STUDY ON FINANCIAL ASSURANCE AND CLOSURE COST FOR MINE RECLAMATION

by

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Abstract

Financial assurance for mine closure has been widely adopted by governments and companies internationally. Concern has grown in and around the global mining and mineral processing industry over potential risks associated with insufficient funding for mine closure.

The motivation of this research is to review financial assurance information from several jurisdictions and to quantitatively assess closure cost for a specific example. This research address the following four objectives:

1. To carry out a literature review on financial assurance for mine reclamation.
2. To compare present regulations and policies on financial assurance for mine closure in Canada, United States and Western Australia.
3. To identify expectations for different types of mining.
4. To develop the closure approaches and apply a method to estimate and calculate the closure cost for a mine site.

Main research results are as follow:

a. Significant reclamation financial assurance information is highlighted, and the expectations of various stakeholder are identified for different types of mines in various jurisdictions across the world.
b. Mine reclamation laws in selected jurisdictions of the Canada, United States, Western Australia have some differences and similarities in regulating agency, closure legislation,

guidelines and other aspects. Regulations and policies on financial assurance for mine reclamation in the United States and Canada can be classified into prescriptive and performance-based approaches. The performance-based approach is preferred by mining companies for mine reclamation regulations.

c. Developing a mine closure cost estimate requires an understanding of the site-specific closure requirements and available software can be used to perform the closure cost estimates. This study applies the Sherpa software to calculate the closure cost of a conceptual gold mine near Winnemucca, Humboldt County, Nevada. ArcGIS Software is used for calculating the size of each small surface water catchment areas for this mine.

The final cost estimate for the total closure cost for the gold mine near Winnemucca, Humboldt County, Nevada is $32,417,400 including $22,574,400 direct cost and $9,843,000 of indirect cost. Considering the Gross Receipt Tax of $677,200, the total financial assurance for this project is $33,094,600. The total overhead costs account for 30.4% of the direct project costs.

Preface

This dissertation is the original and unpublished work of the author, Boxi Shen. All literature review, project design, data collection, and analyses are the independent work of the author.

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List of abbreviations

Abbreviation	**Description**
ARD	Acid Rock Drainage
AG	Asset Agreements
BC	British Columbia
BG	Bank Guarantee
BLM	Bureau of land management
C&R Regs	Conservation and Reclamation Regulation
CIP	Carbon in Pulp
DEM	Digital Elevation Model
DEQ	State's Department of Environmental Quality
DMP	Department of Mines and Petroleum
ELAW	Environmental Law Alliance Worldwide
EPA	Environmental Protection Agency
EPEA	Environmental Protection and Enhancement Act
FLPMA	Federal Land Policy and Management Act
FWS	Fish and Wildlife Service
GB	Government Guaranteed Bonds
HSG	Hydrologic Soil Group
IP	Insurance Policy

LC	Letter of Credit
MNDM	Ministry of Northern Development and Mines
MOE	Ministry of Energy
MOEn	Ministry of Environment
MRMF	Mine Rock Management Facility
MRT	Mining Reclamation Trust
NGO	Non-Governmental Organization
NPS	National Park Service
OSM	Office of Surface Mining
PMP	Probable maximum precipitation
PPP	Polluter Pays Principle
QET	Qualifying Environmental Trusts
QETF	Qualified Environmental Trusts and Funds
ROM	Run-of-Mine
SMCRA	Surface Mine Control and Reclamation Act SMCRA
TMF	Tailings Management Facility
UNEP	United Nations Environment Programme
USFS	United States Forest Service
WA	Western Australia

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CHAPTER 1: INTRODUCTION

1.1 Background

The mining industry has been an important economic driver in the United States, Canada and other countries for more than 200 years. Gerard (1997) stated that:

> *…Claims that the mining industry needs more environmental regulation undoubtedly reflect the fact that in the past many mines were not reclaimed--that is, restored to conditions similar to the state of the land before mining began. The Forest Service began requiring reclamation in 1974 and the Bureau of Land Management in 1981.*

In the mining industry, reclamation financial assurance refers to funds that are available to the regulatory agency in the case of an operator default or bankruptcy. The purpose of financial assurance is to confirm that sufficient funds will be accessible to pay for site reclamation and post closure monitoring and maintenance at any stage of a project life (Sassoon, 2008). It is generally comprised of cost for activities such as backfilling, grading and reshaping of excavated areas, disposal and control of excess spoil, placement of topsoil and re-vegetation. Although traditional environmental regulations and laws can control a mining company's environmental performance during operational phase, they cannot guarantee site reclamation after operation stops (Miller, 2005). Thus, reclamation financial assurance has been implemented by international and national regulatory agencies in the world over recent years.

There are various financial assurance instruments, but in general it can be described as (Miller, 2005):

...guarantees issued by a bonding company, an insurance company, a bank, or another financial institution (the issuer is called the 'surety') which agrees to hold itself liable for the acts or failures of a third party.

There has been growing interest by both the government and industry in the issues regarding reclamation financial assurance. Miller (2005) indicates that while governments are responsible for environmental protection, they wish to minimize the risk of undertaking reclamation costs to the lowest, and at the same time, maintaining an investment-friendly climate to attract mining investment, being aware that the uncertainties of mine exploration and unreasonable high financial assurance can act as a deterrent to mining investors. Most of the mining companies are responsible and financially viable. They develop reclamation plans in accordance with the regulations, and in some cases, take over the responsibilities when other companies have walk out leaving orphaned mine sites (Miller, 2005).

1.2 Research questions

This research addresses the following four overarching questions:

1. What is the current state of financial assurance for mine reclamation, with a reference to the major mining countries like Canada, United States, and Australia?
2. What are the expectations for different types of mining?

3. What are the reclamation laws and regulations in different jurisdictions like British Columbia (BC), Alberta, Ontario, Nevada, and Western Australia?
4. What is the approach and method to calculate closure costs for a specific mine site?

1.3 Research objectives

The objectives of this research are:

1. To carry out a literature review on financial assurance for mine reclamation.
2. To compare present regulations and policies on financial assurance for mine closures in Canada, United States and Western Australia.
3. To identify expectations for different types of mining.
4. To develop the closure approaches and apply a method to estimate and calculate the closure costs for a mine site.

1.4 Thesis outline

The structure and flowchart of this study is depicted in Figure 1-1.

Chapter 2 provides a literature review of the general concepts of reclamation financial assurance, expectations for different types of mining and related regulations and laws.

Chapter 3 examines several regulation and policies of financial assurance for mines in Canada, the United States and Western Australia.

A quantitative model for estimating the closure cost for a gold mine is established in Chapter 4.

Chapter 5 applies the software Sherpa, which is an engineering-based software developed by Aventurine, for reclamation costs based on the approach discussed in Chapter 4.

Chapter 6 explores the limitations of the above calculations and explore its future application.

The conclusions of this study and point out future potential research areas are summarized in Chapter 7.

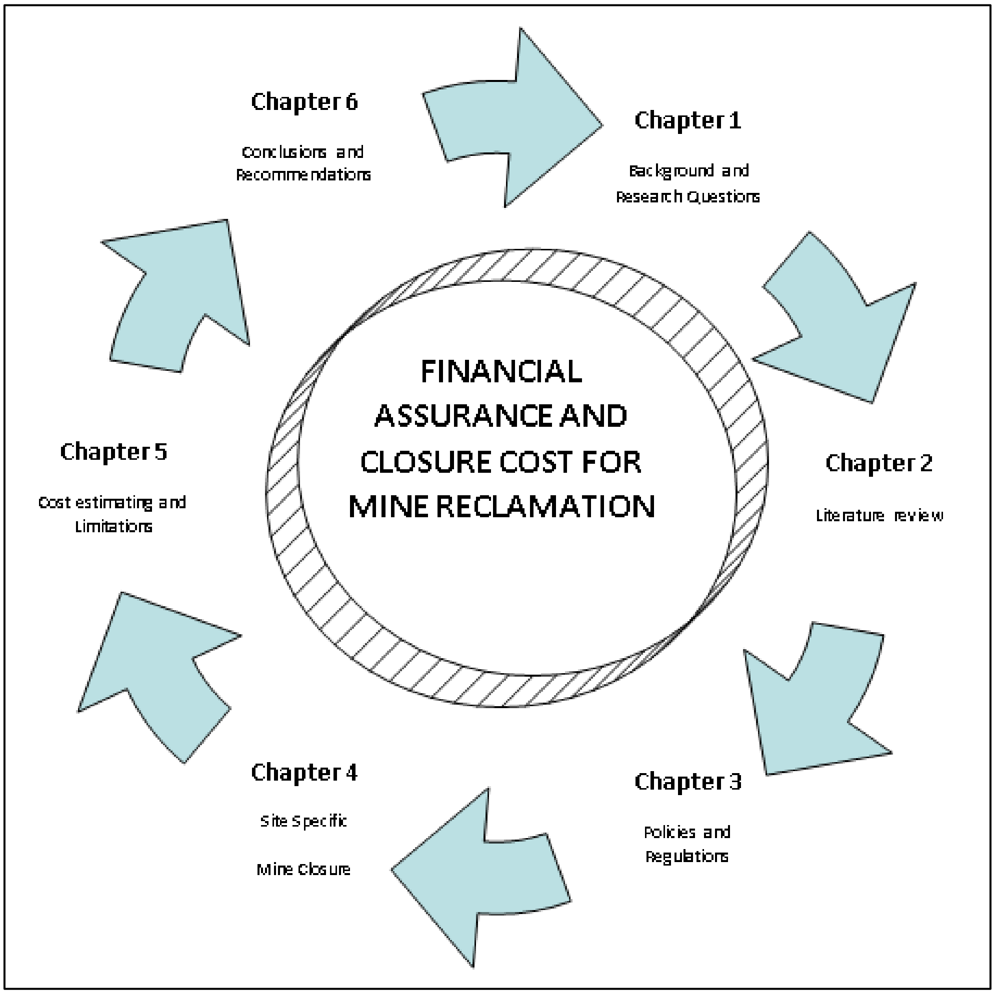

Figure 1-1: Structure and thesis outline

CHAPTER 2: LITERATURE REVIEW

This chapter is a literature review on financial assurance for mine reclamation. Some general concepts for reclamation financial assurance are given. Then expectations for different types of mining activities are identified. It is clearly noted that the amount and seasonal distribution of precipitation and the types of covers for tailings impoundments and waste rock dumps play important roles in the model building and cost estimating. Definitions for different types of mining reclamation activities have been included in this chapter.

2.1 General concepts for reclamation financial assurance

2.1.1 Significance and definition

The reclamation of open pit mines, tailings management facilities and related infrastructures are essential environmental priorities after the mining activity has ended. It was estimated in 2003 that there could have been $1 billion to more than $12 billion clean-up costs in 2003 for hard-rock mining sites in the United States (Kuipers, 2003). The primary purpose of closure cost estimates by the mining industry is to plan, budget and carry out actual closure activities (Parshley, 2009). Taxpayers are left with heavy financial burdens if mining companies cannot fulfill their obligations to close a mine. Financial Assurance is a tool used by the mining industry to provide enough funds to reclaim these disturbed areas so that they are not abandoned thereby minimizing the adverse environmental and social impacts from the mine (Peck & Sinding, 2009).

Kuipers et al. (2005) defined the concept of reclamation financial assurance as: if the mine operator refuses or fails to carry out the required reclamation activities, a third-party contractor can perform the activities at the direction of the responsible party (federal or state land administrator or private landowner). It aims to make sure that the industrial user of lands and resources is the one who pay for the reclamation. This approach is also in compliance with the polluter pays principle (PPP) that is broadly applied in today's mining industry.

The term "financial assurance" refers to any required contractual document and financial instrument used to confirm that an operator will perform reclamation as required in the regulations, in which a bond (insurance product) is one of the most commonly used instruments (Sassoon, 2008).

The term reclamation financial assurance has been substituted by many terms such as reclamation financial guarantees, financial securities, financial surety, and closure bonds in different countries. However, they are all perceived as means to confirm that sequentially, clean and lasting closure activities can be implemented by a third party or the government agency to bring it to a satisfactory state.

While the concept of financial assurance is broadly used in different countries with sound regulatory systems, Clark and Clark (2005) suggested that it is also considered vital in addressing environmental problems in countries with less-developed regulatory frameworks. In British Columbia (Canada), the approach to mine reclamation is that prior to receiving approval to commence mining activities, proponents are required to submit mine closure plans (sometimes referred to as reclamation or rehabilitation plans) which normally includes financial assurance in the amount estimated to be required to complete the closure plan. As the amount of financial assurance is generally based upon costs which would be generated by a third party it is often the proponent or a third party who does the calculation for financial assurance before it is reviewed by government. However, To reduce the cost to initiate a project, proponents always wish to keep the financial assurance at a minimum amount. Thus, the regulator must carefully review the estimates of required financial assurance.

2.1.2 Stakeholders and closure cost estimations

Freeman (2010) proposed a broad definition of stakeholder as:

Any group or individual who can affect or is affected by the achievement of an organization's objectives,

An important aspect that should be taken into consideration when estimating the reclamation cost is to understand for whom the estimate is prepared (Brodie, 2013). The estimate is usually considered for internal use or bonding purposes when preparing for owners. Estimation for internal use such as the viability of the mine and corporate cash flow accounting assumes that the work would be conducted under the direction of the mine manager, maximizing the use of existing staff and equipment, thus the unit cost for all work would be the lowest justifiable total cost. Brodie (2013) also ascribed the comparatively low cost to high productivity of equipment and familiarity of staff working on the site, which can lead to a low contingency cost. No capital cost regarding the use of equipment would apply in this case as it would already have been depreciated and treated as a sunk cost.

Estimation of the owner is generally prepared and submitted by corporation in support of its proposal for providing reclamation security (Brodie, 2013). According to regulations, cost based upon third-party contractors conducting all of the work should be included, with no allowance for salvage value. The contingency cost for bonding purposes would be the same as the internal estimate as they were both based upon the assumptions that the mine development will proceed as planned.

Estimation by the regulator reflects the government's expectation in the case that the company abandon the site. This is prepared when the regulator addresses the level of uncertainty in the closure plan. The contingency cost in this case may be higher as very few mines are developed exactly following the initial plan without any changes. There are also plans based upon new technology which may yield different result than expected.

According to Brodie (2013), the worst-case estimate is usually developed when NGO stakeholders want to prevent the mine development due to the reason that financial constraint excessive the corporation security. It was also noted by Thorton (2003) that most jurisdictions use the "worst-case-scenario" rather than the most "probable scenario" when estimating the amount of security bond.

Traditionally, there has long been an argument between the government and the industry with respect to mine reclamation financial assurance (Hawkins, 2008). Although most governments could recognize the financial benefits that mining brings, they want to make sure that the mining operators are capable of closing and reclaiming the mine (Brodie, 2013). Governments think that the more financial assurance there is, the better it can reduce the taxpayers' burden and their vulnerability to bankruptcy losses by ensuring that a reliable third party has access to a fixed asset that is segregated from the rest of the property in case of a bankruptcy. However, mine operators argue that both the security and the additional regulatory burden can result in an increased cost of doing business and the risk taken by government in the case of a bankrupt debtor can be decreased by less costly means.

2.1.3 Evaluation of mine financial assurance

A methodology to evaluate mine reclamation financial assurance was developed by the Environmental Law Alliance Worldwide (2010) in its publication: Guidebook for Evaluating Mining Project EIAs. This book not only presents an overview of the impacts that different mining project would bring, but also considers the financial assurance regimes in selected countries and suggests a way to evaluate the adequacy of financial assurances. ELAW comments that three factors are essential in an adequate financial assurance:

1. The first is that the reclamation and closure plan should include a commitment by the mining company to pay for closure and the cleanup during the active phase and the closure phase of mining project.

2. The second is that it is important to provide this financial commitment before the commencement of any mining activities and in a form that is irrevocable.
3. The third is that the reclamation and closure plan should specify an amount of money that the mining company would assure is available to pay for closure.

The reclamation expectations are quite different for open pit mines and underground mines. The following section identifies their different key features.

2.2 Expectations for different types of mining

2.2.1 Open pit mine reclamation

Open pit mines include an open pit, waste dump, and industrial site (including concentrator, sewage treatment plant, warehouse, lane or railway). Several jurisdictions in the world, the term "reclamation" means to return disturbed lands to an improved state. In Alberta, Canada, for example, the provincial government defines reclamation as *"the process of reconverting disturbed land to its former or other productive uses"* (Sinton, n.d). Thus, open pit mine reclamation could be considered to include two aspects: basic environmental objectives and end-land use objectives.

Errington (2009) suggested that the basic environmental objectives should include:

1. Site safety and stability, preventing landslides, debris flow and avalanches.
2. Remove hazardous and toxic waste within the mining area to protect the water body and plants from contaminating.

