Water balance and cost evaluation for different scenarios of impermeable covers (raincoats) in heap leach pad operations

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Abstract

Currently, some mining operations which use heap leaching technology and are located in rainy regions use impermeable covers or raincoats on the top of the ore heap to reduce the amount of rainwater that gets into the heap. The raincoats are also used in those areas of the heap still under irrigation. Various experiences of heap leach pads on an industrial scale indicate that the entrance of rainwater into the system causes solution dilution, making metal recovery less efficient. It also produces surplus contaminated water that requires recirculation or treatment before it can be discharged into the environment. These two issues cause significant additional costs.

This paper presents an analysis of two different scenarios involving raincoat placement in heap leach pads. The first case is in a high precipitation tropical region in northern Brazil, where copper ore is processed; the second case is in a mountain range in the Andes in southern Peru, where gold is recovered. The water balance was developed considering differences in percentage of raincoats, treatment plant capacity, stormwater pond capacity, and raincoat pond capacity. The water balance results allowed researchers to determine, on a monthly basis, the operating flows to be stored in the stormwater pond and the flows which had to be purged out of the system and therefore had to be treated before they could be discharged into natural streams. The paper also presents a comparative analysis of capital expenditure (Capex) and operating expenditure (Opex) of different scenarios in the two cases. The cost evaluation indicates that the use of a larger quantity of raincoats reduces the total cost for the operating life of the heap leaching facilities, with significant savings to the project.

Introduction

Some years ago, the use of impermeable covers or raincoats in heap leach pad operations located in high precipitation areas was restricted to minimum areas of the heap for cost reasons; however, experience indicates that as the raincoat installation minimizes the entrance of rainwater into the system, long-term operating costs reduction are achieved. Moreover, raincoats offer an economic and efficient way to divert rainwater flow to a raincoat pond and finally discharge it into the environment without previous treatment, reducing process solution dilution, stormwater pond capacity, treatment plant size, and water treatment cost.

Two cases were analyzed for water balance simulation: the first is a copper heap leach pad located in northern Brazil; while the second is a gold heap leach pad in southern Peru. Both are in high precipitation regions. The hydrology in each region was evaluated based on precipitation and evaporation data from nearby weather stations. Water balance refers to the interconnections among the heap leach pad, the pregnant leach solution (PLS) pond, the intermediate leach solution (ILS) pond if any, the stormwater pond, and the raincoat pond.

Hydrology

Basic information was gathered from nearby weather stations through the Brazilian National Water Agency (ANA, in Portuguese) and the Peruvian Meteorology and Hydrology National Service (SENAMHI, in Spanish).

Precipitation and evaporation

Visual inspection of available precipitation and evaporation data allowed researchers to use a consistency analysis of jumps and trends, which determined that weather station records used had uniform distribution and consistent data. Tables 1 and 2 show monthly average precipitation and evaporation for each analyzed case.

Table 1: Total monthly precipitation (mm)

Month	First case				Second case			
	Max.	Aver.	Min.	% Annual	Max.	Aver.	Min.	% Annual
Jan	414.5	237.4	104.2	14%	511.5	219.7	7.7	23%
Feb	440.2	269.0	152.7	16%	406.4	220.2	81.5	23%
Mar	510.2	280.9	141.7	17%	461.5	200.6	0.0	21%
Apr	608.2	219.5	38.6	13%	301.3	66.7	0.0	7%
May	271.5	114.1	0.0	7%	79.4	15.4	0.0	2%
Jun	101.0	24.9	0.0	1%	47.4	5.9	0.0	1%
Jul	154.7	20.0	0.0	1%	62.8	7.8	0.0	1%
Aug	86.4	24.1	0.0	1%	198.7	17.8	0.0	2%
Sep	131.5	54.2	3.6	3%	75.6	20.8	0.0	2%
Oct	249.0	110.7	3.7	7%	133.3	31.9	0.0	3%
Nov	249.7	139.8	34.2	8%	313.4	44.2	0.0	5%
Dec	495.9	197.3	69.1	12%	279.5	98.7	0.0	10%
Total	**2,415.4***	**1,691.9**	**1,057.8***	**100%**	**1,603***	**950**	**455***	**100%**

*Total annual maximum and minimum precipitation is an annual historical record and is not obtained by adding the maximum values of each single month

Table 2: Total monthly evaporation (mm)

Month	First case				Second case			
	Max.	Aver.	Min.	% Annual	Max.	Aver.	Min.	% Annual
Jan	161.2	130.7	90.6	14%	196.9	93.6	34.8	7%
Feb	158.3	125.3	93.3	16%	121.2	66.8	15.0	5%
Mar	151.1	119.8	99.4	17%	125.0	71.3	23.2	5%
Apr	219.1	134.4	38.7	13%	175.9	92.7	16.9	6%
May	155.1	110.0	73.5	7%	217.0	123.6	32.0	9%
Jun	148.9	124.9	100.2	1%	260.2	131.8	41.1	9%
Jul	207.0	164.7	129.4	1%	259.2	141.1	0.0	10%
Aug	244.7	193.4	137.1	1%	247.6	141.3	0.0	10%
Sep	249.3	194.1	165.0	3%	265.5	136.6	0.0	10%
Oct	206.6	166.6	127.2	7%	246.5	146.2	59.0	10%
Nov	148.4	119.0	100.9	8%	214.9	134.1	36.9	10%
Dec	240.4	142.5	83.0	12%	179.1	121	63.2	9%
Total	**1,939.1***	**1,725.3**	**1,454.5***	**100%**	**2,347.2***	**1,400**	**817.5**	**100%**

