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ARTICLE

Design of Flood Drainage in Golgohar Iron Ore Mine#3

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ABSTRACT

The iron ore minerals reservoir of Golgohar Mine#3 is more than 660 million tons. It is the biggest in Iran and rate of ore extraction is more than 15 million tons per year. The pit takes place on the way of runoff pathway of this watershed and it needs an especial strategy for conserving the pit mine during next imminent floods. The area of Mine# 3 watershed is 20785700 square meters and its general slope in its topography map is 0.59 percent; then initial scheming indicates it can causes a great deal of problems for mining operation n the next floods; particularly, the pit is located into degree 4th sub branch of a main ephemeral river. For this purpose, the Soil Conservation Service Curve Number (SCS) method was employed to estimate intervals period of next floods based on the magnitude, the intensity and the duration of precipitation events data. Conceptual design of runoff drainage of the watershed was designed to lead the flood to a better pathway location. The Mine#3 overburden deposition occupies a huge area on the watershed; and it has been considered and redesigned in terms of size, form, dimensions and location to manage as a physical obstacle against next floods. Hydraulic calculations were applied for designing two essential open channels which can preserve the pit.

1. Introduction

The Golgohar Iron Ore Mine (GIOM) is including six major iron ore mines. The total iron mineral reservoir of these mines is more than 1.3 billion tons, including mainly magnetite iron ore. Currently, five mines are being extracted. Economical geology study in Mine#3 shows the mine, with 660 million tons, is the most principal iron ore reservoir in Iran. Extraction operation of this mine has started in the northern half of the mine from 2004. Mine extraction method has selected open pit.

2. The Study Area

Iran's largest iron ore deposits take place in the GIOM [17,18]. The mine is located 950 km south of Tehran in Kerman province about 55 km southwest of Sirjan city (see Figure 1). The study area, the GIOM, is located in the middle south of Iran (55° 16′ to 55° 20′ E and 29° 05′ to 29° 06′ N) shown in Figure 1 [17,18]. This area has a unique geological history in the Middle East. Many scientists believe that in the south of the Paleotethys Ocean, the block of Central Iran during the movement toward the North has met the block of Eurasia in late Permian [6] Almost at the same time, the Neotethys Ocean appeared in the South between the Arabian and the Central Iran block. The best witness to this event is upper Triassic to Jurassic sediments (Ophiolite) that are presently between

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these two blocks in the southern part of Iran [6,9]. After that, the trend of opening of Neotethys has been reversed and the subduction of ocean crust of Arabic block under the Iran block started [9]).Then, an elongated zone consisting of magma and igneous rocks was created parallel to the Neotethys Ocean, as the Sanandaj-Sirjan structural zone was named after the names of the cities located in the beginning and the end of the zone in Iran. About the time of the closing of Neotethys ocean, some scientists believe the closing occurred in late Cretaceous to Paleocene 6,15], some determine it late Oligocene [1] and even some suggest Miocene [5,10,12].

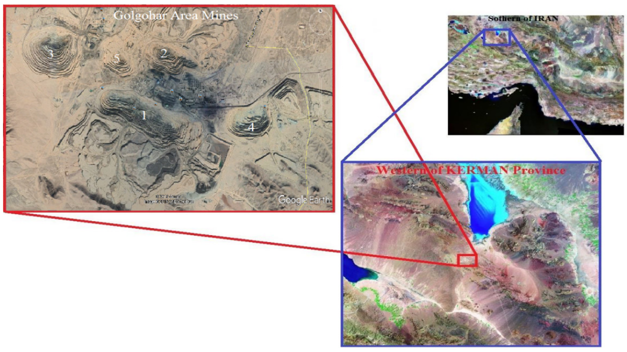

Figure 1. The location of the GIOM

Tectonic Sanandaj-Sirjan zone has many folded igneous and metamorphic rocks accompanied by lots of reversed or normal faults which are formed in an extensive period [8]. The Calc-alkaline and volcanic rocks prove that this zone was an active continental margin in Mesozoic. A kind of magmatic arc is found in Sirjan and many other areas in the zone of Sanandaj-Sirjan [2,3,4,7,11,13,14,16], .

GIOM is located in the margin of the central desert of Iran in the zone of Sanandaj-Sirjan and is bounded by some salt pan in the north and south. Few local, medium height mountains are also seen in the north and south of the area [17,18].

