U.S. Geological Survey
Open-File Report 03-143
Online Only
Version 1.0

Physical Aspects of Waste Storage From a Hypothetical Open Pit Porphyry Copper Operation

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U.S. Department of the Interior

U.S. Geological Survey

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Conversion Factors

Conversion factors for metric to U.S. customary (English units) of measurement

Multiply	By	To obtain
cubic meters	1.30795	cubic yards
hectares	2.471	acres
kilograms	2.20462	pounds avoirdupois
kilometers	0.62137	miles
kilograms per cubic meter	0.672	pounds per cubic foot
metric tons	1.1023	tons, short
meters	3.28084	feet
millimeters	0.03937	inches

Physical Aspects of Mine and Mill Waste Storage From a Hypothetical Open Pit Copper Porphyry Operation

By Kenneth E. Porter and Donald I. Bleiwas

Introduction

Copper porphyry deposits are most often mined as open pit operations. The deposits' relatively low ore grade and high-tonnage production generate significant amounts of solid waste compared with the units of copper recovered. Approximately 98 percent of the material extracted from the mine reports to waste storage. These wastes can be subdivided into three major categories—leach rock, mill tailings, and waste rock. This report describes the physical attributes that compose the "footprint" (the space occupied) generated by a model open pit copper porphyry mining and milling operation. This model represents only one possible scenario for accommodating waste from an open pit copper mine. Other options include waste and tailings storage that uses different geometry and design, placing waste back into the pit (backfilling) following the mine's production life, or using waste material as an aggregate (road base or concrete). Selection of engineering and other criteria presented in this study is based on accepted industry standards. A base model is provided in the main text. In Appendix A, figures and tables are provided with a range of values for various engineering parameters.

Mine Model

The analyses are based on the extraction of copper ore from a porphyry deposit by an open pit mine operator. The data were analyzed by using numerous criteria that affect the generation of mine waste and mill tailings. Several parameters with respect to the hypothetical open pit mining operation that affect mine and mill waste generation were selected (table 1).

They include waste-to-ore ratios, mine ore reserves, ore dilution,[1] ore grade, ore recovery, specific gravity of in situ rock, and percentage of expansion (percent swell) of the broken rock. Some of these criteria were projected over a range of values to reflect the impact on hypothetical waste generation for a typical open pit porphyry copper mine (figure 1).

Table 1. Mine criteria—Base model.
[Mt, million metric tons; %, percent; t/m^3, metric ton per cubic meter]

Rock type = Granite porphyry
Mine type = Open pit
Total in situ reserve (Mt) = 210
Total ore production (Mt) = 200
Waste to ore ratio = 2:1
Coppe ore in situ grade (%) = 0.75
Ore dilution (%) = 1.07
Diluted ore grade (%) = 0.70
Primary ore mineral = Chalcopyrite
Mine ore recovery (%) = 95
In situ rock specific gravity (t/m^3) = 2.24
Blasted rock specific gravity (t/m^3) = 1.82

Figure 1. Phelps Dodge Mining Company's Sierrita open pit copper mine in Sierrita, Arizona. (Arizona State Mine Inspector's Office, 202)

[1] Dilution is the contamination of ore with barren (zero-grade) wall rock.

Mine Waste

Mine Waste Rock Production

Waste rock derived from copper porphyry operations is removed during development and production as a means to gain access to ore. Waste rock is generally coarse material but includes a wide range of sizes from very large boulders that weigh several metric tons to dust-sized particles. The size and shape of the material depends on the characteristics of the rock, extraction methods (ripping, drilling, and blasting), loading equipment (front-end loaders and mechanized shovels), and transport method, which includes mostly trucks, as shown in figure 2, as well as conveyor belts or rail cars. Generally, waste rock contains residual levels of copper and its coproducts or byproducts, if any, that are not economically recoverable during the time of extraction. Copper is recovered by circulating acid through the low-grade waste rock; the waste rock storage site may require additional design engineering that is not addressed in this study. The amount of waste rock generated at the mine depends largely on the shape of the ore body, the mining plan, and the total ore and waste production during the mine's life. For this estimate, the total amount of waste generated during mining was assumed to have been placed in waste storage. The hypothetical waste storage site is based on engineering standards that are used in actual mining operations.

Figure 2. Truck depositing mine waste from an open pit copper mine in Papua New Guinea (Forderkreis >> Rettet die Elbe < < eV, 2001).

Mine Waste Storage Engineering Criteria

Numerous criteria must be considered when estimating the amount of mine waste generated and waste storage site geometry—the amount of development tonnage (preproduction stripping), variations in the waste-to-ore ratio, production and mine life, and waste rock volume and compaction, which is determined by the size distribution of the waste; the angle of repose, or slope angle; and the moisture content (table 2). The diversion of a portion of the waste rock for uses at the mine facilities for embankments, fill construction, impoundments, and road base and off-site sales for such uses as aggregate for concrete, rail ballast, and road base would reduce the waste storage requirements. The use of waste rock to fill open pit mines also as part of a reclamation plan is not included. Local climate and geologic characteristics, which include seismicity of the site, are also design criteria. Federal, State, and local regulations; responses to concerns by the public (social perceptions can be critical to the design and placement of the mill waste tailings because of the belief that tailings impoundments are inherently unsafe); and non-

Government organizations and others can also have a major impact on the intial and ultimate design of the waste rock storage facility (Verburg, 2002, p. 15). These are not specifically addressed in the

Table 2. Mine waste dump criteria—Base model.
[Mt, million metric tons; t/m³, metric tons per cubic meter;
%, percent; m, meter; ha, hectare; 106 m3, million cubic meters]

Rock type = Granite porphyry (copper ore)
Total waste tonnage (Mt) = 400
In-situ rock specific gravity or density (t/m3) = 2.24
Blasted rock specific gravity or density (t/m3) = 1.84
Swell factor = 0.74 (35% expansion)
Compaction factor (%) = 1.11 (10% reduction factor)
Geology of dump site = Acceptable
Dump site topography = Flat
Active dump angle of repose (degrees) = 34 (1.5:1)
Remediated dump angle of repose (degrees) = 27 (2:1)
Height (m) = 100
Total unremediated basal area (ha) = 252
Total volume (106 m3) = 212
Total weight (Mt) = 400
Total remediated basal area (ha) = 267

analyses. The material characteristics and engineering criteria that formed the basis for developing the models are discussed on the following pages, listed in the tables, and discussed in Appendix A.

Topography

Topography can greatly influence waste storage. Waste can be disposed of on many types of areas—from nearly flat topography to valley or canyon deposition. Filling in a topgraphic low can provide side support that allows greater efficiency (and lower cost) in waste storage and allows higher and steeper slope angles. In some situations, excavated portions of the open pit can be backfilled with waste rock, thus reducing the area needed for waste storage. Because topography is a site-specific crtieria, an area of flat topography was selected to model. Hydrology (primarily runoff and flood control) as influenced by topography must also be considered.

Geology

Siting of a waste rock storage site must be evaluated for geologic considerations. Criteria that relate to the competency of the foundation (underlying support) include depth, permeability, shear strength, strength, thickness, and type of rock.   No special conditions are considered in this evaluation.

Mine Waste Rock Characteristics

Although waste rock is generally coarse material, it includes a wide range of sizes from very large boulders that weigh several metric tons to dust (figure 2). The size and shape of the material depends on the chemical and physical characteristics of the ore and waste rock, extraction methods, loading equipment, and transport. The size distribution, the amount of the material, and the composition of the material determine, to a great extent, the volume occupied by the waste rock.

Swell and Compaction Factors

When waste rock is excavated, its volume expands because the spaces between the fragments increase. This expansion, which is called the percent swell, is measured as a percentage increase above the undisturbed in situ volume. The swell factor is the undisturbed in situ volume of the rock divided by the expanded volume of the blasted rock. For this analysis, a swell factor of 35 percent, which is a widely accepted average for waste derived from a blasted open pit copper mine in the mining industry, was selected. Loose material will compact to some degree after placement on the dump. Compaction results from mechanical compaction by equipment, decomposition, and natural compaction over time. The degree of compaction depends on the disposal method, elapsed time, the height of the dump, the moisture content, the size distribution, and the type of material. The compaction factor is the expanded volume of the rock divided by the compacted volume of the rock. Common total compaction estimates range from 5 to 15 percent. For this study, 10 percent was selected.

Specific Gravity (Density)

For this analysis, an in situ specific gravity of 2.24 metric tons per cubic meter (t/m^3) for the waste rock was selected on the basis of the mineralogical components that compose most altered granitic porphyries. Following blasting, swelling, and compaction, the material was estimated to have a specific gravity of 1.84 t/m^3.

Active Dump Angle of Repose

The stability of the slope of the waste storage facility is critical to determining the area of the site. The high shear strength (the maximum stress that a material can withstand before failure in shear) of dry waste rock contributes to high bearing stability and a high angle of repose that ranges from 34 degrees (º) to 37 º (figure 3A). A conservative angle of repose of 34 º (a run to rise of 1.5 horizontal to 1 vertical) was selected for the hypothetical model. The remediated angle of repose used in this study is 27 º (a run to rise of 2 horizontal to 1 vertical). The lower angle of repose is attained by using earth-moving equipment to push material down along the margins of the waste dump, which results in essentially no change in overall height (figure 3B). Keeping the height constant, the material removed from the margins at the top of the waste dump to lower the slope angle will result in a decrease in the area of the top and an increase in the basal area of the site. The lower angle generally ensures long-term stability, minimizes erosion, and provides surfaces suitable for revegetation for use as wildlife habitat and other purposes.

Height

For the base model, a final height of 100 meters (m) for the mine waste storage facility was selected. Some waste rock storage sites can signifcantly exceed this height, but they are usually favored by topography.

Geometry

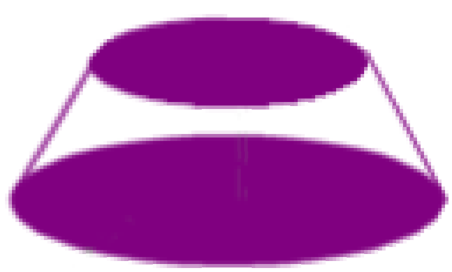
A frustum, or truncated cone, at selected radii was used to model the shape of the mine waste pile. The use of a frustum for model development is an acceptable engineering method (figure 3C).

Mine Waste Rock Storage Facility—Shape, Basal Area, Volume, and Weight

The preceding engineering criteria, as incorporated into the base model, were used to determine the basal area, the top area, and the volume of the unremediated and remediated mine waste rock site. On the basis of those factors, the basal area for the unremediated storage site was calculated to be 252 hectares (ha) at a volume of 212 million cubic meters (10^6 m^3). The remediated storage site would have a larger basal area because of the reduction in slope angle to provide greater long-term slope stability at the site. The basal area would be approximately 264

A.

B.



C.

Figure 3. Waste dumps. A, Mine waste dump; B, mine waste dump in process of remediation; C, frustum, or truncated cone (Mining Association of British Columbia, undated).

ha, and the volume and the maximum height would be essentially the same because only material along the margins of the waste dump is used to lower the angle of repose. The dry weight of the material would be approximately 400 million metric tons (Mt). The detailed calculations are in Appendix A.

Mill Tailings

Mill tailings from the treatment of copper ores are the solid (suspended in liquid that consists mostly of water) residue of the milling or beneficiation process. During this process, ores are first crushed and finely ground and then treated in flotation cells with chemicals to recover copper concentrates. Mill tailings, which consist predominantly of fine particles that are rejected from the flotation process, are generally uniform in character and size and consist of mostly hard angular siliceous particles with a high percentage of fines. Tailings can also contain variable amounts of sulfide minerals, such as pyrite. Mill tailings are usually sent to the tailings impoundment area as a slurry, which contains about 50 percent solids, through a pipleline. Water is either recovered, especially in arid areas, and returned to the mill for ore processing or treated and released to the environment. The design of a mill tailings storage site is dependent on many of the same factors as mine waste storage site.

Mill Tailings Disposal Storage Criteria

Disposal of mill tailings on the surface, especially those that contain sulfide minerals, must be designed to minimize interaction with the environment through dust generation, leakage of fluids, which can be acidic and contain dissolved metals and other harmful or potentially harmful constituents; and from failure of the containment structure. The embankment, stored residues, and ancillary structures at the tailings impoundment must retain their integrity as long as possible because the impoundment will need to function for many years after mining operations cease. Disposal of mill tailings depends on tailings and site-specific characteristics. Those methods include placement of dry or thickened tailings in impoundments or freestanding piles, backfilling underground mines or open pits, and subaqueous disposal. The most common method and the one selected for this evaluation is disposal of tailings as slurry in an impoundment area. Impounded mill tailings are generally stored behind restraining dams to form a retention area, which permits containment of the tails and recovery of excess water; this is especially important in arid areas. Most types of impoundment dams are built sequentially. An upstream tailings dam, which is the most common type of tailings retention dam, was selected for this study (figures 4, 5).

The construction of an upstream tailings dam requires that new parts of the embankment be built on top of the tailings impounded during the previous stage. Embankment material, which consists of the coarser material, forms a beach as it drops out of the tailings slurry shortly after it enters the impoundment by means of spigots. Coarse material is deposited on top on the upstream side of the active dam and is used to construct the subsequent dam with the use of light equipment. Less coarse material is carried further in the slurry and is deposited on the distal portion of the beach. Fine material forms a low density mass as it settles in the pond (United Nations Environmental Program, 1996). This method causes the dam crest to move "upstream" as a series of overlapping deltas. Numerous design criteria for mill tailings storage must be considered; for example, the amount of mill feed over the life of the operation, recovery of commodities, grain size and size distribution of material, concentrate grade, angle of repose, moisture content and permeability, topography, and area available for disposal. Except for use in the construction of the dikes that compose the tailings dams, any diversion of tailings for use on site or from sales are not included in the calclations for the weight and size dimensions of the modeled tailings storage site.

