A Management Plan towards the Flooding of an Open-Cast Mine with Adjacent Underground Sections

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ABSTRACT

The colliery is situated in the Mpumalanga Coalfield, north of Trichardt in the Republic of South Africa. The opencast is already rehabilitated but still acts as an entrance to the underground sections of the mine. The *Life of Mine* indicates active mining until 2035. We were tasked to develop a mine closure plan. Two surface drainage systems are present, namely the Trichardt Spruit and the Steenkool Spruit. Both these systems have been diverted locally around the opencast with the necessary permission, to maximize coal extraction and protect the environment. Several passive treatment options were tabled to minimise the post closure environmental contamination. After careful consideration it was decided to develop a mine flooding plan to exclude oxygen from the mine thereby minimising the sulfate generation inside the opencast and underground sections. To start flooding as early as possible, sections of the underground mine were identified as natural or artificial compartments to store water. The rehabilitated opencast is flooded using recharge from rainfall only. The sulfate content of the decant water is expected to decrease and only passive treatment options will be needed to improve the water quality so that the decant water may be released into the streams.

INTRODUCTION

The colliery is situated in the southern portion of the Witbank Coalfield, being part of the larger Mpumalanga Coalfields in South Africa. The coal is extracted by opencast and underground mining methods. The opencast mining was done in virgin ground, hence dewatering of existing underground workings was not needed. During the mining operations the spoils (overburden) is placed back in the pit. The spoils are levelled according to a surface plan and covered with topsoil and seeded. The opencast mining has since ceased and the rehabilitation has been completed. The underground mining, which consists of four different sections and is connected to the opencast, is by bord-and-pillar method only (**Figure 1**). The life of mine plan does not include any high-extraction and is projected until 2035 after which the mine will apply for closure. Legislation in South Africa requires that water decanting from a mining environment needs to be treated before it may be released into a stream or canal.

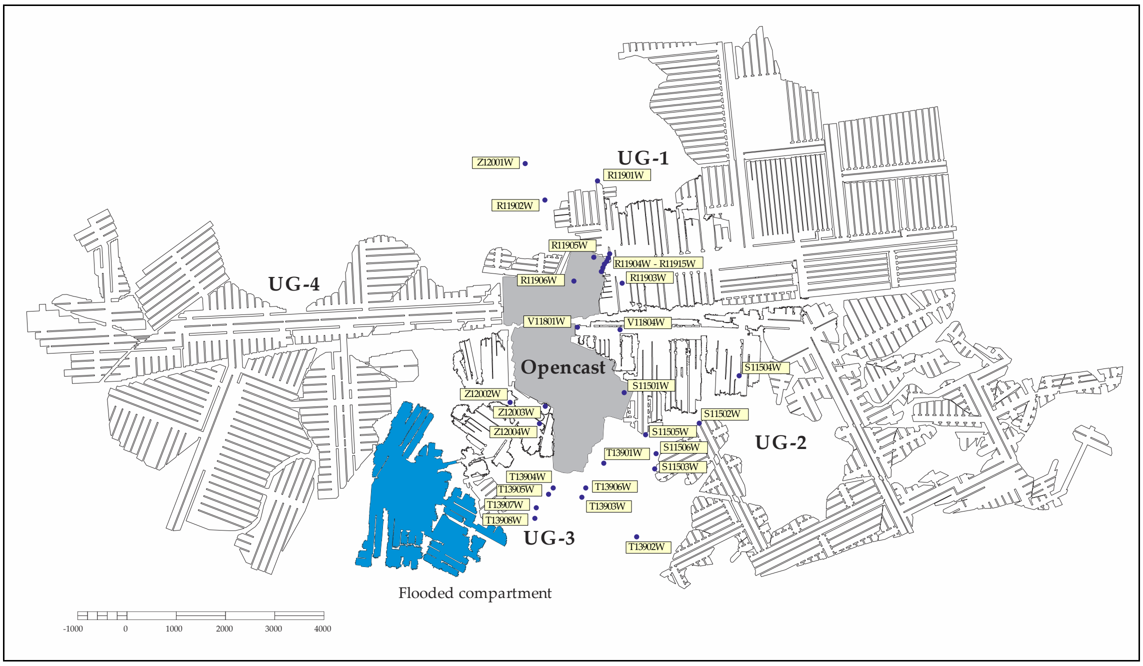


Figure 1 The opencast mine with the connected underground sections and monitoring boreholes.

METHODOLOGY

The underground workings are currently dry, except for one flooded compartment in the southern part of UG-3 (**Figure 1**). The opencast and all the underground sections have mined the same coal seam. This means that the floors of all the sections are connected. After mining has ceased the workings are allowed to be flooded. Water levels in the underground sections and opencast will rise together. The waterbody inside the workings will behave like a water table, or unconfined aquifer. Recharge in the opencast is much faster than in the underground. This means that the water level in the opencast will rise much quicker which in turn will lead to a water flow from the opencast into the underground sections. When the underground workings are completely filled, recharge to these workings will stop and only the opencast will continue to recharge. As the water table rises in the opencast sections so will the pressure in the connected underground and the waterbody in the underground will change into a confined aquifer (the permeability of the roof is much lower than the permeability of the cavity). The water table will continue to rise until the system starts to decant. The decant position and elevation (meters above sea mean level, mamsl) was determined using the surface contours and opencast outline (**Figure 2**).