The structural zone of the area is the most active tectonic zone in Iran and has passed the Cenozoic magmatic and metamorphic phases. The GIOM is placed in the Paleozoic metamorphic rocks as the oldest formations in this area termed as Golgohar Metamorphic Complex (GMC) formation, which includes five hard rock units: (1) serpentinized ultramafic and metamorphic rocks, (2) dolomitic marbles to Calcific Marbles, (3) Mica schist some gneiss and amphibolite, (4) Gneiss and (5) an alternate of marbles, gneiss, mica schist, amphibolite, schist and black quartzite on the gneiss [14]. Units one and two are not exposed in the GIOM area. The complex has no distinct lithological pattern in depth or surface. The complex consists of six ore field sets [17,18].

The topography of the study area of the five rain catchments surrounding the GIOM, i.e. the Chahderaz (CH), the Qatarbaneh (QA), the Ein-ol-Baghar (EB), the Kheyrabad (KH), and the Mine (MI) rain catchment areas is shown in Figure1. The PW-A15 is located nearby the boundaries of the CH, EB and MI catchments. Long period average annual precipitation of the area is 148 mm, which mainly happens in the winter. The potential evaporation is reported to be more than 2800 mm in a year. There is no eternal river in a radius of 200 km of the area. The climate of the area is semiarid to arid with cold winters and warm summers [17,18].

The SSZ structural geology state is formed as a strip with a width of 150 to 200 km parallel to the last remnants of Neotethys to the Zagros Mountains suture. The Closing of this paleo-ocean was coincided the crust subduction of the Neotethys plate beneath the central Iran plate. At the same time, volcanic lava erupted along the SSZ. The SSZ structural geology state is known as a poly-phase deformed zone. The age of the Neotethys closing is not definitely found out. The first group of scientists says it happened in the late Cretaceous to Paleocene [6,15]. But others found it the late Oligocene [1] and some of them discovered it the Miocene [5,10,12].

So far, different theories about the SSZ creation have been presented. Many believes that this zone is a product of the imbricate slice of the ocean crust along with the metamorphic agglomerate in the green schist faces. Some other geologists state the SSZ is as a part of the Central Iran [6,15], which has a subduction toward the north [6,9]. Another theory says the existence of this zone was a micro-continental plate into the paleo-ocean [1]. And some others demonstrate the SSZ is a part of the Arabian plate which was appended to the Eurasian plate as a rifted plate [1]. The recent theory is rejected due to disaffiliation of the lithology.

The lithology of the GMC was generally studied [17,18] (Figure 2). Many parts of the study area were covered by hard formation members of GMC formation [17,18]. The GMC is made of Neotethys sediments formation of Paleozoic (Figure2). But the age of metamorphism in GMC formation is calculated based on the Argon isotopic studies Jurassic [17,18]. In terms of geomorphology, the GIOM takes place on the flat plateau [17,18] (Figure 3). The Lithology of some mountains of the study area is made from carbonate part of the GMC. Alluvial plain in the GIOM is 1730 meters high in average. There are three salt pans in study area, the More and the Meydan-Gel salt pans in the south the Kheyrabad in the north.

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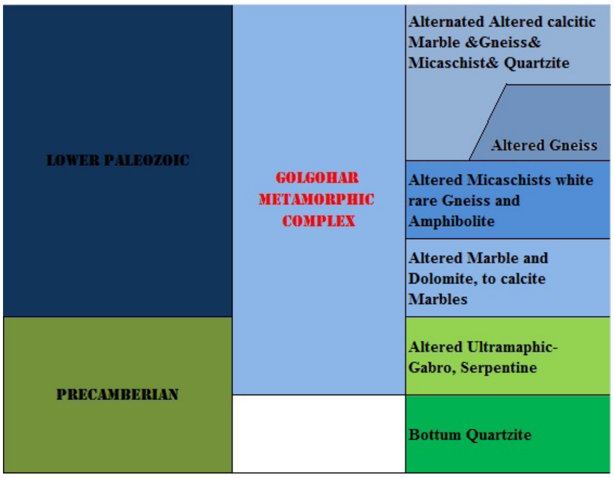

