Staged Development and Environmental Management of the Porgera Gold Mine, Papua New Guinea

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Abstract

The Porgera Gold Mine is presently being constructed in the Central Highlands of Papua New Guinea. The mine is located within the catchment of the Porgera River which drains into the Lagaip, Strickland and Fly River system. Stage I of the mine and ore processing plant commenced production in September 1990.

The staged development of the mine and ore processing plant are described. Information is presented on management of mine wastes, with particular reference to chemical treatment of mill tailings. The predicted environmental effects resulting from riverine disposal of tailings are discussed.

Introduction

The Porgera Gold Mine is located in Enga Province, in the central mountainous region of Papua New Guinea. The Porgera gold/silver deposit has been the subject of mineral exploration since 1960, by a number of companies working singly and jointly. Commencing in 1980, active exploration and development planning have been conducted by a consortium of companies known as the Porgera Joint Venture (PJV). RGC (Papua New Guinea) Pty Limited, Highlands Gold Properties Pty Limited and Placer (PNG) Pty. Limited are equal partners in the venture, with the Papua New Guinea Government holding a 10 percent share.

At an early stage of project planning, the joint venturers made a commitment to ensuring that the environmental effects of the mine were given careful consideration, and that an acceptable balance was achieved between the responsibilities of protecting the environment and extracting minerals economically. Investigations began in 1980, with the collection of preliminary baseline information on the land surrounding the ore body and the river basin containing the proposed mine (NSR, 1980; NSR, 1982).

This was followed by a more detailed baseline survey in 1984 and a series of studies on the characterisation of effluent, the development of methods for treatment of tailing and the assessment of effects on the receiving river system. Detailed environmental investigations culminated in the preparation of an Environmental Plan for the mine (NSR, 1988). In May 1989 the Papua New Guinea Government approved the Project Proposal for Development and the Environmental Plan for the mine. Construction of the mine commenced shortly thereafter.

Physical Setting

The Porgera valley is a high-altitude basin ringed with rugged mountains, with a floor level of about 2000 metres and rising to a maximum height on the rim of 3850 metres. The Porgera gold/silver ore body lies in and adjacent to Mt. Waruwari, elevation 2800 metres.

The predominant climatological feature of the region is rainfall. Mean annual rainfall is approximately 3600 mm and precipitation occurs on over 300 days each year. Rainfall tends to be heavier during the December to February period, and extensive cloud cover is common.

Temperatures in the Porgera area range from a daily average minimum of 11°C to an average maximum of 22°C. Relative humidity is quite high and averages between 80 and 90 percent.

The geology of the upper Strickland catchment is dominated by the Jurassic Maril Formation, comprising fine grained marine sediments in the form of dark grey and black shales. These rocks weather rapidly and are extremely unstable. Landslides are a characteristic feature of the steep valleys of the catchment. River sediment loads consequently are high.

Hydrology

The ore body is located in the headwaters of the Porgera River, which drains into the Lagaip, Strickland and Fly River system (Figure 1). Hydrological records from five gauging stations (SMEC, 1985) have been used to estimate discharge. Daily mean discharges are shown in Table 1, together with corresponding total suspended solids (TSS) concentrations. The variation in flow between low and high extremes at each station is not exceptionally large.