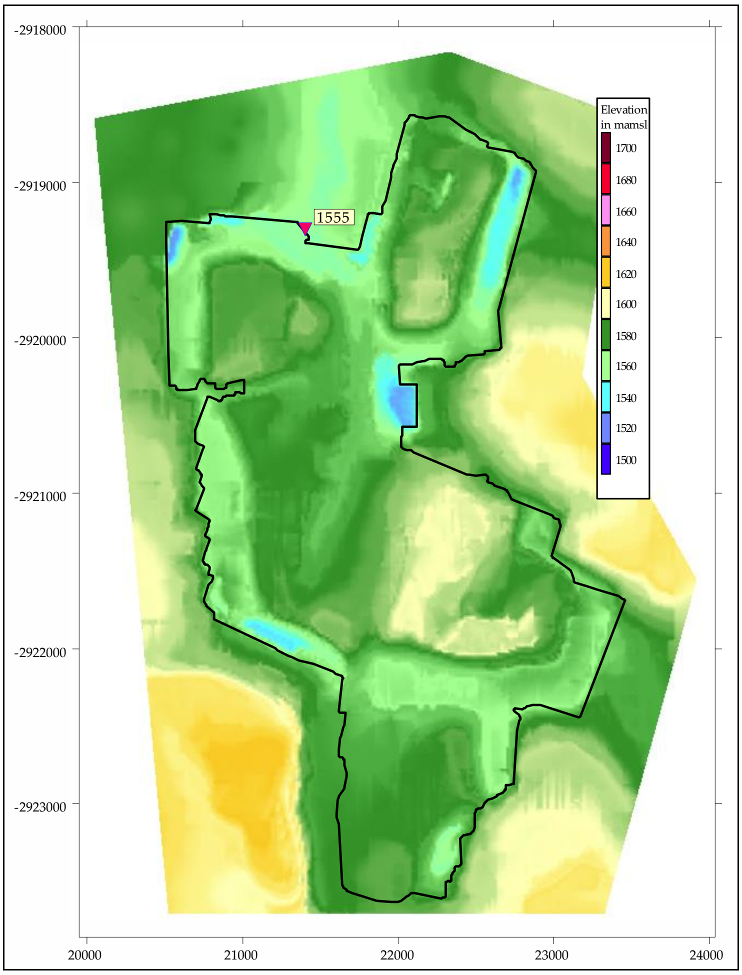


Figure 2 Opencast surface contours with decant point indicated

RESULTS AND DISCUSSION

Waterbalance

In terms of water make, the different mining methods have different recharge factors. Table 1 shows the recharge factors used in the Mpumalanga Area (Vermeulen, 2003). A fixed mining height of 4.60 m and the pillar-plan were used to determine the extraction factors for the four connected underground sections.

A stage-volume curve depicts the relationship between a water level elevation and the volume of water inside the opencast or underground workings. The water level is assumed to be horizontal. Using a stage-volume curve for the rehabilitated opencast pit with a void space of 25 % in the backfilled spoils, a volume can be determined at decant level. A management level at 1 550 mamsl, five meters below the decant elevation, is suggested. This results in a 9 400 Mℓ buffer to be utilized in very wet seasons (**Figure 3**).

Table 1 Recharge values per mining methode

Mining method	Recharge as a percentage of the average rainfall
Bord-and-pillar	1 – 3%
Stooping	6 – 13%
Longwall and shortwall	15 – 20%
Opencast	20 – 30%

