colliery

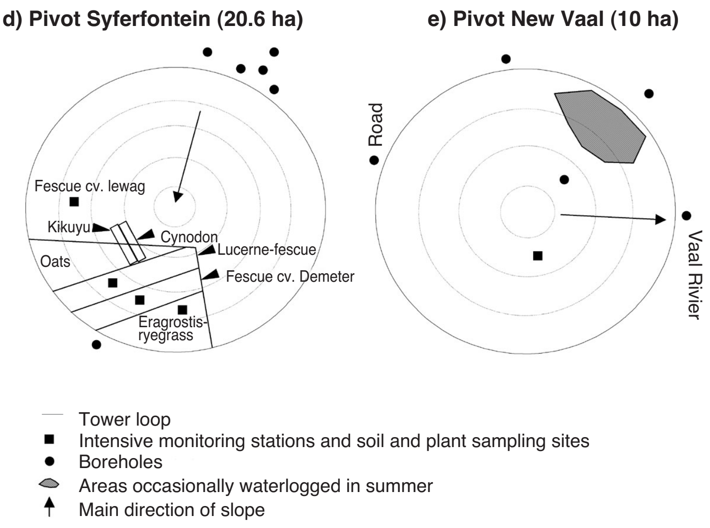

Figure 1b—Experimental scheme of the irrigated fields at Syferfontein and New Vaal

the following instrumentation and measurements:

- ➤ An automatic weather station at each mine to monitor the driving variables for evaporation.
- ➤ Intensive monitoring stations at representative sites of all fields to monitor the soil water and salt balance during the cropping season (Figures 1a and b). The intensive monitoring stations include the following instrumentation:
  - Tipping bucket rain gauges to measure rain and irrigation amounts and intensities.
  - Heat dissipation sensors to measure matric potential at different depths in the root zone in order to estimate soil water fluxes.
  - Wetting front detectors to indicate whether wetting fronts have reached certain depths in the soil profile.
  - Time-domain reflectometry (TDR) probes to measure volumetric soil water content and salinity at different depths in the soil profile.
- ➤ All these instruments are connected to CR10 or CR10X

data loggers (Campbell Scientific Inc., Logan, Utah, USA) for continuous recording. In addition, the following measurements are taken manually in the vicinity of the intensive monitoring stations (Figures 1a and b):

  - Volumetric soil water content with neutron probes for 0.2 m soil layers down to 1.0 m fortnightly.
  - Soil water sampling with ceramic cup soil water samplers and wetting front detectors to monitor the soil solution chemical composition fortnightly.
  - Soil sampling at the beginning of each cropping season for chemical analyses in the laboratory in order to determine changes in chemical composition.
  - Soil sampling below the root zone to locate the salt front between the root zone and groundwater every year.
  - Monitoring of crop growth and development through detailed growth analyses (dry matter partitioning, thermal time requirements, leaf area index) fortnightly as well as yield measurement. Three replications of 1 m^2 ground area were taken at sites close to the intensive monitoring stations for crop growth and yield analyses. Plant samples were also taken at critical crop growth stages to determine possible nutritional deficiencies to be corrected through fertilization.
  - During the 2000/01 summer season at Kleinkopjé, two adjacent intensive monitoring stations were installed in the maize fields of all three pivots. During the 2001/02 season, two adjacent intensive monitoring stations were also installed in the field Fourth (Kleinkopjé mine) planted with potatoes. In all other seasons at Kleinkopjé, as well as at all other mines, one intensive monitoring station was installed in each field. At Syferfontein, the intensive monitoring stations were fenced to prevent grazing animals from damaging instruments.

➤ Runoff weirs to monitor the volume of water running off the fields with a pressure transducer measuring the water level above the weir and the quality of runoff water with a salinity sensor. The instruments were connected to a CR-510 data logger (Campbell Scientific Inc., Logan, Utah, USA) that recorded data every 2 min only during runoff events (weir overflowing). The weirs were built at the lowest points of fields Major and Tweefontein (Kleinkopjé mine). A weir will be built at Syferfontein mine during winter 2002. At field Fourth (Kleinkopjé mine) and New Vaal mine, runoff weirs were not built as no runoff was expected to occur from these fairly flat fields on well-drained, high infiltration capacity soils.