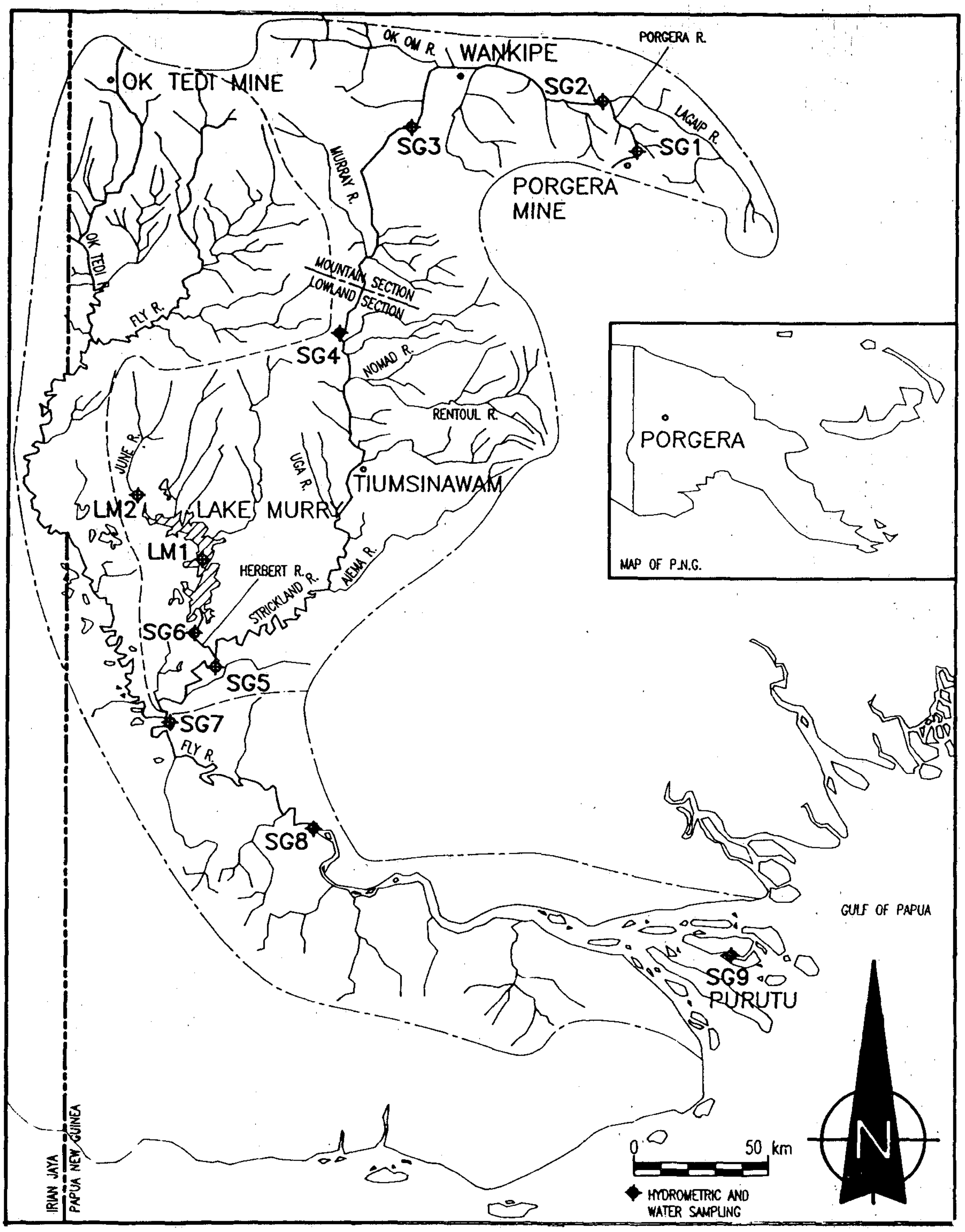

Figure 1. Riverine Sampling Locations.

Table 1. Baseline Flow and Total Suspended Solids concentrations at SG1, SG2 and SG3

STATION	TSS(gm^{-3})	FLOW(m^3s^{-1})
90% E FLOW		
SG1	275	6.2
SG2	165	70
SG3	197	319
10% E FLOW		
SG1	995	28
SG2	7885	320
SG3	6020	1243
MEAN FLOW		
SG1	615	16
SG2	1185	180
SG3	1440	704

Water Quality

The predominant and most variable characteristic of river water quality is TSS. Suspended solids loadings are high, with turbid water always present in the rivers (Table 1). TSS is strongly correlated with discharge (Figure 2).

The waters of the rivers are calcium bicarbonate dominated, characteristic of limestone catchments. The pH is high, at around 8, as are suspended solids and organic carbon. Total heavy metal concentrations of water are high, reflecting the high sediment loading. However, the metal concentration of the solids (Table 2) and the level of dissolved metals are low (PJV, 1990).

Table 2. Background Particulate Metal Concentrations ($mgkg^{-1}$)

STATION	As	Cd	Cu	Fe	Pb	Hg	Zn
SG1	6.8	0.3	30	55000	29	0.2	131
SG2	3.1	0.1	30	45000	23	0.1	108
SG3	6.2	0.5	22	47500	17	0.1	88

The high pH, bicarbonate, suspended solids and organic carbon are all indicative of a system well buffered against the dissolution of heavy metals into the aqueous phase.

Mine Development

The mine is being developed in stages, with a combination of underground and open pit operations. The optimum mining strategy involves the development of an underground mine to extract the higher grade ore during the first seven years of production. The extraction of this deep, higher than average grade ore early in the mine's life is vital to the economic viability of the project.