*Total annual maximum and minimum evaporation is an annual historical record and is not obtained by adding the maximum values of each single month

Generated series

Precipitation and evaporation series with lengthy records of the analyzed cases were implemented for water balance. Synthetic series were obtained using the index sequential method (ISM). Figure 1 shows the variation of total monthly precipitation and evaporation for the first and second case.

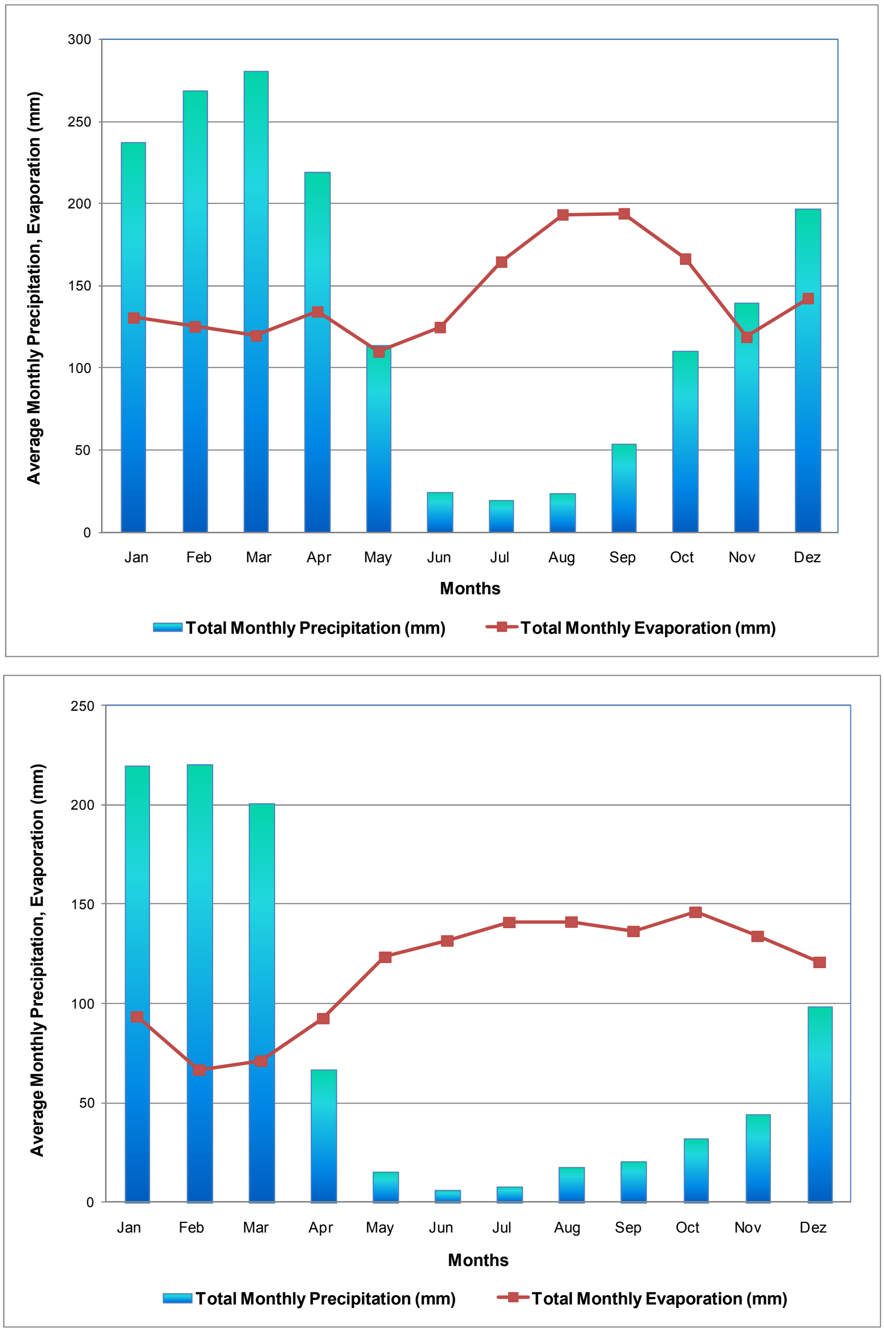


Figure 1: Total monthly precipitation and evaporation (mm) (first case above; second case below)

Extreme hydrological events

The maximum precipitation evaluation was performed based on extreme events at representative weather stations of each analyzed case. Data on maximum precipitation in a 24-hour period were fit to several probabilistic models. Based on various statistical indexes and hydrological criteria, the generalized extreme value index (GEVI) distribution was selected to provide uniform criteria because it presented the best indexes, according to the Kolmogorov-Smirnov goodness-of-fit test. Table 3 shows the maximum precipitation in a 24-hour period for different return periods of the analyzed cases.

