Evaluation of pit lake formation in choghart iron mine of Iran by using simulation approach

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Abstract: After mine closure, open pit mined can be converted to a pit lake under special circumstances, depending on the slope stability, hydrology, climate conditions and water quality. In Choghart open pit iron mine, pit will be extended approximately 280 meters below the existing water table. With regard to ground water inflow, a lake will be formed after mine closure. In order to evaluate future open pit lake level in Ghoghart open pit, a mass balance model has been developed. Analysis of data gathered from mine site, available reports and literatures showed that pit lake will reach to its final depth of approximately 230 meters from pit bottom and it takes about 17 years after mine closure to reach 82% of its pre-mining elevation. By that time, final volume of water in pit will be about 57×10^6 m^3. Under these conditions, ground water would flow towards the pit lake in all directions and water in the lake would not recharge the aquifer system.

  Keywords: Surface mining, environmental assessment, environmental components, impacting factors.

Introduction

Choghart Iron mine is located at 12 km north-eastern of Bafgh city and 125 km south-eastern of Yazd province of Iran. Yazd itself is located at 677 km of south-eastern of Tehran (Figure 1) (CIOCB, 2002). The region has a continental climate which means it is hot and dry in summer days and cools at night. During the year the temperature ranges between -7 in winter to +47 degrees centigrade in summer. The precipitation is concentrated on the winter-spring period with the average annual precipitation of 55.7mm. The relative humidity is ranged from 13% to 100% at 39.8 ^{o}C and 19.5 ^{o}C respectively and minimum relative humidity is 11%. Besides scanty growth of grass, the main vegetation type along the river courses is reported to be Thorn-Bushes and Gaz trees (EBE, 1990).

Conventional open pit mining method is used to extract 134 million tones of reserve at the rate of 3 million tones per year. The overall pit slope angle is ranged between 48 to 53 degrees, depending on the rock mass characteristics. The initial open pit mine was developed at an elevation of 1,286 m above mean sea level (150 meter from surrounding regions) in 1971 and will be continued down to the elevation of 812.5m. Extraction process begins with drilling and blasting and continues with shovel loading and truck transporting out of the pit to the primary crusher. In 1995 pit has reached the water table at the elevation of 1096m. After that, mining of the pit has been associated with pit dewatering. According to the present plans, mining activities will cease in about 30 years. By that time a pit lake will be developed and water level in pit will rise in response to ground water inflows, storm runoff and direct precipitation.

Open pit mines which intersect ground water and develop pit lakes, present a specific environment in which many of the chemical reactions that are normally occurring, accelerated. If sulphide bearing materials (pyrite) are exposed above the pit lake elevation, the sulphide bearing materials in the pit wall will be weathered and the lake will continue to receive acidic seeps, especially during storms. The reaction which results in formation of acid in sulfide bearing material can be stated as follows:

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$$FeSo_4 + H_2O + 7/2O_2 \longrightarrow Fe^{2+} + 2H^+ + 2SO_4^{2-}$$

$$FeS_2 + 8H_2O + 14Fe^{3+} \longrightarrow 15Fe^{2+} + 16H^+ + 2SO_4^{2-}$$

As is cleared from above reactions, Oxygen is a component for sulphide oxidation; therefore, limiting the amount of Oxygen can be effective to suppress sulphide mineral oxidation. When sulphide mineral in pit walls are exposed to both wet and dry periods, optimal Oxygen flux is obtained while also providing water for the maximum rate of oxidation. Covering sulphide minerals with water results in limiting the amount of oxygen available which itself leads to suppression of sulphide mineral oxidation, though not necessarily eliminated (Mayer, *et al*., 1997). Also it may be possible that pit lake water elevation exceeds the surrounding ground water table elevation and hydraulic gradient reversed causing to water migration of acidic pit water into ground water.

Thus, this research is aimed at evaluation of the pit lake formation of Choghart Iron mine and determination of final elevation of water in pit by developing a water balance model.


Figure 1- Choghart Iron mine location.

Open Pit Water Bbalance Model

A water balance model is an accounting for the volume of flow rate of the water from all possible locations. Since density is constant it can be interpreted as a mass balance model. In this study a mass balance approach was performed for calculating the temporal variation of Choghart open pit lake levels and considered flow from several sources. Figure 2 is showing a conceptual model of water budget in Choghart Iron mine of Iran.

