STORMWATER MANAGEMENT AND THE LIMITED DISCHARGE SYSTEM OF THE BATU HIJAU MINE

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ABSTRACT

Managing stormwater runoff and limiting its discharge at the Batu Hijau mine is critical to the success of this copper/gold mining project. As is common in tropical environments, the area experiences frequent high intensity rainfall events, resulting in significant erosion and sedimentation challenges associated with the overburden stockpiles that will ultimately store 2 billion tonnes of potentially acid generating soil and rock. The stormwater management plan developed for the mine included construction of numerous diversion channels constructed through steep terrain, massive sediment control features that provide 9 million cubic meters of storage, and a 3,600 liter per second, high-head pumping system. The result is a limited discharge facility for the entire mine area. The cost of managing stormwater and sediment control is $150 million.

Key Words: Tropical Environment, Rainfall Intensity, Diversion Channels, Construction Costs

INTRODUCTION

PT Newmont Nusa Tenggara (PTNNT) is the owner and operator of the Batu Hijau mine located on Sumbawa Island, Nusa Tenggara Barat, Indonesia. Sumbawa Island is in the Lesser Sunda Island chain in the Indian Ocean, an area of high rainfall, at about latitude 9 degrees south, longitude 117 degrees east. Sumbawa is the third island east of Java. The Batu Hijau mine is located in the southwestern corner of Sumbawa, a heavily forested region that averages 2,500 millimeters (mm) of rainfall annually.

The ore body, a copper/gold porphyry, was discovered in 1990. Following feasibility studies and design, construction of the $1.9 billion project started in October 1996. The mine produces copper and gold from an open pit, and the pit will ultimately be 900 meters below original ground surface. The first shipment of copper and gold concentrate was made in December 1999. Daily mine production is 600,000 tonnes, and the daily plant production averages 142,000 tonnes. The estimated 2 billion tonnes of potentially acid generating overburden material will be placed in three separate stockpiles adjacent to the pit during the 17 year projected mine life, eventually covering an area of about 1,100 hectares. The overburden stockpile areas and the mine are frequently subjected to high intensity rainfall. Managing stormwater runoff in and around the mine pit and overburden stockpiles is essential to the success of the project. PTNNT contracted with Golder Associates Inc. (Golder) to assist with stormwater management at the Batu Hijau mine.

Batu Hijau experiences distinct wet and dry seasons. The wet season is the period from mid-October through the first of May, during which 85 percent of the average annual rainfall occurs. Annual rainfall is much higher in inland areas than along the coast. The mine and overburden stockpile areas are located in these higher rainfall areas.

The average annual rainfall estimate for the mine area is 2,500 mm. A summary of average seasonal climatic conditions is shown in Table 1.

Table 1: Summary of Average Seasonal Climatic Conditions

	Wet Season (Oct.-April)	**Dry Season (May-Oct.)**	**Average Annual**
Temperature (°C)			
Typical Daily Max.	31	27	30
Typical Daily Min.	21	18	20
Precipitation (mm)	2,200	300	2,500
Wind (m/s)	2.5	2.9	2.7
Relative Humidity (%)	91	86	88
Pan Evaporation (mm/day)	4.5	4.3	4.4

Of particular concern at Batu Hijau is rainfall intensity. Areas of the mine have already experienced in excess of 50 millimeters of rainfall during a 15-minute period, and more than 200 mm over 24 hours, since rainfall record keeping began in 1993. Predicted peak storm depths by return period are shown in Table 2.

Table 2: Peak Storm Depths by Return Period

Duration		Recurrence Interval							
		2-Yr	5-Yr	10-Yr	20-Yr	25-Yr	50-Yr	100-Yr	500-Yr
(hours)	(min)	Storm Depth (mm)							
0.083	5	12	14	16	16	17	19	22	30
0.167	10	22	25	28	30	32	35	42	59
0.250	15	30	35	40	45	46	52	59	80
1.000	60	46	61	71	85	87	101	121	170
2.000	120	58	75	88	105	108	125	150	210
3.000	180	65	85	99	119	122	142	170	238
6.000	360	82	106	124	149	152	177	213	298
12.000	720	98	128	150	180	184	214	257	360
24.000	1440	115	150	175	210	215	250	300	420

Topography in the mine area is rugged, with relief up to 700 meters and valley side slopes of 30 to 45 degrees. Numerous incised creeks dissect the side slopes to depths exceeding 20 meters, and most stream beds are heavily armored. Residual soils that cover most of the valley side slopes are primarily low plasticity silt and saprolite covered by a thin (less than 500 mm) organic-rich topsoil layer. Bedrock is typically not encountered near the surface, adding to the difficulties in constructing stormwater conveyance channels along the very steep, frequently incised hillsides.