Table 3: Maximum precipitation frequency in 24 hours (mm)

Return period	2 years	5 years	10 years	25 years	50 years	100 years	500 years
First case	95.8	119.5	135.2	155.1	169.8	184.5	218.3
Second case	30.3	39.9	46.3	54.4	60.4	66.3	80.0

Water balance

Water balance description

As with any other water balance model, the water balance was developed using a spreadsheet based on the following equation:

Inflow − Outflow = Storage change

Inflow comes from precipitation falling over the heap leach pad area and from fresh water for reposition. Outflow (discharge) corresponds to pad evaporation (from active areas under leaching, inactive areas, and losses due to heap irrigation), pond evaporation, and excess outflow of the pad-pond system previous to effluent treatment (detoxification).

Changes in storage capacity are associated with changes in the moisture content stored in ore voids and pond water level fluctuation. Recirculation flows between ponds (PLS, ILS, barren, raffinate, or stormwater) and the heap leaching area are considered as internal flow (do not generate inflow or outflow). The use of raincoats will minimize water entry into the system.

Parameters and simulation criteria

The water balance model depends on the ore production plan, the stacking plan in the heap, the raincoat installation area, ore properties, irrigation type, precipitation, evaporation, the size of the ponds, and their initial storage capacity. As water balance is a function of plant operation conditions, results obtained are directly related to operational parameters introduced in the model and are susceptible to changes. Table 4 presents parameters related to the conditions mentioned above.

In the two cases, use of a raincoat system has been considered. This offers an effective and economic way to separate and deviate rainwater flow to the raincoat pond, where water will be monitored for contamination and then discharged into natural streams or deviated to the stormwater pond in case non-permissible contamination levels are found. This minimizes process solution dilution, reduces stormwater pond storage, and diminishes water treatment cost.

Table 4: Parameters and design criteria

Parameter	Unit	First case	Second case
Daily production rate	t/day	9,400 to 16,000	4,500 to 8,500
Phases 1, 2, and 3 capacity	Mt	8.4 – 26.1 – 35.5	6.4 – 9.0 – 13.7
Phases 1, 2, and 3 extension	Ha	26.8 – 48.2 – 54.7	21.7 – 13.2 – 13.3
Operation period	months	156	118
Ore moist density	t/m^3	1.45	1.53
Application rate	$l/h/m^2$	10	12
Draindown time	hours	12	24
Typical lift thickness	m	5,2	8
Leach cycle	days	120	120
PLS pond capacity	m^3	19,120	15,000
Raffinate pond capacity	m^3	17,000	–
ILS pond capacity	m^3	–	15,000
Stormwater pond capacity	m^3	tbd	tbd
Initial ore moisture	%	19	5
Residual moisture content	%	25.6	7
Absorption, moisture retention	%	6.6	2
Evaporation factor of ponds	–	0.9	0.7
Evaporation factor of leaching area	–	0.65	0.5
Evaporation factor of non-leaching area	–	0.05 – 0.30	0.25
Irrigation losses	%	0.1	1
Raincoat coverage	%	30, 50, and 80	30, 50, and 80
Initial month of simulation	–	January 2016	January 2014

Water balance scenarios

There are four possible water balance scenarios represented. Scenario 1, the base case, consists of the heap leach pad without raincoat coverage, while scenarios 2, 3, and 4 involve placing raincoats on a varying percentage of the heap leach pad area: 30%, 50%, and 80%, respectively.

Pond sizing

The storage capacity of the pregnant leach solution (PLS) pond depends on leaching operating conditions. The stormwater and raincoat ponds were sized taking into account the following considerations:

- Stormwater pond. This pond was sized considering the largest volume for maximum precipitation contingency, determined for the most unfavorable monthly sequence in wet seasons, considering stormwater and raincoat ponds.
- Raincoat pond. This pond was sized considering scenarios 2, 3, and 4 (i.e., 30%, 50%, and 80% of total heap area covered by raincoats), with a raincoat efficiency of 90% (due to its exposure to rips and other defects during heap operation), a design storm event, and 2-hour periodic monitoring.

Contingency volume for extreme storms has been established according to inferred criteria (Van Zyl et al., 1988). Van Zyl et al. list two criteria: adding 24-hour and 100-year return period storm volume to volume fluctuations of an average year, and using water balance evaluations of historical records or total monthly precipitation and evaporation synthetics records. This last criterion was implemented due to existing lengthy records, which have led researchers to carry out a series of water balance simulations. In wet weather this criteria is the most critical.