3. Sites after reclamation should be consistent with the surrounding environment, and the landscape features should fit in the surrounding undisturbed lands.
4. Vegetation in mine pits shall be established where the pit floor is free of water and is safe to access.
5. Soil and water erosion control.
6. A water body where use and productivity objectives can be achieved must be created where the pit will impound water.

Clear identification of end-land use objectives after cessation of mining can also be decisive to the way the land will be reclaimed. Post-mining land uses could include agricultural, commercial, residential, recreational or public facility improvements.

2.2.2 Underground mine reclamation

As higher grades of the ore usually result in lower volumes of waste rock and tailings, reclamation for underground mines is not always a significant problem or cost. Generally, waste rock or tailings are used with in a cement slurry to backfill the slopes, leaving minimal waste at surface. Machinery, equipment and infrastructure such as stairways, ladders, pipes, cables and all other underground installations are removed (Ministry of Energy and Mines, 2016).

2.3 Covers

Covers are constructed on facilities at mine sites such as tailings impoundments and waste rock dumps. A large variety of cover types have been designed and constructed at mine facilities worldwide. The specifics of the cover are determined by the waste covered, the environment of the mine site, especially the climatic conditions, and the governing regulations.

When precious metals like oxide gold is mined, and processed using cyanide for recovery, its tailings often contain cyanide and related compounds. In most cases the tailings are deposited as a slurry. Dry covers have been used in closure of oxide gold tailings and waste rock (Rens et al., 2009). Wet cover, or 'water cover', is a closure method that uses free water as an oxygen diffusion barrier to eliminate sulfide oxidation, as the oxygen diffusion coefficient is 104 times less in water than in air. Wet covers are only used for sulfides (Mylona & Paspaliaris, 2004).

2.3.1 Dry covers

Dry cover systems of waste disposal facilities are composed of multiple layers, Rumer and Mitchell (1995) find that they could be classified into five categories:

1. **Surface layer** is used to separate underlying layers from the ground surface, to resist wind and water erosion, and to protect underlying layers from high temperature and moisture.
2. **Protection layer** (also referred to as an evaporative cover) is to store infiltrated water until it is removed by evapotranspiration, to separate the waste from humans, burrowing animals and plant roots, and to protect the underlying layers from wet-dry and freeze-thaw cycles, which may cause cracking.
3. **Drainage layer** is used to reduce the water head on the barrier layer, and to reduce pore water pressures in the overlying layers to increase slope stability.

4. **Hydraulic barrier layer**, or 'low permeability layer', is the most critical engineered component of the dry cover systems in wetter climates. It is used to inhibit water percolation. Conventional artificial barriers include compacted clay layer, flexible membrane liners (or polymeric geomembranes), and geo-synthetic clay liners.
5. **Foundation layer**, the foundation for the cover.

The performance objectives for the mine waste disposal facility cover are one or more of the following:

- Limit infiltration
- Control air entry
- Resist wind and water erosion
- Remain stable
- Support vegetation.

The design of cover system is site-specific. To minimize percolation, conventional cover system uses low-permeability barrier layers which are often constructed of compacted clay.

CHAPTER 3: REGULATIONS AND POLICIES OF FINANCIAL ASSURANCE FOR MINE RECLAMATION

This chapter discusses reclamation laws and regulations in the Canada, United States, and Western Australia are discussed and compared. It also includes a short discussion on regulatory frameworks following prescriptive and performance-based approaches.

3.1 Reclamation laws and regulations

The increasing environmental awareness and potential burdens on taxpayers result in a higher demand for adequate financial assurance. A key to understanding the difference of financial assurance requirements among different jurisdictions is to review these laws and regulations. To guarantee that enough funds will be in place for mine reclamation, rigorous examinations of the current and past regulations of jurisdictions (either at the federal or provincial/state levels) are central to developing a better understanding of financial assurance requirements for mine reclamation.

Most of the regulations include the following sections:

- Definitions
- Administration
- Rules and regulations
- Permit application details

- Protest and petitions
- Reclamation plans requirements
- Financial assurances/ warrantees
- Operator succession- transfer
- Fees and penalties

It is important to understand the instruments that are used in financial assurance. The followings are some of the most common forms of financial assurance instruments:

a. **Letter of credit**: An irrevocable letter of credit, which may also be called a Bank Guarantee, is an unconditional agreement between a bank institution and a company to provide funds to a third party. In this instance, the third party is the relevant government. The normal term for a Letter of Credit is one year and reviewed annually by the bank. Since the initial cost is relatively inexpensive and needs less administrative requirements, a Letter of Credit is the most commonly used form of financial assurance instruments (Miller, 2005).
b. **Surety (Insurance) Bond**: A Surety Bond, also known as an Insurance Bond or Performance Bond, is an agreement between an insurance company and a mining company to provide funds to a third party, which in this instance, is the government. The operation of a Surety Bond is similar to that of a Letter of Credit, although they are generally more expensive than Letter of Credit.
c. **Trust Fund**: A Trust Fund, which may also be called a Mining Reclamation Trust, a Qualifying Environmental Trust or a Cash Trust Fund, is an agreement between a trust

company and the proponent to pay for site reclamation under certain circumstances. In addition to a Trust Fund, there should be a signed agreement between the proponent and the government.

d. **Cash**: A deposit in the form of Cash, a Bank Draft, or Certified Check can be made for a financial assurance. The fund should be kept under the management of the financial institution in a special purpose account, with the government and the company holding joint signatory powers. One advantage of the Cash trust fund is that the company does not give up total control over its funds, as any surpluses incurred in the fund should be returned to the company after the periodic review (Miller, 2005).

e. **Self-Insurance or Corporate Guarantee**: A Self Insurance, which may also be called a Corporate Guarantee, Corporate Financial Test, or Balance Sheet Test, is based on an evaluation of the company's assets and liabilities, as well as its ability to pay the total reclamation costs. A self-insurance usually requires a long history of financial stability, a credit rating from a specialized credit rating agency, and at least an annual financial statement prepared by an accounting firm (Sassoon, 2008).

The next section reviews mining laws and regulations in selected jurisdictions in Canada, the United States and Australia.

3.1.1 Canada

Canada is one of the leading countries in the international mining industry, Mines, quarries, and primary metals and minerals are found in nearly every province and territory.

British Columbia

BC leads the world in mine land reclamation implementation (Howe & Polster, 2009). In 2013, the total value of production at BC mines was $7 billion and $476 million for mineral exploration (Morris et al., 2016). Open pit mining in BC is about moving massive quantities of material efficiently and effectively. According to the BC Government, there were approximately 45,412 hectares of disturbed land in BC in the late 1960's (Miedema, 2013). Mining companies have been required to reclaim lands disturbed by mining activities since 1969, approximately 19,422 hectares (42%) has been reclaimed. BC was one of the first jurisdictions in Canada to enact mine reclamation legislation, and the first to require companies to post reclamation financial assurance prior to exploration and mining (Mining in BC, n.d.).

The regulating agency for mine reclamation in BC is the Ministry of Energy and Mines. The British Columbia Mines Act requires that mines provide a financial security to cover costs of reclamation and long-term maintenance, and if the company defaults on its obligations it would provide interest payments in the same amount to the anticipated future capital and operating costs.

In BC, the Health Safety and Reclamation Code for Mines in BC in 2008 includes sections on mine closure. Part 10 of the Health, Safety and Reclamation Code for Mines in BC has been revised effective July 20, 2016.

Available financial assurance instruments in BC include the letter of credit (LC, preferred), the Qualified Environmental Trusts and Funds (QETF) held within the Reclamation Trust Fund (recently allowed for), and Asset Agreements (AG) which have been accepted in the past and are acceptable only under specific conditions.

The amount and form of financial security must be acceptable to the Chief Inspector of Mines, and the amount of financial security is reviewed every 5 years or more often if significant site changes took place. Permittees are required to submit a total expected cost of outstanding reclamation obligations over the planned life of the mine together with the annual reclamation reports.

In 2014, a report by the BC auditor general found that there is a $1.2 billion shortfall in reclamation securities. A mine-by-mine breakdown of the shortfall was provided by the B.C. Mines Ministry and is shown below in Table 3-1 (Hoekstra, 2016).

Morris et al. (2016) suggested that the government of British Columbia should create an independent enforcement unit for mining activities, with a mandate to ensure the environmental protection. Within this unit, government should show all stakeholders that sound system has been put in place for regulatory oversight.

Table 3-1: Breakdown in shortfall in reclamation securities (in million dollars). (Adapted from Hoekstra, 2016)

Mine	Owner (2014)	Total Bond Amount	Liability Estimate	Differential
		COAL MINE PERMITS		
Elk Valley	Teck Coal Ltd.	384.460	925.358	540.898
Sage Creek	Sage Creek Coal Ltd.	0.001	0.001	0.000
Tent Mountain	Luscar	0.059	0.059	0.000
Sukunka Coal	Tailsman Energy Inc.	0.050	0.068	0.018
Mt Speiker	Canadian Natural Resources Ltd.	0.010	0.010	0.000
Benson Mt.	Netherlands Pacific Mining Co. Ltd.	0.005	0.005	0.000
Willow Creek	Walter Energy	6.000	11.988	5.988
Quintette	Teck Coal Ltd.	20.083	30.071	9.988
Bullmoose	Teck Coal Ltd.	1.000	1.000	0.000
Benson Mt.	Wolf Mountain Coal Ltd.	0.020	0.020	0.000
Mt Klappan	Fortune Coal Ltd.	0.307	0.123	0.000
Quinsam Coal Mine	Hillsborough Resources Ltd.	7.281	7.281	0.000
Basin Coal	Coalmont Energy Corp.	0.277	0.560	0.283
Brule	Walter Energy	3.350	14.684	11.334
Wolverine	Walter Energy	11.500	12.499	0.999
Trend	Peace River Coal Ltd.	43.900	111.300	67.400
		METAL MINE PERMITS		
Endako	Thompson Creek Mining Co.	15.346	44.560	29.214
Pinchi	Teck Metals Ltd.	2.000	2.000	0.000
Granisle	Glencore Canada Corp.	0.162	4.254	4.092
Red Mountain	Ministry of Energy and Mines	0.465	0.465	0.000
Island Copper	BHP Billiton	4.208	4.637	0.429
Kitsault	Avanti Kitsault Mine Ltd.	0.740	0.270	0.000
High land Valley	Teck Highland Valley Copper	18.250	204.395	186.145
Brenda	Glencore Canada Corp.	5.000	27.333	22.333
Cassiar	Cassiar-Jade Contracting Inc.	0.600	1.530	0.930
Myra Falls Operation	Nyrstar	78.255	118.760	40.505
Copper Mountain	Copper Mountain Mines Ltd.	11.501	12.766	1.265
Gallowai Bul River	R.H. Stanfield	0.492	0.498	0.007
Bell Mine	Glencore Canada Corp.	1.000	45.441	44.441
Taseko Mines Ltd.	Gibraltar Mines Ltd.	45.638	29.800	0.000
Alwin Mine	Dekalb	0.006	0.006	0.000
Giant Nickel	Barrick Gold Inc.	0.027	0.600	0.573
Silvan/Hickey	Slocan/Klondike Gold Corp	0.075	0.185	0.110

Craigmont	Huldra Silver Corp.	0.700	0.706	0.006
Dolly Varden Mine	Dolly Varden	0.006	0.006	0.000
Beaverdell	Teck Resources Ltd.	0.005	0.010	0.005
Mt Copeland	KRC Operators	0.003	0.003	0.000
Sullivan	Teck Metals Ltd.	22.500	22.500	0.000
HB Mine	Teck Resources Ltd.	0.010	0.010	0.000
Dankoe	439813 BC Ltd.	0.010	0.010	0.000
Boss Mountain	Glencore Canada Corp.	0.030	2.434	2.404
Afton	KGHM Ajax Mining Inc.	0.350	0.350	0.000
Equity	GoldCorp	62.447	62.447	0.000
Cusac	Cusac Gold Mines Ltd.	0.264	0.628	0.363
Mosquito Creek	Mosquito Creek	0.005	0.437	0.432
Caroline	New Carolin Gold Corp.	0.256	0.200	0.000
Scottie Gold	Red Eye Resources	0.015	0.015	0.000
Baker	Dupont Canada Ltd.	0.016	0.166	0.150
Goldstream	Bethlehem Resources	0.200	1.048	0.848
Venus Mine	United Keno Mines	0.007	0.007	0.000
Taurus	Cassiar Gold Corp/Inter Taurus	0.010	0.010	0.000
Diamc	Silence Lake	0.010	0.010	0.000
Baymag	Baymag Mines Co. Ltd.	0.015	0.836	0.821
Ashlu Gold	Osprey Mining and Exploration	0.010	0.010	0.000
Four-J/Lussier	Georgia Pacific Canada Ltd.	0.020	0.020	0.000
Perlite	Perlite Canada Inc.	0.000	0.000	0.000
Union Mine	Pearl Resources Ltd.	0.005	0.005	0.000
Blackdome	J- Pacific Gold I nc	0.100	0.100	0.000
Nickel Plate	Barrick Gold Inc.	1.672	96.500	94.828
Cheni/Lawyers	Cheni Gold Mines Ltd	0.015	0.015	0.000
Johnny Mountain	Skyline Gold Corp.	0.562	0.319	0.000
Premier	Boliden	3.000	15.909	12.909
Parson Barite	Highwood Res/Sherritt	0.010	0.054	0.044
Moberly Silica	HCA Mountain Minerals	0.000	0.000	0.000
Candorado	Candorado Mines	0.000	3.000	3.000
Samatosum	FQM Akubra Inc.	7.800	7.276	0.000
South Fork Silica	331670 BC Ltd.	0.001	0.001	0.000
Barrier Feldspar	Kanspar	0.020	0.020	0.000
Golden Bear	Goldcorp	0.210	0.073	0.000
Horse Creek Silica	HiTest Sand Inc.	0.125	0.125	0.000
Sable/Shasta	Int'l Shasta/Sable Resources Ltd.	0.164	1.110	0.946
Snip	Barrick Gold I nc.	1.000	2.941	1.941
CIL	Clayburn Industries	0.001	0.005	0.004
Cirque Mine	Cirque Operating Corp.	0.220	0.220	0.000

Gypo Pit	Pacific Silica and Rock Quarry	0.003	0.003	0.000
Eskay Creek	Barrick Gold Corp.	3.774	118.514	114.740
QR	Barkerville Gold Mines	2.860	10.250	7.390
Elk / Siwash	Almaden/Fairfield Minerals	0.150	0.062	0.000
Mount Polley	Mt Polley Mines Ltd.	19.050	29.500	10.450
Huckleberry	Huckleberry Mines Ltd.	26.000	59.000	33.000
Kemess South	AuRico	18.520	17.145	0.000
Bralorne	Bralorne Gold Mines Ltd.	0.115	1.115	1.000
Bow mines (Tailings)	Golden Dawn Minerals Inc.	0.050	0.070	0.020
Crystal Graphite	Eagle Graphite Corporation	0.000	0.000	0.000
Ainsworth Mill	Blue Bird Mining	0.005	0.250	0.245
Britannia	BC Government	0.000	0.000	0.000
Quinto Mine	Consolidated/Quinto Mining Corp.	0.070	0.005	0.000
Blue Bell	Teck Resources Ltd.	0.000	0.000	0.000
HB Tailings	Regional District East Kootenay	0.000	0.000	0.000
Churchill Copper	Teck Resources Ltd.	0.000	0.000	0.000
Max Molybdenum	Forty-Two Metals Inc.	0.730	1.313	0.583
New Afton	New Gold Inc.	9.500	9.681	0.181
Galore Creek	Teck Metals Ltd.	1.167	1.167	0.000
Ruby Creek	Adanac Molybdenum Corp.	0.100	0.100	0.000
Tulsequah	Chieftain Metals Inc.	1.200	1.200	0.000
Zip Mill	Huakan International Mining Inc.	0.235	0.304	0.069
Lexington-Grenoble	Huakan International Mining Inc.	0.215	0.168	0.000
Yellowjacket	EaglePlains	0.150	0.150	0.000
Mount Milligan	Terrain Metals Corp.	30.000	35.171	5.171
Dome Mountain	Gavin Mines Ltd.	0.579	1.360	0.781
Bonanza Ledge	Barkerville Gold Mines	0.960	4.446	3.486
Treasure Mountain	Huldra Silver Inc.	0.505	0.505	0.000
Red Chris	Red Chris Operating Corp.	12.000	9.774	0.000
Yellow Giant (Tel)	Banks Island Gold Ltd.	0.355	0.284	0.000
	Total	**892.153**	**2133.597**	**1262.770**

Alberta

The regulating agency in Alberta is the Ministry of Environment and Ministry of Energy. The closure plans are prepared under the authority of Environmental Protection and Enhancement Act (EPEA 2000). Both underground and surface coal mines and oil sands mines are covered by the EPEA. The closure guideline in Alberta is the Conservation and Reclamation Regulation (C&R Regs) (115/1993).