As with waste rock, local climate, environmental considerations, geologic characteristics (which include seismicity), and hydrologic characteristics also contribute to its design. Federal, State, and local regulations and responses to concerns by the public, non-Government

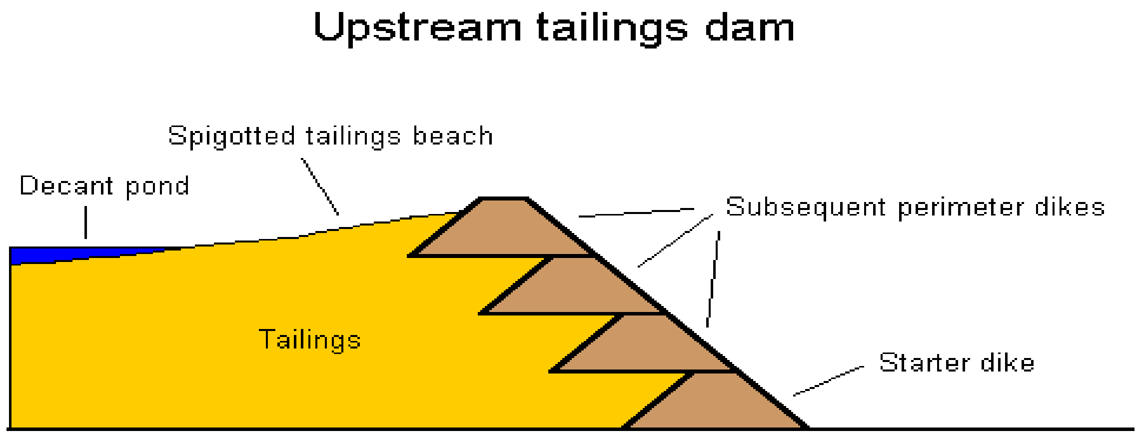


Figure 4. Upstream-type tailings dam, which is the most popular type of embankment for tailings dams. New parts of the embankment are built on top of the tailings impounded during the previous stage. This method causes the dam crest to “move upstream" (World Information Service on Energy, 2002).

Figure 5. Tailings storage facility at the Martha Mine near Waihi, New Zealand, nearing its final height. This aerial photograph, which was taken in early 2000, shows the embankment structure. The lower slopes have been rehabilitated. The impoundment where tailings are deposited as a slurry can be clearly seen as can the light-colored tailings beach at the far left end of the pond (Waihi Gold Mining Company Limited, undated).

organizations, and others can also have a major effect on the initial and ultimate design of the waste rock storage facility. The generalized model does not address all these criteria. The selection criteria used in developing the base model and variations in its design are discussed in the following section and are listed in table 3. Effects of the selection of different values, such as mill recovery, on the production of tailings are provided in the Appendix.

Table 3. Tailings impoundment calculation criteria—
Base model.[%, percent; Mt, million metric tons; t, metric ton; t/m^3, metric ton per cubic meter; m, meter; ha, hectare; 10^6 m^3, million cubic meters]

Ore feed grade (%)	= 0.7
Mill feed tonnage (Mt)	= 200
Mill recovery (%)	= 88
Concentrate grade (% Cu)	= 30
Moisture content (%)	= 15
Tailings/ton ore (t)	= 0.979
Tailings specific gravity or density:	
Dry (t/m^3)	= 1.16
Wet (t/m^3)	= 1.36
Topography	= Flat
Geology of tailing impoundment site	= Acceptable
Tailings dam slope (degrees)	= 22 (2.5:1)
Height (m)	= 50
Total basal area (ha)	= 376
Total top area (ha)	= 296
Total dry and wet volume (10^6 m^3)	= 169
Total dry weight (Mt)	= 196
Total weight at 15% moisture (Mt)	= 231

Topography

Topography can greatly influence tailings waste storage. Like mine waste, tailings disposal on land can take place on areas that range from nearly flat topography to valley or canyon. Filling a topgraphic low can provide side support, which allows greater efficiency in waste storage, primarily in the form of higher and steeper slope angles. Hydrology (primarily runoff and flood control) as influenced by topography must also be considered. Because topography is a site-specific crtieria, an area of flat topography was selected.

Geology

As in designing the mine waste storage site, the mill tailings impoundment site needs to be evaluated for geologic considerations. Criteria that relate to the determination of the competency of the foundation (underlying support) include depth, ground-water conditions, permeability, shear strength, strength, thickness, and type of rock. Frequency, probability, and severity of seismic events must also be evaluated. No special conditions were considered in this evaluation.

Mill Recovery and Copper Concentrate Grade

Mill recovery of copper from typical copper ores ranges from 80 to 90 percent. The model assumes a copper ore feed grade of 0.7 percent and a mill recovery of 88 percent of the copper contained in the ore following crushing, grinding, and the flotation process. The mill concentrate, which consists mostly of chalcopyrite, has a copper grade of 30 percent. Therefore, the vast majority of material entering the mill (approximately 98 percent) reports to the tailings impoundment as a fine slurry that comprises about 50 percent solids. Water is almost always recovered and is eventually recycled for use in the beneficiation plant, especially in arid regions. The tailings contain all constituents of the original ore except for the extracted minerals and the addition of water and some chemicals used in the separation process.

Particle Size and Distribution

Typically, mill tailing particles from the flotation process range in size from sand to clay [40-90 percent passing a 0.075-millimeter (mm) (No. 200) sieve] depending on the degree of processing needed to recover the desired mineral(s) (U.S. Federal Highway Administration, 2002). In general, the lower the concentration of mineralization in the parent rock, the greater the amount of processing needed and the finer the particle size of the resultant tailings. Some ores, such as iron ore, are found in relatively high percentages and are fairly easy to separate. The resultant tailings are coarser than those from other ores, such as copper, which is found in very low percentages in the host rock and requires very fine grinding for separation. Copper tailings are usually quite fine grained with a large percentage passing through a 0.075-mm (No. 200) sieve (North Carolina Division of Pollution Prevention and Environmental Assistance, 2003).

Volume and Specific Gravity

The density per metric ton of tailings depends primarily on the size and shape of the grains and the mass of the materials. The determining factors are based on the physical and mineralogical (chemical) characteristics of the material processed and the method of processing. The moisture content does not significantly effect the final volume of placed tailings because over time, moisture is often reduced to 10 to 20 percent and occupies the interstices between the solid particles. Moisture is lost to tailings through collection for process water, compaction, and evaporation. One cubic meter of mill tailings weighs approximately 1.16 metric tons dry (Mt dry) and 1.36 metric tons wet (at 15 percent moisture). Each metric ton of tailings, dry or wet (15 percent), occupies 0.85 cubic meter. Total volume of tailings, dry or wet (15 percent), occupies 169 10^6 m^3 and weighs 196 Mt dry or 231 Mt at 15 percent moisture.

Height and Angle of Repose

An ultimate height of 50 m was selected for the frustum-shaped upstream tailings embankment model. Actual heights vary depending on the nature and amount of tailings and site-specific criteria. Upstream tailings dams can be thick, approaching heights of 125 m. The tailings impoundment at the Sierrita copper mine in Arizona is a rare exception. The height of the tailings impoundment exceeds 300 m in height (Arizona State Mine Inspector, 2002). The angle of repose of the tailings impoundment used in the model was 22 º or a run to rise of 2.5:1.

Geometry

The geometry of a tailings impoundment facility is dependent on such numerous factors as topography, moisture content, climate, geology, seimicity, the type of dam selected, and regulations. A flat depositional surface was selected for the base model, and the shape was assumed to be a frustum at selected radii at the base (1,094 m) and top (970 m). Using a frustum for model development is an acceptable engineering method (figures 3C, 5).

Tailings Impoundment Facility-Basal Area, Volume, and Weight

Most of the preceding engineering criteria defined in the base model were used to determine the mill tailings impoundment basal area, volume, and weight. On the basis of those factors, the basal area for the site was calculated to be approximately 376 ha with a volume of about 169 10^6 m^3 and a weight, which includes moisture, of approximately 231 Mt. Please see the Appendix for detailed calculations.

Conclusions

Most porphyry copper deposits are relatively low grade. They are generally mined by using high-tonnage open pit methods. Through the course of mining and processing ore and removing waste, large amounts of material with little or no market value must be placed, perhaps in perpetuity, by responsible miners in physically competent and environmentally sound storage sites. The physical aspects that establish the "footprint" generated by this material are determined by on-site engineering and environmental criteria that include climate; hydrology; geology; seismicity; topography; Federal, State, and local regulations; and social acceptance. Physical criteria that affect the volume of material generated include mine production and waste-to-ore ratio, rock type and specific gravity of ore and waste, swell factor, and the method and effectiveness of ore beneficiation.

Parameters, such as rock type, in situ density, and swell factor, were assumed on the basis of typical values for the type of material to be mined and industry practices. Total ore production of 200 Mt and a stripping ratio of 2 t of waste generated per metric ton of ore mined were selected as the base case. A range of values for total ore production from 100 million tons (Mt) to 1 billion metric tons (Gt) and stripping ratios from 0.5 to 1 to 3 to 1 were also investigated. By using a frustum for the shape of the waste storage facility, the aerial extent for waste disposal assumed an angle of repose of 34º (1.5 run to 1 rise) for active waste dumps and 27º (2 run to 1 rise) for remediated waste dumps. The lower slope for the remediated waste allows for a greater degree of stability in the long term. The height of the waste dump has great impact on the area occupied by mine waste. On the basis of the factors selected for the base model, the basal area for the unremediated storage site was calculated to be 252 ha at a volume of 212 10^6 m^3 and a height of 100 m. The remediated storage site would have a larger basal area because of the reduction in slope angle to provide greater long-term slope stability of the site.

The basal area would be approximately 267 ha, and the volume and height would be essentially the same as before remediation. The dry weight of the material would be approximately 400 Mt.

An upstream tailings impoundment, also in the shape of a frustum, was used to estimate the aerial extent and volume of mill tailings. By using a slope angle of 22 º (2.5 run to 1 rise) and other selected engineering criteria defined in the base model, the hypothetical site was calculated to be approximately 376 ha at a volume of about 169 10^6 m^3 and a height of 50 m.

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Appendix A—Supporting Information on the Physical Aspects of Mine and Mill Waste Storage From a Hypothetical Open Pit Porphyry Copper Operation

The design and construction of mine waste dumps and mill tailings impoundments and estimation of the volume of mining waste generated and the surface area covered by the mining waste required a number of assumptions concerning the material being handled. Compaction, density, moisture content, angle of repose, rock type, size distribution, and swell factor were considered in the estimate of the aerial extent of post mining waste materials. A determination of the quantity of mine waste and mill tailings required estimates of the mine-waste-to-ore ratio, grade and mineralogy of the copper ore, and the percentage recovery and grade of the copper concentrate; other parameters considered were shape, climate, disposal site, emplacement method, topography, and ultimate height of the mine waste dump or mill tailings impoundment.

Variation in size distribution of mining and milling waste material was not considered in this analysis because of its site-specific nature. An average distribution of size was assumed. Moisture content was not considered in calculating the volume of waste dumps, but was considered for tailings impoundments, which include process solution, mostly water. Adjustments were necessary to determine the dry density to relate the quantity of solids in the tailings to the ore feed to the mill. Table A.1 lists the material and operating characteristics for estimating the basal extent of mining and beneficiation waste disposal.

Table A.1. Material and operating characteristics of mining and beneficiation of a hypothetical copper operation.

[%, percent; t, metric tons; t/m³, metric tons per cubic meter; º, degrees]

Operation	Description	Value
Mining waste	Rock type	Copper ore (porphyry)
	Density in situ (ore)	2.24 t/m^3 (140 pounds per cubic foot)
	Stripping ratio	2:1 (that is 2 t of mine waste to 1 t of ore)
	Swell factor	0.74 (35%)
	Compaction factor	1.1 [10 percent (5–15%]
	Slope angle (active)	34º (1.5:1), angle of repose (dry)
	Slope angle (remediated)	27º (2:1), final remediated slope (dry)
Milling waste	Mill feed grade	0.7% copper
	Mineralogy	Chalcopyrite (34% copper)
	Copper recovery	88%
	Concentrate grade	30% copper
	Moisture content	15 % by weight (drained tailings)
	Density tailings (d_{85}) drained	1.36 t/m^3 (85 pounds per cubic foot)
	Density tailings (d_{100}) drained	1.60 t/m^3 (100 pounds per cubic foot)
	Density tailings (d_{120}) drained	1.92 t/m^3 (120 pounds per cubic foot)
	Slope angle (drained tailings)	22º (2.5:1), tailings dam slope

Mining Waste

Density for a typical copper ore is estimated to be 2.24 t/m^3 (140 pounds per cubic foot) (Ash, 1990). The lower density for copper ore compared with the average density of 2.72 t/m^3 (170 pounds per cubic foot) for granite, for instance, is due to the alteration of feldspars to clay that has taken place in the ore deposit formation and the weathering processes.

Drilling and blasting operations break the in-place rock to a size that can be handled by loading and hauling equipment. When mined, in situ material will swell from 10 to 60 percent depending on the type of material and fracture frequency. In hard rock operations, the percent swell is commonly between 30 and 45 percent (Bohnet, 1990). In the case of porphyry copper rock, the typical percent swell is 35 percent, which is to say the material, after blasting, occupies 35 percent more volume than the in-place material. This equates to a swell factor of 0.74 (Ash, 1990). The following equation, in cubic meters, shows the method for calculating swell factor:

$$\text{Swell factor} = \text{Volume (original)} / [\text{Volume (original)} + \text{Volume (increase)}]$$
$$0.74 = 1.0\ m^3 / (1.0\ m^3 + 0.35\ m^3).$$

Mined waste material compacts when it is placed on the waste dumps or leach heaps. The degree of compaction will depend on the type of material, method of handling, moisture content, amount of traffic on deposited material, and amount of elapsed time following placement on the dump. Typical compaction percentages range from 5 to 15 (Bohnet, 1990); in the analysis, 10 percent was used. The following equation, in cubic meters, shows the method for calculating compaction factor:

$$\text{Compaction factor} = \text{Volume (initial)} / [\text{Volume (initial)} - \text{Volume (decrease)}]$$

$$1.11 = 1.0\ m^3 / (1.0\ m^3 - 0.10\ m^3).$$

The following equation shows the method for calculating the compacted waste density, in metric tons:

$$\text{Waste density} = \text{In-situ density} \bullet \text{Swell factor} \bullet \text{Compaction factor}$$
$$1.84 \text{ t of mine waste / cubic meter of mine waste} = 2.24\ t/m^3 \bullet 0.74 \bullet 1.11.$$

The stripping ratio is a measure of the quantity of waste that must be removed during the mining operation to recover 1 t of ore. Some porphyry copper deposits have very little overlying waste, and some operations report stripping ratios above 3 to 1 t of mine waste per ton of ore. A range of stripping ratios from 0.5 to 1 to 3 to 1 t of mine waste per ton of ore, with an average of 2 to 1 t of mine waste per ton of ore selected for the analysis. Mine waste volume per ton of ore calculations use the following equation:

$$\text{Volume of mine waste / t of ore} = (\text{t of mine waste / t of ore}) / (\text{t of mine waste / cubic meter of mine waste})$$
$$= (2 \text{ t of mine waste / t of ore}) / (1.84 \text{ t of mine waste / cubic meter of mine waste})$$
$$= 1.0869 \approx 1.09 \text{ cubic meters of mine waste / t of ore}$$

Calculation of mine waste tonnages for stripping ratios that range from 0.5 to 3.0 t of mine waste per ton of ore for ore tonnages that range from 100 Mt to 1 Gt are listed in table A.2.