➤ Irrigation water quality was measured monthly by the mines.

➤ Boreholes to monitor groundwater levels and qualities every 2 to 6 months (Figures 1a and b). Boreholes were not needed at field Tweefontein (Kleinkopjé mine), which is on rehabilitated land.

Irrigations were scheduled by the farming companies to refill the soil profile to field capacity, taking onto account the recommendations of the research team based on volumetric soil water content measurements with the neutron probe. The detailed data on the experimental set-up are available in Annandale *et al.*[12].

The data collected with the intensive monitoring systems were used to determine the components of the soil water and salt balance for each field. For the soil water balance, irrigations and rainfall were measured with automatic rain gauges, evapotranspiration was estimated from soil water measurements with a neutron water meter, and runoff was measured at weirs built at the lowest points of the irrigated fields. Water intercepted by the crop canopy and drainage were estimated with the SWB model. The SWB model was also used to split evapotranspiration into soil evaporation and crop transpiration.

For the salt balance, the mass of salts added was determined from irrigation amounts and chemical analyses, salt runoff was measured at the weirs with salinity sensors, and laboratory analyses of soil samples were carried out to measure salts in the soil solution. The SWB model was used to estimate the mass of salts precipitated in the soil profile in the form of gypsum and salt leaching.

The data collected with the intensive monitoring systems were also used to calibrate and validate the SWB model. For example, soil water potential and content measurements at different depths in the soil profile were used to test the soil water balance subroutine, plant growth analyses were used to test the crop growth subroutine, etc.[8].

Results and discussion

Table IV presents the crops, cultivars and yields obtained at the three mines. The yields of maize and wheat are expressed as air-dry grain masses, while potato yield represents the fresh mass of tubers.

The yields of maize and wheat were measured by the farming companies and the figures in Table IV are representative of the entire fields. It should be borne in mind that some areas, occasionally waterlogged during the summer rainy season (Figures 1a and b), were not planted to maize and this reduced the final yields obtained over the whole irrigated area.

At Syferfontein, the pastures were harvested three times during the 2001/02 summer season and yields are expressed as dry matter production. Pasture yields at Syferfontein represent the average of three replications taken by the research team. The utilization method for the pastures was cutting-and-baling and grazing. The yields were generally satisfactory and definitely better compared to dry land cropping. They could be improved once the farming companies have gained experience in managing the systems.

Tables V to X present summaries of the components of the soil water and salt balance for each irrigated field and the periods of measurement with intensive monitoring stations.

At Kleinkopjé mine, the measuring period included two summer crops and one winter crop. Annual crops require a drying-off period at the end of each season and this resulted in large negative figures for changes in soil water storage (Table V). Seasonal irrigation varied depending on rainfall.

Transpiration of healthy growing crops, which provided a large canopy cover, was higher than soil evaporation. Drainage was limited at pivot Major by a plinthic layer at ~