Theoretically, the regulations are designed to provide full-cost financial security up front as part of the approval process, however some inconsistencies exist. For Oil Sands Mines, full cost reclamation security is assessed forward to the maximum disturbance expected in the next year. For Coal Mines, full cost reclamation security is based on the maximum disturbance that did occur in the previous year.

In Alberta, the allowable Security Instruments include the following: cash (C), cheques and other similar negotiable instruments payable to the Minister of Finance, government guaranteed bonds (GB), debentures, term deposits, certificates of deposits, trust certificated or investment certificates assigned to the Minister of Finance, irrevocable letter of credit (Klco, 1990), irrevocable letters of guarantee, performance bonds or surety bonds, Qualifying environmental trusts (QET), and any other form acceptable to Director (Others). Financial Security is assessed annually, unless it is a new project at which time security must be in hand prior to issuance of approval (Cowan et al, 2010).

In 2009, the Alberta government moved forward with several reclamation initiatives to improve clarity, security and environmental performance within the oil sands and coal mining sector (Woollard, 2015), and this includes the initiative of the Mine Financial Security Program (MFSP). The fundamental principle of the MFSP is that the approval holder under the Environmental Protection and Enhancement Act is responsible for carrying out surface reclamation work to meet the provincial standard.

In 2013, an email inquiry about the statistics of mine financial security in Alberta was sent to the Alberta Environment & Sustainable Resource Development office. The information provided the summary for different mine projects in Alberta from 2004 to 2012 is shown below in Table 3-2 and Figure 3-1.

Table 3-2: Security summary for different mine projects in Alberta from 2004 to 2012 (in million $)

Facility	2004	2005	2006	2007	2008	2009	2010	MFSP 2011	MFSP 2012
Syncrude Aurora North	60.0	71.2	90.2	120.4	136.4	143.0	155.5	n/a	n/a
Syncrude Mildred Lake	42.9	42.9	44.1	45.2	47.0	48.5	49.8	n/a	n/a
Syncrude (combined)								205.3	205.3
Suncor Base Operations	91.7	100.8	176.1	240.2	271.3	285.0	359.1	359.1	359.1
Canadian Natural Horizon	7.8	8.4	20.8	27.6	39.7	45.1	61.2	61.2	61.2
Suncor Fort Hills	0.8	1.7	1.7	14.2	68.7	48.4	39.0	46.6	77.6
Imperial Kearl					5.6	98.4	64.7	64.7	64.7
Shell Albian Jackpine		0.0	5.7	22.3	93.5	54.2	72.4	72.4	72.4
Shell Albian Muskeg River	30.4	34.3	37.9	51.3	73.2	85.7	111.3	111.3	111.3
Total Joslyn North								16.1	16.1

Total	**233.7**	**259.4**	**376.4**	**521.3**	**735.3**	**808.3**	**912.9**	**936.6**	**967.6**

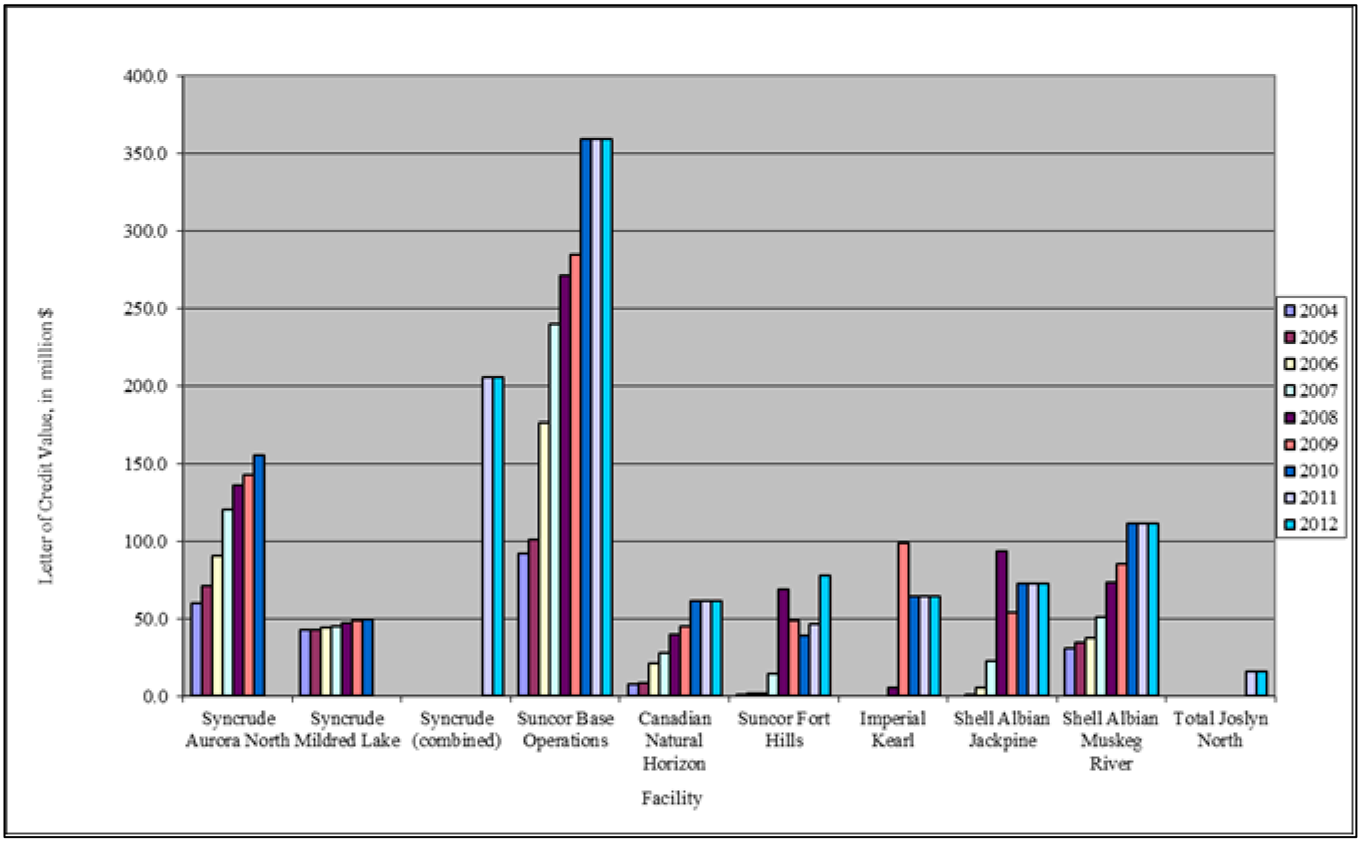

Figure 3-1: Security summary for different mine projects in Alberta from 2004 to 2012

Ontario

In Ontario, the regulating agency is the Mines and Minerals Division, Mineral Development and Land Branch under the Ministry of Northern Development and Mines. Ontario Mining Act is the provincial legislation that governs and regulates mine closure and rehabilitation in Ontario. Part VII of the Act specifically focuses on mine reclamation requirements for a Closure Plan, including Financial Assurance. The closure guidelines in Ontario is the Mine Rehabilitation Code (Ontario Regulation 240/00) and the Financial Assurance Policy Index (2011). In Ontario, the government is in the process of considering introducing a regular review of closure costs either every three or five years.

Section 145 of the Ontario Mining Act identifies the following instruments acceptable as financial assurance: Cash (C), a Letter of Credit from a bank named in Schedule I to the Bank Act, a bond of a guarantee company (GB) approved under the Insurance Act, a mining reclamation trust (MRT) as defined in the Income Tax Act, Compliance (COM) with a corporate financial test in the prescribed manner, and any other form of security or any other guarantee or protection, including a pledge of assets, a sinking fund or royalties per tonne, that is acceptable to the Director (Others).

In 2013, an email inquiry was sent to the Mines and Minerals Division, Mineral Development and Land Branch under the Ministry of Northern Development and Mines. A breakdown of financial assurance collected from 2000 to 2012 in Ontario can be found in Table 3-3 and Figure 3-2. It is clear that there has been a rapid increase in the use of Corporate Financial Test in 2001 which was accounted for most of the funds being held for financial surety. There is also a steady increase in the use of Letter of credit.

Table 3-3: Breakdown of financial assurance forms and amounts in Ontario from 2000 to 2012 (in million $)

Form	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Letter of Credit	29.5	54.8	60.2	62.6	105.4	124.2	193.9	195.6	271.2	327.3	347.3	533.3	608.9
Corporate Financial Test		44.4	582.3	582.3	584.6	585.1	585.1	600.8	610.8	579.1	579.7	483.9	659.8
Cash	4.1	4.1	9.8	18.9	13.5	15.3	15.9	18.6	17.5	23.4	32.7	24.3	26.8
Surety Bond	4.9	20.2	47.0	44.7	6.5	6.4	6.4	6.4	6.2	6.1	10.7	13.3	66.2
Pledge of Assets	2.3	6.0	6.0	6.0	6.0	6.0	6.2	4.4	4.4	3.8	3.8	3.7	3.7
Letter of Guarantee	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0					
Corporate Guarantee	4.6												
Other	0.1							19.9					
Total	**45.8**	**129.7**	**705.5**	**714.5**	**716.0**	**737.1**	**807.6**	**845.8**	**910.1**	**939.7**	**974.2**	**1,058.5**	**1,365.5**

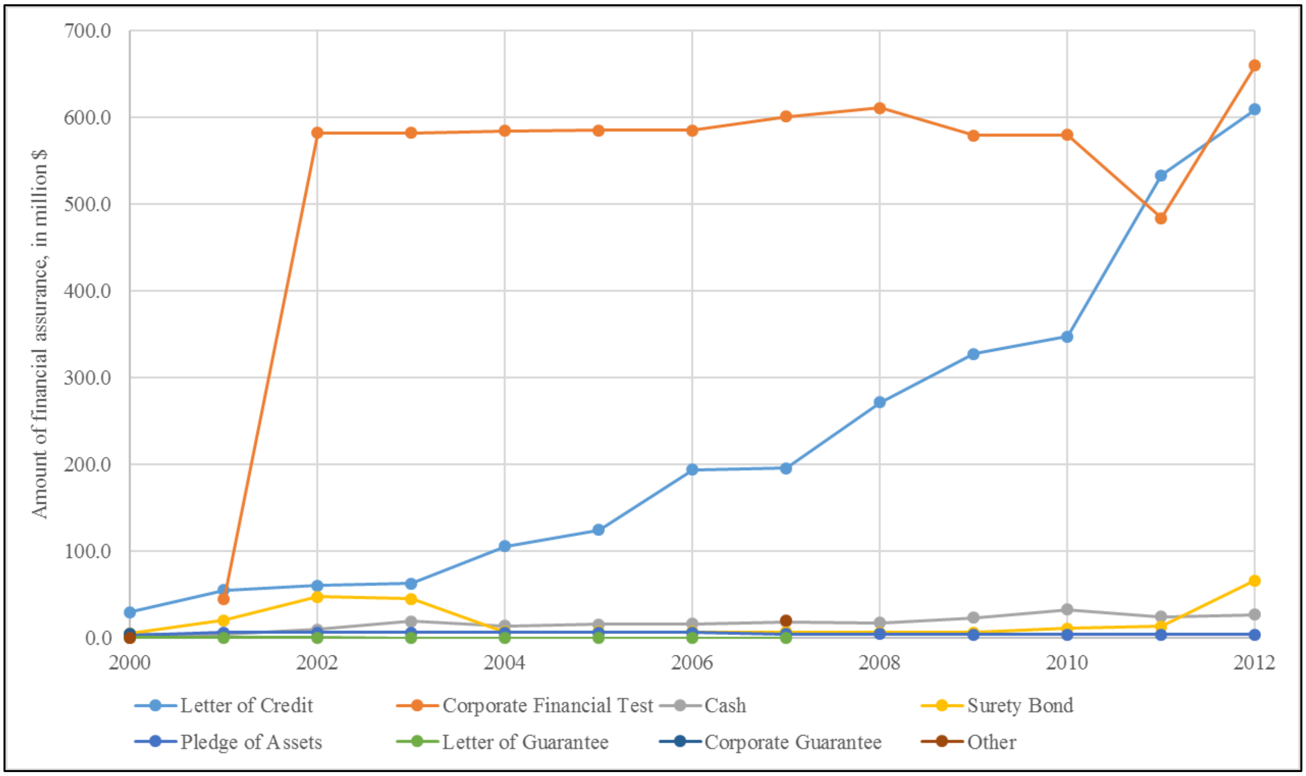

Figure 3-2: Breakdown of financial assurance forms in Ontario from 2000 to 2012

3.1.2 The United States

The United States has had a large and active mining industry for over more than 150 years. The quests of the United States to locate and extract copper, lead, silver, gold and other precious metals from the land had a dramatic influence on the way the region was settled and developed. Mining activities are regulated by many different entities with states playing a key role in oversight.

The closure guidelines/codes are different from state to state in the United States. In Colorado, the Regulations of the Colorado Mined Land Reclamation Board for Coal Mining were first issued in

1980, and was revised in 2005. In Montana, Subchapter 1 Rules and Regulations in Chapter 24 Environmental Quality governs the Montana Hard Rock Mining Reclamation Act, which was first introduced in 1971 and was updated in 2015. In Nevada, the Statute was promulgated in 1989.

For the review frequency, the Colorado division reviews the amount of financial assurance at least every two and one-half years. In Montana, the department conducts an overview of each financial assurance amount annually.

Regulating agencies

There are different regulating agencies in the United States. Nearly one third of the land in the United States are publicly held, with as much as 84.5% in Nevada. The federal government administers its public lands through four agencies: the National Park Service (NPS) that runs the National Park System; the Forest Service (FS), which is an agency within the United Stated Department of Agriculture, that manages the National Forest, the Bureau of land management (BLM), which is an agency within the United States Department of the Interior that manage public land; and the Fish and Wildlife Service (FWS) that runs the National Wildlife Refuge System (Gorte, 2012). Much of the mining activities are related to public lands managed by the BLM and Forest Service as two important agencies in regulating mining activities in the United States.

Regarding the regulating agency, each state in the United State has its own mining related jurisdiction and regulations.

Gorton (2009) refers to four key components in the regulatory system for coal mines: it is regulated by the federal Surface Mine Control and Reclamation Act ("SMCRA") while under auspices of the U.S. Department of Interior, Office of Surface Mining and state analogs as shown in Figure 3-3.

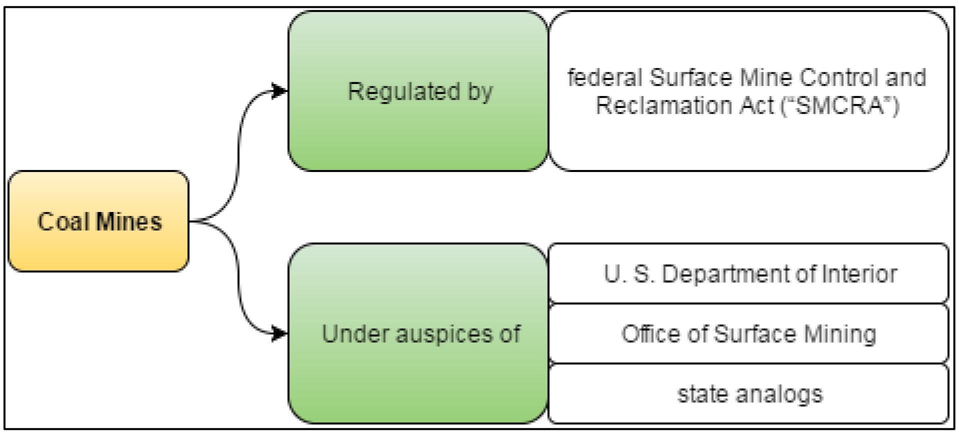

Figure 3-3: Overview of regulation system for coal mine in U.S. (Gorton, 2009)

Non-Coal mines, on the other hand, are not regulated by federal reclamation laws. They are governed by other environmental laws including but not limited to the Federal Clean Water Act, Clean Air Act, Endangered Species Act and other applicable federal and state standards as shown in Figure 3-4. If the mine is on federal land, it is regulated by the BLM under the Federal Land Policy and Management Act ("FLPMA"). Section 302 of FLPMA requires the Secretary of the Interior, in managing the public lands, to "take any action necessary to prevent unnecessary or undue degradation of the lands" (Gorton, 2009).