The analysis also included breakdown or malfunction contingency duration (12- or 24-hour draindown; see Table 4) considered as acceptable and conservative, given the operation capability for responding and restoring operations in each case.

Water balance results

The evaluations were performed for the following maximum, average, and minimum variable values:

- operation and contingency total maximum volume;
- fresh water demand; and
- water discharge needs of pad-ponds system.

Because heap leach pads rise gradually, results depend on heap leach pad size from initial to final configuration. The total estimated storage for simulation scenarios is limited by the capacity of PLS and stormwater ponds. Table 5 shows the water balance storage volumes based on the most critical hydrological situation for each case being analyzed.

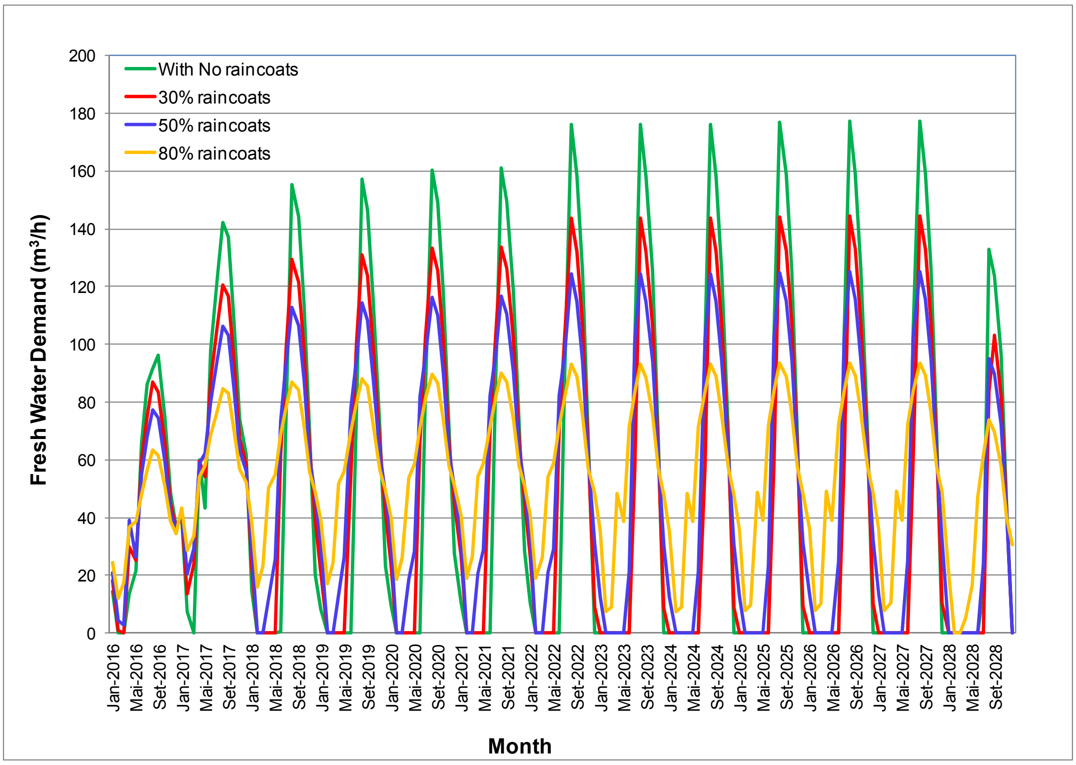
Table 5: Total storage volume in water balance (m^3)

Scenario	First case		Second case	
	Operation volume + contingency	Stormwater pond volume	Operation volume + contingency	Stormwater pond volume
No raincoats	205,240	150,000	129,003	105,000
30% of raincoats	205,240	150,000	124,003	100,000
50% of raincoats	155,240	100,000	115,564	95,000
80% of raincoats	130,240	75,000	100,129	85,000

The demand for fresh water for a proper heap leach pad operation decreases as the percentage of raincoats over the heap increases, because of existing high evaporation in the areas under study. This trend is generated because the raincoats limit water losses from evaporation and the entrance of rainwater into the system. Larger water demands occur in the dry season. This explains why, during years with low precipitation, rainwater captured in the leach pad is not enough to maintain operations during the dry season of that year. Table 6 shows fresh water demands for the system in dry season, considered as the most critical hydrological situation. Figure 2 shows the time variation of the maximum fresh water demand for each scenario simulated, for both analyzed cases.