Table IV

Crops, cultivars and yields under irrigation with minewater

Mine and field		Crops and cultivars	Season	Yield (Mg ha^{-1})
Kleinkopjé	Major	Maize (*Zea mays* cv. PAN 6710)	2000/01	7
	Tweefontein	Maize (*Zea mays* cv. PAN 6710)	2000/01	3.7
	Fourth	Maize (*Zea mays* cv. PAN 6710)	2000/01	5.3
	Major	Wheat (*Triticum aestivum* cv. SST 825)	2001	7.2
	Tweefontein	Wheat (*Triticum aestivum* cv. SST 825)	2001	6.5
	Fourth	Potato (*Solanum tuberosum* cv. Up-to-Date)	2001/02	52
	Major	Maize (*Zea mays* cv. PHI 32P75)	2001/02	4.7
	Tweefontein	Maize (*Zea mays* cv. PHI 32P75)	2001/02	2.1
Syferfontein (3 harvests on 17/10/2001, 27/11/2001 and 30/04/2002)		Fescue (*Festuca arundinacea* cv. Iewag)	2001/02	2.8±0.2 2.7±0.5 4.7±0.8
		Lucerne (*Medicago sativa* cv. SA Standard) - Fescue (*Festuca arundinacea* cv. Iewag)	2001/02	0.5±0.1 2.2±0.5 5.0±0.9
		Fescue (*Festuca arundinacea* cv. Demeter)	2001/02	1.7±0.1 1.1±0.5 4.2±0.3
		Eragrostis (*Eragrostis curvula*) - Ryegrass (*Lolium multiflorum* cv. Midmar)	2001/02	0.9±0.1 2.5±0.7 6.8±1.4
New Vaal		Maize (*Zea mays* cv. PHI 335)	2001/02	7.8

Table V

Seasonal values of the soil water balance components for each pivot and crop at Kleinkopjé Colliery

Pivot	Crop and season	Rainfall (measured) (mm)	Irrigation (measured) (mm)	Soil water evaporation (simulated) (mm)	Crop transpiration (simulated) (mm)	Drainage (simulated) (mm)	Canopy interception (simulated) (mm)	Runoff (measured) (mm)	Change in soil water storage (simulated) (mm)
Major	Maize (2000/01, site 1)	246	253	173	354	63	41	10	-142
	Maize (2000/01, site 2)	246	219	158	338	61	39	11	-142
	Maize (2000/01, average)	246	236	166	346	62	40	11	-143
	Wheat (2001)	135	451	200	316	31	41	12	-14
	Maize (2001/02)	307	101	110	359	55	42	25	-183
	Total (summer 2000/01–summer 2001/02)	**688**	**788**	**476**	**1021**	**148**	**123**	**48**	**-340**
Tweefontein	Maize (2000/01, site 1)	245	271	227	389	0	43	34	-177
	Maize (2000/01, site 2)	245	268	224	389	0	43	34	-177
	Maize (2000/01, average)	245	270	226	389	0	43	34	-177
	Wheat (2001)	135	308	197	280	0	47	6	-87
	Maize (2001/02)	307	126	134	342	0	39	51	-133
	Total (summer 2000/01–summer 2001/02)	**687**	**704**	**557**	**1011**	**0**	**129**	**91**	**-397**
Fourth	Maize (2000/01, site 1)	245	310	192	436	91	45	0	-209
	Maize (2000/01, site 2)	245	322	175	462	67	47	0	-184
	Maize (2000/01, average)	245	316	184	449	79	46	0	-197
	Potato (2001/02, site 1)	243	276	182	330	35	48	0	-76
	Potato (2001/02, site 2)	243	287	179	339	38	49	0	-75
	Potato (2001/02, average)	243	282	181	335	37	49	0	-77
	Total (summer 2000/01–summer 2001/02)	**488**	**598**	**365**	**784**	**116**	**95**	**0**	**-274**

1.0 m soil depth. At pivot Tweefontein, drainage was assumed to be 0 as the spoil layer, also at ~ 1.0 m soil depth, has a hydraulic conductivity several orders of magnitude lower than the overlying soil.

Water intercepted by the canopy and evaporated from it was a minor component of the soil water balance and depended on wetting frequency by irrigation and rain. Runoff was simulated after model calibration against data obtained at the weirs. At pivot Fourth, runoff was assumed to be zero. Salts added depended on irrigation water quality and amounts (Table VI). Salt runoff at pivot Fourth was zero because no runoff of water was assumed. Leached salts at pivot Tweefontein was assumed to be zero because no drainage was simulated.