The following describes the physical character of open pit and description of each of the hydrological components which are used in the water balance model (Linsley & Fronzini,1979):

    1- Precipitation.
    2- Evaporation.
    3- Surface water inflow.
    4-Surface water outflow
    5- Ground water inflow.
    6- Open pit geometry.
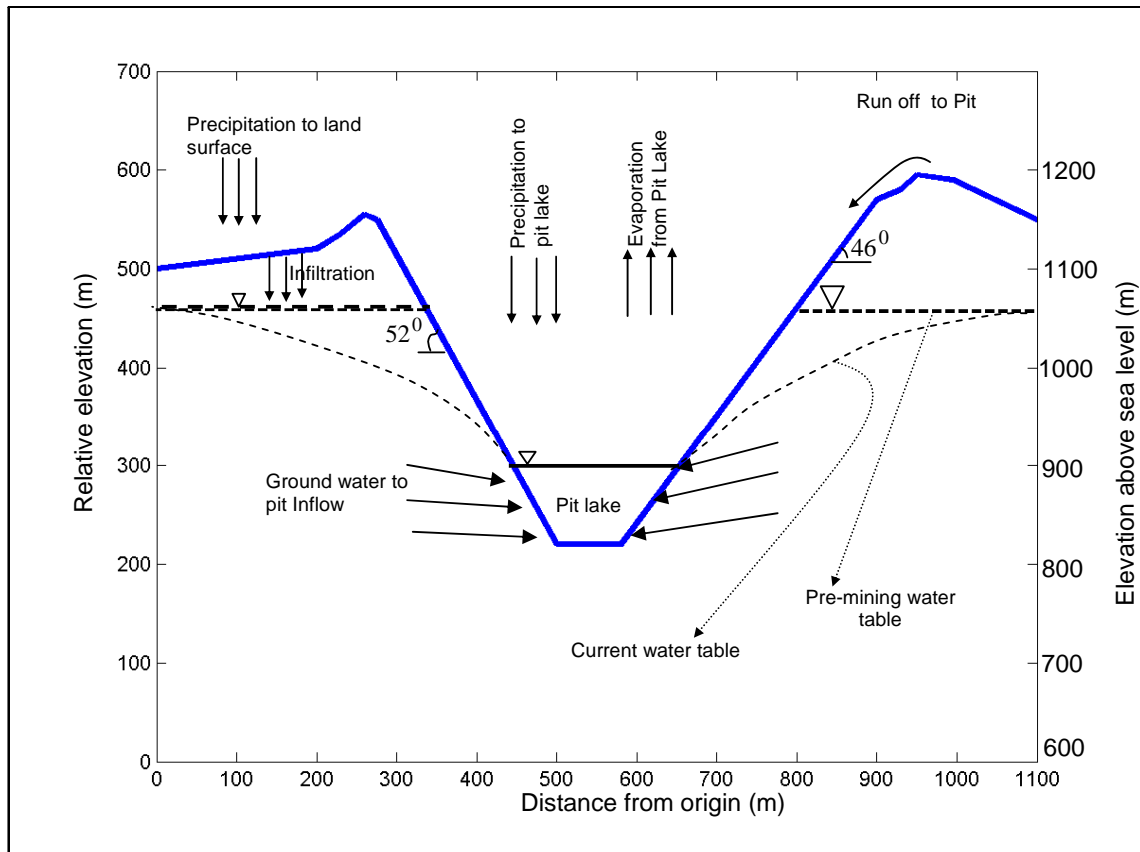
Figure 2- Conceptual model of water balance model in Choghart open pit mine.

In this water balance model, monthly time step was chosen to calculate the changes in volume of the pit lake.

The change in water storage in the open pit at every time step can be defined by the following relationship:

Change in water storage= water inputs – water outputs   (1)

A mass balance equation for pit lake evaluation is (Wanielista *et al*, 1997):

$$\Delta S = P + R + B - E - O \qquad\qquad (2)$$

Where:

ΔS : Changes in storage volume.

P: Direct precipitation reception.

R: Surface water inflow.

B: Ground water flow.

E: Free surface evaporation.

O- Surface water out flow

In the water budget, volumes are measured in units of cubic meters, litters, cubic feet, gallons or inches and centimetres over the watershed area. A common way to express quantities of surface waters is volume per unit time.