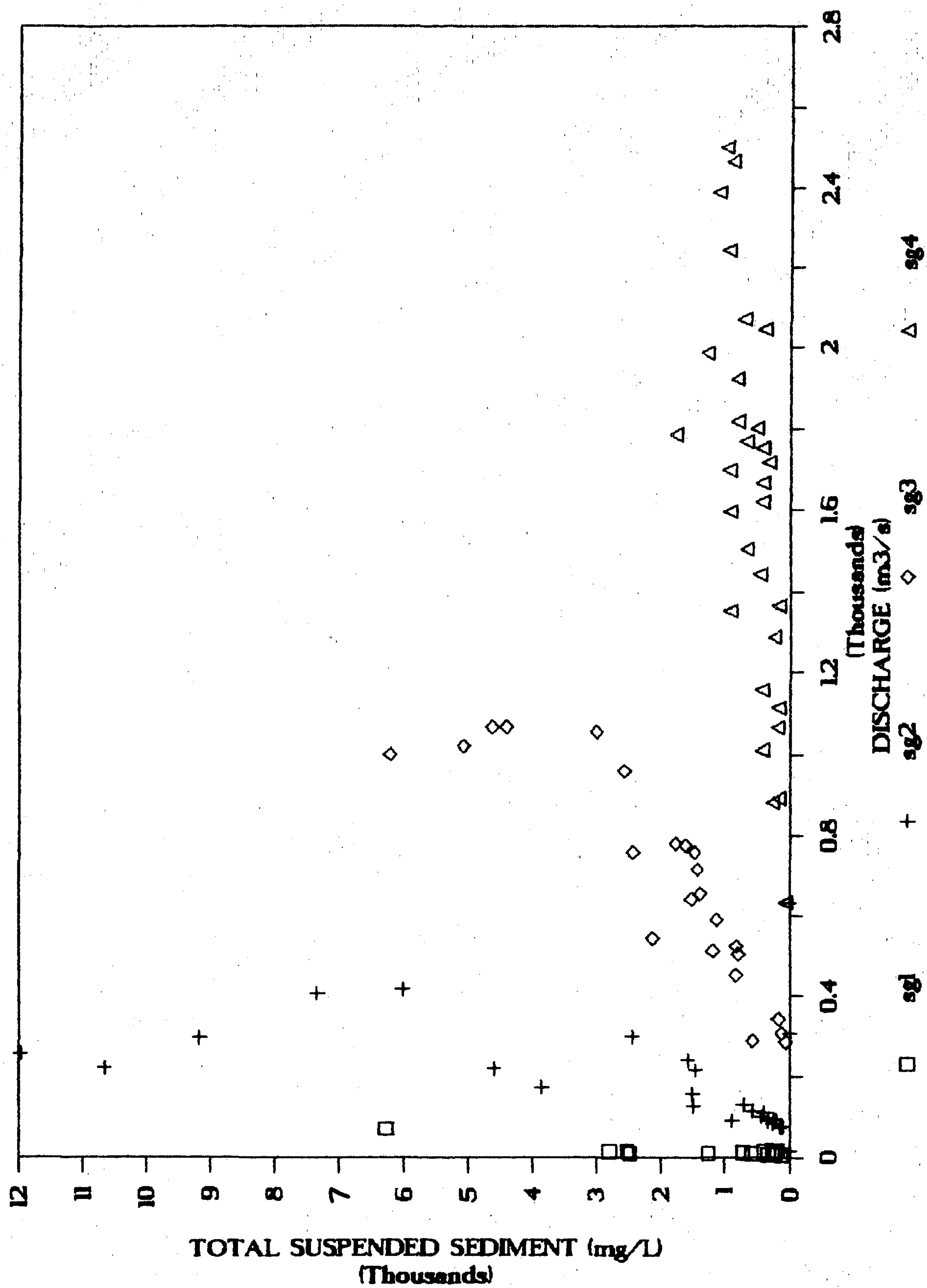

Figure 2. Variation of suspended sediment with discharge.

The open pit will be developed in three stages over the production period of 18 years and will involve the removal of a substantial part of Mt. Waruwari. Approximately 48 million tonnes of ore will be mined from the pit, with 313 million tonnes of waste rock generated.

Both soft and hard waste rock from the pit will be stored in a waste dump immediately to the west of the pit. The proposed dump area is a bowl shaped valley with a downward slope from south to north averaging 9° over a distance of 2.3 kilometres. Foundation conditions in the dump area vary from reasonable to poor. Weak foundation conditions and high rainfall preclude conventional methods of dump construction. Special dump design measures are required to overcome the poor foundation conditions and the weakness of the materials to be stored (Klohn Leonoff, 1986).