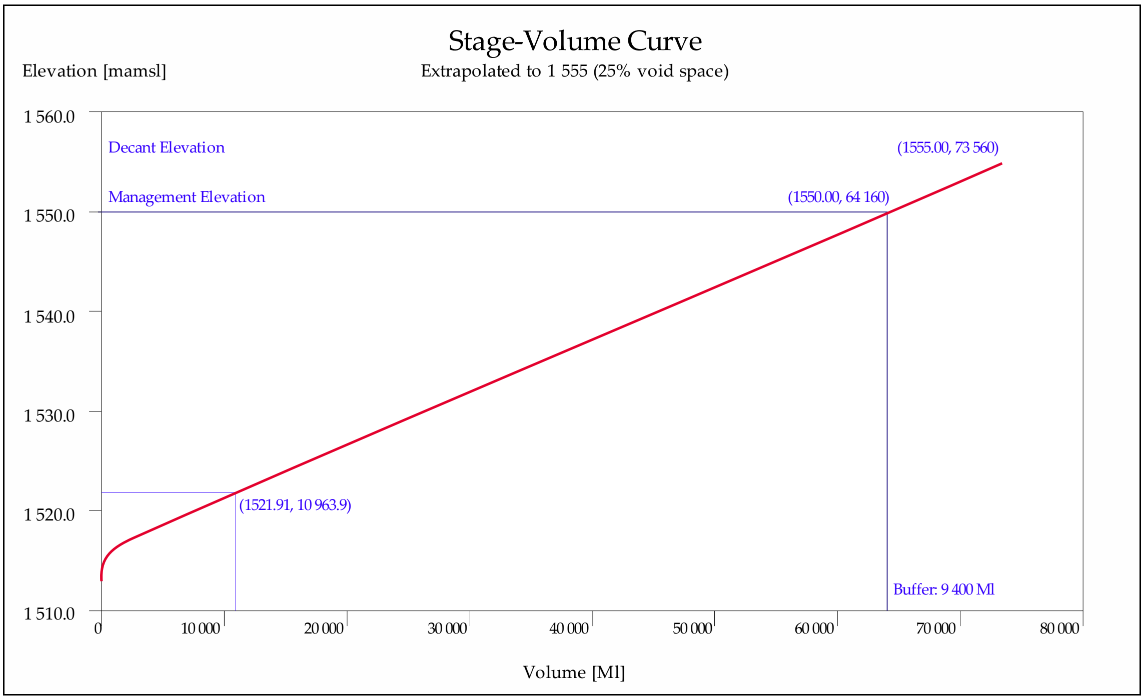


Figure 3 Stage-volume curve for the rehabilitated opencast

The stage-volume curve appears to be a mainly linear because the opencast does not have benches and the walls are almost vertical. The storage capacities for the separate workings were calculated using the outline pillar plan and a fixed mining height of 4.60 m. The opencast is currently not completely dry. Using two boreholes in the northern part of the pit, a water level elevation of 1 521.91 mamsl was determined (Table 2).

Table 2 Water storage capacity for separate working at the colliery

UG Section	Area (ha)	Mining Height (m)	Extraction factor (-)	Capacity (Mℓ)	Remaining Capacity (Mℓ)
UG-1	3 000	4.60	53.5	73 840	73 840
UG-2	2 848	4.60	53.5	70 051	70 051
UG-3	932	4.60	53.0	22 176	9 933
UG-4	3 173	4.60	55.0	80 279	80 279
OC @1550	780	-	25.0	64 160	53 196

Another factor that influences the inflow of water is the depth of mining. Natural permeability usually decreases with depth. This is because calcium carbonate, which is the binding material between the grains of sand (sandstone) and mud (shale), has to some degree been leached by circulating groundwater from the top 40 m of sediments. An empirical relationship between recharge and mining depth has been established through years of observation in the collieries as shown in Table 3 (Hodgson and Krantz, 1998).

Table 3 Bord-and-pillar recharge-values per depth of mining

Depth of mining (m)	Percentage recharge for average rainfall
10	3 – 10
20	2.5 – 5
30	2 – 3
40	1.5 – 2
>60	1 – 1.5

The depth of the underground workings at this colliery varies between 34 and 150 meters below ground level (**Figure 4**) and an average recharge rate of 1.5 % is suggested. Using the recharge rate the area of each section, a water make per section can be calculated, as well as the time it will take to flood the underground sections.

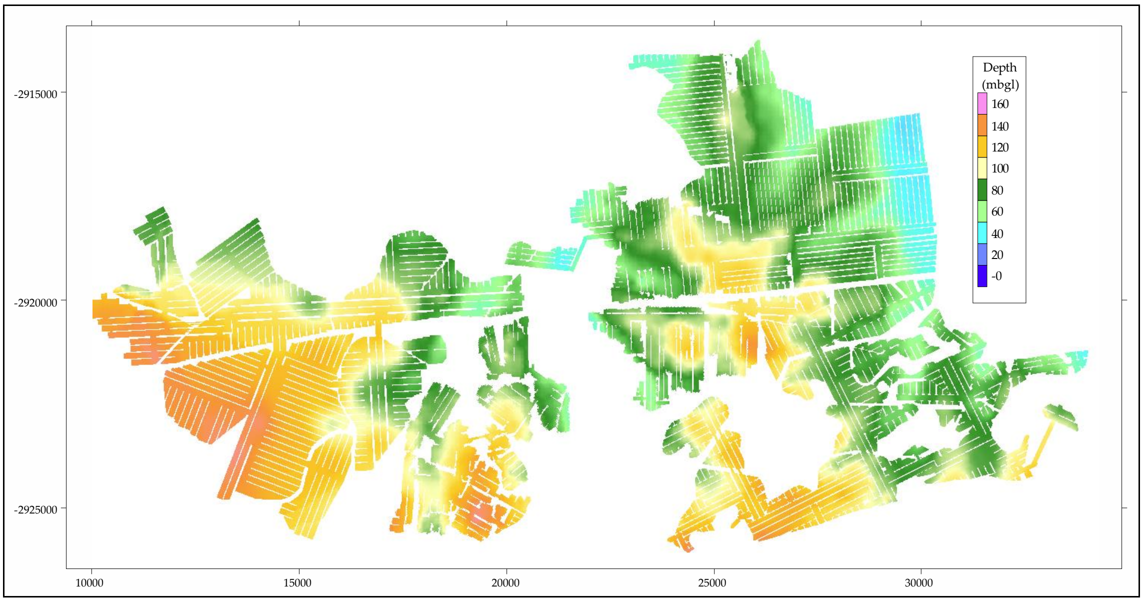


Figure 4 Depth of the coal floor in the current and future underground sections of the colliery