Calculation of waste volumes for stripping ratios that range from 0.5 to 3.0 t of mine waste per ton of ore for ore tonnages that range from 100 Mt to 1 Gt are listed in table A.3.

Table A.2. Mine waste tonnage generation for selected ore tonnages and stripping ratios [Million metric tons unless otherwise specified].

Ore	Mine waste					
	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	.0:1
100	50	100	150	200	250	300
200	100	200	300	400	500	600
300	150	300	450	600	750	900
400	200	400	600	800	1,000	1,200
600	300	600	900	1,200	1,500	1,800
800	400	800	1,200	1,600	2,000	2,400
1,000	500	1,000	1,500	2,000	2,500	3,000

Table A.3. Mine waste volume generation for selected ore tonnages and stripping ratios [Million metric tons unless otherwise specified].

Ore	Mine waste					
	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	28	55	83	111	138	166
200	55	111	166	221	277	332
300	83	166	249	332	415	498
400	111	221	332	443	553	664
600	166	332	498	664	830	996
800	221	443	664	886	1,107	1,328
1,000	277	553	830	1,107	1,384	1,660

The geometry of mine waste dumps depends to a large degree on the topography of the surface on which the material is deposited. Topography can range from a flat horizontal surface to a flat inclined surface to a valley fill composed of multiple inclined surfaces. For the analyses, the mine waste was assumed to be deposited on a horizontal surface in the shape of a frustum

(Levy, 1995). The following volume equation is used to calculate the volume of the frustum for different base radii and dump heights:

$$\text{Volume} = (\text{height} / 3)[A_1 + A_2 + (A_1 \bullet A_2)^{½}],$$

Where A_1 = base area and

A_2 = top area.

Mine waste dump volumes were calculated for specific base angles by varying the base radius and plotting the results for various heights. Best-fit linear equations were determined for the plots for waste dump heights of 50, 100, 150, and 200 m by using the following general equation:

$$y = ax + b,$$

Where y = base area (hectares) and

x = mine waste (million metric tons).

Active Waste Dump

The angle of repose or slope angle for dry run-of-mine rock ranges between 34 and 37 percent. For design purposes, a conservative slope of 34º (1.5 to 1) was used (Bohnet, 1990). Various dump heights are listed in tables A.4 through A.7 and shown in figures A.1 through A.4. The combined results from the waste base areas at various waste dump heights are shown in figure A.5. The best-fit linear equations were estimated for each of the waste dump height evaluations. The following are the best-fit linear equations that relate the base area of the waste dump to the waste tonnage recovered at a 34º slope angle and used later in the analysis:

Height (meters)	Best-fit linear equation
50	$y = 1.1365x + 6.0072$
100	$y = 0.5901x + 15.98$
150	$y = 0.4066x + 28.869$
200	$y = 0.3178x + 37.449$

Where y = base area (hectares) and

x = mine waste (million metric tons).

Table A.4. Mine waste base area calculations for selected mine waste tonnages at 50-meter height and 34-degree slope angle.

Radius (meters)		Area (square meters)		Waste volume (million cubic meters)	Waste tonnage (million metric tons)	Base area (hectares)
Base	Top	Base	Top			
100	25	31,416	1,963	1	1	3
150	75	70,686	17,671	2	4	7
200	125	125,664	49,087	4	8	13
400	325	502,655	331,831	21	38	50
600	525	1,130,973	865,901	50	92	113
800	725	2,010,619	1,651,300	91	168	201
1,000	925	3,141,593	2,688,025	146	268	314
1,200	1,125	4,523,893	3,976,078	212	391	452
1,400	1,325	6,157,521	5,515,459	292	537	616
1,600	1,525	8,042,477	7,306,166	384	706	804

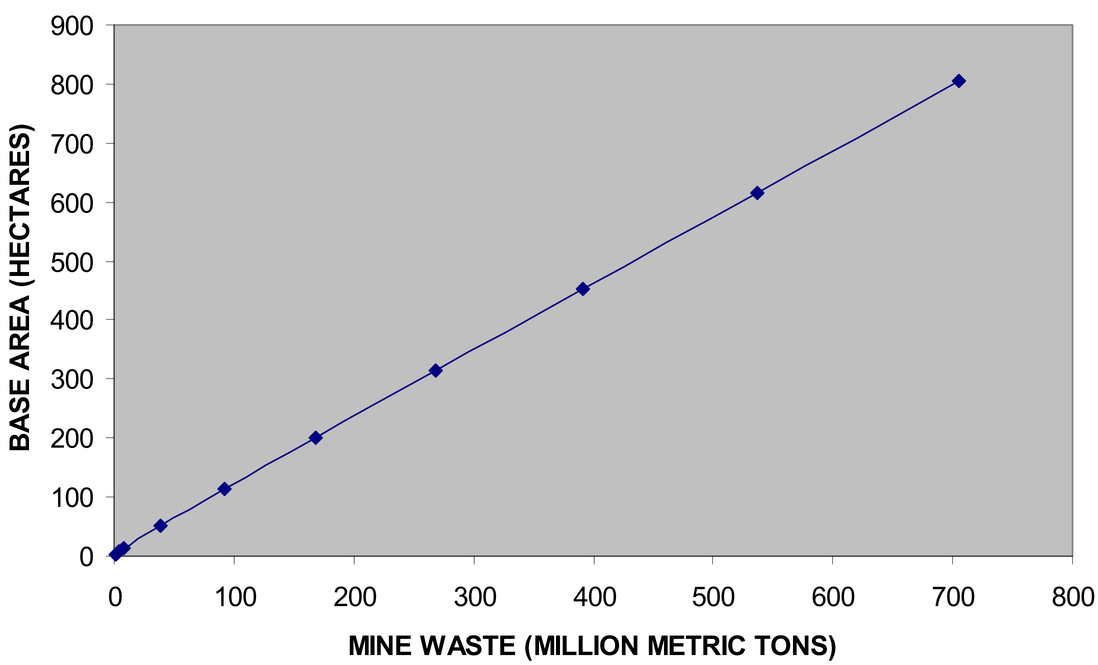

Figure A.1. Mine waste base area calculations for selected mine waste tonnages at 50-meter height and 34-degree slope angle.

Table A.5. Mine waste base area calculations for selected mine waste tonnages at 100-meter height and 34-degree slope angle.

Radius (meters)		Area (square meters)		Waste volume (million cubic meters)	Waste tonnage (million metric tons)	Base area (hectares)
Base	Top	Base	Top			
200	50	125,664	7,854	6	10	13
400	250	502,655	196,350	34	62	50
600	450	1,130,973	636,173	87	160	113
800	650	2,010,619	1,327,323	166	305	201
1,000	850	3,141,593	2,269,801	269	496	314
1,200	1,050	4,523,893	3,463,606	398	733	452
1,400	1,250	6,157,521	4,908,738	552	1,016	616
1,600	1,450	8,042,477	6,605,198	731	1,345	804

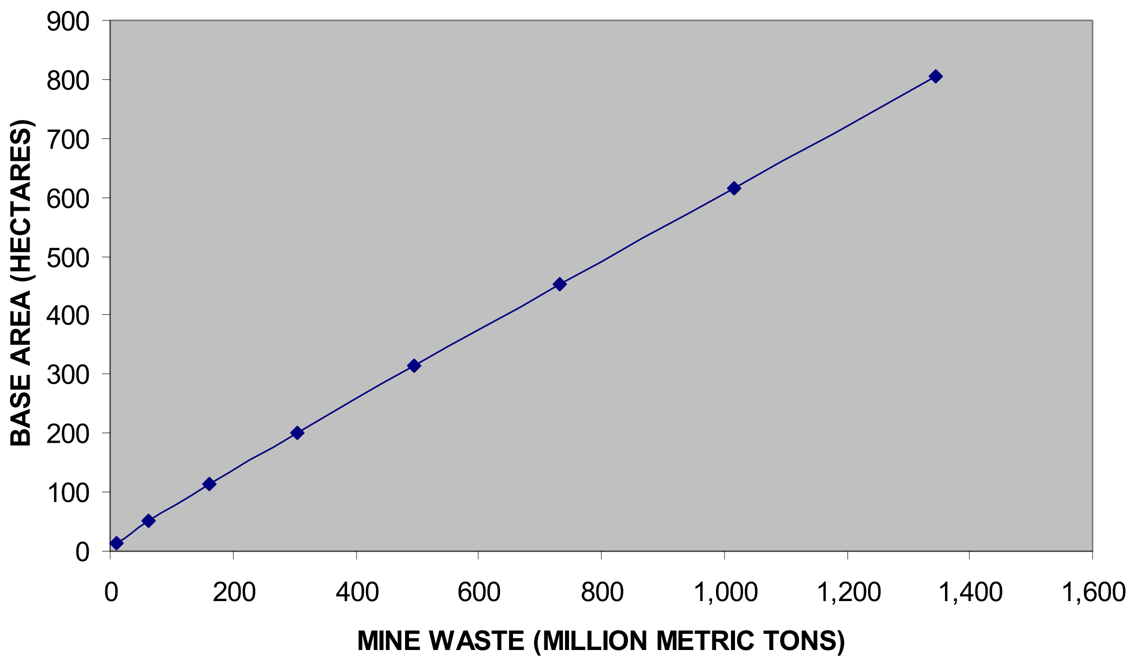

Figure A.2. Mine waste base area calculations for selected mine waste tonnages at 100-meter height and 34-degree slope angle.

Table A.6. Mine waste base area calculations for selected mine waste tonnages at 150-meter height and 34-degree slope angle.

Radius (meters)		Area (square meters)		Waste volume (million cubic meters)	Waste tonnage (million metric tons)	Base area (hectares)
Base	Top	Base	Top			
400	175	502,655	96,211	41	75	50
600	375	1,130,973	441,786	114	210	113
800	575	2,010,619	1,038,689	225	414	201
1,000	775	3,141,593	1,886,919	373	687	314
1,200	975	4,523,893	2,986,476	559	1,029	452
1,400	1,175	6,157,521	4,337,361	783	1,441	616
1,600	1,375	8,042,477	5,939,574	1,045	1,922	804

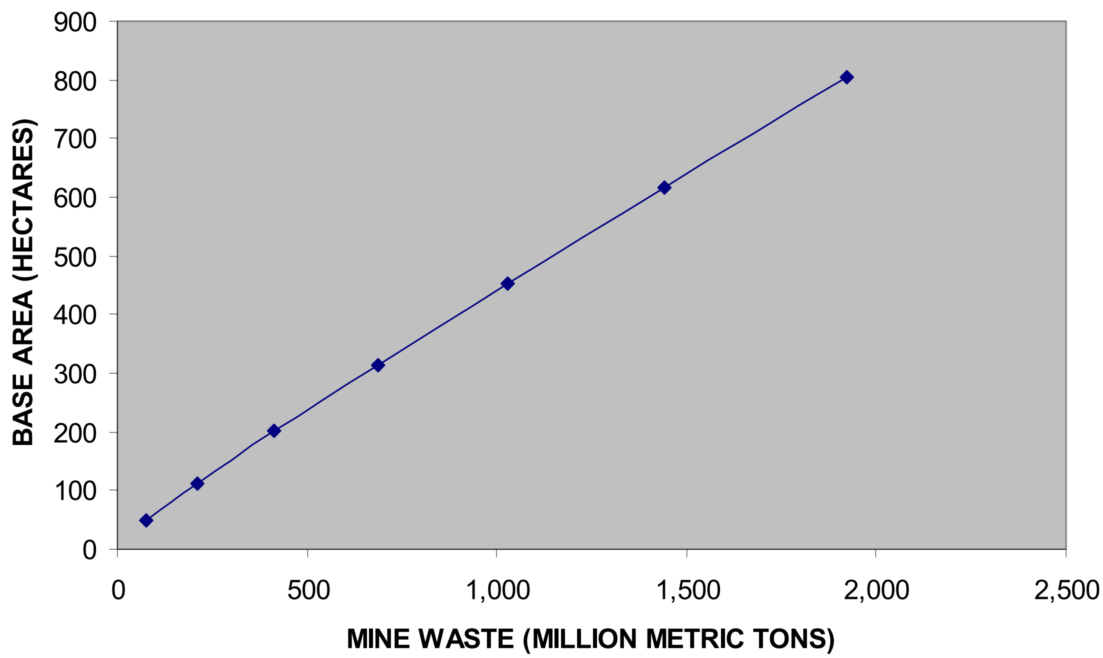

Figure A.3. Mine waste base area calculations for selected mine waste tonnages at 150-meter height and 34-degree slope angle.

Table A.7. Mine waste base area calculations for selected mine waste tonnages at 200-meter height and 34-degree slope angle.