The vegetative cover is a dense, forest canopy typical of a moist, tropical environment. Erosion and sedimentation occur almost immediately once the canopy is removed. The high average annual rainfall, coupled with extreme storm events, resulted in significant stormwater control issues that had to be addressed to manage runoff and potentially acidic drainage, and control erosion and sedimentation during initial construction and operations at the Batu Hijau mine. The project objectives included:

- Constructing a limited discharge system, capable of storing and treating all stormwater runoff from the mine and stockpile areas during an entire wet season, to manage sediment and control potential acid drainage
- Collect and convey stormwater runoff around the mine and stockpiles to minimize erosion and sedimentation, minimize contact with potentially acid generating stockpile soils and rock, and direct runoff into sediment control ponds and treatment facilities
- Limit total suspended solids (TSS) concentrations of water discharged downstream of the property to 60 mg/l or less, a permitted water quality parameter, and
- Ascertain the most economical method of constructing stormwater control facilities to optimize ongoing stormwater management as mining progresses and the stockpiles are constructed.

To achieve these objectives, progressively larger sediment control ponds were constructed in the two valleys downstream of the mine and stockpile areas, and three types of channels were constructed to convey runoff to these ponds. Construction and maintenance costs were monitored to assist in selecting future construction methodology. Finally, a 3,600 liters-per-second pumping system was installed, capable of lifting runoff 300 meters, to complete the limited discharge system.

This paper discusses the stormwater control practices at Batu Hijau, construction methods that proved most economical to build and maintain, the limited discharge system, and the costs of its concomitant infrastructure.

METHODOLOGY

The initial information needed for design of stormwater conveyance structures is an estimate of rainfall intensity and resulting runoff. Prior to site development, the Batu Hijau area was virtually inaccessible with no local rainfall or runoff data available. The nearest rainfall gauge, a coastal installation, was more than 30 kilometers away. PTNNT installed the first 6 tipping bucket and 3 storage rain gauges at the site in early 1993. Four stream gauging stations were also installed at that time. Initially, access to these instruments was available only by helicopter. Additional stream and rainfall gauging stations were subsequently added as the need for additional data arose, and the project area now boasts 4 meteorological stations, 8 additional rain gauging stations and 8 stream gauging stations. Telemetry has been added to simplify data collection.

To supplement the on-site rainfall data recorded at Batu Hijau, regional rainfall records from western Sumbawa were also obtained. The regional gauges are simple non-recording storage-bucket rain gauges that are read manually on approximately 24-hour intervals. Some of the regional gauging stations have length-of-records exceeding 30 years.

Most of the regional gauges are located in readily-accessible coastal areas, and the rainfall records are fairly consistent: 1,200 to 1,400 mm of rainfall annually. This coastal data was confirmed by longer-term rainfall records from weather stations located on neighboring islands (the international airports in Lombok and Bali), and the regional airport on the north coast of Sumbawa. It was apparent from the regional data, and further supported by the recent site data, that inland areas receive significantly more rainfall than coastal areas. The focus was therefore to obtain records from inland areas in Sumbawa.

Four inland gauges were subsequently identified in western Sumbawa and their data obtained. An analysis of some of the data revealed inconsistencies, however, and a further investigation was required.

Golder inspected all 4 inland regional gauges in the vicinity of Batu Hijau. Two gauging stations were determined to be installed and monitored properly, and this information was utilized in the design. The remaining two inland gauging stations were extremely deficient (the rain gauge was stored in a closet at one, and non-existent but recorded daily nonetheless at the other) and their data was discarded. An inspection of remote rain gauging stations is always recommended in these circumstances.

The overburden stockpiles will be constructed over a 17-year period as the mine is developed. The stormwater conveyance channels that will protect these stockpiles and the mine will be constructed on, above and around the stockpiles over the same period. Various frequency storms are used in the design of each channel, based on design life and risks to the project. Most major channels are being designed and constructed for the 100-year recurrence interval storm.

Fortuitously, the Batu Hijau mine area enjoys a nearly 6-month dry season that experiences only 300 mm of rainfall. Whenever possible, major construction projects that involve earthworks are undertaken during this period. However, because high-intensity rainfall can occur at any time during the year, precautions are taken during construction to minimize erosion and sedimentation. Once the forest canopy is removed during a construction project, heavy erosion and subsequent sedimentation can result if heavy rainfall occurs. This is a significant design criteria at Batu Hijau, since the TSS concentration in water released from the project area is limited by permit to less than 60 mg/l, a very restrictive value and less than historical wet season sediment concentrations.

The initial channels were constructed as "hanging channels", or mid-slope channels constructed without the benefit of utilizing the overburden stockpiles, employing various construction methods and subsequently monitored for performance and maintenance requirements. Channels were typically constructed by excavating into the steep hillsides. Bedrock is nearly always non-existent near the surface, and hence most channels were cut into residual, highly erosive surficial soils containing a high percentage of silts and clays. A gradation of typical surficial soils is shown in Figure 1.