Figure 2. The GMC stratigraphy

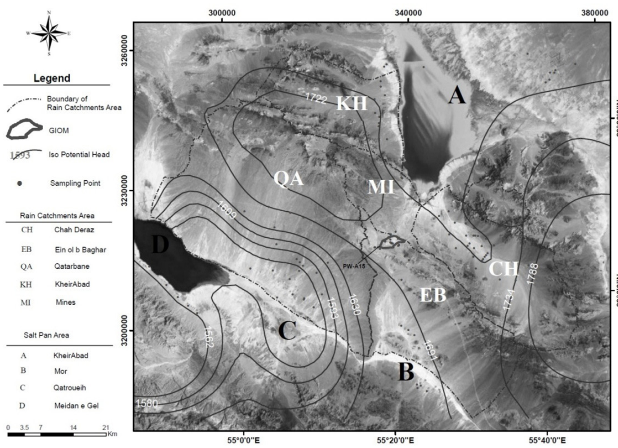

Figure 3. The rain catchment area, salt pans and topography map around of the GIOM

3. Definition of problem

There are numerous problems in mining. Some of them can be due to existence of water. Primarily, it would be better to mention a few of these problems:

(1) Groundwater seepage increasing

(2) Flood damage

(3) Need to increase dynamic drawdown of mine groundwater

(4) Necessity to a tailing dam to collect wastewater of factories (and mine wastewater too)

(5) Incorrect locating of mine deposits (waste, ore, overburden and etc.) in mine rain catchment area

Many techniques have to be applied to solve each of these problems.

In 1992, it precipitated 130 millimeter in the area during three days. The 3 deepest benches of the Mine#1 were under-watered due to flood flow that had started from upstream of the mine. Its subsequent economical detriment was perceptible. In 2017 another flood occurred in this area which affected all of the five mines. This second flood took place after a 170 mm precipitation, that it caused more structure damage of the mines and facilities of them. This paper tries to presents a manner to restrain future floods in a watershed.

4. Materials and Methods

At first, boundaries of the rain catchment areas were determined around the GIOM. For this purpose, *ArcView* GIS software was applied. Then the output of it was transferred to *Gemcom* software which uses in mining operation. The physiography characteristics of the watersheds were also obtained using geological and topographic parameters using topography maps of the area. Precipitation data was obtained from meteorological station which located into the GIOM area. A synoptic meteorological station in the GIOM region was established in 2006. But before then, for more than 20 years, the meteorological data were gathered using another old climatological station where was nearby the same station. Using these digits, distribution of precipitation statistics in these mines was analyzed. The period time of flood was calculated in the area using these 2 softwares: *Distrib 2.13* and *Smada 6.43*. Using the physiological characteristics of the rain catchment area, which was measured on topography map, the hydraulic coefficients of the field were obtained for estimating the runoff. The unit hydrograph of the watershed was calculated applying *Smada 6.43*. Methodical analyzes of the flood characteristics of the selected watershed were calculated for different periods of the floods flow. It was decided that the Mine#3 designing should be protected effects of the 200 year flood. Knowing the hydrological characteristics of the 200 year flood, the location of flood outlet in the watershed and the overburden deposition of the mine was determined. Also, some essential specifications of the watershed are deliberated for hydraulic designing of the flood drainage channels. For this purpose, hydraulic calculations of open channel river were applied.

5. Results

The rain catchment areas of the GIOM area were recognized using the 1/10000 GIOM topography map. There are five following Rain catchment areas which encircle the six mines:

(1) Rain catchment area No.1 or Chahderaz

(2) Rain catchment area No.2 or Ein-ol-Baghar

(3) Rain catchment area No.3 or Ghatar-Bane

(4) Rain catchment area No.4 or Kheyrabad

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(5) Rain catchment area No.5 or Mines

These watersheds are shown in Figure1. The flood of the No.2 and 3 rain catchment areas transfer over the south of the study area towards Mor and Meydan-Gel salt pans. The flood of No.1, 4 and 5 rain catchment areas pour over towards the Kheyrabad salt pan in the North.

Above classification was re-checked. The *ArcView* software researches focuses in the study area where includes all six mines and their industrial units:

(1) Factory watershed

(2) Mine#1 watershed

(3) Mine#2 watershed

(4) Mine#3 watershed

(5) Northern watershed

(6)Tailing Dam#1 watershed

(7) Tailing Dam#2 watershed

(8)Mine#6 watershed

Only the two last watersheds pour over the Ein-ol-Baghar rain catchment area, and the rest of them are geographically the portions of the Ghatar-Bane rain catchment area. This article focuses only on Mine#3 watershed.