Table 6: Fresh water demands (m^3/h)

Scenario	First case			Second case		
	Max.	Aver.	Min.	Max.	Aver.	Min.
No raincoats	177.2	119.9	52.7	59.4	14.7	0.0
30% of raincoats	144.6	98.0	51.3	46.4	11.1	0.0
50% of raincoats	125.0	97.5	60.4	38.9	11.0	0.0
80% of raincoats	93.6	78.2	60.3	25.3	15.3	0.0



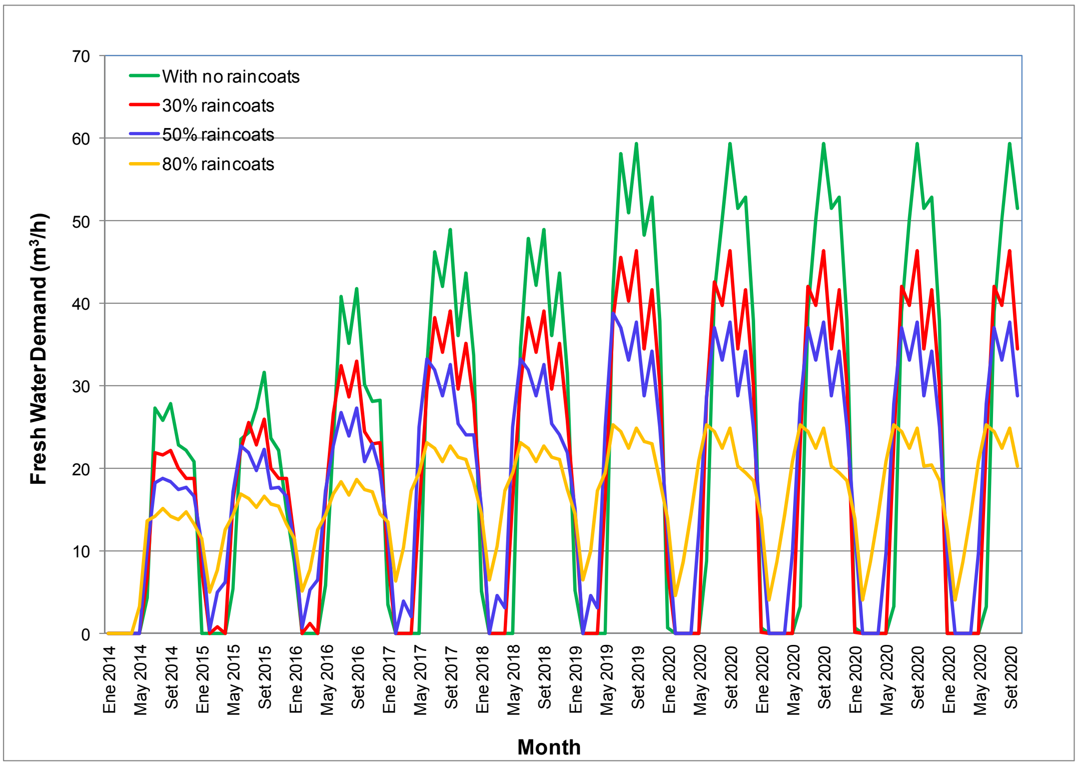


Figure 2: Maximum fresh water demand (first case above; second case below)

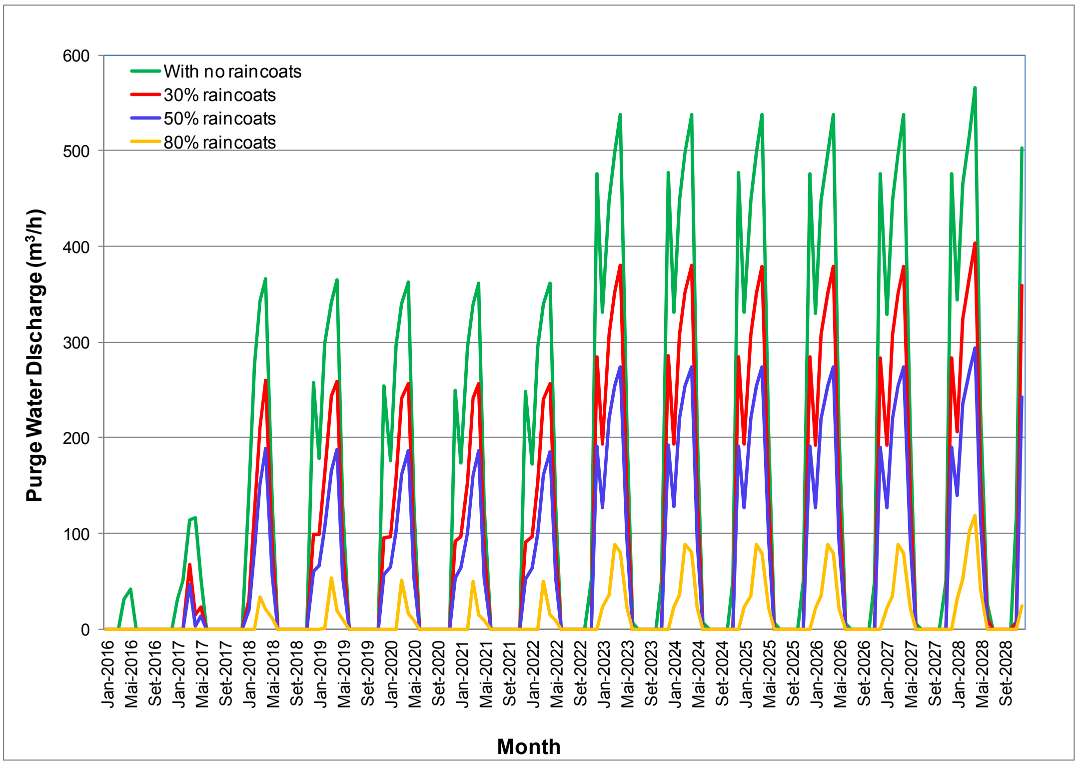
Purge water discharges estimated in the water balance show an increment each year as stacking of the heap leach pads increases. Water discharges from the stormwater pond determine the capacity of the contaminated water treatment plant. This is because, at the beginning of heap leach pad operations, the required capacity for the treatment plant is low; as the volume of the heap leach pad increases, it requires a larger plant capacity. Tables 7 and 8 show purge water discharges of water balance for each simulated scenario, for both analyzed cases. Figure 3 shows the maximum purge water discharges time variation for each simulated scenario for both analyzed cases.