The recharge in the opencast is much higher than the recharge in the underground. Observations over the last twenty years have led to the values in Table 4 (Hodgson and Krantz, 1998). For the entire opencast a recharge value of 20 % is applied. Apart from the mining geometry, the other most important factor controlling water flow in a mine is the coal floor contours. As far as possible the provided peg data and mining height was used to generate a coal floor contour. Where gaps in the data exist, the coal floor was interpolated from exploration borehole information. The result is illustrated in **Figure 5**.

Table 4 Recharge values for opencast pits

Water source	Water into opencast [% rainfall]	Suggested average [% rainfall]
Rain onto ramps and voids	20 – 100	70
Rain onto not rehabilitated spoils	30 – 80	60
Rain run-off from levelled spoils	3 – 7	5
Rain seepage into levelled spoils	15 – 30	20
Rain run-off from rehabilitated spoils	5 – 15	10
Rain seepage into rehabilitated spoils	5 – 10	8
	[% of total pit water]	[% of total pit water]
Surface run-off from pit surroundings	5 – 15	6
Groundwater seepage	2 – 15	10

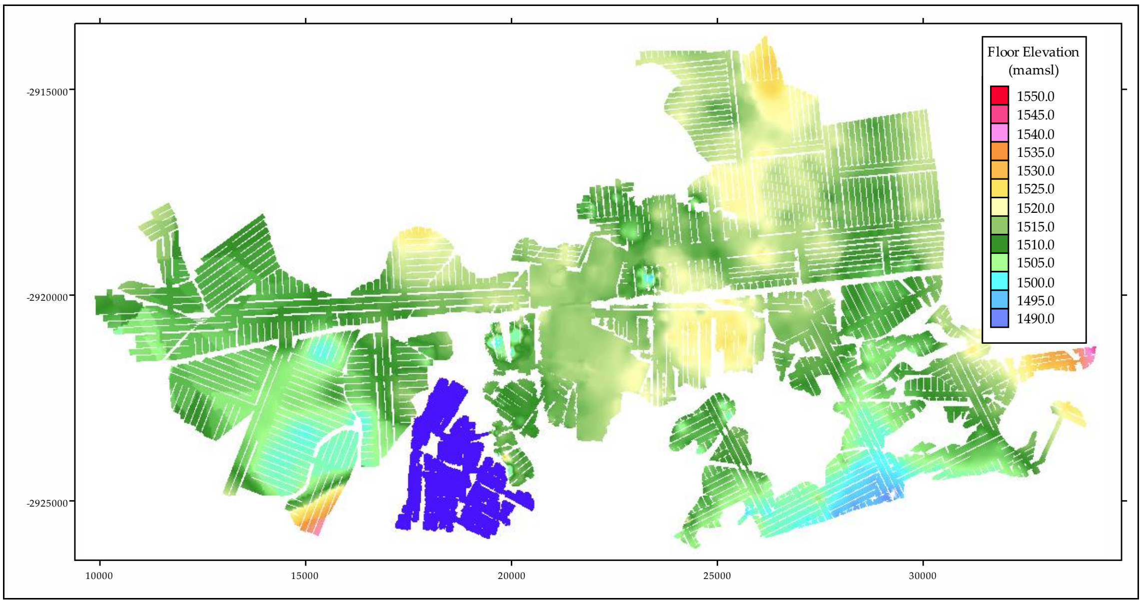


Figure 5 Coal floor contours for the current and future opencast and underground workings

Table 5 Recharge and time to fill values for each section

Section	Capacity Mℓ	Area ha	Rainfall m/a	Recharge %	Recharge Mℓ/a	Recharge m3/d	Time to fill years
UG-1	70 030	2 848	0.7	1.5	299	820	234
UG-2	73 840	3 000	0.7	1.5	315	863	234
UG-3 (Flooded)	0	534	0.7	1.5	0	0	0
UG-3	9 900	399	0.7	1.5	42	115	236
UG-4	80 280	3 173	0.7	1.5	333	912	241
OC @1550	53 196	780	0.7	20	1 092	2 992	49
TOTAL	**287 246**	**10 734**			**2 081**	**5 702**	

UG-3 is divided into a southern and northern part by the presence of a dolerite dyke. A downthrow of 10 m occurs on the southern part. The southern part has been flooded and does no longer partake in the water balance due to the fact that the artificial aquifer has changed from a water table to a confined aquifer.