5.1 Physical Properties of the Mine#3 Watershed

The area of the Mine#3 watershed is 20785700 square meters. This watershed is located in the west of the Mine#1 watershed. The outlet of these watersheds joins together in the South of them. The watershed runoff pours toward the South of the Mine#3 watershed where locates the Southeast of Mine#1. This property of the watershed hazardously affects technical activities of these mines during floods. Because the runoff of floods can pass through the pits of the Mine#3 and 1 before they pour over the Ghatar-Bane rain catchment area basin [17,18].

The area of permeable part of this watershed is 18312800 square meters, and the non-permeable part is 2472900 square meters. The perimeter is 18250 m. Length of the watershed (based on the longest river) is 7600 meters. Other descriptive physical factors of this watershed determined: elongated watershed with 0.359 the shape factor, which indicates a high range and dangerous hydrograph for the facility located on it. The Gravelius coefficient is 1.121 which indicates a low deviation from the circle. Its elongation ratio is 0.677, which is a low rate. The length of rectangle is 4755.9 m and the width of it is 4370.5 m. The mean slope of watershed is calculated 0.59% using contour lines method. Slope direction in the west side of watershed is from the West to the East. But dominant slope direction of this watershed is from the North to the South.

Concentration time of the watershed was calculated using 6 below equations *Izzard, Kerby, Kirpich, Kinematic, Bransby-Williams* and *Federal Aviation Agency*. The average value of them for the concentration time is 237.7 minutes.

5.2 Distribution of Precipitation Statistics

The GIOM meteorological center is located 1 km far from the watershed. This center has proper long-term precipitation data. The 32-year precipitation data of this center was entered to a PC to run on *Distrib 2.13* software. Flood routing was performed by probabilistic method of location of *Weibull* data and distribution function of *Log Pearson type III*.

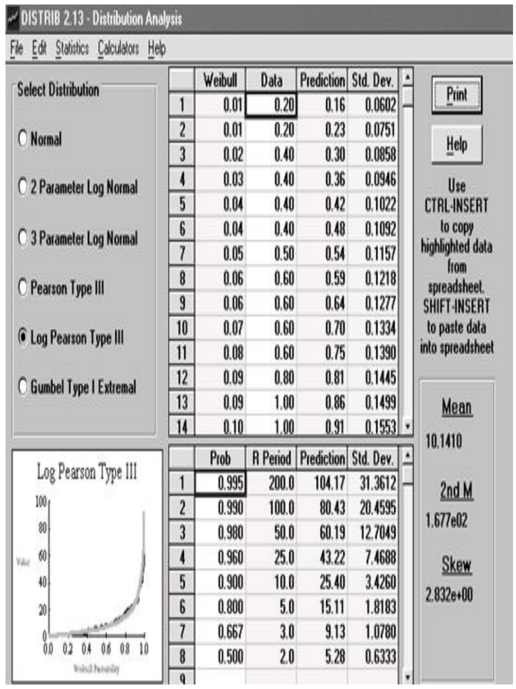

Figure 4. Using the *Distrib 2.13* software to recognize distribution and prediction of precipitation in Mine#3

The reason for choosing this distribution function in spite of its high standard deviation was that the *Log Pearson Type III* distribution function assessed the highest precipitation height and made the most realistic estimation of a 200 year flood of the mine against these five other distribution functions: *2 Parameters Log Normal, 3 Parameter Log Normal, Gamble, Gamble Type I External* and *Pearson Type III* (Figure4). Then, for this temperamental river, the highest precipitation height is preferred.

Table 1. Distribution of precipitation amount with different probability and return periods

Standard Deviation	Precipitation (mm)	Period (year)	Probability
31.36	104.17	200	0.955
20.46	80.43	100	0.99

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12.71	60.19	50	0.98
7.46	43.22	25	0.96
3.42	25.4	10	0.9
1.82	15.11	5	0.8
1.08	9.13	3	0.667
0.63	5.28	2	0.5

Accordingly, the probability of occurrence and height of precipitation runoff in the watershed with different periods are estimated in Table 1. The baseline of flood calculations for the project was assumed to be at least 200 years. Therefore, in future calculations, flood routing was performed for a precipitation of 174.14 mm.

Table 2. Distribution of precipitation intensity with different probability and return periods

Standard Deviation	Precipitation Intensity (mm/hour)	Period (year)	Probability
0.29	3.23	200	0.995
0.25	2.88	100	0.99
0.21	2.53	50	0.98
0.17	2.20	25	0.96
0.12	1.76	10	0.90
0.08	1.44	5	0.80
0.6	1.19	3	0.67
0.4	0.97	2	0.50

According to the GIOM precipitation records, this is equivalent to the 60-hour precipitation that occurred on January 19, 1992, that caused a $ 4 million damages to the mine, plants and their facilities.