Before filling the pit, *O* is zero. *B* can be positive or negative depending upon the level of pit lake relative to the surrounding ground water table. During the early period after mine closure *B* is positive (a net inflow of ground water), where as if the pit lake level raises above

the surrounding ground water table, there is a net ground water outflow from the pit and *B* is negative. It should be noted that the *P, R* and *E* are directly influenced by the surface area of the pit lake.

Precipitation

Precipitation input in this model are expressed by average monthly precipitations (AMP), which obtained based on report presented by Kavoshgaran consultant company from 1997 to 1999 (Kavoshgaran, 1993) and data gathered from regional meteorological information and site characteristics conditions from 1999 up to 2004 (Table 1).

The total annual precipitation in this region is scarce as shown in Table 1. The lowest precipitation belongs to months of June, August and September with the same value of zero and the highest value belongs to January with 14.8mm. The average monthly precipitation is about 5.3mm. Also a 100-year, 24-hours storm event of 50mm was arbitrarily inserted into the analysis in order to take account of uncertainty associated with the meteorological data.

Table 1. Average monthly precipitation in Choghart Iron mine of Iran from 1999 to 2004.

Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Ave.	May	Jun.	Jul.	Aug.	Sep.
AMP(mm)	1.5	1.1	6.8	14.8	13.4	7.9	12.9	4.5	0	0.4	0	0

Precipitation values are added to the open pit water body surface in each time step. These applied over the open pit lake area as measured from the open pit geometry and pit lake level and vary with time.

Evaporation

Evaporation is the sum total of water returned to the atmosphere from surface and ground water, ice and snow. Data gathered from the mine region are used for initial conditions and adjusted down to account for in pit effects (e.g. lower wind speed, higher relative humidity and less solar radiation). The quantity of water lost to the atmosphere via evaporation is proportional to the area of the pit lake and varies with time. As indicated in Table 2, total annual evaporation in this region is very high. The lowest evaporation value belongs to January with 114mm and highest evaporation value belongs to July with 608mm. The average monthly evaporation is about 333mm.

Table 2. Average monthly evaporation in Choghart Iron mine of Iran from 1999 to 2004.

Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Ave.	May	Jun.	Jul.	Aug.	Sep.
AME(mm)	276	176	131	114	149	232	326	437	60	608	555	429

Surface Water Inflow

Surface water inflow (runoff) is the amount of rainfall which is available for discharge. This has two components: runoff from the pit wall within pit perimeter and above the pit lake level and runoff from the catchments area tributary of the open pit. Pit wall area that generates interflow is equal to the pit rim minus the water surface area at any time step. The amount of surface water inflow to the pit depends on rain fall volume and storage volume on and within the soil. Runoff is estimated using the Soil Conservation Service (SCS) curve number method. According to this method runoff can be estimated using the following equations (Wanielista *et al*, 1997):

For $P > 0.2S' \longrightarrow$ $$R = \frac{(P - 0.2S')^2}{P + 0.8S'}$$ (3)

For $P \leq 0.2S'$ $\longrightarrow$ $\qquad\qquad$ $R = 0$ $\hfill$ (4)

Where:

P: Rain fall volume.

S': Storage volume (initial abstraction plus infiltration) at saturation conditions in terms of millimetres which can be obtained using the following equation:

$$S' = \frac{25400}{CN} - 254$$ $\hfill$ (5)

Where:

CN: Runoff curve number.

$\qquad$ Curve number depends on the type of the soil, land use and antecedent moisture condition (AMC) and is ranged from 0 to 100. Higher CN causes higher runoff. It should be noted that curve number is higher for the Choghart pit walls since no vegetation existed and negligible soil development will occur. The exact area over which the pit runoff occurs is determined from the open pit geometry and the pit lake level and varies with time.

Surface Water Outflow

$\qquad$ If open pit reaches its overflow elevation, then the water is allowed to overflow from the pit at the rate equal to the net open pit inflow.