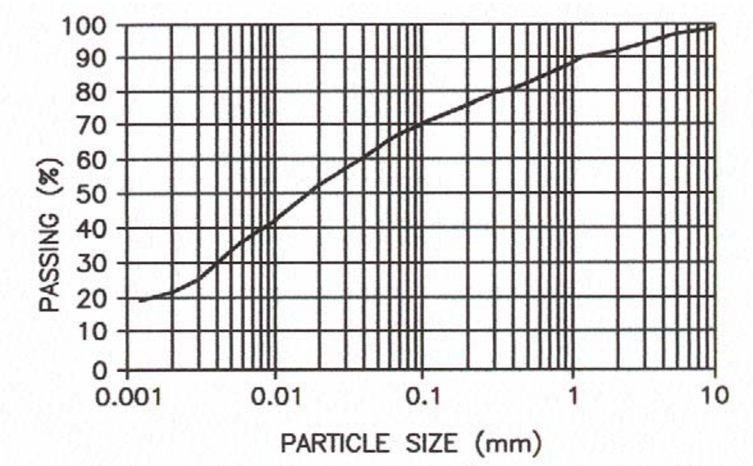

Figure 1: Gradation of Typical Surficial Soils

Channel gradients were designed to maintain a non-erosive flow velocity, while retaining sufficient energy to minimize deposition and reduce the frequency of maintenance. Channels were typically designed as trapezoidal channels with bottom widths to accommodate construction equipment, and 2H:1V side slopes. The depth of each channel varied to satisfy conveyance requirements, but was typically 2 to 3 meters deep. Armoring was placed at high-curvature bends in the channel, and in other potentially erodible areas.

Channels were constructed by excavation since fill material was difficult and sometimes impossible to place on the steep slopes. The excavation angle into the hillsides above the channels ideally would have been 2H:1V or less for long term stability, but since the natural hillside slope angles are as steep as 1V:1H in places, steeper cuts were necessary. The slope angle excavated above some of the channels is steeper than 0.5H:1V.

During construction of many of the channels, excavated soil was side cast, but this resulted in increased sediment loads downstream since the side cast material could not be substantially stabilized prior to the onset of the wet season. Other channels were constructed by hauling excavated soil to spoil dumps, minimizing revegetation, maintenance and sedimentation, but increasing construction costs significantly. This construction method was typically employed only during unavoidable wet season construction.

The majority of the cut slopes above the channels were excavated into the steep hillsides at the maximum practical slope to minimize construction costs, but at increased risk since frequent slope failures were likely. However, high risk channels were constructed at Batu Hijau because heavy construction equipment was readily available, and monitoring and maintenance personnel were present. As expected, slope failures were common until the hillsides above the channels "healed" to a more stable configuration. Stabilization typically occurred after one wet season.

Where possible, the slope angle above the remaining channels was constructed at a flatter slope, which increased construction costs but minimized the effort to maintain them. The construction and maintenance costs for each type of channel were then monitored to determine the most cost effective method for constructing the balance of the channels required at Batu Hijau.

Finally, the entire mine and overburden stockpile area has been constructed as a limited discharge system. Uncontrolled discharges are limited to less than one percent of the operating period of the property, effectively controlling all runoff from the potentially acid generating overburden stockpiles. During wetter periods, nearly 60 million cubic meters of water must be collected, managed, and treated annually. The majority of this water will be used in the beneficiation process, which operates using seawater during drier periods.

All stormwater channels convey runoff to several sediment control ponds constructed downstream of each overburden stockpile. A series of progressively larger ponds reduce TSS concentrations in the runoff, dropping first the coarsest fraction of the sediment, and finally the finer fraction, to satisfy the discharge requirement of 60 mg/l TSS. In addition, runoff that is collected in the sediment control ponds in adjacent valleys is pumped several kilometers, against more than 300 meters of head and at pumping rates of 3,600 liters-per-second, to transfer all stormwater runoff to the final polishing pond prior to downstream release or for use in the beneficiation process. All stormwater runoff at the Batu Hijau mine that has the potential to be impacted is collected, and treated if necessary, prior to offsite discharge.

RESULTS AND CONCLUSIONS

The initial stormwater diversion channels were completed in 1997, and the remainder of the major channels were completed the following year. Channel construction will continue at Batu Hijau to mirror the growth of the overburden stockpiles. Ultimately 186 kilometers of channel will be constructed for the protection of the mine and overburden stockpiles.