Ore Processing

Most of the Porgera ore is highly refractory and requires a complex treatment process to achieve satisfactory gold recovery. Early on, it was clear that direct cyanidation would yield poor recovery because most of the submicroscopic particles of gold were locked within the crystal structure of pyrite. Destruction of pyrite by acid pressure oxidation was selected as the most favourable method of accomplishing this. The ore processing plant is being developed in two stages.

The Stage I plant processes 1500 tonnes of ore per day from the underground mine. It comprises crushing and grinding, followed by gravity recovery of coarse free gold (Figure 3). The sulphide minerals are recovered by conventional flotation then subjected to cyanidation leaching to extract part of the gold. Cyanidation tailing, containing the refractory part of the ore is stored in a lined pond for later treatment by pressure oxidation.

Stage II plant involves the addition of pressure oxidation to the treatment process, commencing in mid-1991 (Figure 4). The sulphide flotation concentrate will be oxidised under pressure in autoclaves, rendering the contained gold amenable to dissolution by cyanide. The residue of oxidised solids will be washed by countercurrent decantation. The gold and some of the silver in the washed solid residue will then be recovered by cyanidation leaching and carbon-in-pulp.

The concentrator capacity will be increased to 4500 tonnes of ore per day in 1993. Underground ore production will increase to 3500 tonnes per day, with 1000 tonnes per day mined from the open pit. Twelve months later the concentrator capacity will be increased to 8000 tonnes per day, with open pit ore production increased to 4500 tonnes per day. The underground mine will cease operation in 1997.

Effluent Disposal

The ore processing produces three main effluent types. These are flotation tailing, acid wash effluent and cyanidation tailing. Individually, these streams will contain a variety of potentially toxic environmental contaminants, including cyanides, acids, alkalis and dissolved trace metals. Mercury present in the ore body is considered the priority trace metal because of the potential for bioaccumulation and bioconcentration. Also there is the potential of increased physical loading of waste solids on the environment.