Ground Water Flow

$\qquad$ According to investigations which were done in 1976 (CIOCB, 2002) and observations during this study, the elevation of water table in this region is estimated 1096m above mean sea level within a metasomatite bed rock aquifer. Due to the extensive disturbed rock zones, blasting and faults the ground water flow near the pit can be considered as porous type flow. Ground water flow to the pit was estimated to be a major component of the pit lake water balance. This component was estimated in this study using an analytical solution for a large well based on the Depuit equation for radial steady state flow to a well fully penetrating an unconfined aquifer. The calculations should be adjusted for the change in hydraulic gradient as the pit lake level increase. The ground water inflow to a large well can be calculated by the following equation (Wickham *et al*, 2001):

$$Q = 1.366 \frac{K(2H - S)S}{\log\left(\dfrac{R + r}{r}\right)}$$ $\hfill$ (6)

Where:

Q- Ground water flow to open pit $\left(\text{m}^3 \big/ \text{day}\right)$.

K- Hydraulic conductivity $\left(\text{m} \big/ \text{day}\right)$.

H- Pre-mining potentiometric surface (m).

S- Draw down in the pit (m).

R- Radius of influence (m); $R = r + 2S\sqrt{KH}$.

r- Reduced radius of the open pit in which $r = \sqrt{A/\pi}$ and A is area of the open pit (m^2).

With regard to fractured rock mass, hydraulic conductivity was estimated to be $8.5*10^{-2}$ m/day.

Open Pit Geometry

In this simulation it was necessary to calculate area and volume of the pit lake in every pit lake stage. For doing this, area and volume of the pit was calculated in specific pit height elevation and then regression analyses were performed to obtain the relation of the area and volume of the pit with the pit lake elevation. The plotted data are shown in Figure 3.
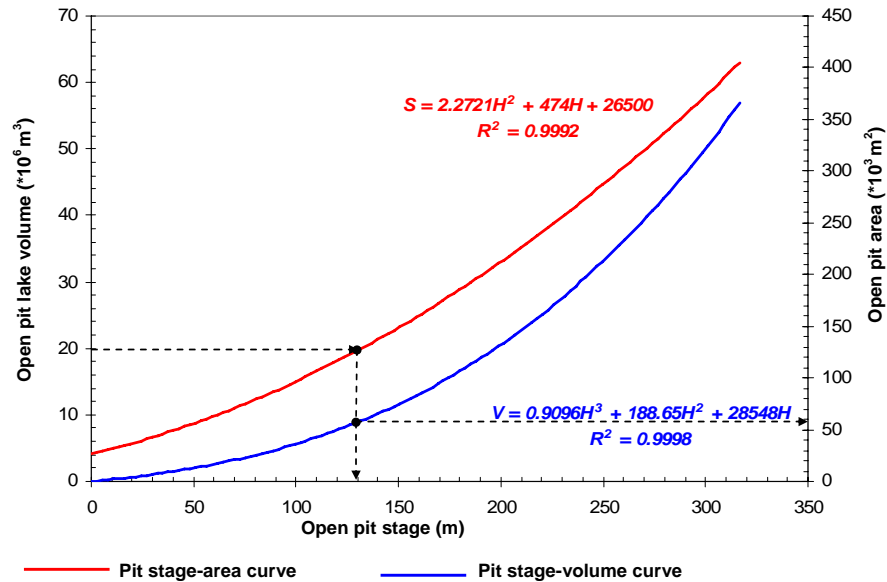
Figure 3. Stage-volume-area relation in Choghart open pit mine.

As can be seen from Figure 3 the relation between area and pit stage and also pit volume and pit stage are nonlinear. This is contributed to irregular shape of open pit. Using these curves the pit lake area and volume can be achieved in terms of pit lake elevation. Suppose that in a specific stage the new pit lake volume is equal to $20*10^6 m^3$. Thus the area and height of pit lake in this stage will be $58000 m^2$ and $129m$ respectively as shown in Figure 3.

Procedure of Calculation

From Figure 2 pit lake stage/area/storage can be calculated after any time step. In this case pit lake stage/area/storage was calculated at the end of each month by equation 2. Once the net charge in volume is calculated for a particular time step, it is added to the previous volume of water in the pit to determine the new volume. The new volume of water is then converted to a pit lake level based on the geometry of the open pit.

All of the variables in the model were considered deterministic. The model assumed that at any point in time, total inflows minus outflows were equal to the rate change in the pit lake water. The rate of rise in the pit lake water level was then equal to the rate change in water volume divided by the pit lake surface area.