The capacity of the opencast is calculated at the management elevation of 1 550.00 mamsl. As the opencast will recharge much faster than the connected underground, water will flow from the opencast into the underground sections. This will help the underground to fill up much faster and a total time of **139** years is calculated for the opencast and underground to be flooded to the management elevation of 1 550 mamsl. The management elevation is much higher than the highest points of the roof contours in each of the underground sections hence the underground will be flooded long before the whole system will start to decant. This also implies that when the water in the opencast is at its management elevation, water in the underground is under pressure and the water make in these sections will cease, resulting in a total water make, for the whole system, that is equal to the recharge of the opencast (1 092 Mℓ /a or 3 Mℓ /d).

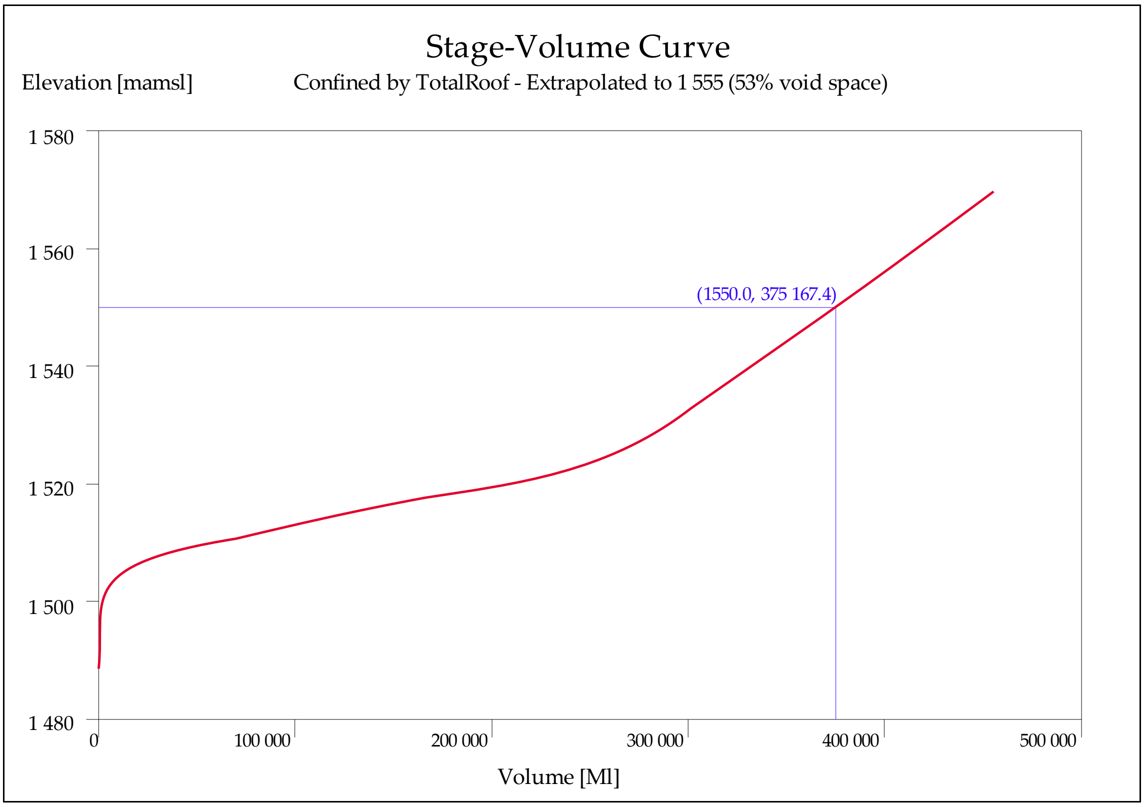


Figure 6 Stage-Volume curve for the combined opencast and underground workings

The recharge factor used in the calculations is the net gain of water in the pit. The gain of water is made up of the actual recharge minus evapotranspiration.

The colliery is situated in the quaternary Sub-Catchment A71H and has an annual evaporation of 1 550 mm (WRC Report: Surface Water Resources of South Africa, 1990).

To prevent future decant the complete water make of the opencast needs to be evaporated. A flooded area of 1 092 000 m^3 / 1.55 m = 70 ha is needed. This is above and beyond the existing final voids that have a combined wet footprint of 30 ha. A total flooded area (evaporation dams and final voids) of 100 ha is needed. Table 6 shows the flooded area on the surface of the rehabilitated opencast at different water level elevations together with the daily evaporation and the net recharge. The text at the decant elevation is in bold and the elevations above the decant elevation are in red. Only at an elevation of 1 561 mamsl the flooded area is large enough to evaporate more than the water make, resulting in a negative recharge. (**Figure 7** & **Figure 8**)