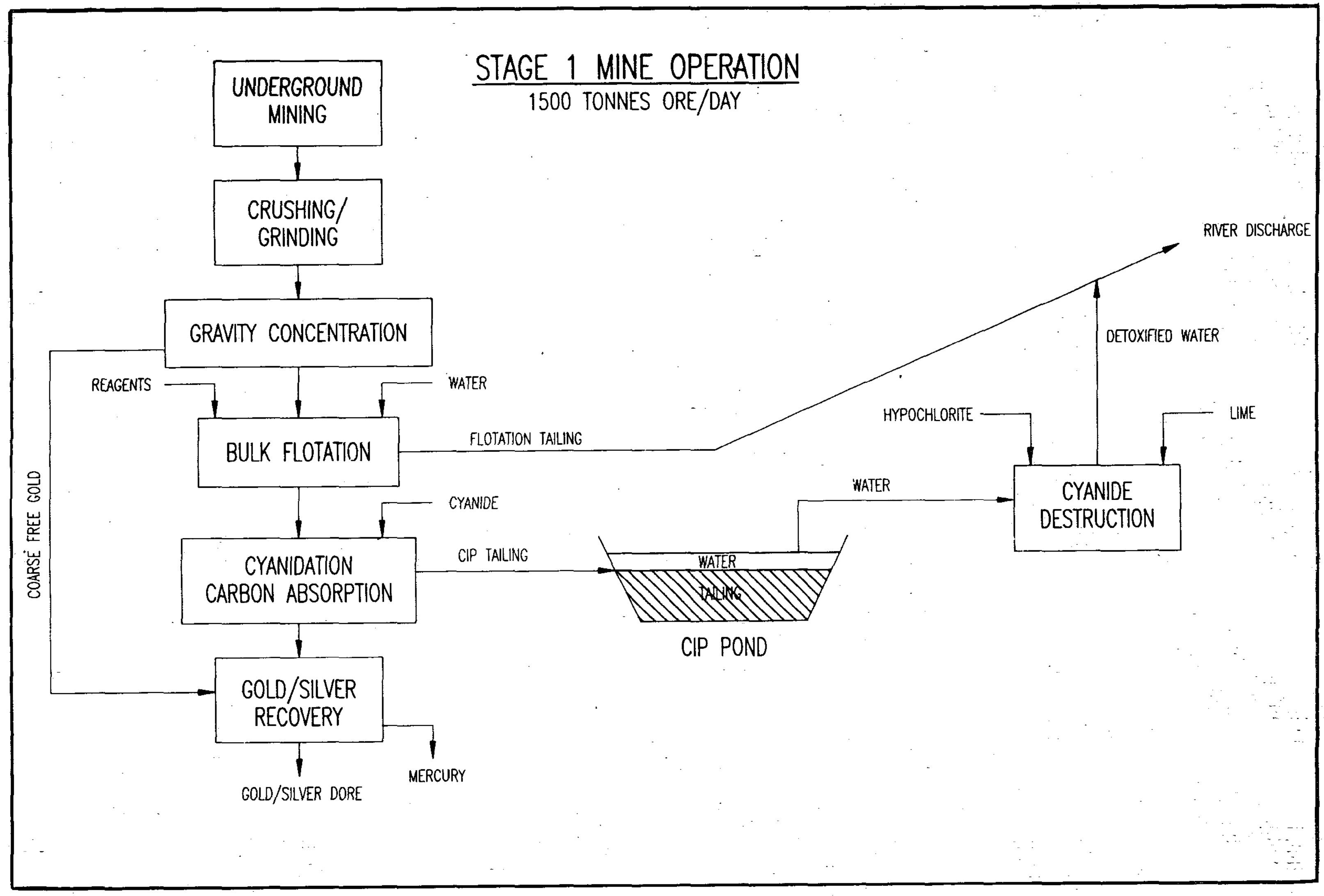

Figure 3. Stage I process flow sheet.

