Mine Waste Management in Papua New Guinea : Practice and Regulation

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Abstract

Major open pit mines in Papua New Guinea employ modern mineral extraction methods which generate significant amounts of waste products that must be disposed. Conventional approach to waste management has been characterized largely by riverine tailings disposal and deep sea tailings placement. Each method presents unique management challenges due to the associated impacts and environmental setting. Effective regulation and monitoring is essential to mitigating adverse impacts on the receiving environment which includes the ecological and human aspects. This paper describes the types of mine waste disposal practices employed and general overview of the regulatory framework governing environmental management in Papua New Guinea

Keywords: mine waste, riverine tailings disposal, deep sea tailings disposal, sedimentation, heavy metals , upwelling.

1. INTRODUCTION

Papua New Guinea has an extended history of large-scale open pit mining since the late 1960s mining given its favorable setting in the Pacific Ring of Fire. Its geology harbors large quantities of mineral reserves ranging from high grade gold, copper, and silver to nickel and molybdenum which offer great potential for exploration and development. Mining currently accounts for more than 65 percent of the country's total export revenue and 15 percent of the GDP apart from the non-mineral and services sector (Anderson & Moramoro 2002).

Despite its economic significance, the environmental risks posed by mining and its subsequent impacts on the socioeconomic livelihoods of host communities have always remained contentious largely due to the mine waste management practices allowed under the existing legal regime. Against the backdrop of increased exploration activities, public demand for greater corporate social responsibility on the conduct of mining operations and the effectiveness of the Government in regulating the industry has become more pronounced in recent times in light of best available technologies and standards globally recognized and accepted.

In accordance with this, the National Government through the Department of Mineral Policy & Geohazards Management since 2009 has been embarking on a comprehensive review of the policy and legislative framework regulating mining operations including the drafting of a mine waste management policy for Papua New Guinea to address some of the pressing environmental issues regarding mine waste management.

2. DEFINITION OF MINE WASTE

Waste' is a generic term used to describe the various materials remaining at a mining operation after recovery of the metals such as liquid wastes, domestic solid waste from campsites, tires and other waste from the maintenance of equipment, laboratory waste, etc (Lappako 1994).

However, the focus here will be on the wastes originating from mineral extraction and processing as these have been renowned for their potential to cause severe and widespread

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destruction to receiving environments. Hence the common types of wastes generated from mining are as follows:

- **Overburden:** The rock above the mineral resource that must be removed in order to mine the mineral resource.
- **Waste rock:** Barren or uneconomic mineralized rock that has been mined, but is not of sufficient value to warrant: treatment and is therefore removed ahead of processing.
- **Low grade ore stockpiles:** Rock that has been mined and stockpiled with sufficient value to warrant processing, either when blended with higher-grade rock or after higher-grade ore is exhausted, but often left as 'waste'.
- **Tailings:** The solid product of the treatment and mineral concentration process that are considered too low grade to be treated further. Tailings are the finely ground host rock materials from which the desired mineral values have been largely extracted.
- **Heap leach Spent Ore:** Rock remaining after recovery of metals and some soluble constituents through heap leaching and heap rinsing of ores.

3. MINE WASTE CHARACTERISTICS

The volume of waste generated by mining depends on the geological characteristics of the ore body, the method of (underground or open pit), the type of metal being mined and the subsequent mineral processing technology employed as well as the size of the mining operation (Van Zyl et al 2002). Comparisons done by the authors (ibid) on both open and underground mining indicate that less mine wastes are generated from underground mining than open cut mining due to high ore grade and less tonnage. Furthermore, mine production rates in open cut copper mines are higher hence produce more wastes than at gold and silver open pit mines.

4. RATIONALE FOR WASTE DISPOSAL OPTIONS

Selecting a suitable disposal site is very much determined by the proximity of the ore body or processing plant (mill site) taking into consideration land availability and/ or costs of transporting the tailings (Murray & Thompson 2005) However, the location of a waste disposal site often requires compromise from various stakeholders with differing interests. For instance, the location may contain scared sites that are revered by traditional landowners whilst conservation groups may want to preserve it for species protection. However, choices have to be made on whether to have a mine with a tailings disposal facility with some acceptable impact or no mine at all.

5. MINE WASTE DISPOSAL METHODS IN PAPUA NEW GUINEA

Historically, most mining operations in Papua New Guinea have been discharging their wastes mostly through riverine tailings disposal method. With some projects located within coastal proximity, the deep-sea-tailings placement (DSTP) system has been feasible for tailings discharge following the success of the method in the Misima mine.