Table 6 In-pit water level elevations with the size of the flooded areas

Elevation mamsl	Volume in Pit Ml	Flooded Area ha	Evaporating m³/d	Net Recharge m³/d
1 550	2 363	32.2	1 367	2 992
1 551	2 602	32.6	1 384	2 975
1 552	2 851	32.7	1 389	2 971
1 553	3 109	33.4	1 418	2 941
1 554	3 380	33.6	1 427	2 933
1 555	**3 689**	**34.8**	**1 478**	**2 882**
1 556	4 026	52.9	2 246	2 113
1 557	4 442	57.3	2 433	1 926
1 558	4 892	59.8	2 539	1 820
1 559	5 376	62.5	2 654	1 705
1 560	5 935	68.8	2 922	1 438
1 561	6 730	137.7	5 848	-1 488
1 562	7 823	153.4	6 514	-2 155
1 563	9 080	164.4	6 981	-2 622
1 564	10 476	173.6	7 372	-3 013
1 565	12 026	187.5	7 962	-3 603

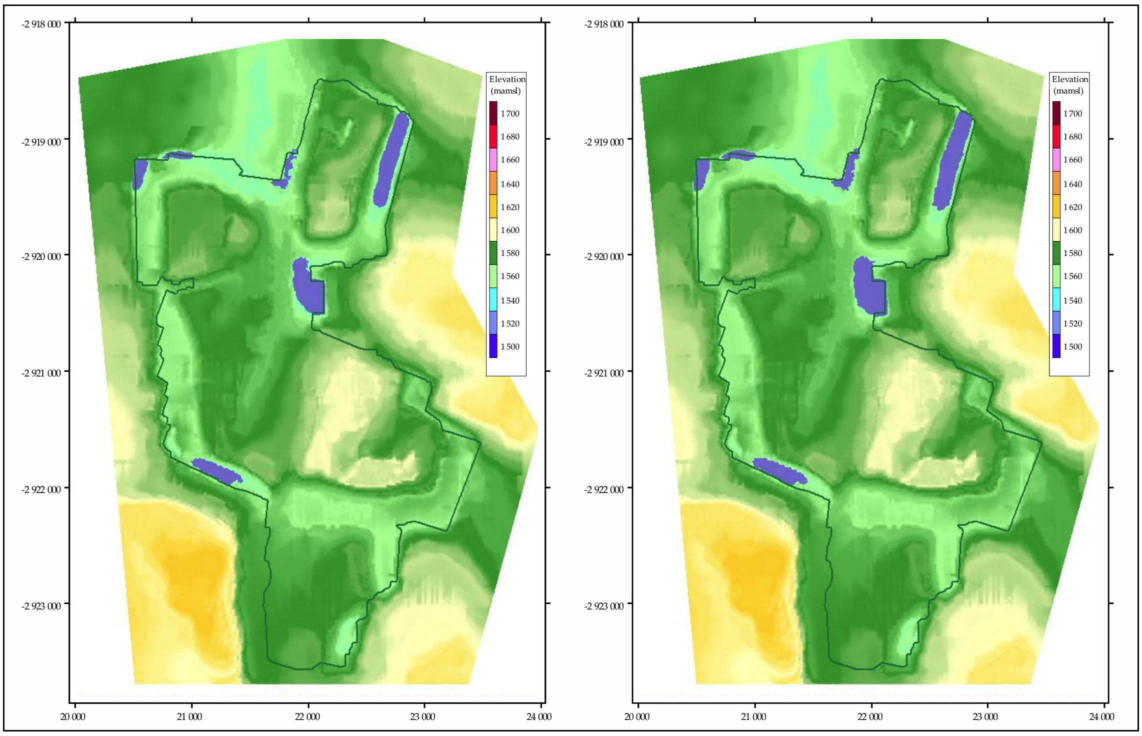


Figure 7 Flooded areas in the rehabilitated opencast - WL elevations at 1 550 & 1 555 mamsl