Radius (meters)		Area (square meters)		Waste volume (million cubic meters)	Waste tonnage (million metric tons)	Base area (hectares)
Base	Top	Base	Top			
400	100	502,655	31,416	44	81	50
600	300	1,130,973	282,743	132	243	113
800	500	2,010,619	785,398	270	497	201
1,000	700	3,141,593	1,539,380	459	844	314
1,200	900	4,523,893	2,544,690	697	1,283	452
1,400	1,100	6,157,521	3,801,327	987	1,815	616
1,600	1,300	8,042,477	5,309,291	1,326	2,439	804

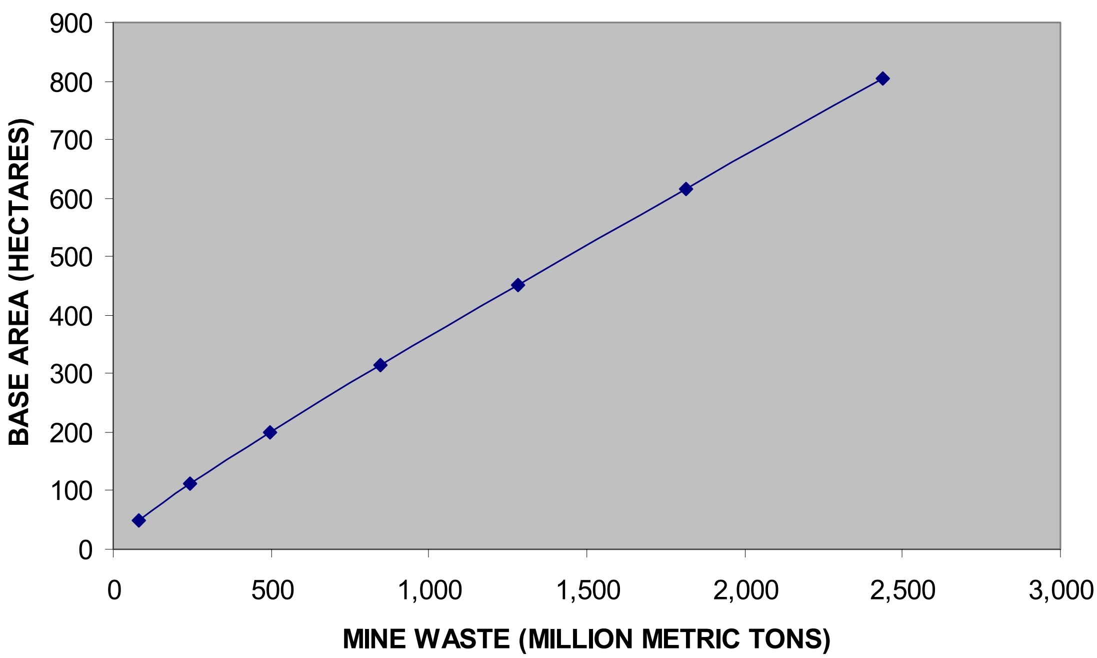

Figure A.4. Mine waste base area calculations for selected mine waste tonnages at 200-meter height and 34-degree slope angle.

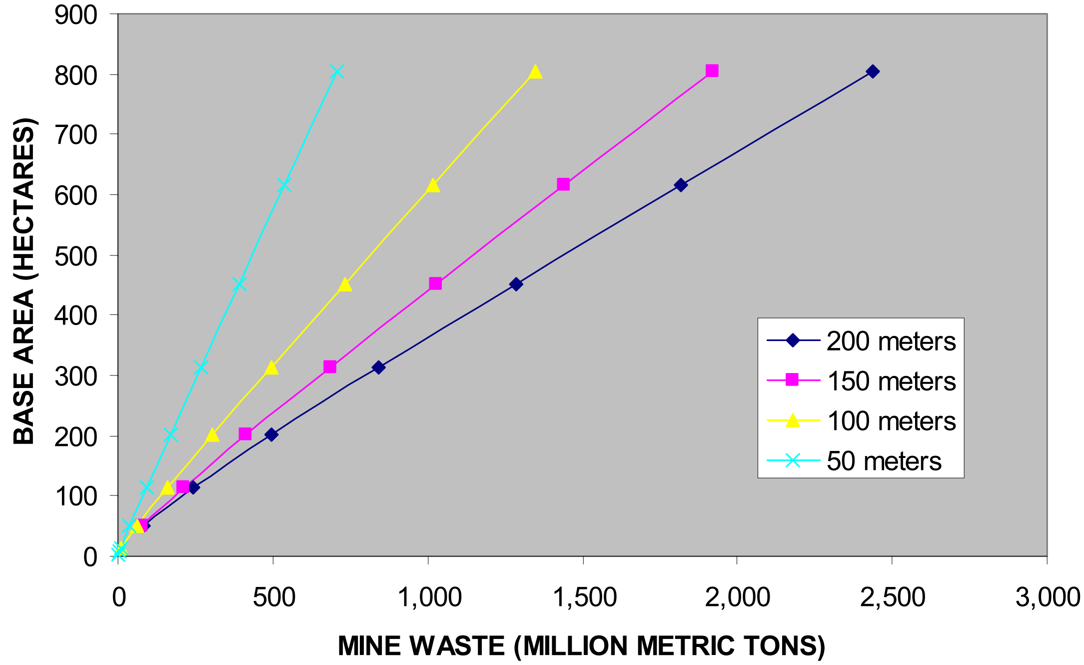

Figure A.5. Mine waste base area versus waste tonnage at selected waste dump heights and 34-degree slope angle.

The best-fit linear equations are used to determine the base area for stripping ratios that range from 0.5 to 3.0 t of mine waste per ton of ore and for ore tonnages that range from 100 Mt to 1 Gt. The base area results are plotted for the 1.0 to 1, 2.0 to 1, and 3.0 to 1 stripping ratios for each of the mine waste dump heights. The relationship between ore tonnage and base area for various stripping ratios are listed in tables A.8 through A.11 and are shown in figures A.6 through A.9.

Remediated Mine Waste

The slope angle for remediated dry waste rock is estimated to be 27 º (2 to 1 slope) (Robert Reisinger, Environmental Engineer, Knight Piésold Consulting Company, oral commun., 2002). The various mine waste dump heights are listed in tables A.12 through A.15 and are shown in figures A.10 through A.13. The combined results from the mine waste base areas at various mine waste dump heights are shown in figure A.13. The best-fit linear equations are estimated for each of the waste dump height evaluations. The following are the best-fit linear equations that relate the base area of the mine waste dump to the mine waste tonnage recovered at the 27 º slope angle and used later in the analysis:

Height Meters	Best-fit linear equation
50	$y = 1.1511x + 9.2025$
100	$y = 0.6017x + 25.881$
150	$y = 0.4237x + 37.449$
200	$y = 0.3306x + 57.535$

Where y = base area (hectares) and

x = mine waste (million metric tons).

Table A.8. Mine waste base area for selected ore tonnages and stripping ratios at 50-meter height and 34-degree slope angle.

Ore	Base area (hectares)					
(million metric tons)	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	63	120	176	233	290	347
200	120	233	347	461	574	688
300	176	347	517	688	858	1,029
400	233	461	688	915	1,143	1,370
600	347	688	1,029	1,370	1,711	2,052
800	461	915	1,370	1,824	2,279	2,734
1,000	574	1,143	1,711	2,279	2,847	3,416

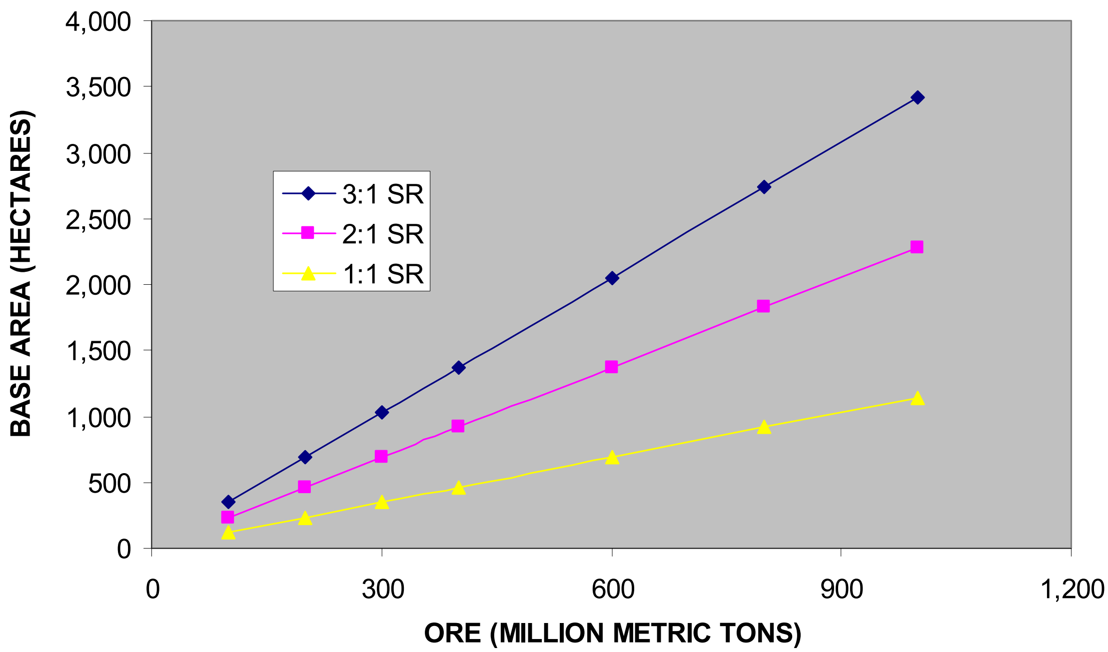

Figure A.6. Mine waste base area for selected ore tonnages and stripping ratios (SR) at 50-meter height and 34-degree slope angle.

Table A.9. Mine waste base area for selected ore tonnages and stripping ratios at 100-meter height and 34-degree slope angle.

Ore (million metric tons)	Base area (hectares)					
	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	45	75	104	134	164	193
200	75	134	193	252	311	370
300	104	193	282	370	459	547
400	134	252	370	488	606	724
600	193	370	547	724	901	1,078
800	252	488	724	960	1,196	1,432
1,000	311	606	901	1,196	1,491	1,786

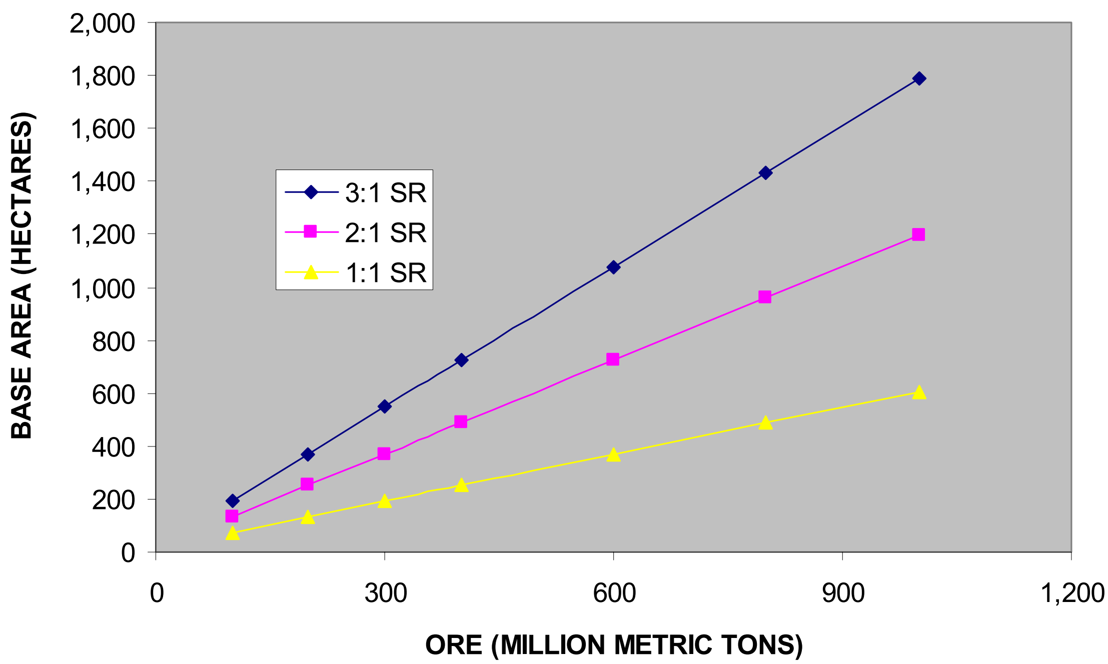

Figure A.7. Mine waste base area for selected ore tonnages and stripping ratios (SR) at 100-meter height and 34-degree slope angle.

Table A.10. Mine waste base area for selected ore tonnages and stripping ratios at 150-meter height and 34-degree slope angle.

Ore (million metric tons)	Base area (hectares) 0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	49	70	90	110	131	151
200	70	110	151	192	232	273
300	90	151	212	273	334	395
400	110	192	273	354	435	517
600	151	273	395	517	639	761
800	192	354	517	679	842	1,005
1,000	232	435	639	842	1,045	1,249

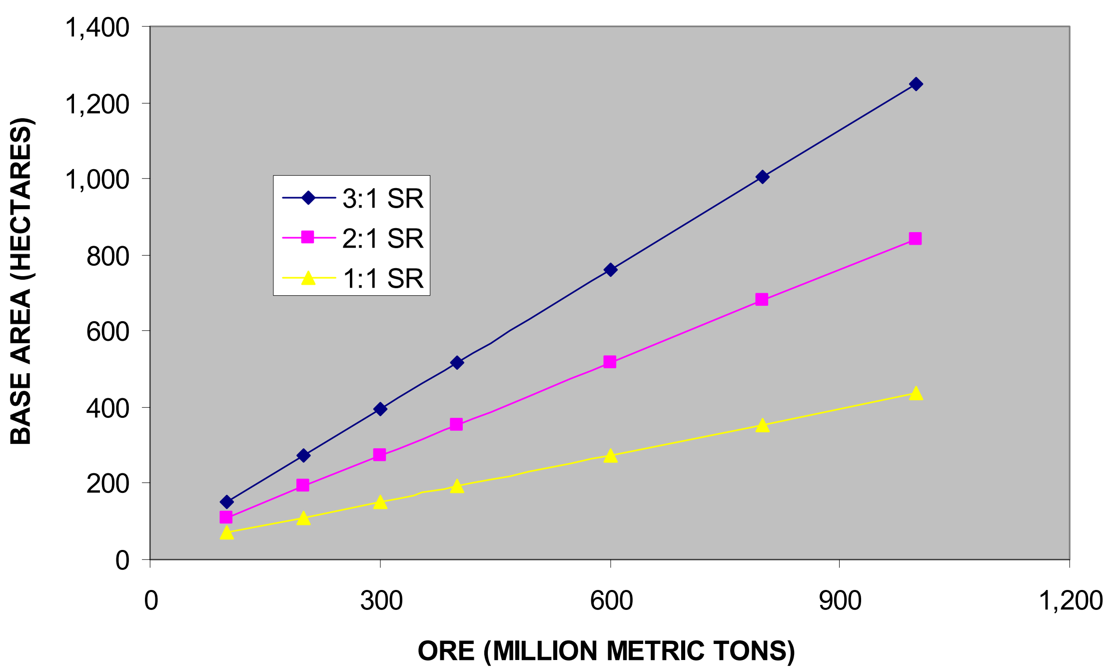

Figure A.8. Mine waste base area for selected ore tonnages and stripping ratios (SR) at 150-meter height and 34-degree slope angle.