Table 7: Purge water discharges (m^3/h) – first case

Year	No raincoats			30% of raincoats			50% of raincoats			80% of raincoats		
	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.
1	41.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	116.9	0.0	0.0	66.9	0.0	0.0	46.6	0.0	0.0	0.0	0.0	0.0
3	366.1	123.9	0.0	260.1	36.9	0.0	189.4	13.3	0.0	33.8	0.0	0.0
4	364.5	125.5	0.0	258.8	60.9	0.0	188.3	28.7	0.0	53.3	0.0	0.0
5	362.2	123.8	0.0	256.8	58.7	0.0	186.6	21.6	0.0	51.3	0.0	0.0
6	361.5	123.1	0.0	256.2	58.1	0.0	186.0	15.9	0.0	49.8	0.0	0.0
7	476.5	122.9	0.0	284.9	57.9	0.0	191.6	15.0	0.0	49.4	0.0	0.0
8	538.3	216.4	59.9	379.9	133.2	7.8	274.4	88.5	0.0	89.1	0.0	0.0
9	538.2	216.7	59.9	379.9	133.2	7.8	274.3	88.5	0.0	89.0	0.0	0.0
10	537.8	215.9	59.6	379.5	132.9	7.7	274.0	88.2	0.0	88.8	0.0	0.0
11	537.4	214.1	59.3	379.2	132.6	7.5	273.7	87.1	0.0	88.6	0.0	0.0
12	537.3	213.8	59.1	379.1	132.5	7.4	273.6	86.2	0.0	88.5	0.0	0.0
13	566.1	247.8	84.1	403.1	150.0	20.8	294.4	103.9	6.6	118.5	0.0	0.0

Table 8: Purge water discharges (m^3/h) – second case

Year	No raincoats			30% of raincoats			50% of raincoats			80% of raincoats		
	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.
1	96.3	14.4	0.0	36.0	2.4	0.0	10.2	0.2	0.0	0.0	0.0	0.0
2	106.5	19.4	0.0	75.8	6.9	0.0	23.2	1.5	0.0	0.0	0.0	0.0
3	108.8	16.1	0.0	64.4	4.4	0.0	35.5	1.0	0.0	0.0	0.0	0.0
4	189.0	50.3	0.0	122.2	25.0	0.0	87.5	7.3	0.0	0.0	0.0	0.0
5	188.0	43.7	0.0	122.0	17.4	0.0	84.0	5.4	0.0	0.0	0.0	0.0
6	188.0	45.0	0.0	122.0	19.1	0.0	84.0	5.7	0.0	0.0	0.0	0.0
7	268.8	82.2	0.0	177.4	45.5	0.0	124.7	21.0	0.0	0.0	0.0	0.0
8	268.8	84.6	0.0	188.6	47.3	0.0	124.7	22.0	0.0	0.0	0.0	0.0
9	268.8	87.3	0.0	188.6	50.6	0.0	124.7	23.5	0.0	0.0	0.0	0.0
10	268.8	81.6	0.0	188.6	45.7	0.0	124.7	21.7	0.0	0.0	0.0	0.0