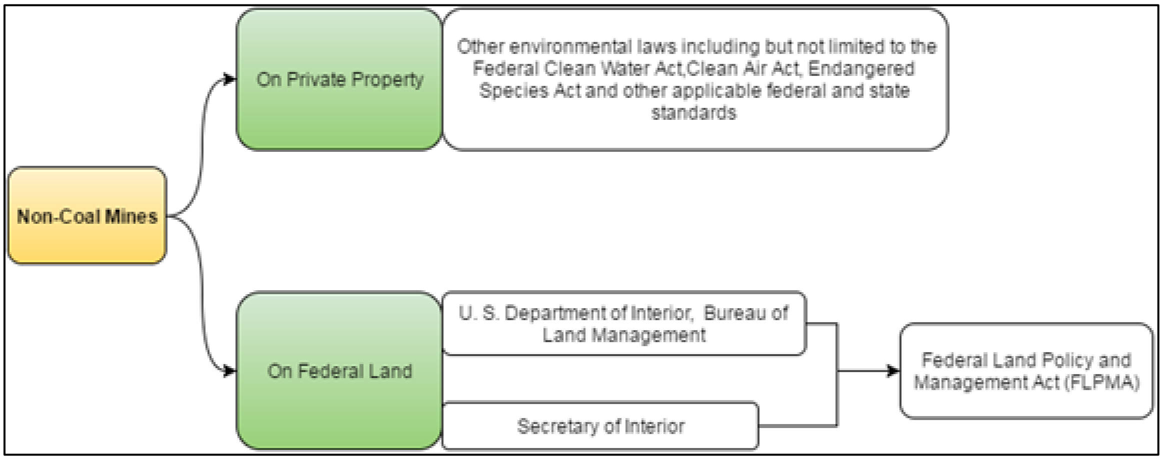

Figure 3-4: Overview of regulation system for non-coal mine in U.S. (Gorton, 2009)

Due to the substantial overlap of federal and state requirements, the state and federal agencies negotiate over which agency has the primary regulatory responsibilities. State agencies are in primary charge mostly for permitting the mine, conducting on-site inspections, and enforcing the requirements, even when it is located on federal lands.

In the United States, federal laws only require reclamation of surface mined lands for uranium mines and coal mines. There are no specific federal provisions for reclamation of hard rock open pit or surface mined lands. Each state government sets its own legislation. The related regulations in three states in the United States is summarized in Table 3-4.

Table 3-4: Related regulations and laws for mine closure and financial assurances in three states in the United States

Jurisdiction	Agency	Legislation Date	Guidelines/Codes	Review Frequency
Nevada	BMRR	Statutes, 1989, Applicable 1990	Administrative Code, 1990	Every 1, 2 or 3 years
Colorado	OMLR	Colorado Mined Land Reclamation Act. 1976	Regulations of the Colorado Mined Land Reclamation Board, revised in 2008	At least every 1.5 or 2 years.
Montana	DEQ	Montana Code Annotated, 2002, updated in 2015	Environmental Quality; Mining Reclamation Act	Annually or at least every 5 years.

Hard-rock reclamation

Starting from the exploration phase all the way to post closure phase, hard-rock mining will impact the surrounding environment. Apart from the evident disturbance of the landscape, mining may also result in impacts to the groundwater, surface water, aquatic and territorial vegetation and wildlife, soil and air quality, and cultural resources (National Research Council, 1999).

The State of Arizona has led copper production in the U.S since 1910, producing approximately 64% of domestic copper (Mining Arizona, 2013), while Nevada has led gold production in the US.

In the United States, hard-rock mining is governed by a complex and extensive regulatory structure that consist of federal statutes, regulations from federal land agencies.

Coal mine reclamation

Coal production in U.S reached a milestone of 1,171.5 million short tons in 2008. Approximately 390 million short tons were produced from the Appalachia Region, 147 million short tons from the Interior Region, and 634 million short tons from the Western Region. In the United States, coal mine reclamation is subject to a national regulatory system in accordance with national performance standards, which is developed by the Office of Surface Mining (OSM) under the U.S. Department of the Interior (Warhurst & Noronha, 1999). OSM is an agency that has combined the national concern for energy with the national need for environmental protection. Although most states today have developed their own programs to clean-up the abandoned mine lands, the OSM still retains oversight of the state programs and developing new tools to help the States and Tribes implement their activities. Prior to the Surface Mining Control and Reclamation Act of 1977 (SMCRA), which was the first act that provides a legal framework for regulating coal mining. However, with the issuing of the legal requirements to provide financial assurance in the US in the mid-1970s, the use of closure cost estimating switched to ensuring the government and the public that sufficient funds would be available in the case that the company became insolvent and unable to fulfill their closure obligations.

As Klco and Gypsum (1990) point out, for the State of Colorado the Mined Land Reclamation Act of 1976 stands as a watershed of change in the mining industry. Reclamation costs are integrated into daily mining costs like any other operational cost.

Financial assurance provisions in the United States

In the past, there were two approaches used in the US to set financial assurance amounts. The first one calculates the amount using a per-acre cost. The second one is based on the expected reclamation costs, including administrative and monitoring expenses and a profit margin for the third-party contractor (Gerard, 2000b). More recently the latter is broadly used for hard-rock mines.

Under the first approach, the BLM regulations required projects at their exploration stage to be covered with the bond amount at $1000/acre, and the development stage at $2000/acre. If the operations included the use of cyanide or had the potential for acid drainage, then the bond would be calculated based on the expected reclamation cost. A study of multi-national mining companies by Miller (2005) found that the annual surety premiums range from 0.37 to 1.5 percent of the face value of the bond.

Gerard (2000a) summarized the bonded acres and bond amounts for operators in Montana, as per a survey by the Montana Department of Environmental Quality in 1999, which showed that for mines in Montana with less than 100 acres, the average amount is $143,341, over $3 million for mines with disturbed acres between 101 to 500, and over $20 million for large mines that has more than 500 acres disturbed.

Nevada

As mentioned earlier, as much as 84.5% of the land in Nevada is federal land, most of which is managed by the Bureau of Land Management (BLM) and the US Forest Service (USFS).

The regulating agency for mining in Nevada is the Nevada Division of Environmental Protection (NDEP) while its Bureau of Mining Regulation and Reclamation (BMRR) regulates mine closure and reclamation. The reclamation legislation is the Nevada Revised Statutes (NRS) 519A (1989) which was promulgated in 1990.

The closure regulations are found in the Nevada Administrative Code (NAC) 519A which was issued in 1990. The regulations specify that the type of financial assurance accepted in Nevada include Letter of Credit, Corporate Financial Test, Cash, Trust Fund, and Surety Bond.

In Nevada, a financial assurance that is sufficient to cover 100% of the reclamation cost must be in place before start of the mining operations. However, as specified in the BLM Nevada 3809 Reclamation Bonding Guidelines (2005), up to 60% of the total financial assurance may be released at the completion of all reclamation related earthworks. The remaining portion of the financial assurance may be released at the removal of all facilities, and when discharged effluent quality has been met without the need for further treatment.

3.1.3 Western Australia

In Australia, like Canada and the US mine closure is regulated at the State Governmental level. In Western Australia, mine closure and reclamation is regulated by the Department of Mines and Petroleum (DMP) or Environmental Protection Agency (EPA).

The related regulations are the Mining Act of 1978 and the Environmental Protection Act of 1986. The Mining Act 1978 requires lodgment of a surety or security to acquire exploration licenses and prospecting licenses (Miller, 2005).

Closure guidelines in Western Australia are the Strategic Framework for Mine Closure (ANZMEC/MCA 2000) and the Draft Guidelines for Preparing Mine Closure Plans in 2010. The Environmental Protection Act 1986 specifies that the allowable forms of financial assurance in Western Australia include a Bank Guarantee (BG), a Bond (GB), an insurance policy (IP), and another form of security that the CEO specifies.

DMP and the EPA recognize that providing closure cost estimates at the early stages of a mine's life is subject to many assumptions and unforeseen events. DMP and the EPA expect assumptions to be summarized and cost variation to be provided. This per cent variation should then be refined during operations and decommissioning.

Estimated costs must consider all aspects of closure costs, including costs for earthmoving and land forming, management of problematic materials, research and trials, decommissioning and removal of infrastructure, survey, remediation of contamination, maintenance and monitoring, rehabilitation, closure project management costs and provision for unplanned closure/care and maintenance.

According to Miller (2005), the financial assurance amount in Western Australia is calculated based on the Guideline, which provides for a minimum amount. The final amount is then calculated according to any additional risk factors related with each project.

According to the Annual Report as of June 2007, the Western Australian Department of Industry and Resources held 3,336 performance bonds (surety bond) with a total value of $608.3 million. This accounts for approximately 25% of the expected total reclamation costs. In 2013 the Mine Rehabilitation Fund replaced the previous performance bonds and all bonds were returned to the mining companies. Under the Mine Rehabilitation Fund regulations mines are required to pay an annual amount based on the area of the mine lease and the land use. The target is to establish a fund of $500 million.

3.1.4 Comparison of reclamation regulations

Canada, United States and Australia revised their mining legislation in similar ways which require that every company present a reclamation plan before beginning operations or within a specific period for existing operations, and sufficient financial assurance is required to ensure that the plan is carried out.

For the types of mining covered by laws and regulations, both Canada and Australia are applicable to all mines. With some provinces like Alberta, only coal mines (underground and surface) and oil sands mines are applicable. In Ontario, underground and surface hard rock mining activities should be abided by related laws and regulations.

A review of mine reclamation laws in selected jurisdictions of Canada, U.S., and Western Australia, some differences and similarities in regulating agency, closure legislation, guidelines and others are summarized in Table 3-5.

Table 3-5: Comparison of regulations and laws for mine closure and financial assurances in Canada, U.S. and Australia

Jurisdiction	Agency	Legislation Date	Guidelines /Codes	Review Frequency	Types of Mining	Allowable Instruments[1]
BC, Canada	Ministry of Energy and Mines	Mines Act,1996	Reclamation Code, 2008, Revisions to part 10 effective as of July 20, 2016; Mine reclamation security in BC, Fact Sheet, Ministry of Energy and Mines, May 20, 2016	Every 5 years	All mines	LC;QETF;AG
Alberta, Canada	MOE MOEn	Environmental Act 2000;	Reclamation Regulation 115/1993, With amendments up to and including Alberta Regulation 103/2016	Annually	Coal and Oil sands mines	C;Ch;GB;LC;QET; Others
Ontario, Canada	MNDM	Mining Act, 1990	Rehabilitation Code; Policy Index 2011	Every 3 or 5 years.	All hard rock mines	C;LC;GB;MRT;COM;Others
Nevada, U.S	NDEP-BMRR	Nevada Revised Statutes (NRS) 519A, (1989)	Nevada Administrative Code (NAC) 519A, 1990	Every 2 years	All hard rock mines	LC; C; SI; QETF; SB
Western Australia	DMP; EPA	Mining Act, 1978; Environmental Act, 1986	Strategic Framework； Guidelines, May, 2015	3 years	All mines	BG;GB;IP;SI

[1] *Refer to the list of abbreviations in the front is piece of the thesis for clarification*

3.2 Regulation classification

Regulations can be classified into prescriptive and performance-based approaches (May, 2011). The prescriptive approach focuses on control and accountability for specific dimensions or material parameters, whereas the performance-based approach underlines flexibility with accountability for specific outcomes, e.g. water quality.

Prescriptive regulations elaborate on the design and process to fulfill the regulations. Even though prescriptive regulations are easier to monitor and enforce, there are very little room for flexibility (Natural Resources Canada, 2013).

On the other hand, a performance-based approach relies on analyses and concentration range of interest. The process of how the constructed facility achieve these is not important if the specifications are met (Poppiti, 1994). In many cases performance-based regulations are more flexible and less costly. It can overcome the restrictions of prescriptive regulations and there has been an increasing suggestion among regulatory scholars to adopt performance-based approaches when dealing with difficult problems (May, 2011). The performance-based approach also allows for better use of site-specific materials.

3.2.1 Regulation classification in Canada and the United States

Many regulations in the United States are still using the prescriptive approach in specifying to regulated entities what and how to implement design and construction, and the performance-based approach is often presented as an alternative to existing prescriptive regulation.

For example, in BC, Canada, the Health Safety and Reclamation Code (the Code) for Mines in BC (2016) provides prescriptive guidance about the use of reference documents for specific designs as listed below. However, these documents are not consistently prescriptive in their guidance. The prescriptive guidance also includes detailed specifications such as the mine plan should include a map at a scale of 1:10,000 or less. Further detailed design standards can be found in sections 10.1.4, 15 and 10.6.5 of the Code, which states that the major impoundments and water dam should be designed according to the criteria in HSRC Guidance Document.; Major dumps should be designed according to the Interim Guidelines of the B.C. Mine Waste Rock Pile Research Committee; and the plans for preventing metal leaching and acid rock drainage should follow the Guidelines for Metal Leaching and Acid Rock Drainage at Mine sites in B.C.

3.2.2 Classification comparison

Both prescriptive approach and performance-based approach can be found in the closure legislation and guidelines in BC of Canada.

Health, Safety and Reclamation Code for mines in British Columbia

This code provides several examples in different sections with respects to the mine plan and reclamation program information, design and reclamation standards, land use and others and is summarized in Table 3-6.

Table 3-6: Comparison of prescriptive approach and performance-based approach based on the Health, Safety and Reclamation Code for Mines in British Columbia 2016

Stages	Prescriptive approach	Performance-based approach
Mine Plan and Reclamation Program Information	Section 10.1.3d (i-xii) Section 10.4.4	Section 10.1.3g (i-ii) 10.1.3(i)
Design Standard	Section 10.1.4(1)-(3) Section 10.5.6	Section 10.1.4
Reclamation Standard	Section 10.7.13(2) Section 10.7.13(4)	Section 10.6.15 Section 10.6.16
Land Use		Section 10.7.4

- **Mine Plan and Reclamation Program Information**: for the prescriptive approach, section10.1.3d (i-xii) establishes the mine plan before the commencement of mining and the mine plan should include a map at a scale of 1:10,000 or less; section 10.4.4 requires to submit an annual report; section 10.1.4(1)-(3)establishes the design standards for major impoundment and dumps. For performance-based approach, section 10.1.3g (i-ii) requires that operational reclamation plans be prepared for the next five years.
- **Design standards**: for the prescriptive approach, sections 10.1.4(1)-(3) establish that major impoundments, water facilities and dams shall be designed in accordance criteria in Dam Safety Guidelines; major dumps shall be designed in accordance with Interim Guidelines of the B.C. Mine Waste Rock Pile Research Committee; plans for predicting and prevention of

metal leaching and acid rock drainage shall follow the Guidelines for Metal Leaching and Acid Rock Drainage at mine sites in B.C; material with high probability of spontaneous combustion shall be placed in a separate dump (10.5.6).

- **Reclamation standards**: For the prescriptive approach, section 10.7.13(2) requires that where the pit floor is free from water and is safely accessible, vegetation shall be established and section 10.7.13(4) requires that where the pit floor will impound water and it is not part of permanent water treatment system, a water body must be created for use and productivity. For the performance-based approach, section 10.6.15 establishes that after the closure of a mine and the chief inspector being satisfied that permit conditions have been met, some or all security under section 10(4) or 10(5) of Mines Act shall be refunded. Section 10.6.16 establishes when applying for security release. An application shall be submitted that details the reclamation activities completed under the act, code and plan. For the performance-based approach, sections 10.1.4 establish tailings impoundment, water facilities, dams and waste dumps should be designed by a professional engineer; major dumps shall be designed consistent with the end land use. In addition, section 10.1.3(i) establishes the cost estimate as an estimate of total expected costs of reclamation, including long term monitoring and maintenance costs.
- **Land Use**: for the performance-based approach, section 10.7.4 requires that land surface shall be reclaimed to an end land use approved by the chief inspector that considers previous and potential uses.

3.2.3 B.C. Mines Act in 1996

The B.C. Mines Act [RSBC 1996] provides two parts of differences between the prescriptive approach and the performance-based approach. The first difference derives from the mine plans. The Mine Plans, Chapt.293-27, establish that for prescriptive approach each manager must keep at the mine site accurate plans that are updated every 3 months and contain established by the regulations or the code. For the performance-based approach, the plan should be prepared on a scale that accords with good engineering practice (Chapter 293-27 (b)).

The second difference is about permit establishment. For the performance-based approach, the chief inspector may require the permittee to give security for mine reclamation and provide protection of, and mitigation of damage to, watercourses and cultural heritage resources affected by the mine (ARD mines).

3.2.4 Mineral and Exploration Code

This code was enabled under Section 34 of the Mines Act, which forms Part 9 of the larger Health, Safety, and Reclamation Code. It provides two aspects of difference in soil salvage for reclamation and terrain stability classification as shown in Table 3-7. For the prescriptive approach, it requires that:

- Soil collected for reclamation should include roots, small woody debris and plant fragments.
- Stockpiles in place for two or more months, should use temporary vegetation covers.
- Short-term stockpiles (up to one year), should use annual cover crop such as fall rye.