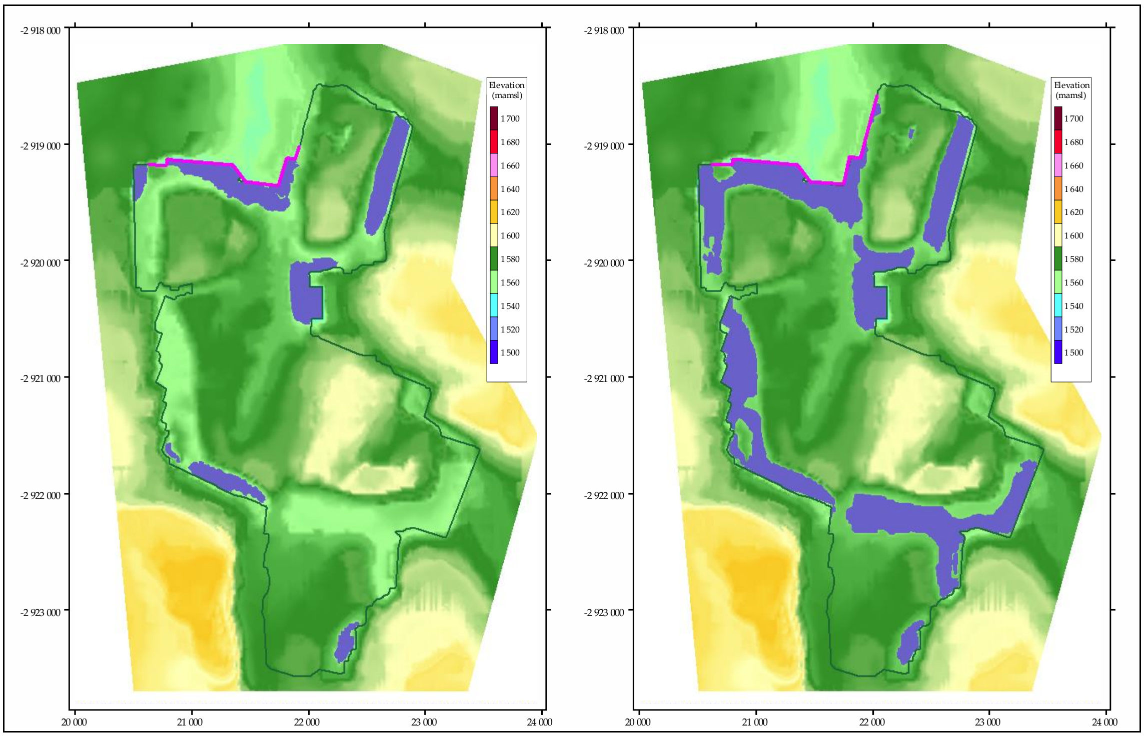


Figure 8 Flooded areas in the rehabilitated opencast - WL elevations at 1 560 & 1 565 mamsl

Sulfate generation

The remaining pillars in the underground as well as the spoils in the opencast will have a fair amount of pyrite. This in combination with the recharge water and oxygen will result in a sulfate generation that will continue until either the pyrite or the oxygen is depleted. The sulfate concentrations recorded during the last few years are erratic to say the least (**Figure 9**).

The expected long-term salinity of the opencast pit water can be calculated from the regional reaction rate within opencasts **7 kg/ha/d SO_4**. (Hodgson and Krantz, 1998). This rate appears to be fairly constant despite differences in degree of spoils saturation, age of spoils or regional impacts. It is therefore possible that the observed rates, as derived from flow and concentration calibration, reflect a maximum sulfate concentration with a consistent recharge. The maximum sulfate concentration is determined by the gypsum solubility (Usher, 2003). Hodgson has suggested that gypsum precipitation will play a role under low flow conditions (Hodgson, 2000). The sulfate generation in the underground is expected to be **1.2 kg/ha/d** (Vermeulen and Usher, 2006).

After mining has ceased the workings are allowed to be flooded. When the water level reach an elevation of 1 532 mamsl all the underground section, except for two little high parts in UG-2 and UG-4 will be flooded. The water volume will be 262 447 Mℓ and with a total recharge of 5.70 Mℓ/d (see Table 5) it will take 126 years to reach this stage.

The sulfate generated on a daily basis can be calculated:

For the opencast:	780 ha x 7 kg/ha/d	= 5 460 kg/d
For the underground:	9 420 ha x 1.2 kg/ha/d	= 11 304 kg/d
The average sulfate concentration:	16 764 kg/d ÷ 5 700 m^3/d	= 2.94 kg/m^3 (g/ℓ)

The opencast will continue to recharge with a 1092 Mℓ/d (see Table 5) with an expected sulfate concentration of: 5 460 kg/d ÷ 2 992 m^3/d = 1.82 kg/m^3 (g/ℓ)