Table A.11. Mine waste base area for selected ore tonnages and stripping ratios at 200-meter height and 34-degree slope angle.

Ore (million metric tons)	Base area (hectares)					
	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	53	69	85	101	117	133
200	69	101	133	165	196	228
300	85	133	180	228	276	323
400	101	165	228	292	355	419
600	133	228	323	419	514	609
800	165	292	419	546	673	800
1,000	196	355	514	673	832	991

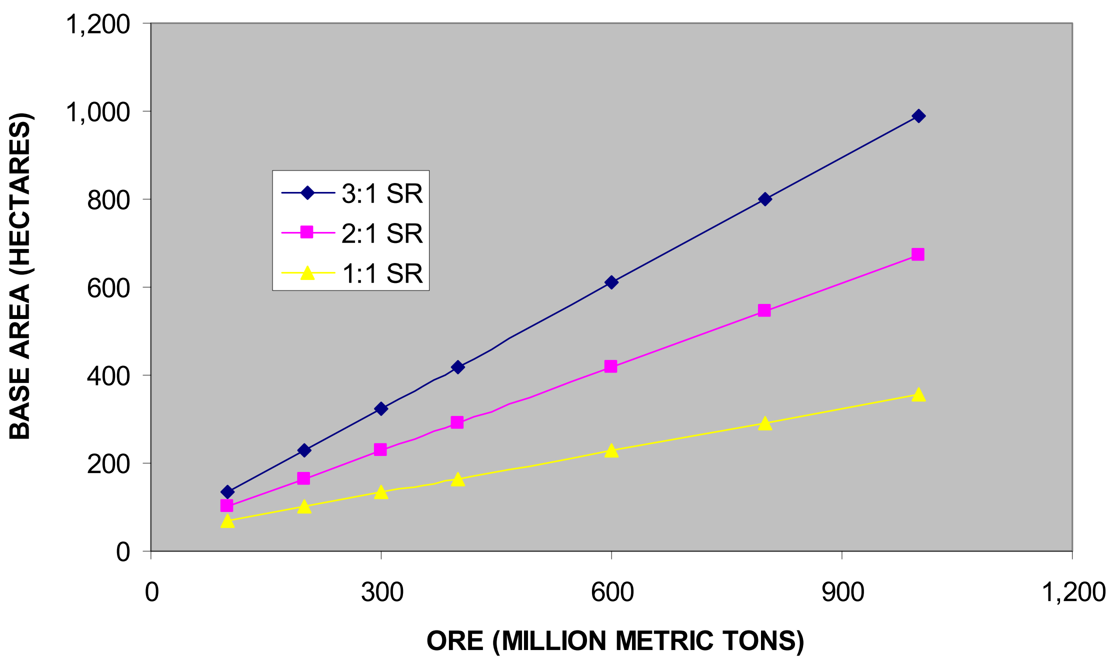

Figure A.9. Mine waste base area for selected ore tonnages and stripping ratios (SR) at 200-meter height and 34-degree slope angle.

Table A.12. Remediated mine waste base area calculations for selected mine waste tonnages at 50-meter height and 27-degree slope angle.

Radius (meters)		Area (square meters)		Waste volume (million cubic meters)	Waste tonnage (million metric tons)	Base area (hectares)
Base	Top	Base	Top			
150	50	70,686	7,854	2	3	7
200	100	125,664	31,416	4	7	13
400	300	502,655	282,743	19	36	50
600	500	1,130,973	785,398	48	88	113
800	700	2,010,619	1,539,380	89	163	201
1,000	900	3,141,593	2,544,690	142	261	314
1,200	1,100	4,523,893	3,801,327	208	383	452
1,400	1,300	6,157,521	5,309,291	286	527	616
1,600	1,500	8,042,477	7,068,583	378	695	804

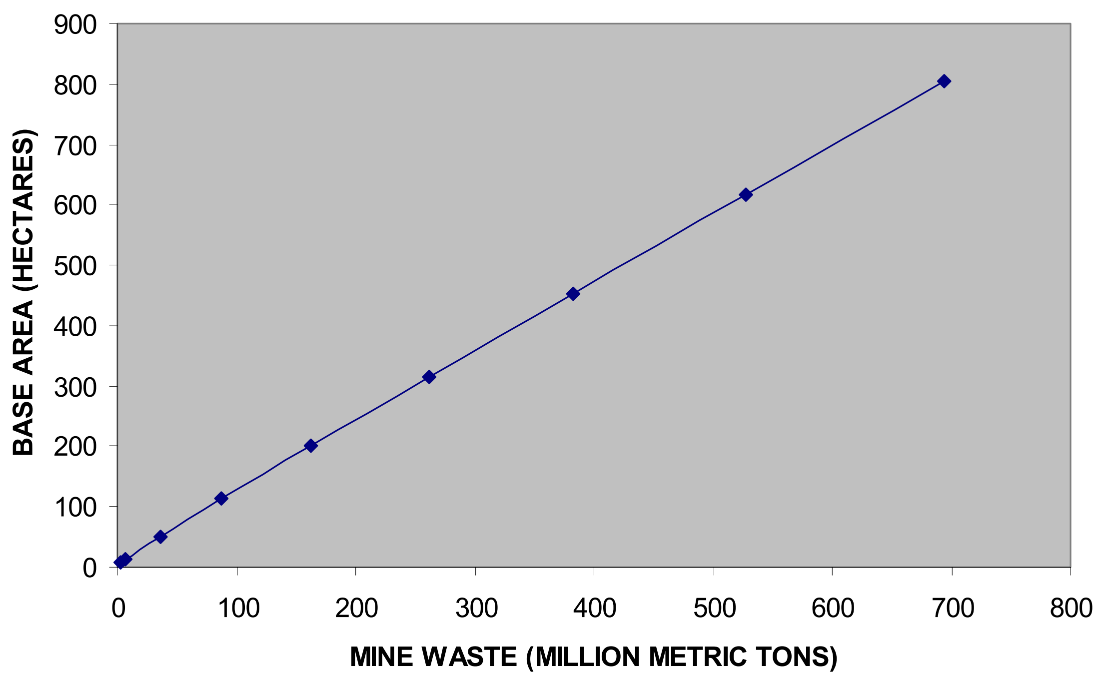

Figure A.10. Remediated mine waste base area calculations for selected mine waste tonnages at 50-meter height and 27-degree slope angle.

Table A.13. Remediated mine waste base area calculations for selected mine waste tonnages at 100-meter height and 27-degree slope angle.

Radius (meters)		Area (square meters)		Waste Volume (million cubic meters)	Waste Tonnage (million metric tons)	Base Area (hectares)
Base	Top	Base	Top			
400	200	502,655	125,664	29	54	50
600	400	1,130,973	502,655	80	146	113
800	600	2,010,619	1,130,973	155	285	201
1,000	800	3,141,593	2,010,619	256	470	314
1,200	1,000	4,523,893	3,141,593	381	701	452
1,400	1,200	6,157,521	4,523,893	532	979	616
1,600	1,400	8,042,477	6,157,521	708	1,303	804

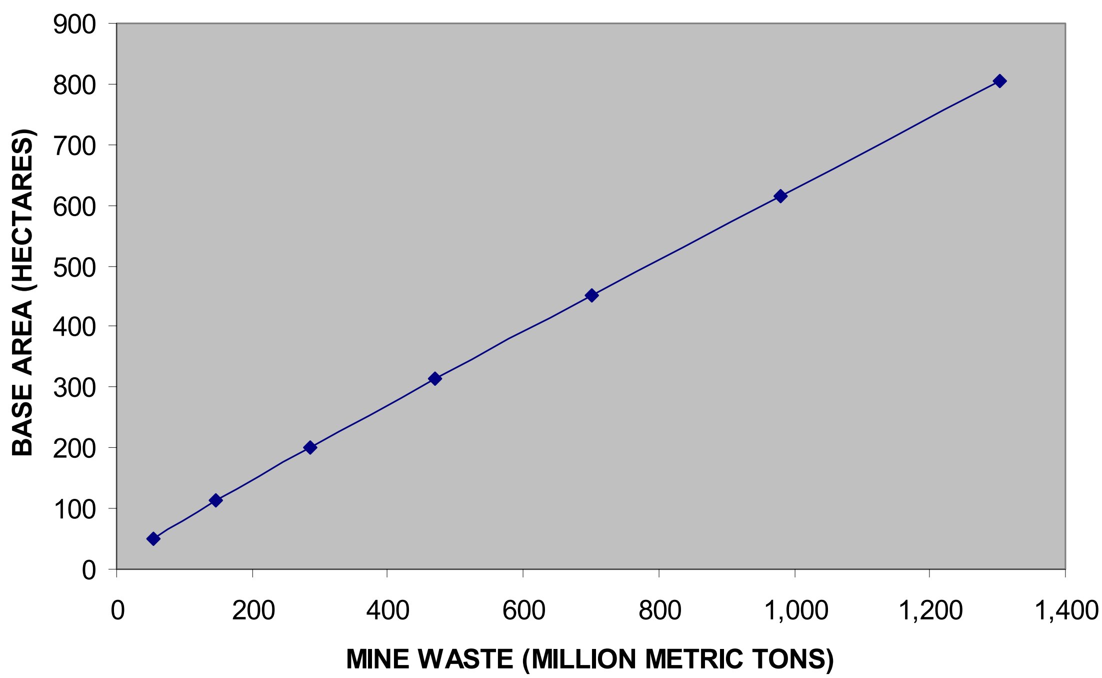

Figure A.11. Remediated mine waste base area calculations for selected mine waste tonnages at 100-meter height and 27-degree slope angle.

Table A.14. Remediated mine waste base area calculations for selected mine waste tonnages at 150-meter height and 27-degree slope angle.

Radius (meters)		Area (square meters)		Waste volume (million cubic meters)	Waste tonnage (million metric tons)	Base area (hectares)
Base	Top	Base	Top			
400	100	502,655	31,416	33	61	50
600	300	1,130,973	282,743	99	182	113
800	500	2,010,619	785,398	203	373	201
1,000	700	3,141,593	1,539,380	344	633	314
1,200	900	4,523,893	2,544,690	523	963	452
1,400	1,100	6,157,521	3,801,327	740	1,361	616
1,600	1,300	8,042,477	5,309,291	994	1,830	804

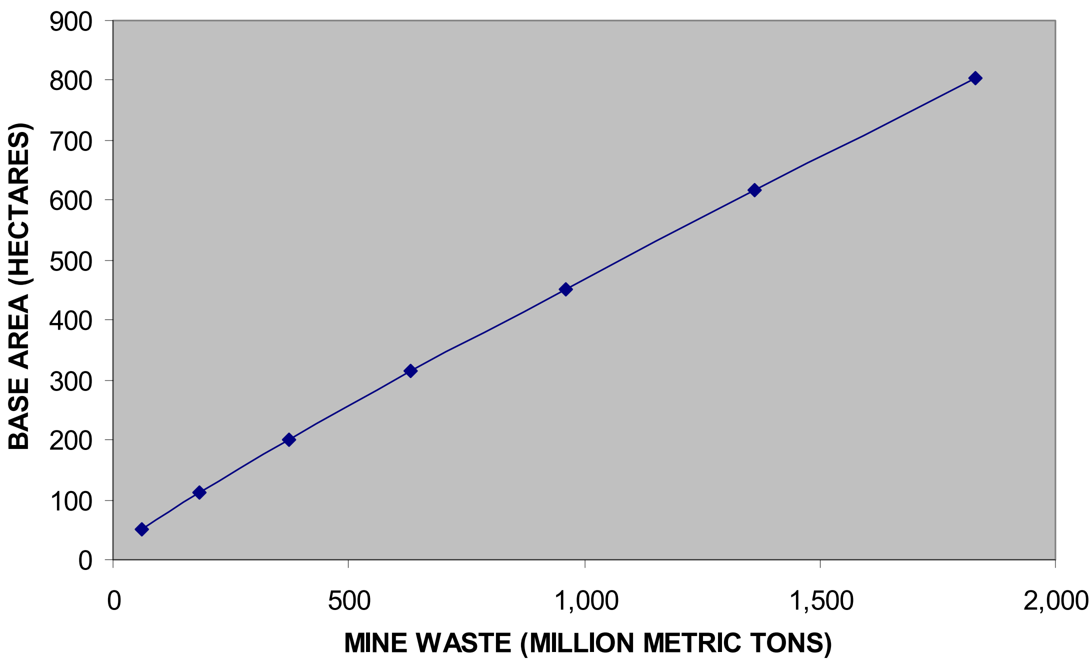

Figure A.12. Remediated mine waste base area calculations for selected mine waste tonnages at 150-meter height and 27-degree slope angle.

Table A.15. Remediated mine waste base area calculations for selected mine waste tonnages at 200-meter height and 27-degree slope angle.