- Soils to be stored for 2 or more years, should use a mixed cover of annuals and perennial grasses and legumes.

For performance-based approach, it requires that:

- Soil should be removed from one area to reapplying it to another site immediately if practicable to avoid stockpiling the soils.
- If unavoidable, the stockpile should be in a convenient spot easily accessible for reclamation.
- Potential contaminants should be kept in non-porous ponds or specially constructed tanks.

Table 3-7: Comparison of prescriptive approach and performance-based approach based on the Mineral and Exploration Code

	Prescriptive approach			Performance-based approach
Soil Salvage for Reclamation	Soil collecting Stockpiles Soils processing			Soil removal Stockpile location Potential contaminants
Terrain Stability Classification	Terrain class	Slope class		Survey Mine Plan Preparation (P36)
	I	0-20%	No Engineering design and survey	
	II	20-40%	Demonstration	Engineering design required
	II to III	40-60%	Access to the deposit and exploration development methods planned	
	IV	60-70%	A permit required An engineering design necessary	Detailed topographical survey may be necessary

Four levels of terrain class from I to IV are specified. According to the mine survey plan preparation:

- For class I, the prescriptive approach does not require engineering design and survey.
- For class II, absence of adverse soil types and subsurface water must be demonstrated and for the performance-based approach engineering design may be required depending on site-specifics.
- For class II to III, access to the deposit and exploration development methods must be planned and executed in consideration of site-specific terrain issues.
- For class IV, the prescriptive approach establishes that a permit pursuant to the Mines Act would be required and an engineering design based on appropriate topographic survey and detailed geotechnical site assessment would be necessary to assure due diligence, while the performance-based approach requires that detailed topographical survey may be necessary.

CHAPTER 4: CONCEPTUAL GOLD MINE AND CLOSURE DESIGN

Closure cost estimating is a fundamental step for assessing the magnitude of financial assurance. This chapter describes a conceptual gold mine project and the closure design which will be used to calculate the closure cost for this gold mine.

4.1 Gold mine

4.1.1 General background

The project site is located east of Winnemucca, Humboldt County, Nevada. It is on the alluvial fan to the north of Buffalo Mountain. Gold oxide ore with no acid rock drainage potential will be mined and gold recovery will be through milling and cyanide recovery. The mine has a production rate of 15,000 tonnes per day and will operate for 15 years, based on 350 days per year and 2 weeks per year for mill maintenance. The strip ratio refers to the ratio of the mass of waste rock required to be handled to extract a unit mass of ore. In this study, the strip ratio is 2:1, which means that mining one tonne of ore will require mining two tonnes of waste rock. Thus, the waste rock produced per day is 30,000 tonnes.

4.1.2 Mine rock management facility (MRMF)

All mining related waste produced at the mining and milling operation can be divided into mine rock and tailings. Mine rock is the product that is mined but not processed before being placed on a mine rock management facility (MRMF), while tailings are the deposited in the tailings management facility (TMF) after processing to extract the economic products.

- It is assumed that the MRMF is 50 meters high with a side slope of 3:1 (horizontal/ vertical). The unit weight of mine rock is 1.8 tonnes/m^3.
- The shape of MRMF is assumed to be a trapezoid as shown in Figure 4-1.
- Assuming flat ground, the footprint area for the MRMF is 2,250,000 m^2 (Calculation details are provided in Appendix A).

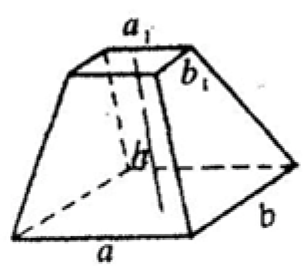

Figure 4-1: Trapezoid shape for calculating MRMF footprint area

4.1.3 Tailing management facility (TMF)

Figure 4-2 and Figure 4-3 illustrate the shape of a conventional hillside dam. The total mass of TMF can be calculated by multiplying the total production by the with the assumed dry density of ρ=1.3 tonnes/m^3. Thus, the total volume of the TMF is 60,576,923.08 m^3 (Calculation details are provided below and in Appendix B).

$$M_{TMF} = 15{,}000\ tonnes/day \times 350\ days/year \times 15\ years = 78{,}750{,}000\ tonnes$$

$$V_{TMF} = M_{TMF} / \rho = 78,750,000\ tonnes / \left(1.3\ tonnes / m^3\right) = 60,576,923.08\ m^3$$

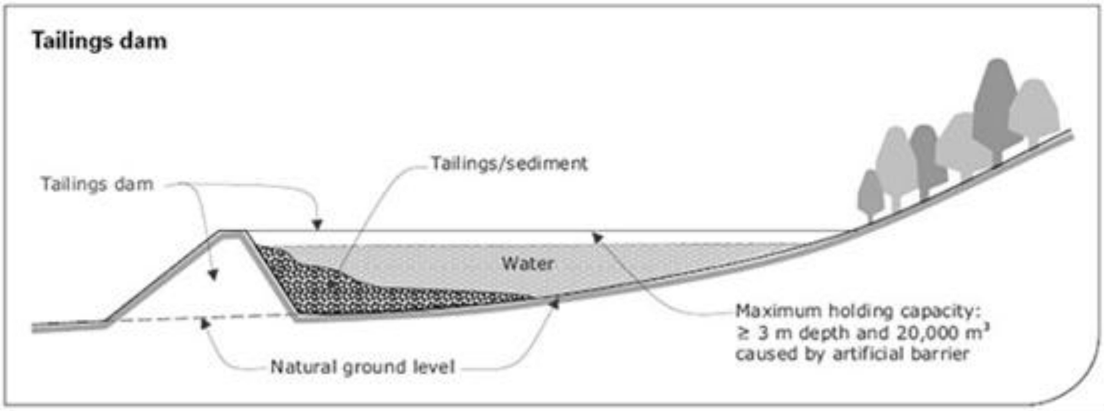

Figure 4-2: Cross section of a conventional hillside tailing dam

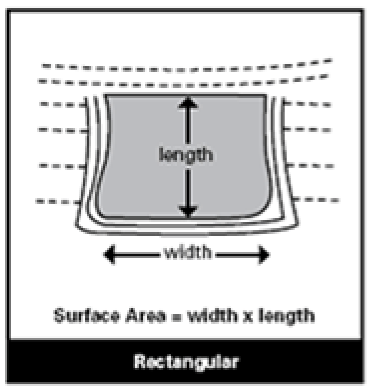

Figure 4-3: A plan view of a tailing dam

To define the dimensions of the dam, it is assumed that the width of the dam is 3.0 km and length is 2.5 km. Figure 4-4 illustrates the dimension relations of the dam cross section, the volume of the dam was calculated to be 72,810,000 m^3.

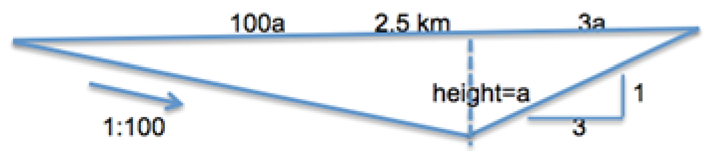

Figure 4-4: Cross Section of the Dam

A Digital Elevation Model has been used to create the topography giving in Appendix B. Figure 4-5 showing the slope, catchment area, flow accumulation, and contour lines around Buffalo Mountain area in Winnemucca, Nevada is created from a DEM (digital elevation model), the data set is provided by the International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences. The coordinate system used in data frames is UTM/WGS84.

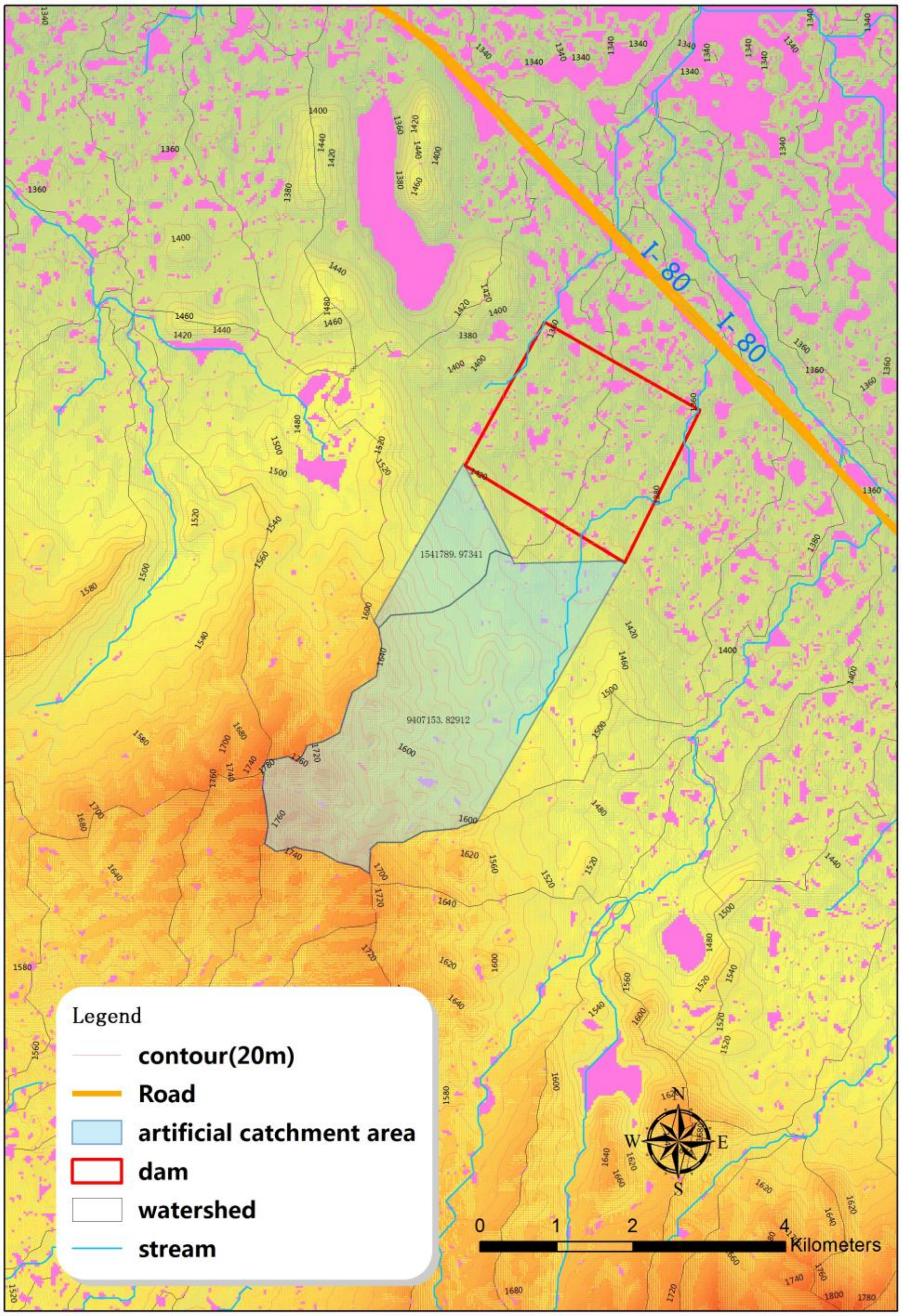

Figure 4-5: Total upstream catchment area

The size of tailing dam is 2200m x 2300m, and has a slope on the base of 1:100. Thus, the elevation for the dam is around 25m. When creating the graph showing contour lines in ArcGIS, the contour interval is set at 20 meters.

The assumption is to place the TMF in the red rectangular area. As the area came across two watersheds, the upstream catchment area (a light black line which illustrates the drainage divides is at the center of the dam) for this TMF should be the total area of the two watersheds, which can be obtained from Figure 4-5. Using the ArcGIS Software, the size of each small catchment area around Buffalo Mountain, Winnemucca, Nevada can be calculated.

4.1.4 Open pit

According to the design, there are 15,000 tonnes of ore and 30,000 tonnes of waste rock coming out of the open pit per day. The total mass of ore and waste rock being excavated is calculated below:

$$45{,}000\ tonnes/day\ \times 350\ days\ \times\ 15\ years\ =\ 236{,}250{,}000\ tonnes$$

Assuming the density for ore and waste rock together is 2.65 tonnes/m^3, then the volume of the open pit is 89,150,943.4 m^3 (Calculation details are provided below and in Appendix C).

$$V =\ m_{total}\ /\ \rho\ =\ 236{,}250{,}000\ tonnes\ \ /\ \ 2.65\ tonnes/m^3 =\ 89{,}150{,}943.4\ m^3$$

The shape of the open pit is usually a frustum of a cone, as shown in Figure 4-6.

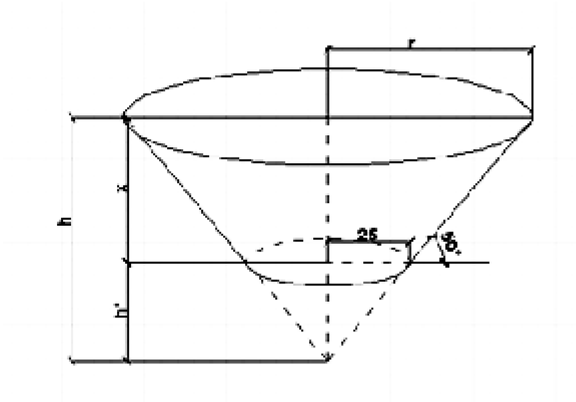

Figure 4-6: Open pit: Frustum of a cone

The final dimensions assumed for the pit are:

- Bottom radius: 25 m
- Depth of pit: 630 m
- Top radius: 366 m
- Top area: 420,734 m^2 (103 acres 42063 ft^2)

4.1.5 Mineral processing plant

Comminution includes crushing and grinding stages. The run of mine ore is fed to the primary crusher and the product is transferred to the processing SAG Mill. Gold is recovered using a Knelson Concentrator. Cyanidation followed by carbon in pulp is used to recover the gold ion complexes from the slurry and through adsorption onto the activated carbon that flows countercurrent to the pulp. Loaded carbon fines are then treated with carbon elution solutions to strip gold from the carbon. Electrowinning is used to treat the high-grade gold solutions, and smelting is followed to produce gold ore. A typical mineral processing flow sheet is illustrated in Figure 4-7.

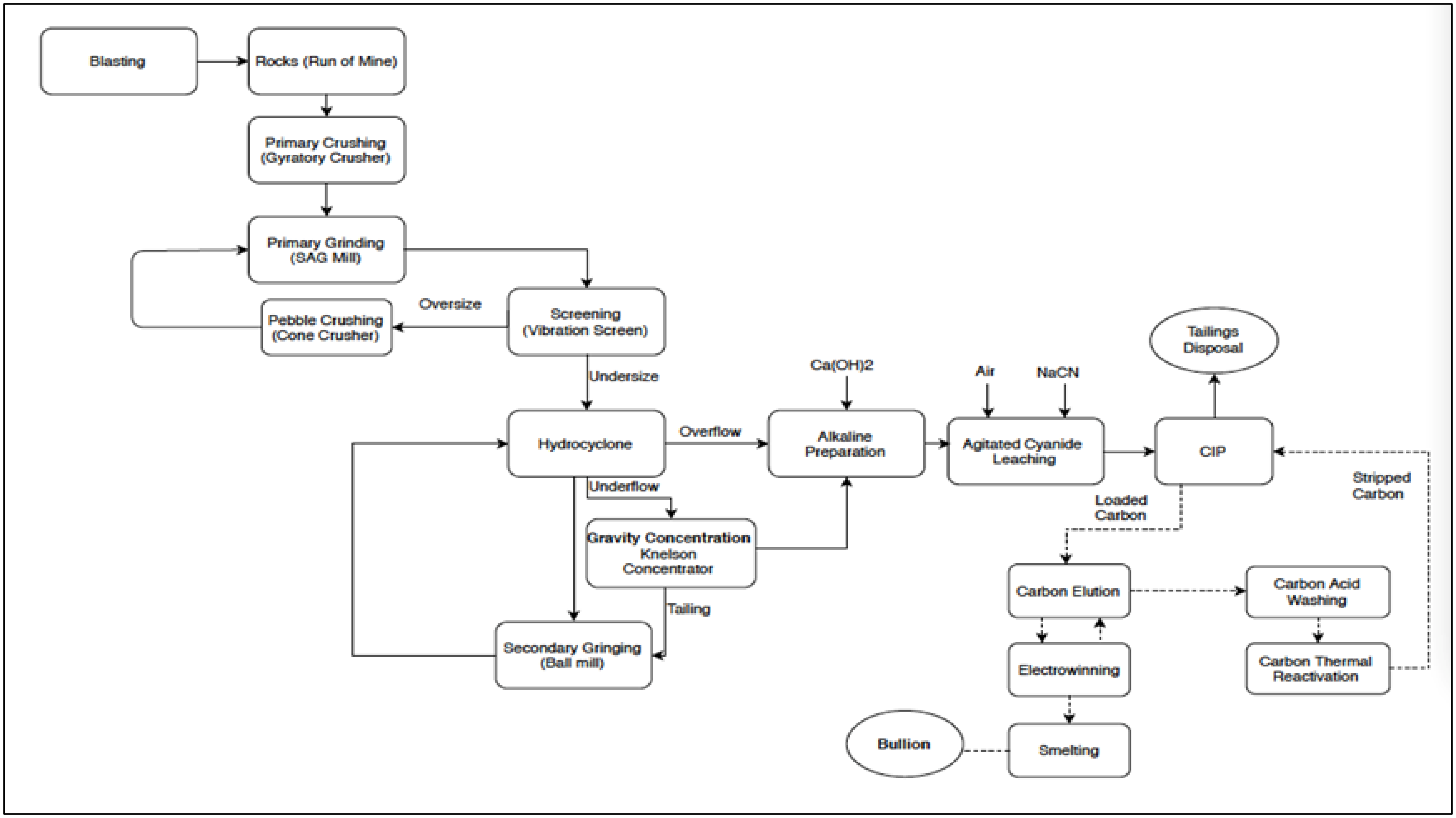
Blasting
Rocks (Run of Mine)
Primary Crushing (Gyratory Crusher)
Primary Grinding (SAG Mill)
Oversize
Pebble Crushing (Cone Crusher)
Screening (Vibration Screen)
Undersize
Hydrocyclone
Overflow
Underflow
Gravity Concentration Knelson Concentrator
Tailing
Secondary Gringing (Ball mill)
Ca(OH)2
Alkaline Preparation
Air
NaCN
Agitated Cyanide Leaching
Tailings Disposal
CIP
Stripped Carbon
Loaded Carbon
Carbon Elution
Carbon Acid Washing
Electrowinning
Carbon Thermal Reactivation
Bullion
Smelting

Figure 4-7: Schematic for mineral processing of a cyanide gold mine

4.2 Runoff and Manning's equation

In this study, the effluent from rainfall or snowmelt will flow through open channels into the holding basins dam. Thus, the cross-section design of the open channels is determined by the precipitation. The details of this theory can be found in Appendix D.