Table 1. Annual Tailings Discharge Volumes (tons) for Mining Projects in Papua New Guinea

Project & Ore Type	Tailings (tons/pa)	Disposal Method
Panguna (Au/Cu)	>500Mt	Riverine
Ok Tedi (Au/Cu)	>600Mt	Riverine
Porgera (Au)	>100Mt	Riverine
Tolukuma (Au)	~1.5 Mt	Riverine
Misima (Au/Ag)	>60Mt	DSTP
Lihir (Au)	>80Mt	DSTP
Ramu (Ni/Co)	140 Mt	DSTP
Hidden Valley (Au/Ag)	>37 Mt	TSF (On-land)
Solwara 1 (Cu/Au) *(Offshore)*	>1Mt	DSTP

Both of these methods consist of sub-aqueous discharge of tailings directly to the receiving environment. DSTP relies on the use of natural valleys and canyons on the sea floor to contain the waste, whereas riverine disposal utilizes the natural sedimentation processes present in rivers to disperse the tailings.

The type of waste disposal method adopted in a mine is usually determined by the developer during the pre-feasibility, feasibility and final design phases of the project in consultation with other key stakeholders (Hutchison & Ellison eds; 1992).

The mass or volume of the mine waste produced is an indicator of the potential physical impact on the land surrounding the operation and not necessarily of the amount of pollution that may result. Rather it provides an indication of the type of options that can be considered for mine design in order to minimize the overall volume of waste disposed

(Van Zyl et al 2002).

6. RIVERINE TAILINGS DISPOSAL

It has been argued over the years that the physical condition of the mine site has been the main criterion for adopting the riverine disposal option (e.g. Van Zyl et al 2002, Murray & Thompson 2005). Building a land-based tailings impoundment depends very much on the physical stability of the project landscape. Areas of high rainfall and seismicity can poses serious engineering challenges and risks to tailings impoundments given probability of a dam collapse which could endanger human lives as well as the condition of the natural environment. Examples of this are the accidents in Aberfan (Wales, 1966), Ok Tedi (Papua New Guinea 1984), Stava (Italy, 1985), Aznalcóllar (Spain, 1998), Baia Mare and Baia Borsa (Romania, 2000).

Riverine tailings disposal has also been considered as a cheap way of discharging wastes, although an undesirable one. Locating ore processing plants in close proximity to a river system meant that wastes could easily be disposed into the river without incurring additional costs. While it may require minimal infrastructure, the downstream rehabilitation costs associated with environmental and social damages can outweigh the capital costs of ore extraction (Hutchison & Ellision; eds 1992). This has been the crux of the ongoing debate on whether or not the economic gains can be balanced with environmental and social concerns. In the Papua New Guinea, this scenario can be best evaluated through the Panguna, OK Tedi and Porgera experience in which evidence of declining water quality and ecosystem health and subsequent impacts on people's social livelihoods is well documented.

6.1. Environmental Impacts

The type and extent of environmental impacts resulting from riverine waste disposal may vary depending on the nature of the river. Disposing of large volumes of mine waste into a river system will increase particulate load and may result in the downstream deposition of sediments. With elevated levels of total suspended solids already present in some rivers due to natural sediment load and deposition along the river system, the addition of mine derived ore residues further aggravates the problem of sedimentation.

6.1.1. Increased Sedimentation

Sediment deposition downstream of the mine depends on the size of particles and the nature of the river's flow. Coarse tailings and waste rock can deposit closer to the discharge point if the energy of the river system decreases sufficiently. Fine tailings are more easily transported through the entire river system. Sedimentation of finer particles occurs to a higher degree in the flatter reaches of river systems. Sediment deposition results in riverbed aggradations and over-bank deposition thus reducing oxygen levels to such an extent that the vegetation along the river bank is killed off in what is commonly referred to as *die back* . This can affect availability of food sources for terrestrial animals and humans which depend on riverbank vegetation for survival as in the case of sago palm (*Cicad revoluta*) trees.

6.1.2. Degradation of Water Quality

Riverine disposal of mine waste also introduces metals or other minerals into the river water as well as process chemicals, which may affect water quality. Fine sediments, in particular tailings, may increase heavy metal concentrations in the solid fraction known as the particulate load or suspended solids. Metals and other elements may also be present in a dissolved form that is more easily bio-available. At different distances from the discharge point, the dissolved and particulate levels of lead, mercury, zinc and copper are of varying degrees of concern as observed in Porgera, Tolukuma and Ok Tedi (Shearman 1995).