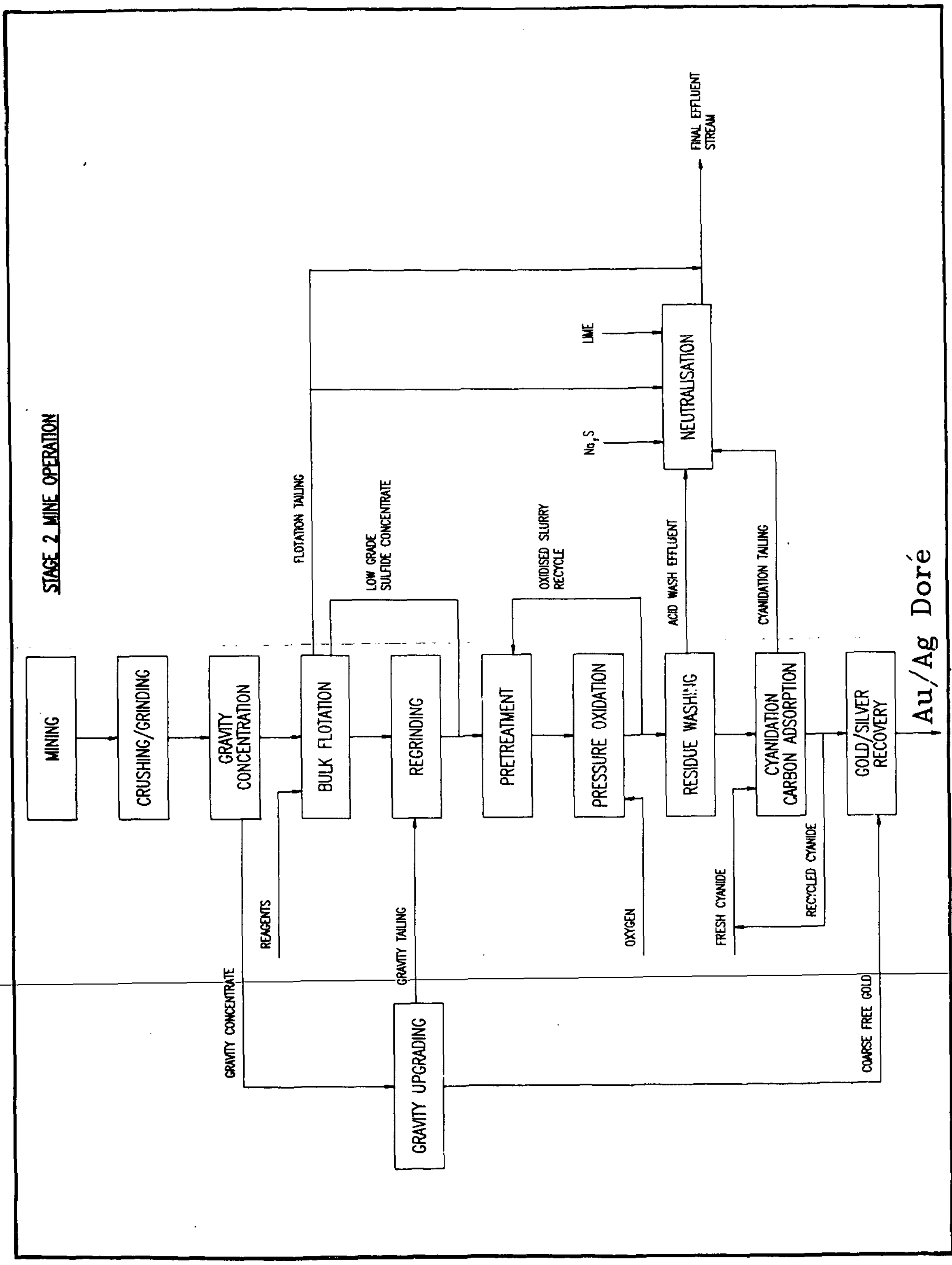

Figure 4. Stage II process flow sheet.

At an early stage of development planning it was recognised that the foundation conditions of the Porgera valley were unable to support an impoundment for safe, permanent storage of tailing (Klohn Leonoff, 1984). The implications of river disposal of tailing have been investigated in detail and this is the main issue addressed in the Environmental Plan.

Laboratory Testwork

The extensive metallurgical program to test the processing of ore provided an ideal opportunity to optimise in-plant treatment of wastes to minimise the downstream impact of riverine disposal. The components of the environmental testwork were:

- Determination of the chemical characteristics of process waste streams for different ore types.
- Optimisation of waste treatment, in particular residual cyanide destruction, neutralisation of acid autoclave effluent and precipitation of dissolved metals.
- Laboratory simulation of downriver water quality and analysis of mixed and diluted effluent for chemical indicators of toxicity.
- Acute toxicity testing of waste streams by bioassay screening.
- Determination of particle size and settling characteristics of tailing solids.
- Assessment of the deportment of mercury through the process.
- Determination of the potential for the transformation of metals from the solid phase of the waste stream to the liquid phase of the receiving river system.

Effluent Treatment

Flotation tailing consists of waste rock and residual alkaline flotation reagents. Bioassay tests demonstrated that flotation tailing has low toxicity, and does not require treatment prior to discharge (Rescan, 1987a).

However, the acid wash effluent from the pressure oxidation circuit contains high concentrations of trace metals, while the cyanidation tailing contains significant concentrations of residual cyanide. An effluent treatment process has been developed which involves neutralising the acid wash effluent and precipitating dissolved trace metals by addition of alkaline flotation tailing and lime.

Cyanide destruction testing has demonstrated that "Prussian Blue" precipitation offers a reliable means of cyanide detoxification. This in-situ process involves the formation of highly insoluble and stable ferric-ferro-cyanide complexes under acid conditions. Additional testwork has shown that treatment of the acid wash effluent and cyanidation tailing with sodium sulphide will precipitate mercury as mercury sulphide of low solubility and inherently low biological availability.

Toxicity of Mine Waste

The potential toxicity of mine wastes can be attributed to trace metals, cyanide and the physical effects of sediment.

The environmental testwork programme has demonstrated the feasibility of treating tailing chemically to produce an effluent with low concentrations of trace metals in the aqueous phase (Rescan, 1987b). The river conditions of high pH, alkalinity and suspended solids concentrations are such that mobilisation of metals into the liquid phase will be minimal.

Since the acute toxicity of metals depends primarily on the concentration of the free, uncomplexed metal in solution, rather than the total metal concentration, toxicity in the main river system from trace metals is expected to be of minor importance.

Bioassay tests of the "Prussian Blue" treated final effluent showed low toxicity associated with the solids fraction of tailing. The toxicity was attributed mainly to residual concentrations of ammonia. Upon discharge, the residual ammonia present in tailing will be diluted rapidly to innocuous levels with the receiving waters.

Predicted Environmental Impacts of the River System

The zone of mine waste impact on the river system is determined by the physical effect of solids on biota rather than by chemical effects.