The surface runoff from the impoundment would flow via a diversion ditch toward the nearby creek. The diversion structures designed for the Probable Maximum Flood event would remain to rout runoff into the permanent diversion channel. Following reclamation, seepage through the tailings embankments would continue. Seepage collected in the seepage collection pond will be pumped to the tailings impoundment for irrigation or evaporation.

During operations for a 1/100 storm, the diversion channel dimensions will be,

$$B = 6.5 \text{ ft}, Y = 1.6 \text{ ft and } Z = 2 \text{ ft}$$

and for closure, when the PMF is accommodated, the dimensions will be,

$$B = 7.5 \text{ ft}, Y = 2.5 \text{ ft and } Z = 2 \text{ ft.}$$

The detailed calculation can be found in Appendix E. Due to these differences in dimensions, it is assumed that the operational channel was constructed to accommodate the PMF storm.

4.3 List of facilities

Closure of an open pit mine includes all the facilities on the mine site including:

- Removal of buildings and other infrastructure,
- Management of remaining fluids, such as tailings supernatant, oil, and hydraulic fluids,
- Establishing access controls such as blocking the access road and placing a fence or bund around the pit,
- Grading and re-contouring as required to establish positive drainage. Positive drainage refers to a condition where there is no ponding on the landform, all precipitation runs off.
- Tailings Management Facility (TMF): The TMF provides storage for all tailings generated during the life of the project and contains approximately 78.75 million tonnes. At mine closure, the TMF will be reclaimed to allow a small pond to form during the wet seasons at one corner. The TMF will also have two permanent surface diversions on the east and west sides. The design of these diversions is presented in Appendix E.
- Mined Rock Management Facility (MRMF): Mine rock will be transferred directly to the MRMF north of the open pit. During the life of the mine, approximately 157.5 million tonnes of rock will be deposited in the MRMF. At closure this facility will be covered with topsoil and seeded establish a vegetative cover that conforms to the natural landscape.
- Cover: Covers are constructed on facilities at mine sites such as tailings impoundments and waste rock dumps. The tailings are subject to wind erosion when dry, and could also be taken up directly by animals. Thus, it is required to build covers to isolate the tailings from the outside environment.

  The cover design consists of 300 mm waste rock as a subgrade layer on top of the tailings, and 300 mm of topsoil on top of the waste rock layer to provide as a growth medium for vegetation. This will also minimize the amount of topsoil required while utilizing waste rock from other areas of the mine site.

4.4 Reclamation plan

The reclamation plan of this project will be updated and revised annually. All areas disturbed by mining activities will be reclaimed in accordance with the closure plans that will be based on the concepts described below. The cost summary will be discussed in the next chapter.

4.4.1 Tailings management facility

During operations, the tailings are discharged at a solids content between 35 and 40%, followed by sedimentation and self-weight consolidation as the subsequent layers are deposited during the mine life. To avoid the formation of ponding on the final closure cover, material such as coarse tailings or mine waste rock will be required to cover depressions which may result from consolidation of the tailings over time. For the proposed reclamation and stabilization tasks such as regrading, placing topsoil and revegetation, the entire impoundment surface must be firm enough.

The reclamation plan for the top of the tailings management facility would consist of the following:

- Spreading an average of 300 mm of waste rock on the impoundment surface,
- Placing 300 mm topsoil on the waste rock layer preparing a seedbed,
- Establishing vegetation on the final surface through seeding or planting of seedlings, etc.

The embankment slopes will also be covered with 300 mm topsoil before establishing vegetation.

4.4.2 Mine rock management facility

Waste rock is expected to be used in various construction activities. However, the construction requirements will not exceed waste rock production. In this case a mine rock management facility would remain and be graded to 3H:1V slopes. It would then be covered with a 300mm topsoil followed by vegetation. Calculations for the quantity of earthwork that will be required for the MRMF and TMF can be found in Appendix F.

The reclamation plan for each facility are summarized in Table 4-1.

Table 4-1: Reclamation plan

Facility	Reclamation plan
Bucket Load Earth	This include earthworks related to spreading 300mm of waste rock on the TMF. It also includes spreading 300mm of topsoil on the tailings surface and the waste dump. Earthworks only included the earthworks for covering tailings and the waste rock dump surface, if the tailings embankment was after constructing the last raise.
Processing Plant	Removal and sale of useable equipment (assume zero value), demolition of building. Demolition debris is hauled to an appropriate waste facility assumed to be 140km away.
Processing Plant Foundation	Concrete slab with rebar reinforcement foundation demolished by equipment. The debris is then loaded and hauled 2.5 km to the waste dump.
Maintenance Shop	Steel building that is demolished. Demolition debris is hauled to an appropriate waste facility assumed to be 140km away.
Maintenance Shop Foundation	Concrete slab with rebar reinforcement foundation demolished by equipment. The debris is then loaded and hauled 2.5 km to the waste dump.
Warehouse	Steel building that is demolished. Demolition debris is hauled to an appropriate waste facility assumed to be 140km away.
Warehouse Foundation	Concrete slab with rebar reinforcement foundation demolished by equipment. The debris is then loaded and hauled 2.5 km to the waste dump.

Office Foundation	Concrete slab with rebar reinforcement foundation demolished by equipment. Demolition debris is hauled to an appropriate waste facility assumed to be 140km away.
Dry	Steel building is demolished. Demolition debris is hauled to an appropriate waste facility assumed to be 140km away.
Dry Foundation	Concrete slab with rebar reinforcement foundation demolished by equipment. The debris is then loaded and hauled 2.5 km to the waste dump.
Fences Removal	Fences are initially dismantled by a bulldozer.
Well Construction	A drilling contractor will be hired to install the wells.
Large Wheel Loaders Disposal	Operating machinery and mobile equipment such as the wheel loaders will be sold.
Pavement Demolition	Gravel roads are used as base material. Equipment such as backhoe and loader are used to break and load the broken material. Haul truck is used to transport the broken material 2.5 km to the waste dump.
Seeding	An approved seed mixture of grass and forbs is used for 1,623 acres which include the TMF surface, waste dump surface using aerial seeding method. The type of seed mixture can be found in Appendix I.
Mine Yard Scarify	Scarifying equipment is used to break up soil surface in preparation for vegetation establishment.

CHAPTER 5: CLOSURE COST ESTIMATION USING SHERPA COST ESTIMATING SOFTWARE

Closure cost estimation is one of the main tasks to estimate the financial assurance requirements for mine reclamation. This chapter introduces a software called Sherpa used to estimate the closure costs for the gold mine described above.

5.1 Introduction to Sherpa

Sherpa for reclamation cost estimation is an engineering-based software developed by Aventurine. The software is distributed by CostMine. This software is used to develop project closure costs while using site-specific information. The software estimates the closure cost based on multitude of common reclamation tasks listed in Table 5-1.

Table 5-1: Reclamation tasks used in the Sherpa software

No.	Reclamation Tasks	Detailed Tasks	Estimated Costs	Notes
		Excavate and stockpile		
		Excavate, load, haul, and dump	$14,993,243	
		Load, haul, and dump		
1	Earthwork	Slope reduction		
		Road rehabilitation		
		Spread and contour		
		Fine grade		
		Ditch excavation		
		Buildings	$1,396,150	
		Foundations	$3,661,539	
2	Demolition	Pavement of roads	$609,054	
		Culverts & pipes		
		Fencing	$111,551	Appendix G
3	Site work	Soil stabilization		
		Armoring		
		Mine yard scarifying	$217	
		Vehicles recycled in scrapyard	$1,118	
4	Disposal	Machinery		Appendix H
5	Monitoring	Well construction	$10,135	
		Sample collection & analysis		
		Audits		
		Shafts		
6	Closure	Drill holes		Appendix I
		Leach pads		
		Pumping		
		Seed of approved seed mixture	$1,791,429	
7	Planting & seeding	Live plants		
		Soil amendment		

5.2 Project data

The project site in this study located near Winnemucca, Humboldt County, Nevada, is assumed to be located on BLM managed land. The Davis-Bacon wage scale is used by Sherpa to calculate the wage rates. This is done because of the regulatory requirements for mines on Federal Lands in the United States.

The estimation of closure costs is based on the following assumptions:

- Average haul distance for cover and other materials will be 2.5 km within the mine property
- All hazardous waste will be removed from site and transported to the nearest facility

Demolition and removal costs of this project are calculated based on steel frame/steel siding construction with debris hauled 140 km to a dump. Putting the above information into the Project Data window in Sherpa Software, the mobilization parameters for the project was established as shown in Figure 5-1.

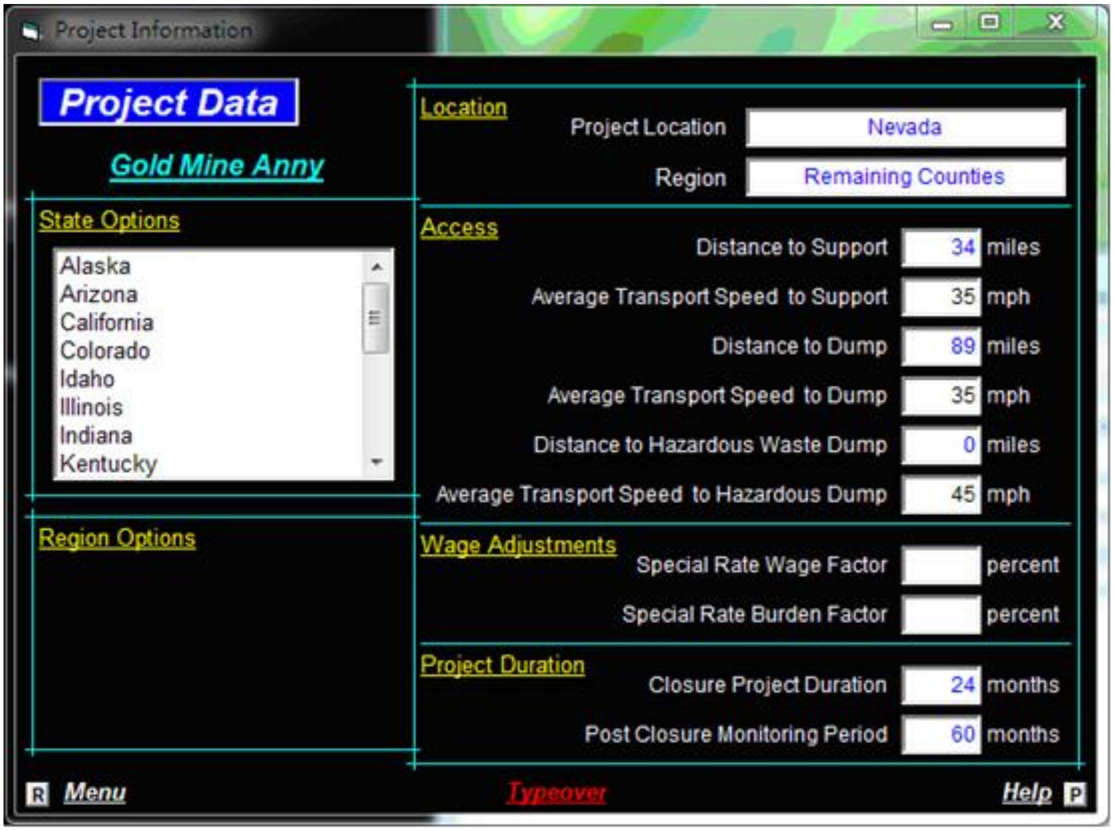

Figure 5-1: Project Data window in Sherpa

5.3 Earthworks

Most of the reclamation work at any surface mine is attributable to excavating previously liberated rock, loading it into some sort of conveyance, hauling it to either an engineered stockpile or back to the original excavation site, and then dumping it (Reclamation Cost Service, 2014). The cost for reclaiming the TMF and waste dump is associated to much great extent with a series of earth-moving tasks, such as excavating, loading, hauling and dumping.

To estimate excavating and hauling costs, cycle times for both the excavators and haul trucks should be determined, which are eventually used in conjunction with machine capacities to estimate the operation costs. Almost every earthwork task requires some sort of cycle time calculation as illustrated below. The cycle time calculation scenario is listed in Table 5-2.

Table 5-2: Cycle time calculation scenario

Scenarios	Magnitude
Shift length	8 hours
Production schedule	2 shifts/day
Waste production capacity	15,000 tonnes/day or 16534.67 tons/day
Wheel loader bucket capacity (volume)	16.0 cubic yards
Wheel loader bucket capacity (weight)	54.2 tons
Average bucket fill factor	95%
In-place material weight	1.8 tonnes/m^3 = 3,034 pounds/cubic yard
Material swell	55%
Wheel loader cycle time	0.31 minutes (18.6 seconds)

Bucket Load:

$$\frac{3{,}034 \text{ pounds/cubic yard}}{1 + \frac{55\%\ swell}{100}} = 1{,}960 \text{ pounds/cubic yard}$$

$$\frac{16.0 \text{ cubic yards} \times 1{,}960 \text{ pounds/cubic yard} \times 0.95}{2{,}000 \text{ pounds/ton}} = 14.896 \text{ tons}$$

Total Cycle Requirement:

$$\frac{36{,}534.67 \text{ tons/day}}{14.896 \text{ tons/cycle}} = 1{,}110 \text{ cycles/day}$$

$$\frac{31{,}110 \text{ cycles/day} \times 18.6 \text{ seconds}}{60 \text{ seconds/minute}} = 344.1 \text{ minutes/day}$$

Loader operators:

$$\frac{344.1 \text{ minutes/day}}{0.83 \text{ (efficiency)x } 60 \text{ minutes/hour}} = 6.91 \text{ hours/day}$$

$$\frac{6.91 \text{ hours/day}}{8 \text{ hours/shfit}} = 1 \text{ operators}$$

Entering above data into the Earthwork window in Sherpa, the cost for excavating, loading, hauling and dumping of the project is $14,993,244 as shown in Figure 5-2.

Figure 5-2: Earthwork window in Sherpa

5.4 Demolition cost estimation using Sherpa

There are five items in the demolition submenu: building, foundations, pavement, culvert and fencing.

5.4.1 Buildings

The buildings and their characteristics are listed in Table 5-3.

Table 5-3: Buildings to be demolished

Building	Dimensions	Floor thickness
Maintenance Shop	60 m*31 m*9 m	30 cm
Dry	38 m*19 m*4 m	10 cm
Office	42 m*21 m*4 m	10 cm
Warehouse	41 m*21 m*5 m	10 cm
Processing plant	180 m*120 m*8 m	20 cm

Demolition and removal costs for each building are shown in Table 5-4. Detailed screen shot of the result in Sherpa can be found in Appendix G.