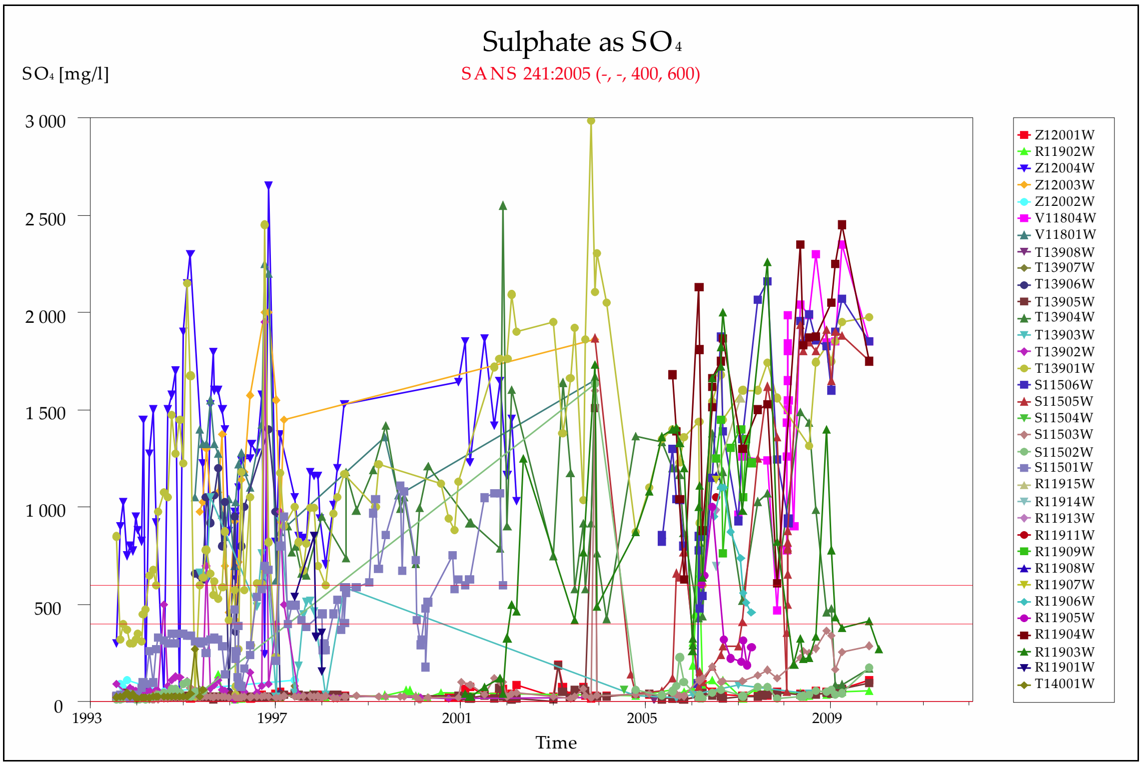
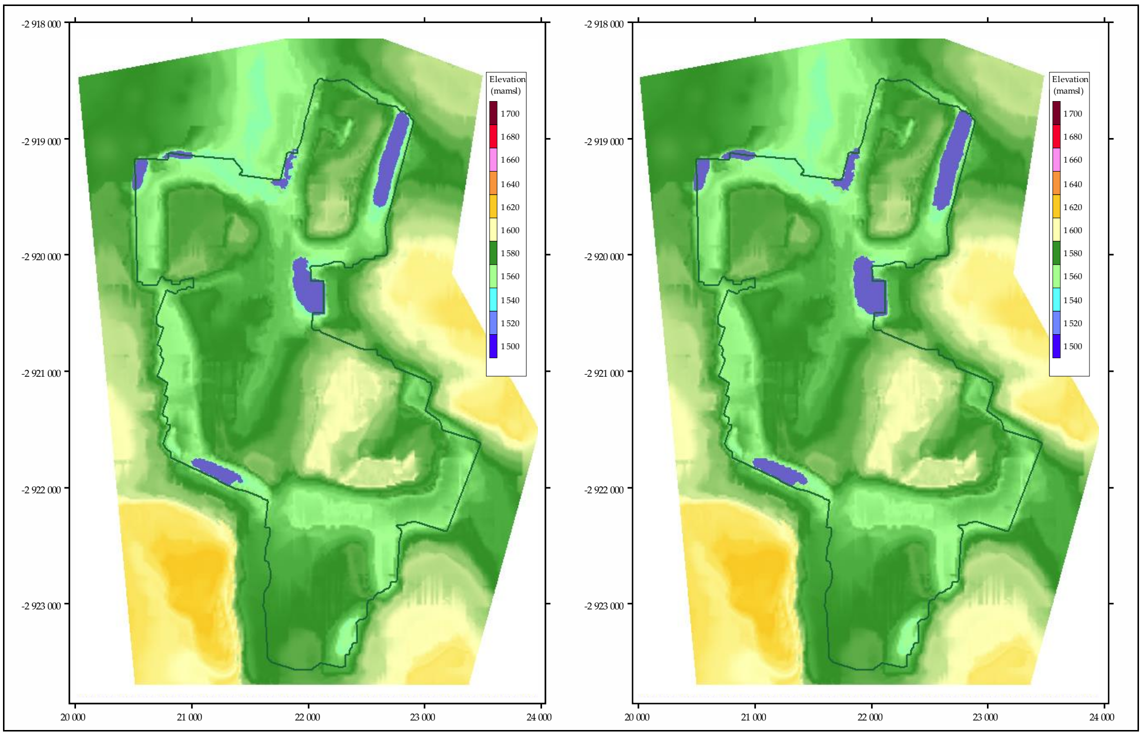


Figure 9 Recorded sulfate concentration at the colliery

CONCLUSION & RECOMMENDATIONS

To evaporate the excess water in the boundary of the opencast, three options may be considered:

1. Lower the current rehabilitated surface of the opencast, or at least some parts thereof in such a way that the flooded area at management level (1 550 mamsl) is 100 ha in size.
2. Raise the decant height to an elevation of 1 565 mamsl, a berm needs to be constructed at the northern part of the opencast allowing the water level to rise to 1 561 mamsl without the possibility of decanting. The berm needed will have to be 2.1 km long and 10 m high at places.

3. 

4. **Figure 7** rightmost picture shows the partly flooded surface of the opencast pit with the position of the dyke displayed in magenta.
5. A combination of the above options.

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