The evaporation and precipitation components of pit lake water balance were estimated from monthly average values multiplied by the lake surface area. For example after first month of mine closure (October), the precipitation component of inflow is equal to:

$$\frac{1.5}{1000} \times 3.14(92)^2 = 40 m^3$$

Because average monthly precipitation in Choghart is low, precipitations falling on the pit walls were not considered. Another component is ground water inflow. The amount of ground

water inflow at the end of the first month (October) is calculated by the equation 6and is equal to:

$$Q = 191974 \text{m}^3$$

To estimate the runoff component of inflow, first CN should be achieved according to site characteristics and guiding tables in (Wanielista *et al*, 1997), CN is selected to be 85; hence, according to equation 4 the S' can be achieved as follows:

$$S' = \frac{25400}{85} - 254 = 44$$

The precipitation flow (40m^3) is less than 22 (44*0.2); consequently, with reference to equation 3, runoff is considered to be zero.
Thus, total inflow volume is equal to:

$$191974+44+0=192018\text{m}^3$$

According to the Figure 3 the height and the area of pit lake in this stage are equal to 6.40m and 29652m^2 respectively.

The outflow runoff (evaporation) is equal to new pit lake surface multiplied by the amount of monthly evaporation in October is:

$$29652 \times 0.276 = 8184 \text{m}^3$$

So, pit water storage at the end of the October is equal to:

$$192018 - 8184 = 183834m^3$$
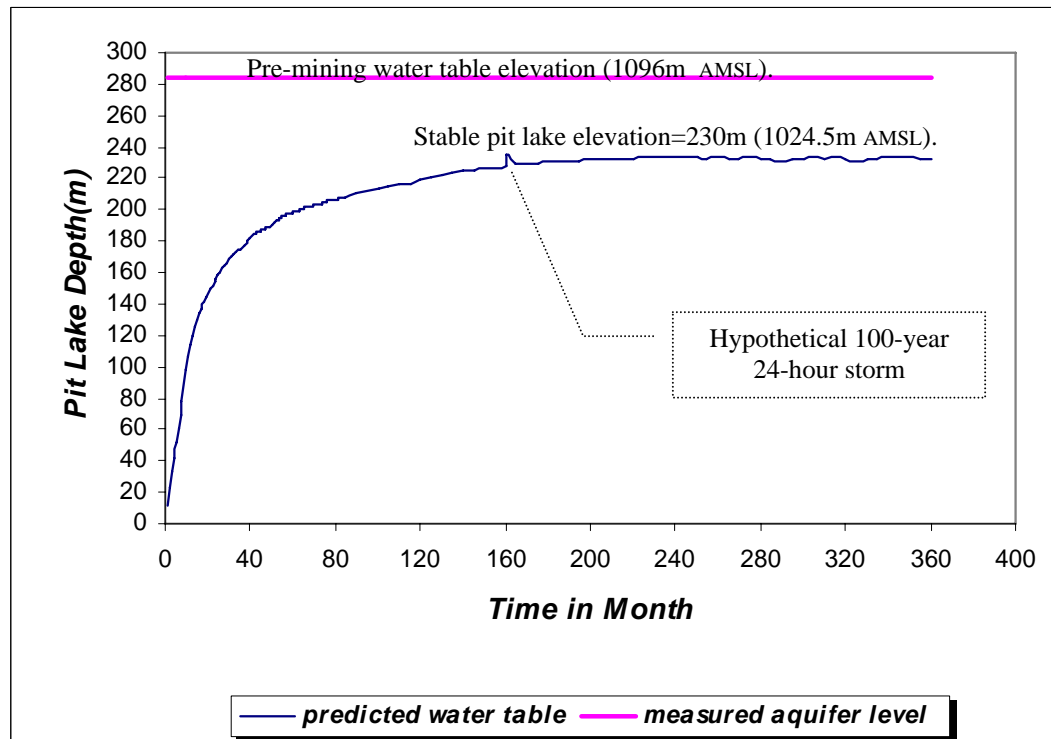
Figure 4. Pit Lake Water Balance Prediction in Choghart Iron Mine