Table 5-4: Building demolition and removal cost

Items	Building	Foundation	Sub-total
Maintenance Shop	$121,062	$323,905	$444,967
Dry	$21,032	$72,938	$93,970
Office	$26,168	$89,592	$115,760
Warehouse	$31,368	$106,689	$138,057
Processing Plant	$1,196,520	$3,068,415	$4,264,935
Total	**$1,396,150**	**$3,661,539**	**$5,057,689**

5.4.2 Foundation

It is assumed that the concrete block wall foundation are dismantled by equipment and that they then load the debris into the haul truck and the debris is hauled 2.5 km to the waste dump..

Demolition and removal costs for each building are shown in Table 5-4. Detailed screen shot of the result in Sherpa can be found in Appendix G.

5.4.3 Pavement

Pavements within the mine site are generally constructed in the form of flexible pavements which are layered systems with better materials on top and inferior materials at the bottom. Gravel roads are used as base material. Detailed calculation in Sherpa can be found in Appendix G.

Given that the minimum running width is three times the width of largest haul truck with 15 meters in width and 2 kilometers in length, the cost for pavement demolition is $609,054. Detailed screen shot of the result in Sherpa can be found in Appendix G.

5.4.4 Fence removal

Fencing is made from 10,000 meters of chain link/ barbed wire construction with 5 gates and a transport distance of 90 miles. Entering the above information in Sherpa the fencing removal cost is estimated at $111,551. Detailed calculation in Sherpa can be found in Appendix G.

5.4.5 Seeding

The Nevada Administrative Code (NAC) 519A stated that 'Operator may rely upon available technical data and the results of field tests when selecting seeding practices and soil amendments which will result in viable vegetation. To meet the reclamation goals, the Reclaimed Desired Plant Community (RDPC) is selected to use on the disturbed mine site. The Bureau of Land Management and the United States Forest Service (2016) defined RDPC as ‘A perennial plant community established on a disturbed site which contributes to stability through management and land treatment.’ The proposed reclamation seed mix for this study includes grasses and forbs which can be found in Appendix I. The total surface area for seeding is 1,623 acres using aerial seeding method. The cost for seeding is $1,791,400 and is shown in Appendix I.

5.5 Closure cost summary and comparison

The total project costs are made of two parts: project closure cost and overhead cost. The following two sections discuss the components and main features of these and then compare their shares and roles in the project bond.

5.5.1 Project cost summary

By calculating all items of closure costs of the project, the total costs are shown in Table 5-5. It should be noted that high accuracy was applied when estimating the closure cost in Sherpa. The costs have been rounded to its nearest hundreds.

Table 5-5: Summary of the project cost estimation

Unit Processes	Project Costs
Bucket Load Earth	$14,993,200
Processing Plant	$1,196,500
Processing Plant Foundation	$3,068,400
Maintenance Shop	$121,100
Maintenance Shop Foundation	$323,900
Warehouse	$31,400
Warehouse Foundation	$106,700
Office	$26,200
Office Foundation	$89,600
Dry	$21,000
Dry Foundation	$73,000
Fence Removal	$111,600
Well Construction	$10,100
Large Wheel Loaders Disposal	$1,100
Pavement Demolition	$609,000
Seeding	$1,791,400
Mine Yard Scarify	$200
Total	**$22,574,400**

5.5.2 Overhead cost estimation

Every mine closure financial assurance estimation should include overhead cost apart from the above project cost. Project Overhead usually consists of the following: salaried and administration personal, field office, shop and facilities, temporary utilities, fees and insurance except those applicable to labor and equipment, site specific training, performance and payment bonds, quality assurance/quality control, safety, surveying, construction equipment general (buses, ambulance, etc.). The total overhead costs of 30.4% were applied to the direct project costs. Details of the overhead costs are shown in Table 5-6.

Table 5-6: Overhead cost summary

Titles	Percentage	Costs
Agency Contract Administration	14.00	$3,160,400
Contractor's Profit	10.00	$2,257,400
Project Contingency	7.00	$1,580,200
Engineering and Design	6.00	$1,354,500
Bond Premium	3.00	$677,200
Agency's Indirect Costs	21.00	$663,700
Liability Insurance	1.50	$149,600
Total		**$9,843,000**

5.5.3 Comparison of closure costs

For most sites, the direct reclamation costs for the mine components are probably 50% to 75% of the total estimated cost (Brodie, 2013). According to the estimate of the project in this study, the project direct costs accounted for 70% as listed in Table 5-7 which falls into the above reasonable range.

Table 5-7: Closure cost for the gold mine at the Winnemucca (Humboldt County, Nevada)

Types	Titles	Costs	Percentage (%)
Project Costs	Earth Moving	$14,993,200	70%
	Demolition	$5,778,300	
	Site Work	$217	
	Monitoring	$10,100	
	Disposal	$1,100	
	Planting and Seeding	$1,791,400	
	ISL Remediation	$0	
	Mobilization	$0	
Overhead Costs	Administration	$9,843,000	30%
Total		**$32,417,400**	**100%**

5.6 Financial bond estimating and limitation

For most mine sites, the total required bond should include the total direct costs and indirect cost plus gross receipt tax as shown in Equation 1. In this study, the total bond is amount to $33,094,600 in which the sum direct cost is the project cost as shown in Table 5-5 with the amount of $22,574,400. The indirect cost is the overhead cost listed in Table 5-6 with the amount of $9,843,000 and the Gross Receipt Tax is calculated by the Sherpa software as $677,200 that amounts to 3%.

$$Total\ Bond\ Amount\ (\$) = Sum\ Direct\ Cost\ (\$) + Indirect\ Cost\ (\$) + Gross\ \mathrm{Re}ceipt\ Tax\ (\$) \qquad \textbf{Equation 1}$$

As mentioned in Chapter 2, reclamation bond is the payment by which a third-party contractor can perform the activities at the direction of the responsible party (federal or state land administrator or private landowner) in the case when the developer refuses or fails to carry out the required reclamation activities.

If the model was applied for other mineral resources except for gold, others factors should be considered. Taking coal mines as an example, the cost share of processing plant may be less than those of gold mines. In contrast, if some non-ferrous metal mines are assessing, the cost percentage of the processing plant may be very high as of their heavy pollution and serious damage to the neighbor ecosystem and environment.

5.6.1 Limitations

The objective of this research was to compare present regulations and policies on financial assurance for mine closures in Canada, the United States and Western Australia. Ultimately, a quantitative model has been established to be applied in the Sherpa software as an example case for calculating the reclamation bonds for a gold mine.

The cost estimating of mine reclamation is a task in which several factors should be considered. It is also widely recognized that financial reclamation cost estimation can vary considerably for the same mine site. Although the Sherpa software, is state of the art modeling, different estimates may arise due to changes in parameters.

It should be admitted that the methodology in this study may have some limitations. First, the location of the model in this study was chosen at the Winnemucca, Humboldt County, Nevada in the United States, where the topography and precipitation are site-specific. This indicates that different mines in different regions have various geographic conditions which may impose to some extent on the financial calculations of the mine reclamation costs. Second, the tasks involved in earthmoving have a great influence on the cost of mine reclamation because the expenditure of earthworks for a specific mine account for the most proportion in its whole reclamation cost. Therefore, different designs in the shape of tailing dam and mine rock management facility may result in some discrepancies in the total cost. Third, financial policies at different jurisdictions may impact the overhead costs including burdens on personal salaries, infrastructure, fees and taxes and others.

This study is also limited by the data and documents being examined. Some unit costs in the model of this study are directly derived from the Sherpa software and some documentation in regarding to regulations of financial assurance is unavailable.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The objective of this research is to compare present regulations and policies of financial assurance for mine closures in Canada, United States and Australia. Through a literature review and evaluations, the implications in general and regulations and financial assurance requirements selected jurisdictions in Canada, United States and Australia are presented. The closure cost of a conceptual mine in Nevada was calculated using the Sherpa Software. Some main findings are obtained as below:

a. Reclamation financial assurance is an essential instrument when the developer refuses or fails to carry out the required reclamation activities and a third-party contractor can perform the activities at the direction of the responsible party (typically the regulator). Various stakeholder expectations should be taken into consideration when estimating the reclamation cost for different types of mines and different jurisdictions of the world.

b. The literature review found that mine reclamation laws in selected jurisdictions of Canada, US and Western Australia have some differences and similarities in regulating agencies, closure legislation, guidelines and others. Most governments have developed regulations, guidelines or codes of practice that specify in depth the requirements for reclamation and the financial assurance mechanisms. Through the comparison, this study finds that the regulation laws in the US is more integrated and address more details, whereas Western Australia has a younger system as compared to the US.

c. Regulations and policies about financial assurance for mine reclamation in the United States and Canada could be classified into prescriptive and performance-based approaches. The former provides details on the design and process of how to comply with regulations whilst the latter is more flexible and less expensive. Moreover, the performance-based approach is preferred by companies as it promotes better understanding of their regulatory obligations and encourages innovation.

d. Estimating mine closure costs is a focused discipline and could be quantitatively made using software. This study took account of location and other factors into the Sherpa software developed by Aventurine. Closure cost estimation was made for a near Winnemucca, Humboldt County, Nevada.

e. After determining the above key factors and their parameters, the cost estimation for mine closure was developed by the Sherpa software. The whole project closure costs include the project closure cost and overhead cost. As for the project in this study, the final cost estimate for the total closure cost for the gold mine near Winnemucca, Humboldt County, Nevada is $32,417,400 including $22,574,400 direct cost and $9,843,000 of indirect cost. Considering the Gross Receipt Tax of $677,200, the total financial assurance for this project is $33,094,600. The total overhead costs account for 30.4% of the direct project costs.

6.2 Recommendations for future research

There is a gap in the current literature on the financial assurance regimes in different countries in Europe, South America, Africa, and Asia. Future studies should look at the regulatory frameworks in these countries to compare and understand the similarities and differences. This might help to form better policies and regulations in Canada. Specifically, this study recommends that the government should use clear expressions of intent in the permit requirements in order to develop clear and comprehensive reclamation guidance.

A more in depth study of the major closure cost components is also possible. Analyzing the effective measures to reduce the total closure cost would be valuable to mining companies to reduce the overall closure cost.

A study of financial assurance estimations undertaken by a mining company of one of its mines would be persuasive. As the cost estimates in this thesis are conceptual, it would be more constructive when the data for the project is in-situ and more accurate, such as climate, location, and others.

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Appendices

Appendix A- Calculation of the volume and area for the mine rock management facility

It is assumed that the MRMF is 50 meters high with a side slope of 3:1 (horizontal/ oriental). The unit weight of mine rock is 1.8 tonnes/m^3. Assume it to be constructed on flat ground, the calculation of the MRMF footprint area is shown below:

$$M_{total} = 30,000\,tonnes/day \times 350\,days/year \times 15\,years = 157,500,000\,tonnes$$

$$V_{total} = M_{total}/\rho = 157,500,000\,tonnes/\left(1.8\,tonnes/m^3\right) = 87,500,000\,m^3$$

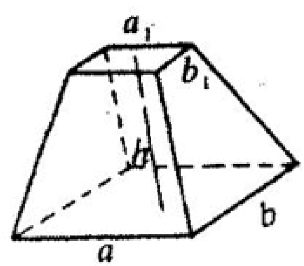


Figure A-1: Trapezoid shape for calculating MRMF footprint area

The shape of MRMF is assumed to be a trapezoid as shown in Figure A-1. The equation for the volume of Figure A-1 is:

$$V_{trapezoid} = \frac{h}{6}\left[ab + (a + a_1)(b + b_1) + a_1 b_1\right]$$

In this case, $a=b=a_1+2\times(150)=a_1+300$, substitute the given values and solve for the unknown variable, $a_1=1{,}170.0$ meters.

Assume $a_1 \approx 1200$ meters, $a= a_1+2\times 150= 1{,}500$ meters.

$$\textbf{MRMF area} = \mathbf{1{,}500^2 = 2{,}250{,}000\ m^2}$$

Appendix B- Calculation of the volumes for the tailing management facility

Total mass of TMF

$$M_{TMF} = 15{,}000\ tonnes/day \times 350\ days/year \times 15\ years = 78{,}750{,}000\ tonnes$$

ρ=1.3 tonnes/m^3, thus total volume of TMF:

$$V_{TMF} = M_{TMF}/\rho = 78{,}750{,}000\ tonnes/\left(1.3\ tonnes/m^3\right) = 60{,}576{,}923.08\ m^3$$

From NSW Department of Water and Energy (2007), dam capacity can be calculated in the following equation:

$$\mathbf{Dam\ Volume}\ \left(\mathbf{m^3}\right) = \mathbf{0.4} \times \mathbf{Surface\ Area}\ \left(\mathbf{m^2}\right) \times \mathbf{Depth}$$

(“Water affecting activities dams - factsheet,” 2004) Where 0.4 is a conversion factor that considers the side slopes of the dam. Figure B-1 and B-2 illustrate the shape of a conventional hillside dam.

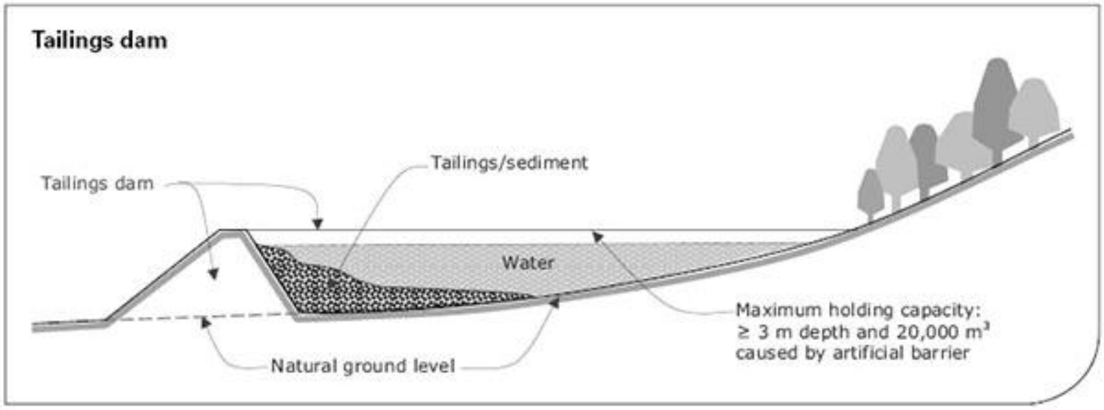


Figure B-1: Cross section of a conventional hillside tailing dam

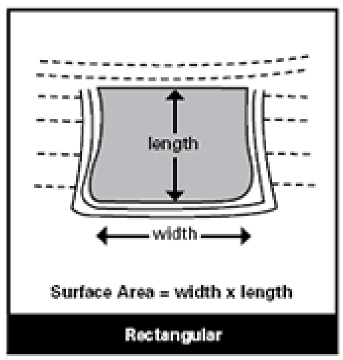


Figure B-2: A plan view of a tailing dam

To define the dimensions of the dam, I assume the width of the dam is 3.0 km, and length is 2.5 km.

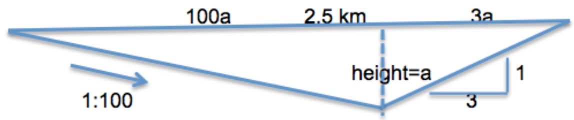


Figure B-3: Dimension relations of the dam cross section

According to Figure B-3,

103a= 1,500m, depth a= 14.56m.

Substituting the numbers into equation,

$$\begin{aligned}&\mathit{Volume}\ (\mathrm{m}^3) \ = \ 0.4 \ \times \ \mathit{Surface\ Area} \ \times \ \mathit{Depth} = \ 0.4 \ \times \ 3{,}000\ m \ \times 2{,}500\ m \ \times 24.27\ m \\ &= \ 72{,}810{,}000\ m^3 > V_{Tailing} \ = \ 60{,}576{,}923.08\ m^3\end{aligned}$$

It is required to leave 5% to 15% room for freeboard so the dimensions above are reasonable. To further support the hypothesis, conventional geometry was used to check if the volume of the TMF suits the proposed dimensions of the model. Figure B-4 and B-5 show the modeling perspective of the dam and its dimensions.