Discharging mercury into rivers can be particularly problematic as it is bio-accumulative and remains in the environment. Groundwater sources can also be impacted depending on the hydrological regime. Acid drainage from over-bank deposition of mine waste also affects water quality (Hutchinson & Ellsion; eds, 1992).

6.1.3. Ecological Impacts

Riverine waste disposal also poses significant impacts on ecological communities along the river system. Increased sediment loads and changes to flow regime may change the number of population of aquatic species such as migratory fish which may not reach tributary rivers for spawning. The uptake and bioaccumulation of heavy metals in freshwater or marine species such as bivalves and fish species is possible and can lead to smothering of some species thereby triggering an imbalance in the ecosystem food chain.

6.2. Ok Tedi Case Study

There is overwhelming empirical data indicating that riverine tailings disposal is ecologically unsustainable with significant health and social risks (e.g; Macdonald 2004; Shearman 1995;). The present degraded condition of the Fly River Catchment due to accumulated levels of tailings and waste rocks transported downstream from the giant Ok Tedi mine perhaps underscores the grey side of mining in PNG.

Figure 1. Forest and Vegetation Die-back along the Ok Tedi River Catchment (Photo by Stuart Kirch 1996)

Since its commencement, high sediment levels from both waste rocks and fine mill tailings from the mine resulted in riverbed aggradations which subsequently led to over-flooding on the riverbanks. The high pyrite content of waste rocks gave rise to the problem of acid rock drainage (ARD) as these rocks came into contact with water along the river channel. Consequently, the Ok Tedi Mine is renowned worldwide in the mining circles for widespread environmental damage along the river as evidenced by vegetation dieback, degraded water quality and depletion of fish stocks.

Since then it has become the focus of much publicity hence leading to intensive lobbying and campaigning by environmental and human rights groups for the government to do away with riverine disposal. Despite company reports asserting compliance monitoring results to be within acceptable levels, public outcry on both the local and international front resulted in a litigation case brought against the developer BHP Limited by affected communities along the river which resulted in the US$500 million out of court settlement compensation package (Van Zyl et al 1992)

6.2.1. Treatment & Rehabilitation

The Ok Tedi river catchment is beyond any repair in the foreseeable future although rehabilitation programs have been undertaken by the mine to re-vegetate impacted areas and to reduce the problem of sedimentation through a riverbed dredging program. Mitigating such a scale of environmental impact on the river system is quite challenging as it requires innovative technology with improved engineering design and standards for waste treatment and rehabilitation programs of impacted sites.

6.2.2. Socioeconomic Impacts

Ok Tedi' riverine tailings disposal method and its associated environmental impacts have had undesirable socio-economic consequences on the livelihood strategies of downstream communities in view of the different ecosystem services provided by the river. Degraded water quality and increased sediment levels led to the following socioeconomic constraints:

- Limited or no access to river water for drinking, cooking, cleaning and bathing;
- Decrease in local fish populations hence affecting subsistence or commercial fishing;
- Widened river channels and changes in the flow regime may alter river transportation and crossing points.
- Reduction in areas used for riverside gardening and hunting due to over-bank deposition and die back;
- Health risks posed by exposure to bio-accumulated heavy metals.

Providing alternative food security measures with safe and adequate water supply sources apart from sustainable economic activities are necessary for communities which are faced with such environmental dilemma. The PNG Sustainable Program is an example of a mine-sponsored scheme which administers State equity in the Ok Tedi project to provide alterative food security programs and infrastructure services to the mine-impacted areas of Western Province. Similar programs are put in place by other mining companies to improve community livelihoods.

6.2. Deep Sea Tailings Placement (DSTP)

Tailings discharge through a deep sea tailings placement option is considered to be the most economically viable option for mining projects located coastal and nearshore regions of Papua New Guinea despite the environmental risks associated with the practice. The Misima mine was the first project to utilize this method for its tailings disposal followed by Lihir and Ramu Nickel. It involves discharge of tailings slurry form a submerged outfall with the ultimate deposition at 1000m or deeper.

Jones and Jones 2001 define deep sea tailings disposal as the discharge of a tailings slurry form a submerged outfall with the ultimate deposition at 1000m or deeper as shown by the Figure 3 below.