The primary sediment control ponds were completed in December 1999 and are successful at limiting TSS concentrations in discharged runoff to less than 60 mg/l. The pumping system was completed in 2000, effectively creating a limited discharge system for stormwater runoff at the mine. Uncontrolled discharges have not occurred, and are predicted to occur less than 1 percent of the operating period of the project.

Rainfall estimates for the mine are consistent with recorded results. No rainfall event recorded to date has exceeded expectations. Stormwater runoff has also been consistent with predicted values. The highest intensity rainfall recorded to date has been 53 mm during a 15-minute interval, equivalent to the 50-year storm short-duration intensity. The stormwater diversion channels all performed adequately during this event. Nearly 550 mm of rainfall were recorded during the 6-day period encompassing that event. The largest 24-hour event recorded on site has been 225 mm, equivalent to the 25-year, 24-hour event. A peak discharge of 125 cubic meters per second from a forested drainage area of 900 hectares resulted from that storm, and is the largest runoff event recorded to date.

Rainfall and runoff have been monitored since 1993, and rainfall/runoff relationships have been verified. The Soil Conservation Service curve number (CN) that represents typical runoff from high-intensity storm events from the forested areas (Hydrologic Soil Group B soils) during the wet season is 68. During the dry season, when antecedent moisture is less, the CN from forested areas is a much lower 55. The CN that typifies overburden stockpile areas, which are also characterized as Hydrologic Soil Group B soils due to their high fines content, is 76 during the dry season and 82 during the wet season.

For channels constructed with steep slope angles into the hillside above, most slope failures occurred during the first wet season. Less than 10 percent of the channels required emergency maintenance. However, some channel repairs and slope maintenance were required following almost every major storm event. During the second wet season, required maintenance and repairs decreased by nearly 75 percent and was similar to the channels constructed at more conservative slopes.

As expected, channels excavated at steep slope angles with side cast material were the least expensive to construct. The average cost of constructing channels with maximum slope angles and side cast material averaged $500 per meter of channel (all costs are US$). The length of channel constructed in this manner totaled about 6,000 meters. Maintenance costs during the first wet season for this method of construction averaged about $85 per meter of channel. Photo 1 shows a typical channel.

Photo 1: Channel with steep slopes and side cast material.

The average construction cost increased to $750 per meter for channels constructed at more moderate slope angles. The excavated material was also side cast. Maintenance costs for channels constructed in this manner averaged about $25 per meter of channel. The total length of this type of channel to date has been 2,500 meters. An example of this channel is shown in Photo 2.

Photo 2: Channel with moderate slopes and side cast material.

Finally, channels were constructed by eliminating side cast material, and cut slopes above the channel were lower-risk. The average construction cost of this effort soared to $1,600 per meter, and maintenance was again about $25 per meter of channel. Nearly 3,500 meters of these channels were initially constructed. A portion of the high construction cost can be attributed to partial construction during the wet season, which is avoided whenever possible. In addition, sediment control facilities had not been completed downstream, further justification for this high cost construction method. Photo 3 shows an example of this type of channel. Construction costs are summarized in Table 3.

Photo 3: Channel with moderate slopes and no side cast.

Table 3 – Construction Costs

Channel Excavations	Side Cast	Length Constructed (Meters)	Construction Cost (per meter)	Maintenance Cost (per meter)
Steep	Yes	6,000	$500	$85
Moderate	Yes	2,500	$750	$25
Moderate	No	3,500	$1,600	$25

PTNNT is vigilant and proactive in maintaining water quality downstream of the Batu Hijau mine, and is cognizant of the effort necessary to accomplish this. In addition to expenditures exceeding $10 million for initial major channel construction, an additional $25 million was expended on sediment control reservoirs and nearly $30 million for water treatment facilities in the event acid is generated. Other related infrastructure, including the pumping and piping systems for the limited discharge stormwater management system, has brought the total cost of stormwater management at Batu Hijau to about $150 million, representing nearly 8 percent of the overall construction budget for the project. This type of effort is required of responsible companies that develop mines in a tropical, high rainfall environment to maintain water quality.

From experience gained at Batu Hijau, sediment control costs can be reduced by delaying construction of stormwater channels on steep slopes in a tropical rain forest until adequate sediment controls are in place downstream, allowing excavated material to be side cast. PTNNT has now constructed in excess of 9 million cubic meters of sediment retention capacity downstream of its mine, protecting an ultimate disturbed area of about 1,100 hectares (including areas that are concurrently reclaimed).

It is possible to construct channels in erodible soils with 30 to 45 degree slopes by using steep slope angles in the excavations above the channels, but significant maintenance will be required the first year to correct slope failures above the channel. Flatter slopes, while requiring less initial maintenance, are typically not economical and in some cases impractical. Finally, it is more economical to side cast excavated soils, but concurrent reclamation of the material and downstream sediment control are necessary to avoid significant downstream impacts.

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