Approximately 74 million tonnes of mine-derived sediments, comprising construction spoil, tailing and solids eroded from the waste rock dump, are expected to enter the river over the 18 year mine life. All tailing and 90 percent of the soil, totalling 63 million tonnes are finer than 0.2 mm. Sediment transport calculations show that the entire river system can easily transport the anticipated 3.4 million tonnes annually of the fine sediments. Coarser materials are expected to be deposited in some sections of the rivers during low flow. However the deposition is expected to be minimal over the very large surface area of the river system.

The natural sediment load of the river system already is high due to numerous slope failures in the catchment. In order to assess the aquatic biological impacts of mine sediments, predictions have been made of the increase of suspended solids concentrations above background levels, for a range of river flows. With the exception of the Porgera River, operational inputs of mine sediments will increase TSS concentrations fractionally, and most of these predicted TSS concentrations lie within the background range of concentrations already experienced by Lagaip River mainstream fish populations.

The predicted biological impact zones shown in Figure 5 have been derived from consideration of the increment of mine derived sediment above background levels. For mean flow conditions at SG2 on the Lagaip River, mine derived sediment will increase TSS by approximately 51 percent above background levels (NSR, 1986). This reduces to a 10 percent increment of TSS at SG3 on the Strickland River. The biological impact of mine derived sediment decreases downstream from the mine, with no predicted effects below the Lagaip-Ok Om confluence.