Considerable masses of salt were predicted to precipitate in the soil profile in the form of gypsum. The initial gypsum precipitated in the soil profile was due to six seasons of irrigation with gyspiferous minewater at pivots Major and Tweefontein and four seasons of irrigation at pivot Fourth during the previous project[8] and prior to the beginning of this trial. The negative change in salt content in the soil indicates a decrease in soil salinity through salt leaching and gypsum precipitation during the measuring period.

At Syferfontein, the measurement period was from 01/10/2001, when the pastures were fully established, until 17/04/2002 (Table VII). Almost full canopy cover of pastures ensured high transpiration and low soil evaporation. Drainage was limited by the heavy texture of the soil. Runoff was assumed to be zero as the weir was not built and no data were available for model calibration, but this is likely to be incorrect due to the low infiltration rate of the soil.

The change in soil water storage was relatively small as the field was irrigated throughout the season. Variability in the components of the soil water balance was observed due to variability of irrigations and water use measured on the four plots with different pastures where the intensive monitoring stations were installed. The components of the salt balance varied accordingly (Table VIII). Initial gypsum precipitated in the soil profile was assumed to be zero. The positive change in salt content in the soil indicated an increase in soil salinity due to irrigation with water rich in highly soluble Na_2SO_4.

At New Vaal, the measurement period included only the summer 2001/02 season (Table IX). Only a few irrigations were applied due to high rainfall. Drainage was high and runoff was assumed to be negligible for the sandy soil with a high infiltration capacity. The negative change in soil water storage indicates the drying-off period at the end of the cropping season. Due to the low mass of salts added through irrigation, very little gypsum was predicted to precipitate in the soil profile (Table X). The model predicted some leaching of natural salts present in the soil profile during the rainy season and the change in salt content in the soil was therefore negative.

The results of the groundwater monitoring generally indicated a negligible impact of irrigation with gypsiferous minewater. However, the system will have to be monitored for a longer period in order to draw definite conclusions. The detailed results of this research are available in Annandale *et al.*[12].

Conclusions

In this study, major accent was given to the development of a monitoring system for measuring and modelling the soil water and salt balance components under irrigation with

Table VI

Seasonal values of the salt balance components for each pivot and crop at Kleinkopjé Colliery

Pivot	Crop and season	Salts added (measured) ($Mg\ ha^{-1}$)	Salts runoff (measured) ($Mg\ ha^{-1}$)	Salts leached (simulated) ($Mg\ ha^{-1}$)	Gypsum precipitated in the soil – beginning of season (simulated) ($Mg\ ha^{-1}$)	Gypsum precipitated in the soil – end of season (simulated) ($Mg\ ha^{-1}$)	Change in soluble salt content in the soil (simulated) ($Mg\ ha^{-1}$)
Major	Maize (2000/01, site 1)	6.66	0.06	0.95	26.59	33.20	-0.96
	Maize (2000/01, site 2)	5.77	0.07	0.91	26.59	32.49	-1.11
	Maize (2000/01, average)	6.22	0.07	0.93	26.59	32.85	-1.04
	Wheat (2001)	11.83	0.17	1.16	35.28	42.54	3.24
	Maize (2001/02)	2.52	0.02	1.75	43.95	48.00	-3.30
	Total (summer 2000/01– summer 2001/02)	**20.57**	**0.26**	**3.84**	**26.59**	**48.00**	**-4.71**
Tweefontein	Maize (2000/01, site 1)	7.51	0.21	0	20.54	27.11	0.73
	Maize (2000/01, site 2)	7.43	0.21	0	20.31	27.10	0.43
	Maize (2000/01, average)	7.47	0.21	0	20.43	27.11	0.58
	Wheat (2001)	8.59	0.001	0	31.95	37.96	2.58
	Maize (2001/02)	3.52	0.05	0	42.87	46.50	-0.16
	Total (summer 2000/01– summer 2001/02)	**19.58**	**0.26**	**0**	**20.43**	**46.50**	**-6.75**
Fourth	Maize (2000/01, site 1)	8.62	0	0.87	5.33	12.42	0.66
	Maize (2000/01, site 2)	8.95	0	0.36	5.90	12.77	1.72
	Maize (2000/01, average)	8.79	0	0.62	5.62	12.60	1.19
	Potato (2001/02, site 1)	7.68	0	0.97	14.28	20.04	0.95
	Potato (2001/02, site 2)	7.98	0	1.06	14.27	20.18	1.01
	Potato (2001/02, average)	7.83	0	1.02	14.28	20.11	0.98
	Total (summer 2000/01– summer 2001/02)	**16.62**	**0**	**1.64**	**5.62**	**20.11**	**0.49**