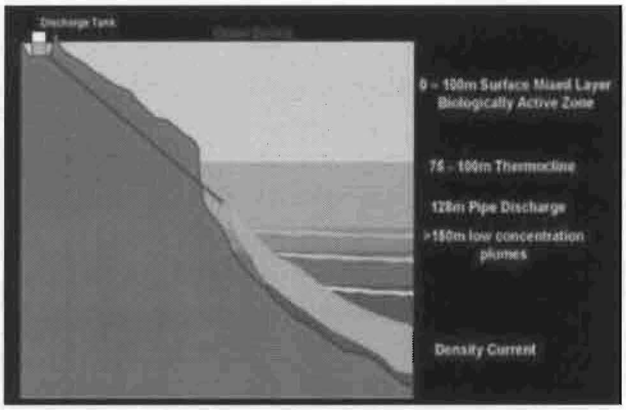

Figure 2. Schematic diagram of a typical Deep Sea Tailings Placement system

The method essentially involves piping of neutralized tailings into a mixing tank at a near shore facility undergoing de-aeration and dilution with seawater. The tailings are finally pumped at high pressure into the sea through a submerged pipe usually as a coherent flow eventually descending to deeper regions of the ocean.

The density differences in the ocean water column cause stratification which theoretically is said to be effective in trapping the tailings material at those depths (Van Zyl et al 2002). Within the stratified column, there is distinct boundary between an upper well-mixed layer and a lower unmixed layer. If tailings are mixed to a density the same as that of the bottom water they will usually form a 'density current' and travel to the bottom of the lower water body. Such turbidity currents generally require a seabed slope that is greater than 10-12° to occur on a continuous basis (Jones & Jones 2001). The probability of plum shearing along the density current raises serious concerns as fine suspended particles always break off from the main stream and can be carried to the top by up-welling currents. This may pose serious threats to marine organisms and coral reefs in the upper layer of the ocean strata.

6.2.1. Environmental Impacts

It is not known as to whether the benthic organisms can regenerate and coexist with the tailings at great depths. The extent of this impact is difficult to predict because little is known about deep sea benthic organisms and deep sea ecosystems. However there may be possible interactions and dependence between benthic fauna and surface fauna would imply risks to marine species throughout different ocean depths.

A study done by the Scottish Association of Marine Sciences on the impacts of DSTP operations in Misima, Lihir and Ramu mining projects (Shimmeld 2010) to some extent supports the following general observations:

- Smothering of benthic organisms along the pathway of tailings movement.
- Increased turbidity due to plume shearing which affects species relying on bioluminescence to survive at those depths.
- Plume shearing can also distribute tailings to areas wider than expected hence increasing the area of impact.
- Bioaccumulation of toxic heavy metals in marine organisms which feed along the edges of subsurface plumes thus having serious implications on the health of organisms further up the food chain including human beings.

It is therefore critically important to ensure the safety and integrity of tailings pipelines are maintained as these are known for breaking and leaking both on land and sea due to landslides, shipping, storms, and tsunamis. Incidents such as these must be avoided as much as possible through precautionary approach and strategies given the potential impact on shallow and coral-rich areas.

6.2.2. Socioeconomic Impacts

Many island and coastal communities are heavily dependent on the sea and its marine resources for food security, recreational purposes, and customary practices. The ecological and human risks posed by DSTP is yet to be fully understood due to the complexity of biological interactions within deep ocean ecological communities and those of the upper and shallow layers. It is therefore critical to apply the precautionary principle and strategies in DSTP operations.

7. RISK ASSESSMENT

Risk assessment is a fundamental component of waste management strategies in mining in order to identify the potential environmental and socioeconomic impacts of waste disposal systems. Determining the magnitude and extent of impacts of waste disposal systems has been a challenging task for mining companies due limitations in obtaining credible scientific data and the existing gaps in knowledge in order to make accurate predictions. Accurately predicting impacts is important for a number of reasons given below (Van Zyl et al 2002):

- Successful compensation negotiations depend on a sound knowledge of potential impacts and their extent. This is also vitally important in order to enter into any balanced negotiations on trade-offs between the economic, environmental and social impacts.

- Mitigating unanticipated impacts implies taking into account changes in circumstances through ongoing or periodic risk assessments. The large percentage of error in predictions made by risk assessment models justifies monitoring and re-evaluations to understand why predictions are inaccurate.

Detailed risk assessment of predication models can help establish the level of confidence in decision making regarding the mineral extraction, processing and waste disposal options. This is vital to ensuring that the proposed disposal options do not present unacceptable risks to the physical or social environment. Additionally, independent assessments and peer review of predication models are also an effective way to increase the level of confidence on the risk management strategy.