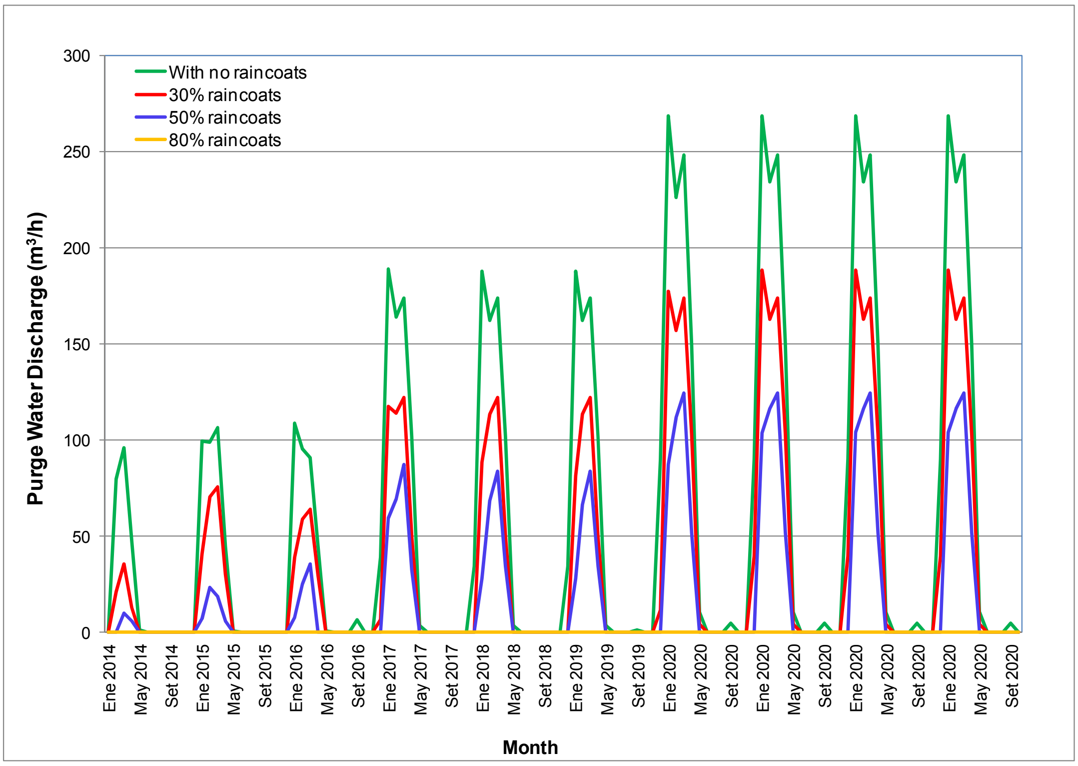


Figure 3: Maximum purge water discharges
(first case above; second case below)

The stored volume in the raincoat pond is estimated considering a design storm for a 100-year return period, a heap leach pad covered area, and raincoat efficiency of 90%. Raincoat pond volume has a discharge time of two hours before monitoring. Table 9 shows raincoat pond storage capacities for each simulated scenario, for both analyzed cases.

In summary, the heap leach pads' water balance shows relationships between stored volumes in stormwater and raincoat ponds and water treatment (detoxification) plant capacity for the simulated scenarios. This is illustrated in Table 10.

Table 9: Raincoat pond stored volume (m³)

Scenario	First case	Second case
No raincoats	–	–
30% of raincoats	25,000	8,000
50% of raincoats	35,000	13,000
80% of raincoats	55,000	20,000

Table 10: Water balance summary

Scenario	First case			Second case		
	Stormwater pond volume (m^3)	Raincoat pond volume (m^3)	Treatment plant capacity (m^3/h)	Stormwater pond volume (m^3)	Raincoat pond volume (m^3)	Treatment plant capacity (m^3/h)
No raincoats	150,000	–	500	105,000	–	250
30% of raincoats	150,000	20,800	400	100,000	8,000	150
50% of raincoats	100,000	34,600	300	95,000	13,000	100
80% of raincoats	75,000	55,300	100	85,000	20,000	–

Cost evaluation

The water balance was analyzed considering four scenarios (see Table 9). According to the obtained results, Capex and Opex were estimated for each scenario. The following aspects were considered:

- Stormwater and raincoat ponds construction cost, which was considered as Capex.
- Raincoat system per year. This corresponds to geomembrane used as raincoat as Opex. We assumed that 30% of geomembrane can be reused or recovered.
- Treatment plant per stages. The year when it needs to be acquired is indicated in Tables 7 and 8. In Year 1, plant cost corresponds to Capex; if the plant is acquired afterwards, it is considered a sustaining capital cost.
- Discharge volume is estimated per year according to Tables 7 and 8.

- For the first case (copper process), the estimated treatment cost was US\$ 2.5/m^3 and the treatment plant cost of 100 m^3/h has been estimated at US\$ 10 million.
- For the second case (gold process), the estimated treatment was US\$ 3.0/m^3 and the treatment plant cost of 100 m^3/h has been estimated at US\$ 2 million.
- Tables 11 and 12 show estimated costs (Capex + Opex) for average purge water discharges for each simulated scenario, for both analyzed cases.