Precipitation distribution was also considered in this process. In this estimation, the two-parameter log-normal distribution was used, that has the highest estimation intensity among 200-year-old period. The results of this estimation are presented in Table 2. Accordingly, the highest precipitation intensity with a 200-year period is 3.23 millimeter in hour.

Precipitation duration was also analyzed by above method and software; the results are presented in Table 3.

Table 3. Distribution of precipitation duration with different probability and return periods

Standard Deviation	Precipitation Duration (hour)	Period (year)	Probability
15.4	54.81	200	0.995
10.4	43.44	100	0.99
6.7	33.56	50	0.98
4.1	25.06	25	0.96
2.0	15.79	10	0.90
1.1	10.12	5	0.80
0.7	6.62	3	0.67
0.4	4.19	2	0.50

Therefore, the duration of flooding of a 200 year period is calculated 54.81 hours.

5.3 Watershed Runoff

In addition to using a cylindrical precipitation gauge, an automatic precipitation gauge was also installed at the GIOM meteorological station to calculate the runoff and to determine the watershed unit hydrograph.

Due to the lack of any hydrometric device in the river of the watershed there is not hydrography data during the flood, then the conventional Curve Number (CN) method was applied to estimate the surface runoff volume of the watershed and to obtain the unite hydrograph. The runoff CN is usually an empirical parameter which applied for flood or infiltration predicting from precipitation. The CN method was established by the USDA Natural Resources Conservation Service, and was previously called the Soil Conservation Service or SCS , the number is still commonly recognized as a "SCS runoff CN" in the hydrological studies. The CN is extensively applied in new studies too and is a proper method for deceiving a rough quantity of flood in each study area. According to the type of soil and the green cover quality, the CN value of the Mine#3 watershed was considered 70. Then, the precipitation statistics of one of the major floods in the watershed were calculated, that occurred in 1992, and was plotted using the above CN method (Figure 5).

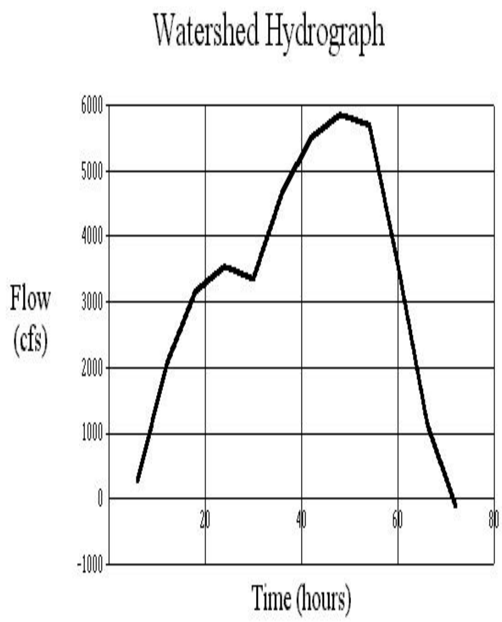

Figure 5. The hydrograph of Mine#3 watershed

Flood routing was performed applying *Smada 6.43* software using unit hydrograph of watershed. In this way, the flood hydrograph in the watershed was obtained by extending of the existing unit hydrograph (Figure3). Then, the 200-year flood peak discharge was calculated. The discharge of flood is 5206 cubic feet per second (147 cubic meters per second).

5.4 Flood Discharge Location

Determining of a deposit locating for flood is one of the major problems for the GIOM due to the following complications:

(1) The study area is factually a wide savannah; therefore, there is no bulky reservoir for flood accumulation.

(2) The pit Mine#3 takes place at the southern end of the watershed. The watershed flood should not be aggressing towards the pit, but its topography makes it flowing toward.

(3) The cost of tailing dam construction for this purpose is enormous.

(4) The Mine#1 is in the east of the Mine#3 watershed and the western heights overlooking Mine#3 restricts flood outlet of watershed (Figure 7).