8. ENVIRONMENT REGULATOY FRAMEWORK IN PAPUA NEW GUINEA

8.1. Mining Act 1992 and Mining (Safety) Act & Regulations 1977

Mining operations in Papua New Guinea are governed by the Mining Act 1992 in terms of licensing and regulation in addition to the Mining (Safety) Act & Regulations 1977 which basically focuses on health and safety aspects. Both legislations are administered by the Mineral Resources Authority whilst the Department of Mineral Policy & Geohazards Management is responsible for providing policy advice on pertinent issues in mining apart from reviewing existing mining legislations and policies to make them compatible with globally competitive standards and practices. The Ok Tedi Mine however operates under its own legislation namely Mining (Ok Tedi Mine Continuation (Ninth Supplement) Agreement Act 2001 due to the unique circumstances surrounding the operations of the mine.

The Mining Act 1992 requires the developer to submit proposals for development as part of its mining license approval process of which an Environment Impact Statement (EIS) is also included. The EIS identifies and defines various aspects of the project and the associated impacts, the receiving environment and detailed mitigation plan and strategies. The approval for a mining lease is therefore contingent upon the approval of the EIS as required by the permitting process of the Environment Act 2000.

8.2. Environment Act 2000

The principal legislation overseeing environmental management in general including mine waste management is the Environment Act 2000 and is administered by the Department of Environment & Conservation (DEC).

Environmental quality within each segment of the environment is defined within the EIS by establishing the characteristics of the natural environment and the values that it supports. Where environmental quality has been modified as a result of anthropogenic input, the existing status quo would be appraised before deciding, with inputs from relevant stakeholders, the level of protection that can be offered to protect certain environmental values but to forego others due to the level of impact.

The Environment Act 2000 also provides the legal basis for the establishment of a range of mechanisms for the protection and management of the environment, including:

- **Regulations:** Environment (Permits & Transitional) Regulation, Environment (Prescribed Activities) Regulation, Environment (Fees& Charges) Regulation, Environment (Water Quality Criteria) Regulation and Environment (Procedures) Regulation. The requirements in each of the Regulation, apart from Environment (Procedures)

Regulation, are specific for a variety of pollution control purposes.

- **Environment Permit:** Environment Permit is issued to the mining company once the State, through the Department of Environment and Conservation (DEC) is satisfied that all environmental concerns are addressed for each development phase of the mine. The granting of a mining license is therefore contingent upon the issuance of the environmental permit. The permitting process enables DEC to have direct control of activities that may impact on the environment. The permit is a tool that is employed by the Department to have an early input into the design of a project to ensure that the overall objectives of the *Environment Act* are complied with. Specific discharge conditions are also incorporated into the permit to ensure that those objectives are met.

- **Enforcement:** Enforcement tools available under the Act include issuance of notices in situations where an environmental problem has occurred or is likely to occur. Depending on the nature of the problem, the appropriate notice is served on the person who is effectively in charge of the premises requiring an evasive action or clean up after an incident has occurred.

Over the years DEC has been poorly resourced and understaffed hence constraining the Department to effectively discharge its statutory responsibilities. Ensuring that development activities with potential for causing environmental harm are adequately regulated remains a bid challenge for such an important government body.

8.3. Mine Waste Management Policy Framework.

Due to the complexity of environmental issues and their unique challenges in the mining industry in Papua New Guinea, the Department of Mineral Policy & Geohazards Management has embarked on developing a specific policy for the management of mine waste in Papua New Guinea. This is basically to address the policy gaps in both the environment and mining legislations and to create a mandatory environment for developers to adopt best available technologies and standards in their waste management programs.

8.4. General Guidelines for Deep Sea Tailings Disposal Systems in Papua New Guinea

This guideline is currently in place to monitor and regulate mining projects employing the DSTP method for waste disposal. However, specific guidelines have also been developed for the Lihir and Ramu Nickel Projects respectively in view of the unique environmental conditions of the DSTP sites for each project.

9. CONCLUSION

The mining industry in Papua New Guinea is confronted with many challenges given the environmental and socioeconomic impacts of mine waste disposal. The waste discharge options currently practiced in the industry are riverine waste disposal and deep sea waste disposal. The magnitude and level of risk and impact on the environment varies accordingly with each type of disposal practice. Waste storage in tailings containment facilities is also an option that presents major engineering challenges given the environmental and physical setting of most projects.

Given the economic importance of mining, further developments in the sector are vital however must be guided by effective regulation and enforcement to ensure that mining is conducted in an environmentally responsible and socially acceptable manner. Current waste management options need to be reviewed and aligned with government policy on environmental protection and sustainability. While there may be trade-offs involved with riverine and deep sea tailings disposal systems, instituting best practice standards with proper enforcement mechanisms go a long way in ensuring good environmental governance. The Mine Waste Management Policy is anticipated to address these pertinent issues in a holistic manner with input from relevant stakeholders.

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