Table 11: Estimated costs – first case

Description	No raincoats (US$)	30% of raincoats (US$)	50% of raincoats (US$)	80% of raincoats (US$)
Stormwater pond	871,693.9	871,693.9	444,262.5	384,521.4
Earthworks	476,594	476,594	254,812	224,321
Geosynthetics	395,100	395,100	189,450	160,200
Raincoat pond	0	196,277.8	275,844.4	473,246.2
Earthworks	0	154,428	210,144	368,981
Geosynthetics	0	41,850	65,700	104,265
Raincoat system	0	760,099	1,261,082	2,017,731
Year 1	0	271,496	452,494	723,990
Year 2	0	139,516	232,526	372,042
Year 3	0	69,014	115,024	184,038
Year 4	0	6,140	10,234	16,374
Year 5	0	5,972	9,954	15,926
Year 6	0	7,787	12,978	20,765
Year 7	0	233,218	388,696	621,914
Year 8	0	2,201	3,668	5,869
Year 9	0	2,940	4,900	7,840
Year 10	0	3,385	5,642	9,027
Year 11	0	5,922	9,870	15,792
Year 12	0	7,678	12,796	20,474
Year 13	0	4,830	2,300	3,680
Treatment plant and discharge volumes	65,552,735	44,394,095	32,288,795	10,000,000
Year 1	10,000,000	5,000,000	5,000,000	0
Year 2	25,000,000	20,000,000	15,000,000	0
Year 3	416,973	112,863	24,818	0
Year 4	505,534	157,272	66,878	0
Year 5	488,493	150,272	50,926	0
Year 6	472,877	148,040	39,517	0
Year 7	21,469,404	15,147,493	10,037,571	10,000,000
Year 8	1,167,100	590,224	326,889	0
Year 9	1,167,687	590,287	327,018	0
Year 10	1,163,536	5,873,629	324,882	0
Year 11	1,156,926	583,629	320,452	0
Year 12	1,153,575	582,024	317,633	0
Year 13	1,390,630	744,739	452,212	0
Total cost	**66,424,429**	**46,222,166**	**34,269,984**	**12,875,499**

Table 12: Estimated costs – second case

Description	No raincoats (US$)	30% of raincoats (US$)	50% of raincoats (US$)	80% of raincoats (US$)
Stormwater pond	2,047,752	1,857,689	1,848,618	1,840,965
Earthworks	1,889,965	1,700,660	1,692,394	1,686,427
Geosynthetics	157,787	157,029	156,224	154,538
Raincoat pond	0	422,700	463,688	499,126
Earthworks	0	404,623	423,966	451,345
Geosynthetics	0	18,077	39,721	47,781
Raincoat system	0	528,606	881,010	1,409,616
Year 1	0	193,635	322,725	516,360
Year 2	0	21,762	36,270	58,032
Year 3	0	123,201	205,335	328,536
Year 4	0	19,890	33,150	53,040
Year 5	0	9,302	15,503	24,804
Year 6	0	120,920	210,533	322,452
Year 7	0	39,897	66,495	106,392
Year 8	0	0	0	0
Year 9	0	0	0	0
Year 10	0	0	0	0
Treatment plant and discharge volumes	7,800,689	4,297,942	2,500,283	0
Year 1	2,047,573	7,426	761	0
Year 2	91,009	2,031,364	5,440	0
Year 3	2,089,555	23,689	2,004,517	0
Year 4	266,325	114,350	31,317	0
Year 5	1,217,854	84,419	25,626	0
Year 6	227,901	1,088,016	26,060	0
Year 7	454,861	229,563	94,448	0
Year 8	469,858	238,195	102,871	0
Year 9	477,817	245,532	106,243	0
Year 10	457,936	235,389	103,000	0
Total cost	**9,848,441**	**7,106,937**	**5,693,599**	**3,749,707**

Table 13: Total cost summary (US$)

Scenario	First case	Second case
No raincoats	66,424,429	9,848,441
30% of raincoats	46,222,166	7,106,937
50% of raincoats	34,269,984	5,693,599
80% of raincoats	12,875,499	3,749,707

Conclusions

- Fresh water entrance is required every month, even in wet year conditions.
- Earthworks and geosynthetics costs for pond construction (stormwater and raincoat) are very low compared with operating costs.
- The higher the raincoat coverage in the heap, the lower the total project cost (Capex + Opex).
- If water treatment or plant costs are higher than those considered in analysis, the differences between scenarios would be even higher; the best option would always be to cover as large a heap area as possible.

Recommendations

- The water volume in ponds should be kept as low as possible, and the entrance of fresh water should be regulated based on additional rainwater volume. This common practice in the mining industry has been one of the assumptions of this model.
- In heap leaching projects located in rainy regions, the use of raincoats is strongly recommended to minimize process solution dilution, reduce the need for stormwater pond storage and thereby the size of storage ponds, reduce treatment plant size, and reduce water treatment cost.

References

Van Zyl, D.J.A., Hutchinson, I. and Kiel, J. (1988) *Introduction to evaluation, design and operation of precious metal heap leaching projects.* Littleton, Colorado: Society of Mining Engineers, Inc., pp. 352−353.

Bibliography

Bell, F.C. (1969) Generalized rainfall-duration-frequency relationships. *J. Hydraul Div. ASCE, 95*(1), pp. 311−327.

Chow, V.T., Maidment, D.R. and Ways, L.W. (1994) *Hidrología aplicada*. Bogotá: McGraw-Hill Interamericana.

Linsley, R.K.E., Kohler, M.A. and Paulhus, J.L.H.P. (1977) *Hidrologia para ingenieros*. Bogotá: McGraw-Hill Interamericana.