Radius (meters)		Area (square meters)		Waste volume (million cubic meters)	Waste tonnage (million metric tons)	Base area (hectares)
Base	Top	Base	Top			
600	200	1,130,973	125,664	109	200	113
800	400	2,010,619	502,655	235	432	201
1,000	600	3,141,593	1,130,973	411	755	314
1,200	800	4,523,893	2,010,619	637	1,172	452
1,400	1,000	6,157,521	3,141,593	913	1,680	616
1,600	1,200	8,042,477	4,523,893	1,240	2,281	804

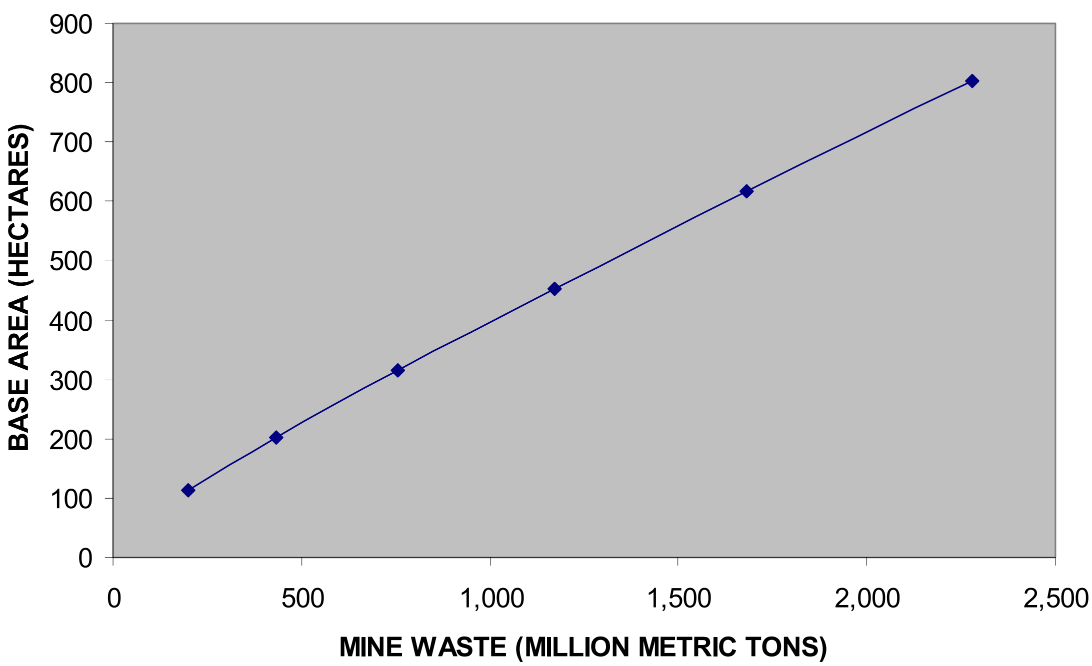

Figure A.13. Remediated mine waste base area calculations for selected mine waste tonnages at 200-meter height and 27-degree slope angle.

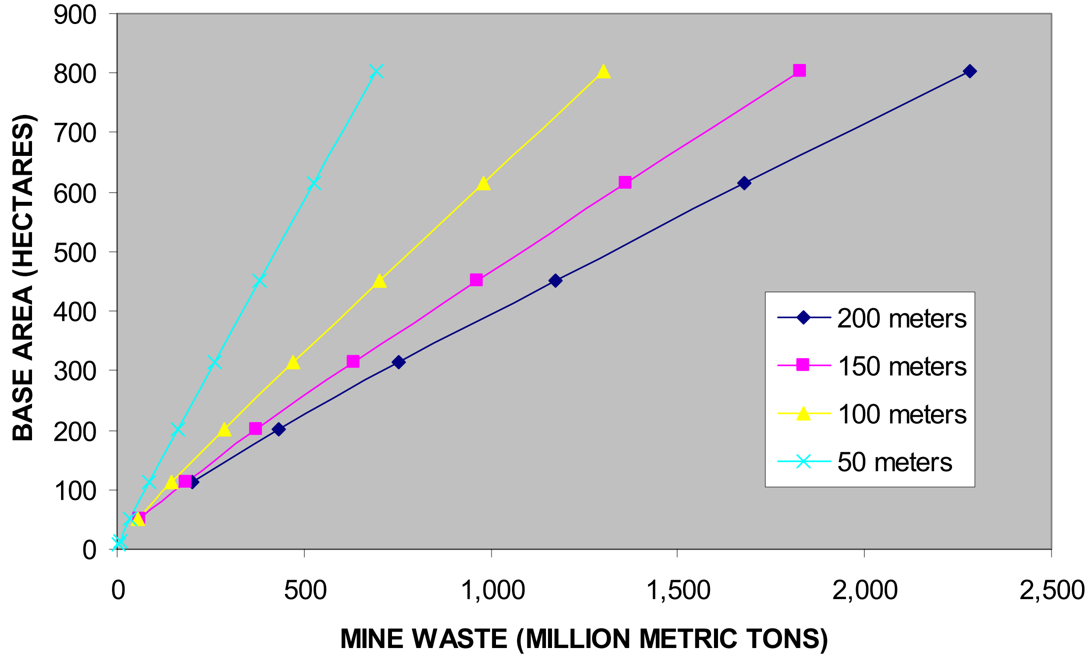

Figure A.14. Remediated mine waste base area versus waste tonnages at selected waste dump heights and 27-degree slope angle.

The best-fit linear equations are used to determine the base area for stripping ratios that range from 0.5 to 3.0 t of mine waste per ton of ore and for ore tonnages that range from 100 Mt to 1 Gt. The mine waste base area results are plotted for the 1.0 to 1, 2.0 to 1, and 3.0 to 1 stripping ratios for each of the mine waste dump heights. The relationship between ore tonnage and remediated mine waste base areas for various stripping ratios are listed in tables A.16 through A.19 and are shown in figures A.15 through A.18.

Table A.16. Remediated mine waste base area for selected ore tonnages and stripping ratios at 50-meter height and 27-degree slope angle.

Ore (million metric tons)	Base area (hectares)					
	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	67	124	182	239	297	355
200	124	239	355	470	585	700
300	182	355	527	700	873	1,045
400	239	470	700	930	1,160	1,391
600	355	700	1,045	1,391	1,736	2,081
800	470	930	1,391	1,851	2,311	2,772
1,000	585	1,160	1,736	2,311	2,887	3,463

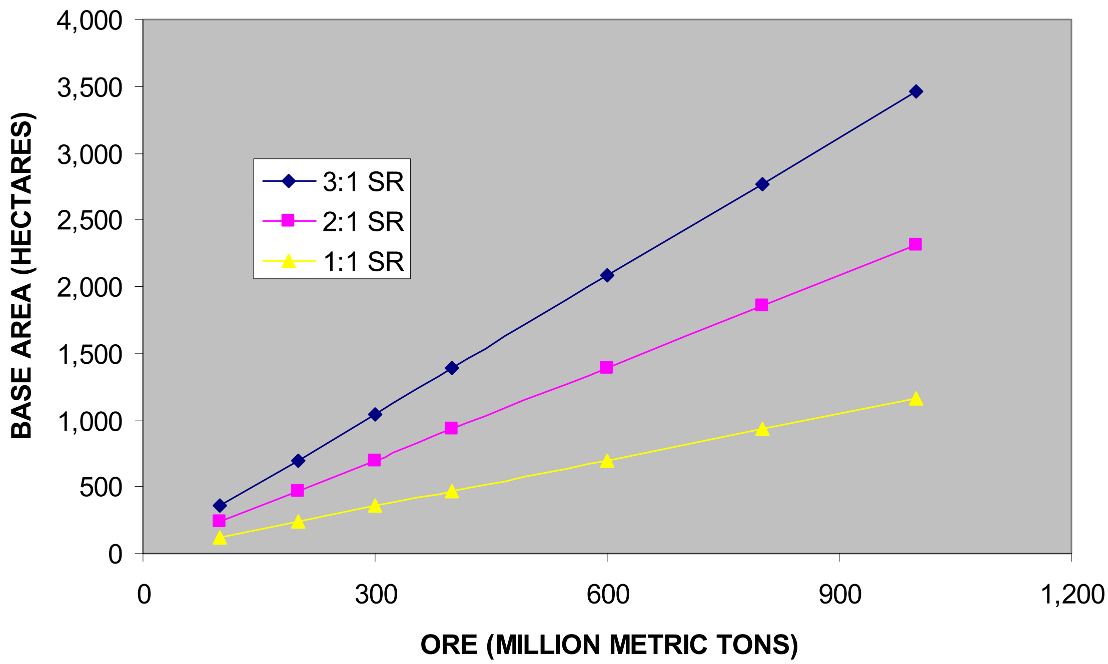

Figure A.15. Remediated mine waste base area for selected ore tonnages and stripping ratios (SR) at 50-meter height and 27-degree slope angle.

Table A.17. Remediated mine waste base area for selected ore tonnages and stripping ratios at 100-meter height and 27-degree slope angle.

Ore (million metric tons)	Base area (hectares)					
	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	56	86	116	146	176	206
200	86	146	206	267	327	387
300	116	206	297	387	477	567
400	146	267	387	507	628	748
600	206	387	567	748	928	1,109
800	267	507	748	989	1,229	1,470
1,000	327	628	928	1,229	1,530	1,831

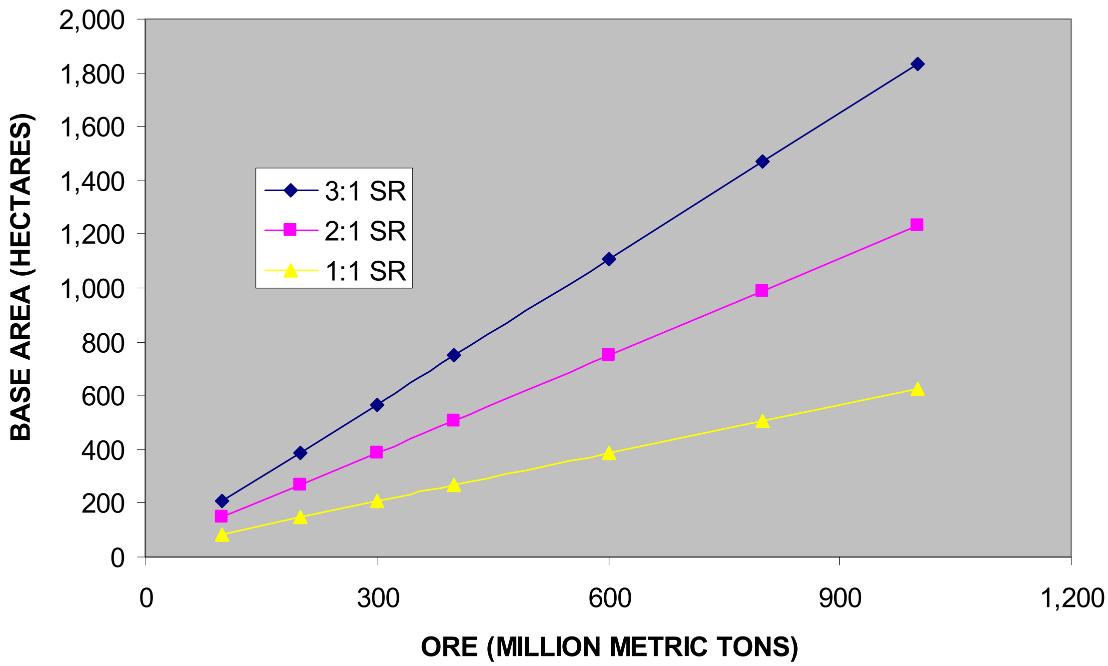

Figure A.16. Remediated mine waste base area for selected ore tonnages and stripping ratios (SR) at 100-meter height and 27-degree slope angle.

Table A.18. Remediated mine waste base area for selected ore tonnages and stripping ratios at 150-meter height and 27-degree slope angle.

Ore (million metric tons)	Base area (hectares)					
	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	59	80	101	122	143	165
200	80	122	165	207	249	292
300	101	165	228	292	355	419
400	122	207	292	376	461	546
600	165	292	419	546	673	800
800	207	376	546	715	885	1,054
1,000	249	461	673	885	1,097	1,309

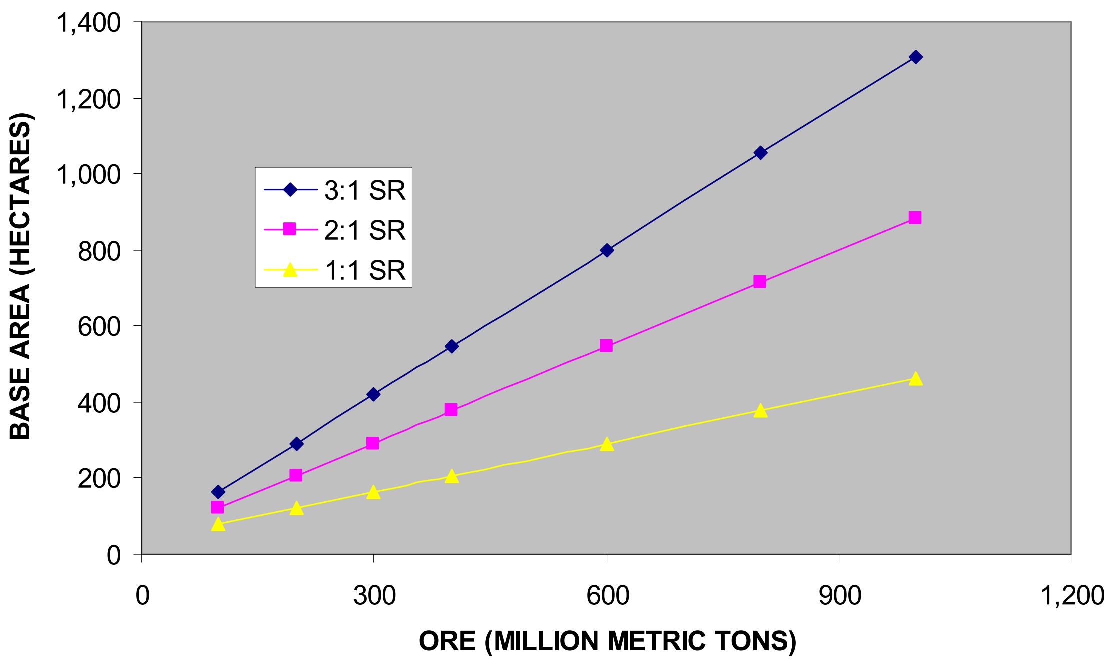

Figure A.17. Remediated mine waste base area for selected ore tonnages and stripping ratios (SR) at 150-meter height and 27-percent slope angle.