Table VII

Seasonal values of the soil water balance components for each crop at the Syferfontein coal mine

Crop and season	Rainfall (measured) (mm)	Irrigation (measured) (mm)	Soil evaporation (simulated) (mm)	Crop transpiration (simulated) (mm)	Drainage (simulated) (mm)	Canopy interception (simulated) (mm)	Runoff (measured) (mm)	Change in soil water storage (simulated) (mm)
Fescue (cv. Iewag) (from 01/10/2001 to 17/04/2002)	574	321	174	522	65	78	0	56
Lucerne-fescue (cv. Iewag) (from 01/10/2001 to 17/04/2002)	574	278	121	659	21	91	0	-40
Fescue (cv. Demeter) (from 01/10/2001 to 17/04/2002)	574	279	181	590	46	79	0	-43
Eragrostis-ryegrass (from 01/10/2001 to 17/04/2002)	574	278	172	594	51	76	0	-41
Average (from 01/10/2001 to 17/04/2002)	**574**	**289**	**162**	**591**	**46**	**81**	**0**	**-17**

Table VIII

Seasonal values of the salt balance components for each crop at the Syferfontein coal mine

Crop and season	Salts added (measured) (Mg ha^{-1})	Salts runoff (measured) (Mg ha^{-1})	Salts leached (simulated) (Mg ha^{-1})	Gypsum precipitated in the soil—start (simulated) (Mg ha^{-1})	Gypsum precipitated in the soil—end (simulated) (Mg ha^{-1})	Change in soluble salt (simulated) (Mg ha^{-1})
Fescue (cv. Iewag) (from 01/10/2001 to 17/04/2002)	8.02	0	0.93	1.61	0	8.70
Lucerne-fescue (cv. Iewag) (from 01/10/2001 to 17/04/2002)	6.94	0	0.53	0.07	1.57	4.91
Fescue (cv. Demeter) (from 01/10/2001 to 17/04/2002)	7.00	0	0.57	0.01	0.95	5.49
Eragrostis-ryegrass (from 01/10/2001 to 17/04/2002)	6.99	0	0.53	0	0.19	6.27
Average (from 01/10/2001 to 17/04/2002)	**7.24**	**0**	**0.64**	**0.42**	**0.68**	**6.34**

Table IX

Seasonal values of the soil water balance components at New Vaal Colliery

Crop and season	Rainfall (measured) (mm)	Irrigation (measured) (mm)	Soil evaporation (simulated) (mm)	Crop transpiration (simulated) (mm)	Drainage (simulated) (mm)	Canopy interception (simulated) (mm)	Runoff (measured) (mm)	Change in soil water storage (simulated) (mm)
Maize (2001/02)	**419**	**39**	**129**	**236**	**124**	**33**	**0**	**-64**

Table X

Seasonal values of the salt balance components at New Vaal Colliery

Crop and season	Salts added (measured) (Mg ha^{-1})	Salts runoff (measured) (Mg ha^{-1})	Salts leached (simulated) (Mg ha^{-1})	Gypsum precipitated in the soil—start (simulated) (Mg ha^{-1})	Gypsum precipitated in the soil—end (simulated) (Mg ha^{-1})	Change in soluble salt content in the soil (simulated) (Mg ha^{-1})
Maize (2001/02)	**0.40**	**0**	**1.50**	**0**	**0.07**	**-1.17**

gypsiferous minewater. The detailed description of the monitoring system allows repeatability of the experiments presented in this study. The measurements obtained in the experiments were used to assess the feasibility and sustainability of irrigation with gypsiferous mine water.