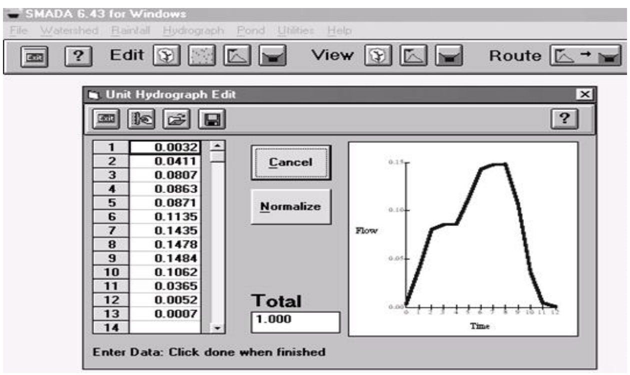

Figure 6. The unit hydrograph of the watershed using *Smada 6.43* software

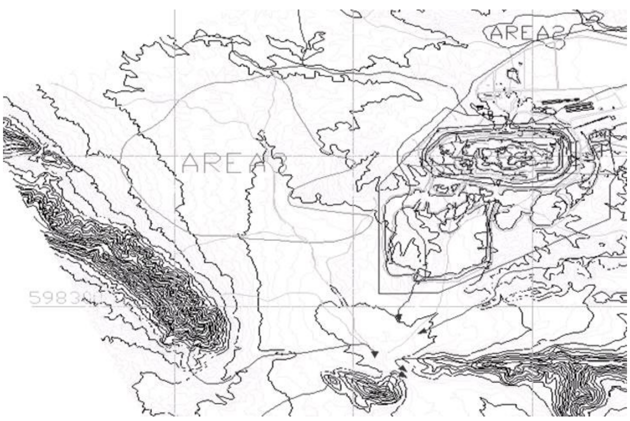

Figure 7. Topography map of Mine#3, watershed Mine#1 and these catchment outlet by *Gemcom 4.0* Software

After further field studies and investigates on the topographic maps of the area, it was decided that the flood of this watershed would diverge in two branches of river in the East and the West. From an environmental point of view, although this will be accompanied by a change in the natural path of the flood in the Northern half of the watershed, but it seems the existing technical and structural problems leave no other way to avoid it.

5.5 Channel Specifications

According to the flood characteristics of the watershed, the channel characteristics were calculated through open channel hydraulic calculations and river engineering references:

(1) Confidence factor: 1.80

(2) Wide of channel: 30 meters,

(3) Channel depth: 4 meters,

(4) Channel slope: 0.21%

(5) Section of channel: trapezoidal

(6) Channel slope is 1:2 or 26.58°

(7) The length of the main channel: 3650 meters

(8) Channel width : 14 meters

(9) Area of channel surface: 96 square meters

(10) The wet-channel environment: 33.88 m

(11) The hydraulic radius of the channel: 2.83 meters

(12) Water velocity in channel: 2.78 meter per second

(13) Maximum water discharge: 266 cubic meters per second

Accompany with the main channel designing, as shown in Figure 8, a hydraulic gabion wall is need to restricted flood water into the channel. And a smaller channel is designed in the East of the Mine#3 to keep away the water from the pit. The final drainage design within the Mine#3 watershed was prepared using the *Gemcom* software (Figure 8).

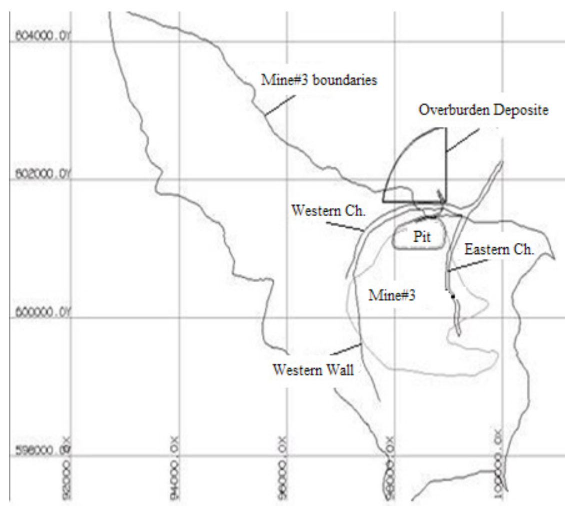

Figure 8. The schematic flood drainage design for the Mine#3

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6. Conclusion

(1) Due to the location of the Mine # 3 on the way to the watershed river, next flooding events is inevitable.

(2) The special channel construction is necessary to gather the flood by two channels and a hydraulic wall..

(3) Finally, overburden deposit and facility location of Mine#3 was redesigned with hydrological and flood control perspectives.

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