Table A.19. Remediated mine waste base area for selected ore tonnages and stripping ratios at 200-meter height and 27-degree slope angle.

Ore (million metric tons)	Base area (hectares)					
	0.5:1	1.0:1	1.5:1	2.0:1	2.5:1	3.0:1
100	74	91	107	124	140	157
200	91	124	157	190	223	256
300	107	157	206	256	305	355
400	124	190	256	322	388	454
600	157	256	355	454	553	653
800	190	322	454	586	719	851
1,000	223	388	553	719	884	1,049

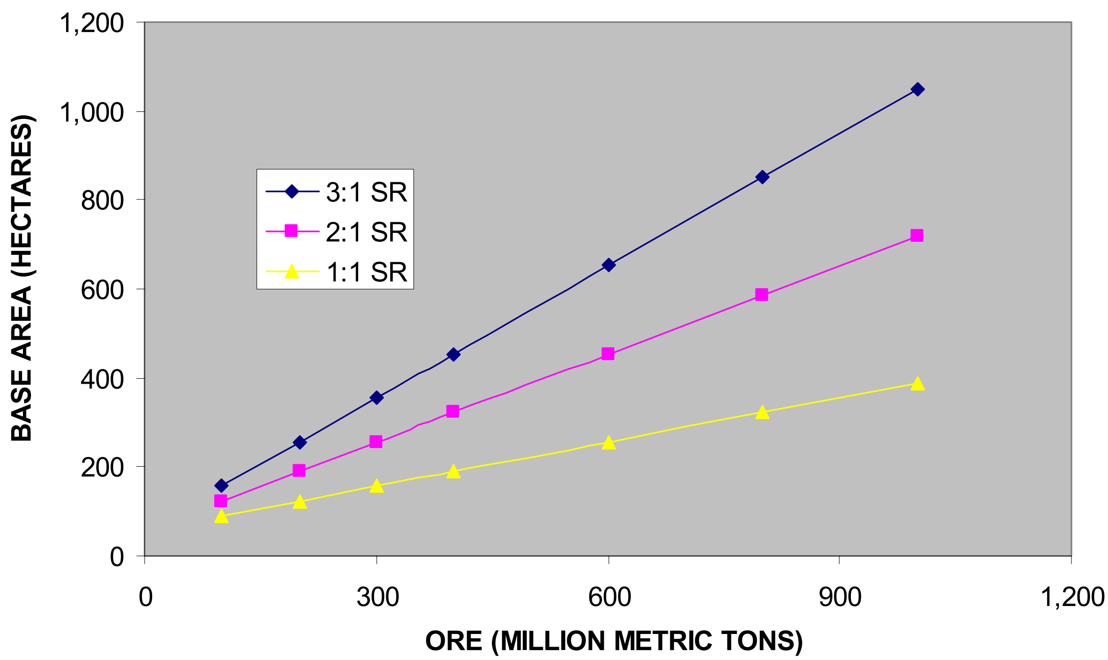

Figure A.18. Remediated mine waste base area for selected ore tonnages and stripping ratios (SR) at 200-meter height and 27-degree slope angle.

Mill Tailings Waste

Mill tailings waste production is the balance of material that remains from ore feed to the copper milling process and the copper concentrate produced. Tailings typically consist of finely ground gangue particles that are deposited hydraulically as a slurry on the tailings impoundment area. Concentrate production is estimated by accounting for concentrate grade, mill feed grade, and mill recovery. Because variations in concentrate grade, mill feed grade, and mill recovery have only a nominal affect on the amount of tailings produced, average values were used for these parameters. Operating characteristics used to determine concentrate amount were 0.7 percent copper mill feed; 88 percent mill recovery; and 30 percent copper concentrate grade. The following equation was used to estimate tailings per metric ton ore:

$$\text{t tailings/ton of ore} = 1\text{ t of ore} - [(0.007\text{ t Cu/ton of ore x }.88) / (0.30\text{ t Cu/ton of concentrate})]$$
$$= 0.979\text{ t tailings/ton of ore.}$$

Tailings density measurements are for drained tailings material and depend primarily on the dry rock density, size distribution, and moisture content. A dry rock density of 2.24 t/m^3 and 15 percent moisture content was assumed. Three densities were considered in this evaluation—85, 100, and 120 pounds per cubic foot. Measurements given in units of pounds per cubic feet can be converted to tons per cubic meters as follows:

Conversion factor = (0.0004536 metric ton per pound) / (0.02832 cubic meter per cubic foot) =

0.01603 t/m^3 / pound per cubic foot

d_{85m} = 85 pounds per cubic foot • 0.01603 = 1.363 t/m^3 (15 percent moisture)

d_{85d} = 1.36 t/m^3 • 0.85 = 1.158 t/m^3 (dry)

d_{100m} = 100 pounds per cubic foot • 0.01603 = 1.600 t/m^3 (15 percent moisture)

d_{100d} = 1.60 t/m^3 • 0.85 = 1.363 t/m^3 (dry)

d_{120m} = 120 pounds per cubic foot • 0.01603 = 1.924 t/m^3 (15 percent moisture)

d_{120d} = 1.92 t/m^3 • 0.85 = 1.635 t/m^3 (dry)

Calculation of tailings volume per metric ton of ore is shown in the following equations:

Volume of tailings / ton of ore = (0.979 t of tailings / ton of ore) / (1.158 t of tailings / cubic meter of tailings)

= 0.85 m^3 tailings / ton of ore.

Volume of tailings / ore = (0.979 t of tailings / ton of ore) / (1.363 t of tailings / cubic meter of tailings)

= 0.72 m^3 tailings / ton of ore.

Volume of tailings / ton of ore = (0.979 t of tailings / ton of ore) / (1.635 t of tailings / cubic meter of tailings)

= 0.60 m^3 tailings / ton of ore.

Table A.20 lists the relationship between ore and mill tailings tonnage and volume.

Table A.20. Mill tailings volume generation for selected ore tonnages and dry densities. [t/m^3, metric tons per cubic meter]

Ore (million metric tons)	Mill tailings (million metric tons)	Mill tailings volumes (million cubic meters)		
		1.16	1.36	1.64
100	97.9	84.6	71.9	59.9
200	195.9	169.2	143.7	119.8
300	293.8	253.7	215.6	179.7
400	391.8	338.3	287.4	239.6
600	587.7	507.5	431.2	359.4
800	783.6	676.7	574.9	479.2
1,000	979.5	845.8	718.6	599.1

The volumes of tailings were estimated by using the same methodology as in the mining waste section. A flat topography was selected as the depositional surface for the analyses, and the tailings waste was modeled in the shape of a frustum. For design purposes, a slope of 2.5:1 (22 º slope angle) was assumed for the tailings impoundment (Robert Reisinger, Environmental Engineer, Knight Piésold Consulting Company, oral commun., 2002). Tailings waste impoundments were evaluated for heights that ranged from 25 to 100 and for drained densities of 1.36 t/m^3 (85 pounds per cubic foot), 1.60 t/m^3 (100 pounds per cubic foot), and 1.92 t/m^3 (120 pounds per cubic foot). Ranges of tailings waste volumes were calculated by changing the base radius and plotting the results for various heights (25, 50, 75, and 100 m). The various tailings heights and densities are listed in tables A.21 through A.23 and shown in figures A.19 through A.21.

Table A.21. Mill tailings base area for selected tailings dump heights at 1.16 metric tons per cubic meter dry density.

[0.7 percent Cu feed grade, 88% recovery, and 30 percent Cu concentrate grade]

Ore	Tailings base area (hectares)			
(million metric tons)	25 meters	50 meters	75 meters	100 meters
100	358	195	145	128
200	710	376	270	224
300	1,061	557	395	320
400	1,413	738	520	417
600	2,116	1,100	770	609
800	2,820	1,462	1,021	801
1,000	3,523	1,825	1,271	994

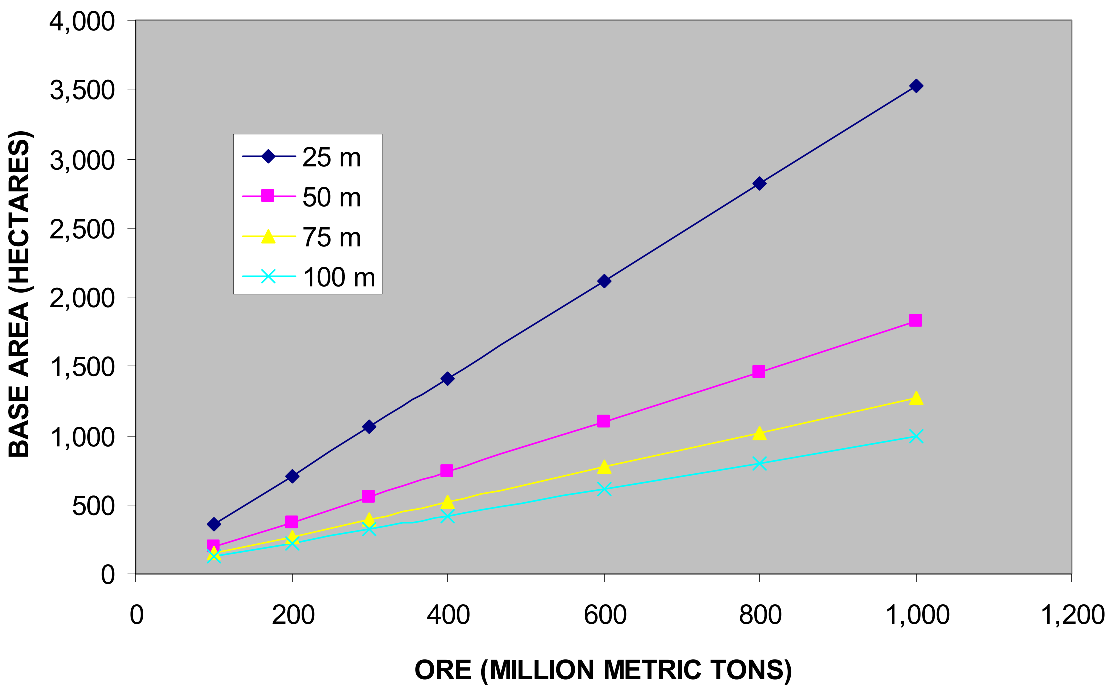

Figure A.19. Mill tailings base area for selected tailings dump heights, in meters (m), at 1.16 metric tons per cubic meter dry density.

Table A.22. Mill tailings base area for selected tailings dump heights at 1.36 metric tons per cubic meter dry density.

[0.7 percent Cu feed grade, 88% recovery and 30 percent Cu concentrate grade]

Ore	Tailings base area (hectares)			
(million metric tons)	25 meters	50 meters	75 meters	100 meters
100	305	167	126	114
200	604	321	232	195
300	903	475	339	277
400	1,201	629	445	359
600	1,799	937	658	522
800	2,397	1,244	870	686
1,000	2,994	1,552	1,083	849

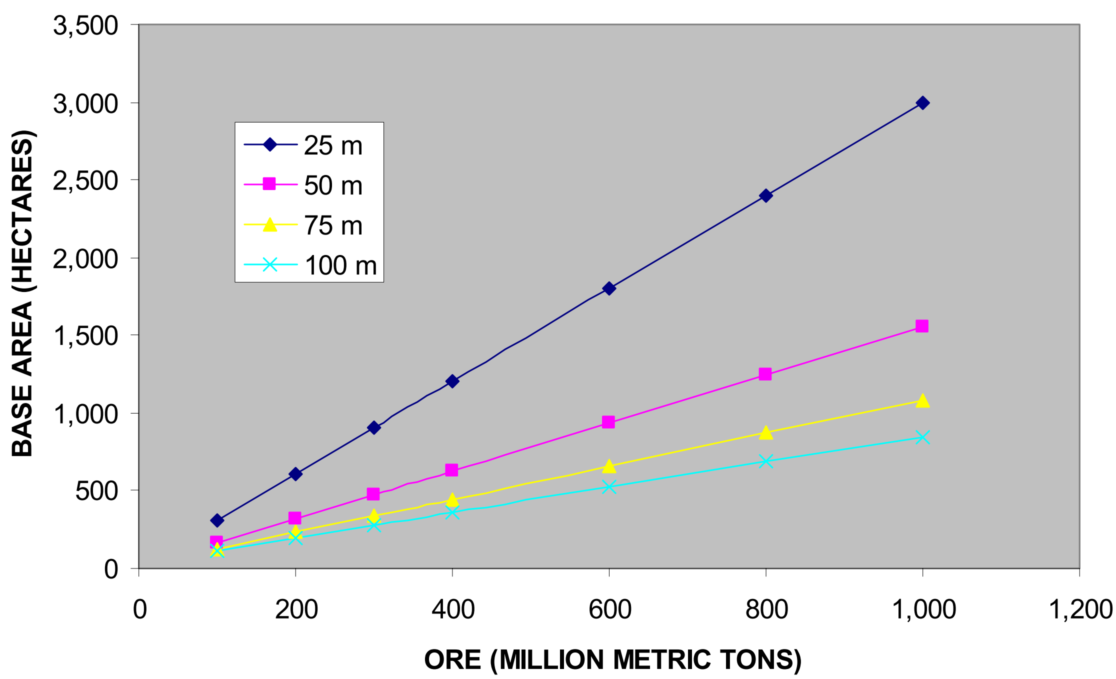

Figure A.20. Mill tailings base area for selected tailings dump heights, in meters (m), at 1.36 metric tons per cubic meter dry density.

Table A.23. Mill tailings base area for selected tailings dump heights at 1.64 metric tons per cubic meter dry density.