Thus, the height and the area of the pit lake at the end of the October are equal to 6.15m and 29500m^2 respectively. This procedure was repeated for 360 months using a program written

in MATLAB. The results of water table evaluation in 30 years (360 month) after mine closure are shown in Figure 4. In this Figure the elevation of pit lake water at the end of each month was determined. As can be seen the rate of increasing of pit lake depth is high at the beginning and it will gradually decrease. This is contributed to drawdown decreasing and increasing pit lake area with rising of water level. Evaporation begins once a shallow pit lake forms and maintains the pit lake about 50 meters below ground water level in the adjacent aquifer. It will take about 200 month (17 years) for Pit Lake to reach to its final level in pit and after that water level in pit will be maintained at 230m from pit bottom in about 82% of its pre-mining elevation. In this condition total volume of water in pit estimated to be about $57 \times 10^6 \, \text{m}^3$. Also Figure 4 shows that hypothetical 100-year 24 hours storm event has little effect on the water level in the pit. This is due to the large storage capacity of the pit relative to the runoff produced by such a storm event. The plan view of the pit after lake formation is shown in Figure 5.

Under this condition ground water would flow always towards the pit lake and water in the pit lake would not recharge the aquifer system. Thus, pit lake water would have no chemical effect on the adjacent aquifer.

Figure 5. The Plan View of The Pit after Lake Formation in 17 Years of Choghart Iron Mine Closure.
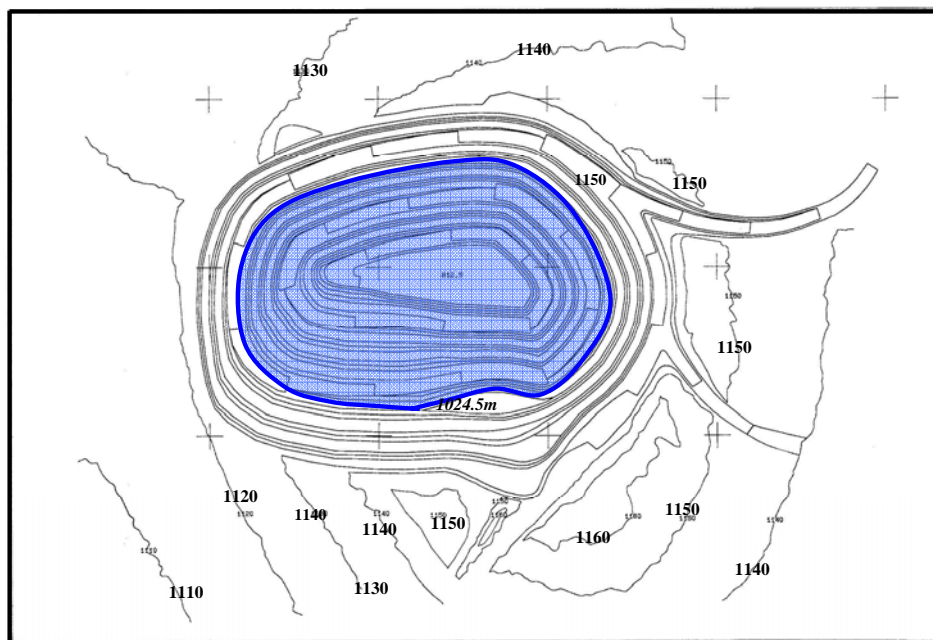
According to the present extraction planes, the highest elevation of pyrite contained material exposure in pit wall is approximately 160m from pit bottom. According to the Figure 4, the pyrite contained material will be covered by pit lake after about 2 years from mine closure; therefore, since that time no acid production will occur near the pit lake. But it should be noted that during the periods that sulphides are exposed above the pit lake elevation, storm and water run will lead to acid producing; consequently, some model should be developed to water quality description during that periods.

Conclusion

Based on the data gathered from the Choghart Iron Ore mine of Iran, the condition of pit lake formation after mine closure was evaluated. The results of this study are summarizing as follow:

1-A pit lake will certainly develop.

2-As soon as mining activity cease, pit lake will develop and reach to 230 meters from pit bottom, 17 years after mine closure.

3-Evaporative losses from pit lake will maintain water table in pit 50 meters below the ground water table in the adjacent aquifer. So pollutant water in the pit lake would not recharge the aquifer system.

4-Pit lake will cover the sulphide material in the pit wall after two years and after that no acid flows produce.

5-The most important parameters in pit lake formation in this region are ground water inflow and direct evaporation from pit lake.

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