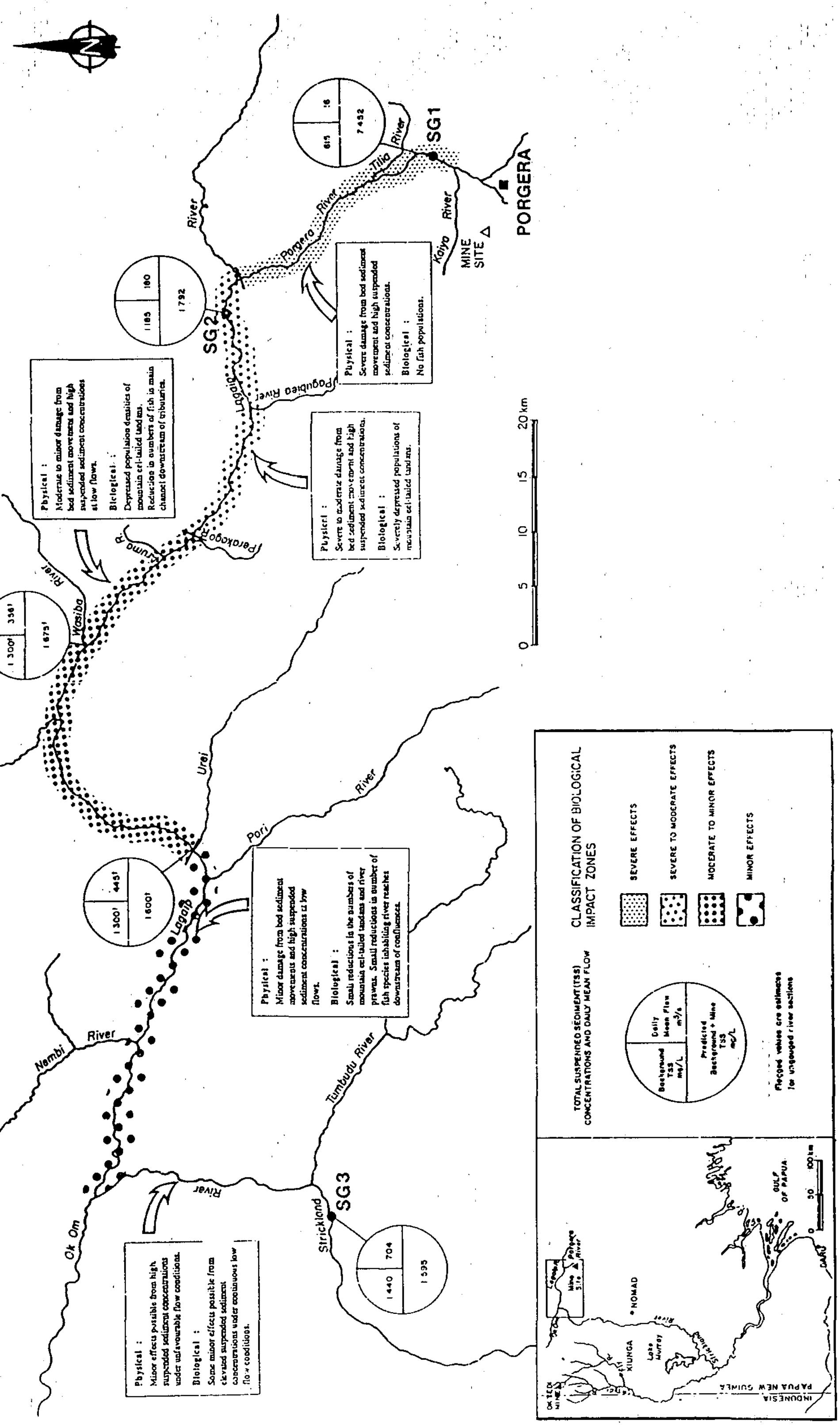

Figure 5. Biological Impact Zone of mine sediment on the river system (After NSR, 1988).

Effects on Lake Murray

A pathway exists for mine tailing to enter Lake Murray, a large off river water body. Lake Murray normally drains into the Strickland River via the Herbert River. However, when the Strickland River floods and the water level in Lake Murray is low, back flow can occur up the Herbert River.

The extent and significance of increased mercury loading on Lake Murray has been investigated in detail by means of hydrological data collection, suspended and bed sediment sampling, geomorphological analysis and geochemical analysis. The results of the investigations show that for bio-available mercury, bed sediment concentrations in Lake Murray may increase by less than one percent over background levels after 18 years of mining. Although this predicted increase is small, mercury levels will be monitored closely to check for any changes.

Effects on the Fly Delta

Given the sediment transport capacity of the river system and the very fine size of the tailing particles, all tailing solids are predicted to be carried in suspension to the Fly Delta. Assuming that all tailing solids reach the Fly Delta, the average annual loading on the Delta from Porgera is estimated at 3.16 Mta^{-1}. This represents an increase of 3.2% above the estimated natural sediment loading at the Delta of 100 Mta^{-1}. The small increase in suspended sediment derived from Porgera will have negligible physical effects on the biota of the Delta.

The increment in mine derived mercury is unlikely to be environmentally significant for the following reasons:

- There will be high dilution of Porgera tailing by natural deltaic sediments and by solids from the Ok Tedi Mine, low in mercury.

- Tailing solids from the mine will not be permanently resident in the Delta, but will be reworked within the high energy deltaic environment prior to eventual deposition in deep waters off the Gulf of Papua.

- Mercury will be either in the residual mineral phase in the solids, or as mercuric sulphide, and is unlikely to be available to estuarine and marine biota.

- There will be little mercury in the ion-exchangeable fraction, which is the component most likely to be released in saline environments.

- The eventual burial of mine solids in the low-oxygen bottom sediment will maintain the chemical stability of mine derived mercuric sulphides.

Effects on Torres Strait

Tailing and sediment from the Porgera Mine are predicted to have no significant effect on the Torres Strait. Because of the large dilution by natural sediment, mine derived tailing will comprise but a small fraction of solids moving through the deltaic front.

These solids will be deposited in deep waters off the Gulf of Papua. For the same reasons outlined above for the Fly Delta, mercury present in tailing is predicted to have no significant effect on Torres Strait.

Monitoring

The receiving river system is being monitored closely to check the predictions made in the Environmental Plan and to assess the significance of any changes brought about by riverine disposal of tailing. The monitoring program includes collection of data on hydrology, water quality, sediment transport, fish biomass and trace metals.

Summary

The Porgera Gold Mine is a relatively small scale operation in terms of the quantity of ore mined and processed.

Consideration of environmental effects at an early stage of mine planning and design enabled the optimisation of on site treatment of tailing.

A method has been developed for chemical treatment of tailing to produce a low toxicity effluent.

Mercury present in tailing will occur as mercuric sulphide of low solubility and inherently low biological availability.

The river conditions of high pH, alkalinity and suspended solids concentrations inhibit the mobilisation of trace metals into the aqueous phase.

The main impact of the mine on the receiving river system will be due to the physical effect of increased solids on biota.

Apart from the Porgera River, mine sediments will increase TSS fractionally.

Most of the predicted TSS concentrations lie within the background range of TSS already experienced by the Lagaip River fish population.

There are no predicted effects of solids on biota below the Lagaip-Ok Om confluence.

Although a pathway exists for tailing to enter Lake Murray, the increase in bio-available mercury in bed sediments is expected to be insignificant.

All tailing solids are predicted to be carried to the Fly Delta.

The increment of mine derived mercury is unlikely to be environmentally significant in the Fly Delta.

Tailing from the mine is predicted to have no significant effect on the Torres Strait.

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