[0.7 percent Cu feed grade, 88% recovery and 30 percent Cu concentrate grade]

Ore	Tailings base area (hectares)			
(million metric tons)	25 meters	50 meters	75 meters	100 meters
100	218	123	95	90
200	430	232	171	148
300	642	341	246	206
400	855	450	322	264
600	1,279	669	472	380
800	1,703	887	623	496
1,000	2,127	1,106	774	612

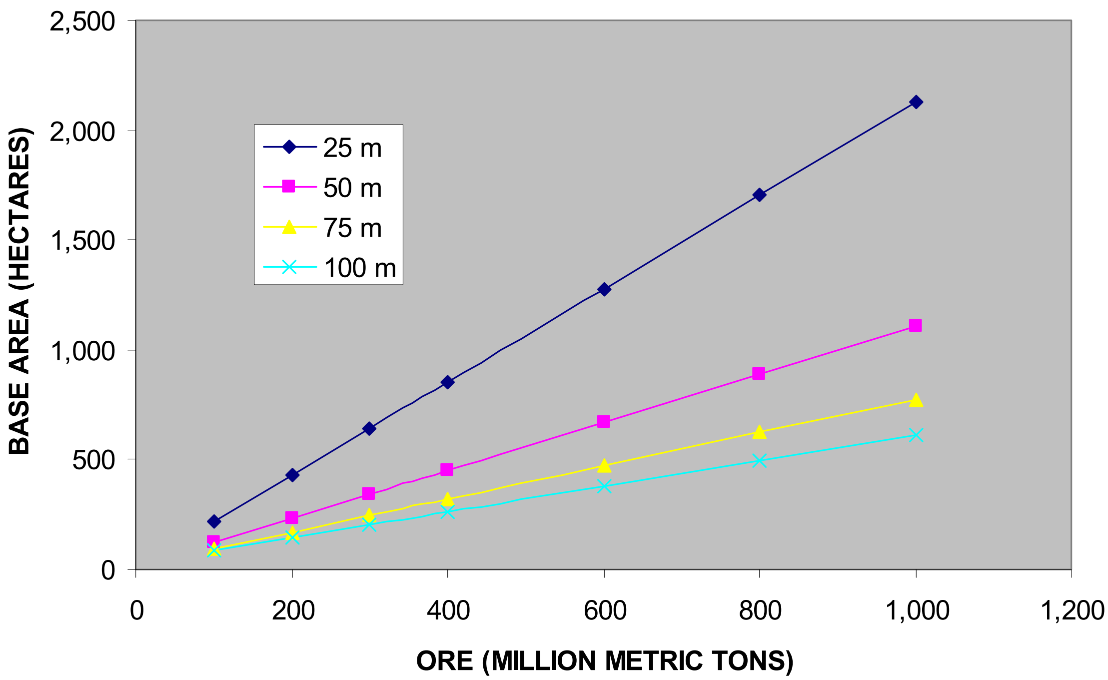

Figure A.21. Mill tailings base area for selected tailings dump heights, in meters (m), at 1.64 metric tons per cubic meter dry density.

Following are the best-fit linear equations for various tailings heights, in meters that use various assumed densities:

Density = 1.36 t/m^3 (85 pounds per cubic foot) (drained); 1.16 t/m^3 (dry)

Height	Best-fit equation
25	y = 3.5909x + 6.0985
50	y = 1.8491x + 13.463
75	y = 1.2775x + 19.636
100	y = 0.9823x + 31.794

Density = 1.60 t/m^3 (100 pounds per cubic foot) (drained); 1.36 t/m^3 (dry)

Height	Best-fit equation
25	y = 3.0508x + 6.0985
50	y = 1.5709x + 13.463
75	y = 1.0854x + 19.636
100	y = 0.8345x + 31.794

Density = 1.92 t/m^3 (120 pounds per cubic foot) (drained); 1.64 t/m^3 (dry)

Height	Best-fit equation
25	y = 2.1658x + 6.0985
50	y = 1.1152x + 13.463
75	y = 0.7705x + 19.636
100	y = 0.5924x + 31.794

Figures A.22 through A.25 show the influence of densities on the base area for various tailings heights.

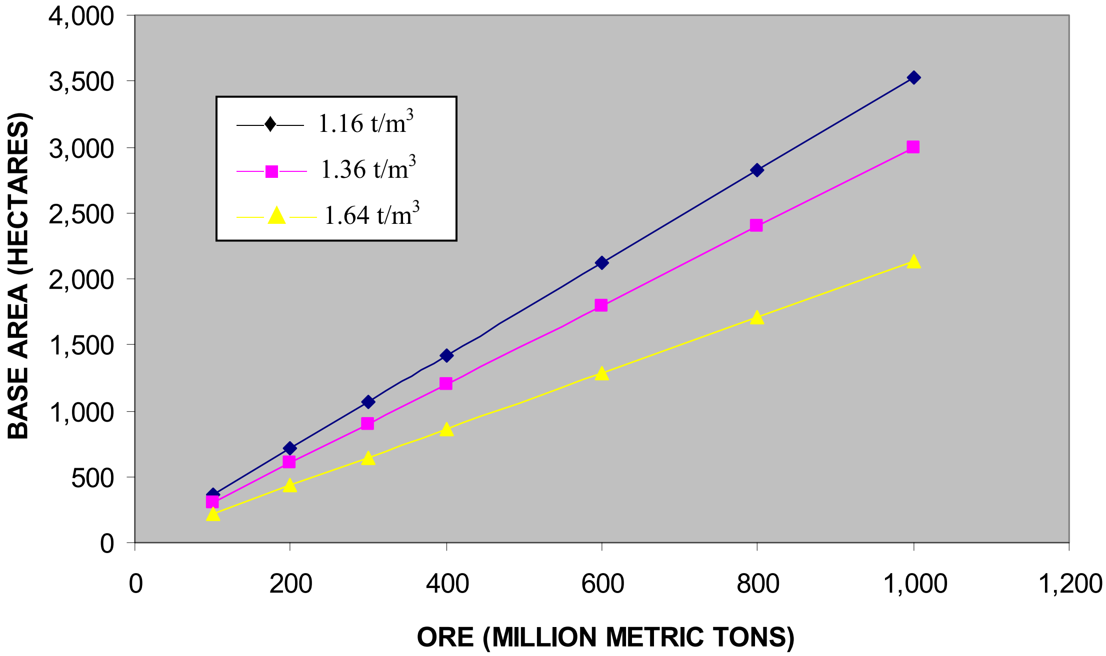

Figure A.22. Mill tailings base area for selected mill tailings densities, in metric tons per cubic meter (t/m^3), at 25-meter height.

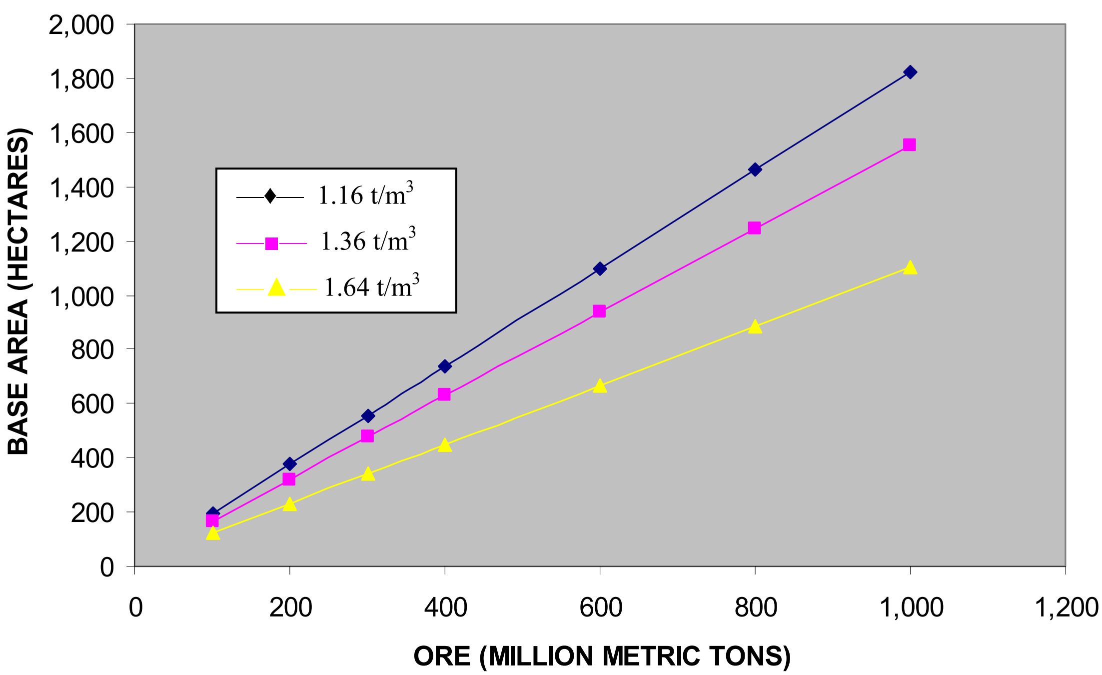

Figure A.23. Mill tailings base area for selected mill tailings densities, in metric tons per cubic meter (t/m^3), at 50-meter height.

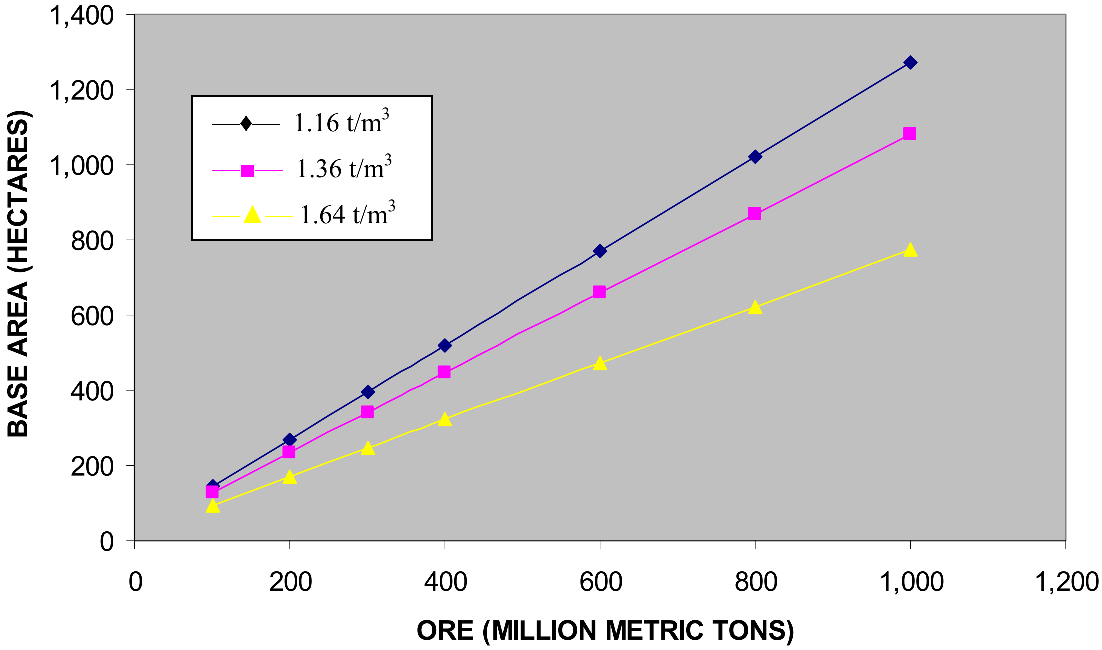

Figure A.24. Mill tailings base area for selected mill tailings densities, in metric tons per cubic meter (t/m^3), at 75-meter height.

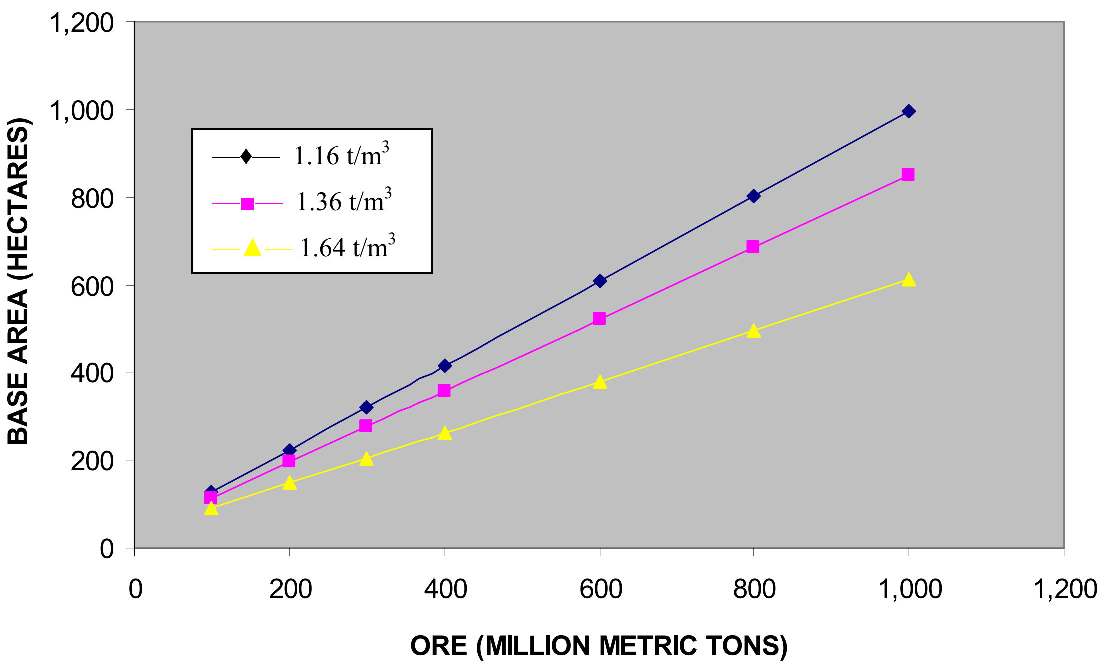

Figure A.25. Mill tailings base area for selected mill tailings densities, in metric tons per cubic meter (t/m^3), at 100-meter height.

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