Crop yields indicated that crop production is not only feasible but can be very profitable on a commercial scale, at least in the short term (nine seasons at Kleinkopjé mine including the previous project and one season at Syferfontein and New Vaal).

At Kleinkopjé, where irrigations were carried out with $CaSO_4$ and $MgSO_4$ water, soil salinity oscillated depending on seasonal rainfall, and considerable amounts of gypsum were predicted to precipitate in the soil profile.

At Syferfontein mine, where irrigations were carried out with predominantly Na_2SO_4 water on a poorly drained profile, an increase in soil salinity was observed during the 2001/02 season, indicating that a leaching fraction will be required for sustainable crop production. With appropriate management, excess runoff and drainage, saline water can be intercepted and reused, thereby minimizing the impact on groundwater.

At New Vaal, no impact on soil salinity was observed during the first cropping season as very little irrigation water was applied due to high rainfall. Monitoring at all mines should continue in order to obtain results for more seasons.

The monitoring system presented in this study could be of great interest and benefit to technical people and to the industry, and numerous other applications are possible. Data collected in the field trials will also be used for further improvement, development, calibration and validation of the mechanistic soil water and salt balance model (SWB). Once improved and validated for the different sites, the SWB model will be used to predict the soil water and salt balance in the long term (many decades) and, linked to a geohydrological model, it will be used to predict the impact of irrigation with minewater on groundwater quality at any site[8] as well as to recommend the best management strategies in order to limit environmental pollution. This will also create the chance to link the findings of this work to other research oriented towards management of water and salt balances on a catchment scale.

Appropriate management of minewater is essential for the long-term sustainability of irrigation. At this stage, this technology looks promising, but a longer monitoring period is required in order to draw definite conclusions. It is clear that this technology holds potential to be implemented on a large scale with considerable benefits to the community. For example, irrigation with minewater will improve and stabilize yields of crops grown during the summer season, and make production of crops in the dry winter season in Mpumalanga Province possible.

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* *Issued by:* Lynne Medhurst
Maney Publishing
Tel: +44 (0) 113 2497481
Email: l.medhurst@maney.co.uk

De Beers to conduct $25 million study at Gahcho Kué*

Toronto—1 December, 2003—De Beers Canada Corporation is pleased to announce that the De Beers Board of Directors has approved a full technical investigation of the Hearne, 5034 and Tuzo kimberlites on the Gahcho Kué Project.

The investigation will include engineering, geotechnical, resource, and environmental studies.

'Advancing our Canadian projects into production as soon as possible is one of our priorities and we see this decision as an important step for the benefit of De Beers, Mountain Province Diamonds Inc., Camphor Ventures Inc. and both their shareholders,' said Richard Molyneux, president and CEO of De Beers Canada.

'In anticipation of a positive decision by our Board, the camp has been renovated in preparation for winter site work,' added Molyneux.

Site work will focus on geotechnical aspects to firm up mine designs and waste and water management. The existing environmental baseline work will be extended to support a potential environmental assessment for a mine. The study will include stakeholder consultation with the primary affected aboriginal groups and federal and territorial agencies.

If the project proceeds toward mine development, it is expected that permitting and stakeholder consultation will take a further two to three years, followed by an additional three years for mine construction.

Gahcho Kué (formally known as Kennady Lake, situated on the AK Block of Claims, is a joint venture between De Beers Canada Exploration Inc. (51%), Mountain Province Diamonds Inc. (44.1%), and Camphor Ventures Inc. (4.9%). The resource is located approximately 300 km east-northeast of Yellowknife, NWT. ◆

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* *Contact: Linda Dorrington, Manager,*
Public & Corporate Affairs, De Beers Canada,
Tel: 1 (416) 645 1710, 1 (905) 8498 0619,
1 (416) 818 2254