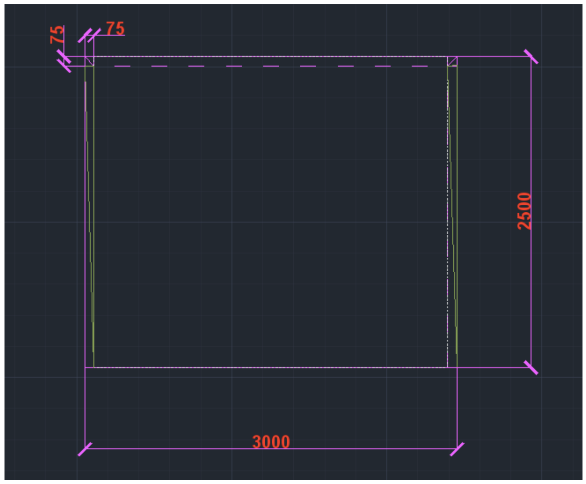


Figure B-4: Perspective of the dam looking from the top

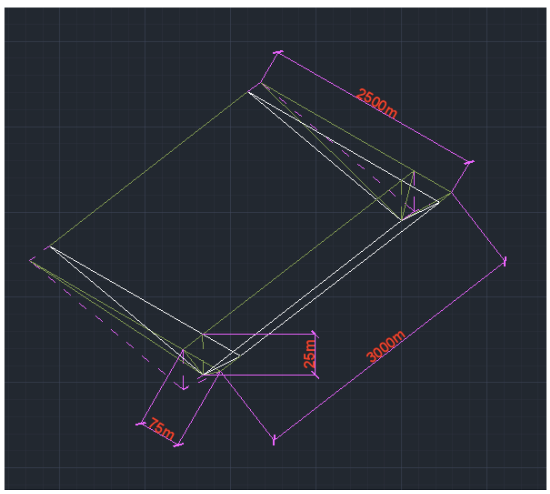


Figure B-5: Perspective of the dam

Calculations of the dam volume using geometry way is shown below:

$$V_{white\ area} = \frac{1}{2}(x) \times 25 \times (3000 - 75 \times 2) = \frac{1}{2} \times 2500 \times 25 \times 2850 = 89{,}062{,}500\ m^3$$

$$V_{two\ side\ triangle\ area} = 2\times\left[\frac{1}{2}\times 75\times 25\times\left(2500-75\right)-\frac{1}{2}\times 75\times 25\times\left(2500-75\right)\right]$$
$$= 75\times 25\times 2425-\frac{1}{2}\times 75\times 25\times 2425 = 2,273,437.5\ m^3$$

$$V_{bottom\ triangle\ area} = \frac{1}{2}\times 25\times 75\times \left(3000-2\times 75\right) = 2,671,875 m^3$$

$$V_{tailing} = \Sigma V = 89,062,500+2,273,437.5+2,671,875$$
$$= 94,007,812.5\ m^3 > V_{tailing} = 60,576,923.08\ m^3$$

Table B-1: Tailing management facility volume checking using geometry way (width=2500m)

Width	Length	V_{base} (m^3)	$V_{two\ side\ triangle\ area}$ (m^3)	$V_{bottom\ triangle\ area}$($m^3$)	Total Volume (m^3)
2500.0	2000.0	58750000	1804687.5	2203125	62757812.5
2500.0	2300.0	67562500	2085937.5	2203125	71851562.5
2500.0	2500.0	73437500	2273437.5	2203125	77914062.5
2500.0	3000.0	88125000	2742187.5	2203125	93070312.5

$$V_{base} = \frac{1}{2} length\times 25\ m\times\left(width-75\ m\times 2\right)$$

$$V_{two\ side\ triangle\ area} = 2\times\left[\frac{1}{2}\times 75\ m\times 25\ m\times(length-75\ m)-\frac{1}{2}\times\left(\frac{1}{2}\times 75\ m\times 25\ m\times\left(length-75\ m\right)\right)\right]$$

$$V_{bottom\ triangle\ area} = \frac{1}{2}\times 25\ m\times 75\ m\times\left(width-2\times 75\ m\right)$$

$$Total\ Volume = \sum V = V_{base} + V_{two\ side\ triangle\ area} + V_{bottom\ triangle\ area}$$

Sample calculation: (width=2.5km, length=3.0km)

$$V_{base} = \frac{1}{2} length \times 25\ m \times \left(width - 75\ m \times 2 \right) = \frac{1}{2} \times 3000\ m \times 25\ m \times 2350\ m = 88{,}125{,}000\ m^3$$

$$V_{two\ side\ triangle\ area} = 2 \times \left[\frac{1}{2} \times 75\ m \times 25\ m \times (length - 75\ m) - \frac{1}{2} \times \left(\frac{1}{2} \times 75\ m \times 25\ m \times \left(length - 75\ m \right) \right) \right]$$
$$= 2 \times \left[\frac{1}{2} \times 75\ m \times 25\ m \times \left(3000\ m - 75\ m \right) - \frac{1}{2} \times \left(\frac{1}{2} \times 75\ m \times 25\ m \times \left(3000\ m - 75\ m \right) \right) \right] = 2{,}742{,}187.5\ m^3$$

$$V_{bottom\ triangle\ area} = \frac{1}{2} \times 25\ m \times 75\ m \times \left(width - 2 \times 75\ m \right) = \frac{1}{2} \times 25\ m \times 75\ m \times (2500\ m - 2 \times 75\ m) = 2{,}203{,}125\ m^3$$

$$Total\ Volume = \sum V = V_{base} + V_{two\ side\ triangle\ area} + V_{bottom\ triangle\ area} = 88{,}125{,}000\ m^3 + 2{,}742{,}187.5\ m^3 + 2{,}203{,}125\ m^3$$
$$= 93{,}070{,}312.5\ m^3 > V_{tailing} = 60{,}576{,}923.08\ m^3$$

Table B-2: Tailing management facility volume checking using geometry way

Width	Length	$V_{whitearea}$(m^3)	$V_{two\ side\ triangle\ area}$ (m^3)	$V_{bottom\ triangle\ area}$($m^3$)	Total volume (m^3)
2200.0	2200.0	56375000	1992187.5	1921875	60,289,062.5
2200.0	**2300.0**	**58937500**	**2085937.5**	**1921875**	**62,945,312.5**
2200.0	2400.0	61500000	2179687.5	1921875	65,601,562.5
2200.0	2500.0	64062500	2273437.5	1921875	68,257,812.5

The topography of the Buffalo Mountain is shown in Figure B-6:

- The green dot indicates Buffalo Mountain

- The pink area is where the slopes is equal to or flatter than 1:100.
- Highway I80 is illustrated in orange.
- Red lines are the contour lines; the contour interval is 20 meters.
- Blue lines show the surface water flow locations.

In Figure B-7 the light black lines are the drainage divides of watersheds.

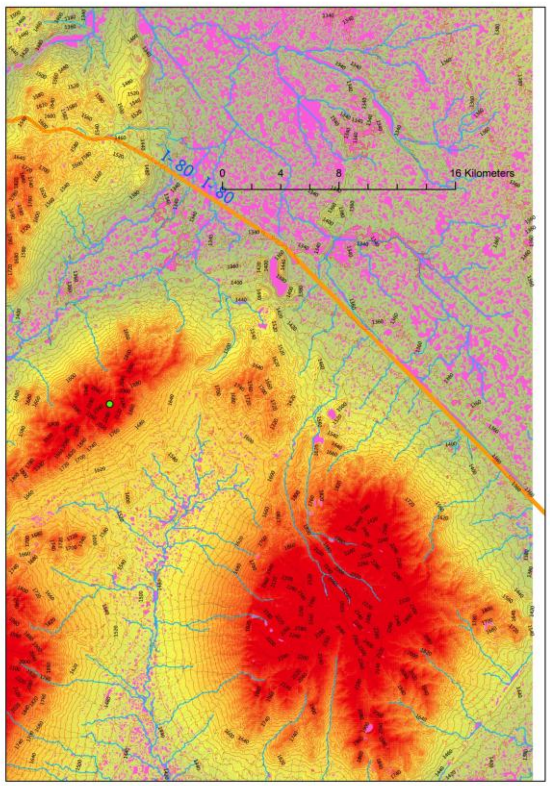


Figure B-6: Topography of Buffalo Mountain area

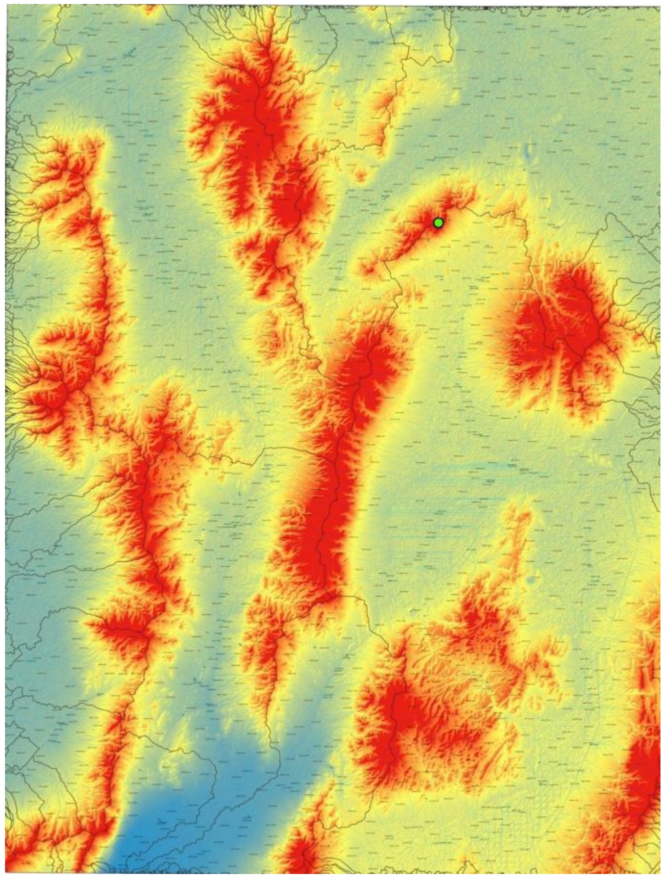


Figure B-7: Catchment areas around Buffalo Mountain, Winnemucca, Nevada

Appendix C- Calculation of the volume and area for the open pit

The total mass of ore and waste rock being excavated is calculated below:

$$45,000\ tonnes/day\ \times 350\ days\ \times\ 15\ years\ =\ 236,250,000\ tonnes$$

Assuming the density for ore and waste rock together is 2.65 tonnes/m^3, then the volume of the open pit can be calculated as

$$V =\ m_{total}\ /\ \rho\ =\ 236,250,000\ tonnes\ \ /\ \ 2.65\ tonnes/m^3 =\ 89,150,943.4\ m^3$$

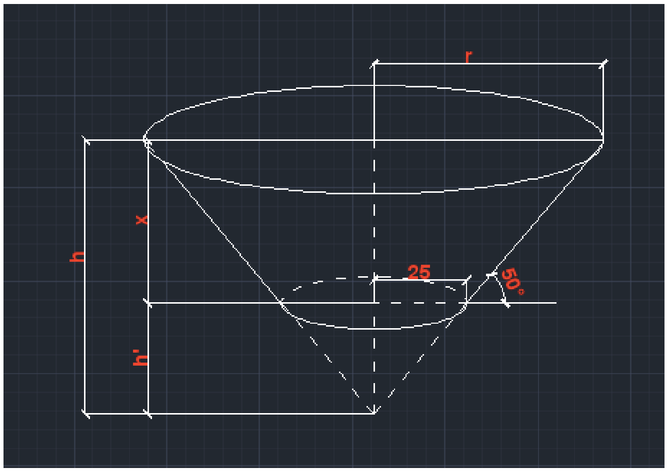


Figure C-1: Open pit: Frustum of a cone

The volume for the above frustum of a cone can be calculated by,

$$V = \frac{1}{3}\pi h(r'^2 + r^2 + rr') = 89,150,943.3\, m^3$$

.

Assuming the bottom radius of the open pit r'=25m, and the angle of the slope is 50°, r is 365.956m. Area of the top surface is 420,734 m^2 (103 acres 42063 ft^2).

$$x = 630.895 \text{ m.}$$

To find the relationship between the change of depth and top surface area of the pit with different bottom radius, an excel spreadsheet is used for calculations as shown in Table C-1. Figure C-2 is a line chart illustrating changes of depth and top surface area at different bottom radius. The blue line shows the change of depth at different bottom radius, and the red line shows the change of top surface area at different bottom radius.

Table C-1: Change of depth and top surface area with different bottom radius for open pit

Bottom Radius r	Depth h	Top Radius R	Top Surface Area T
r=bottom diameter/2	h= (R-r)/tan40 °	$R=[(3*Volume*\tan 40°)/\pi+r^3]^{1/3}$	$T=\pi*R^2$
25.0	464.7	415.0	540945.8
50.0	435.2	415.2	541497.7
75.0	406.1	415.7	542994.3
100.0	377.6	416.9	545902.9

Volume (m^3) fixed at $V=m_{total}/\rho$=89,150,943.4

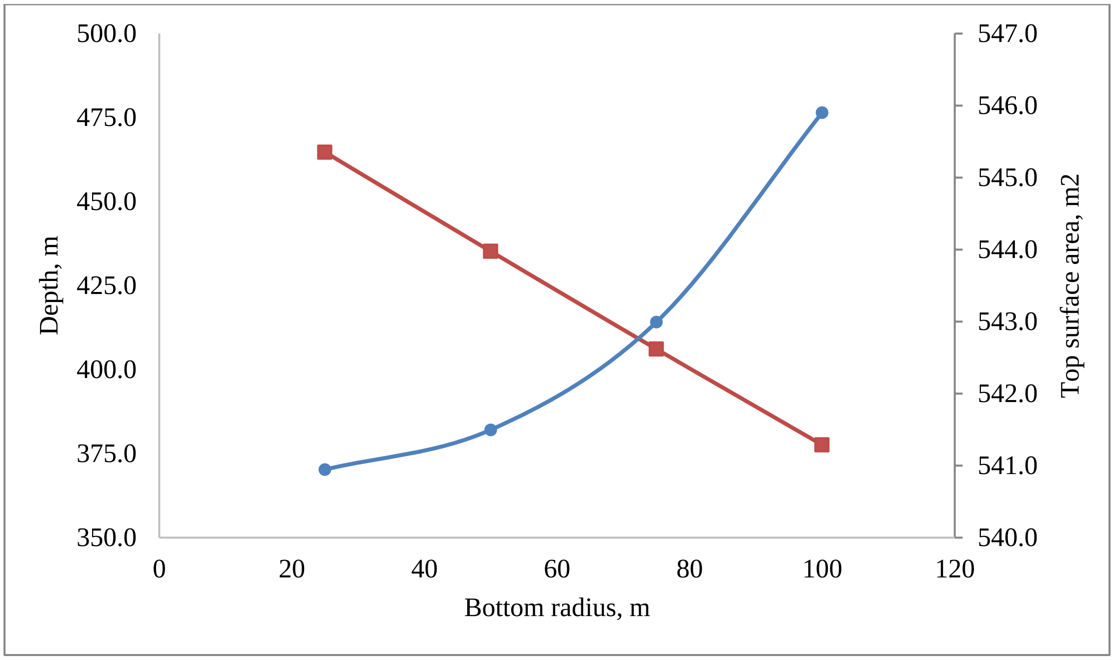


Figure C-2: Change of depth and top surface area with different bottom radius for open pit

Appendix D- Runoff and Manning's equation

Here a trapezoidal concrete channel is chosen which is a typical open channel and commonly used. Variables of the channel are defined in Figure D-1.

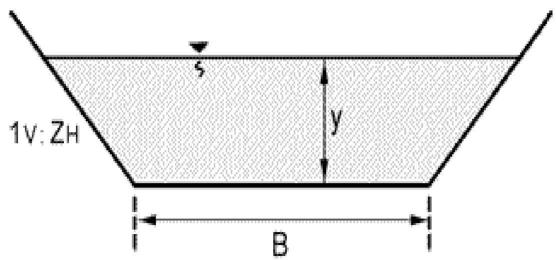


Figure D-1: Cross section of a trapezoidal channel

According to the above Figure D-1,

- A means the flow cross sectional area;
- P is the wetted perimeter;
- and hydraulic radius that is the ratio of flow cross sectional area and wetted perimeter.

$$A = By + Zy^2$$

$$P = B + 2y\sqrt{1+Z^2}$$

$$R = \frac{A}{P}$$

It is assumed that the precipitation is uniform steady flow which happens when discharge remains the same and depth does not change, as illustrated in Figure D-2.

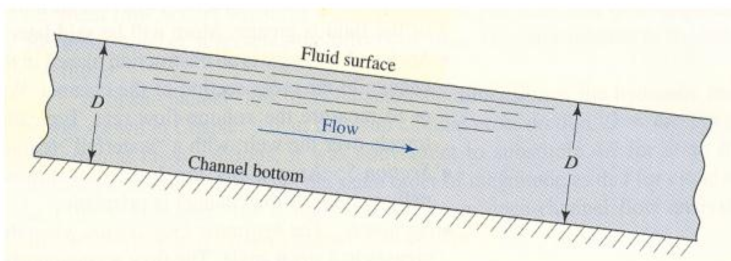


Figure D-2: Uniform steady flow

S is the slope of the channel, and can be expressed as an angle (1 degree), as percent (1%) or as fraction (0.01 or 1 in 100). Velocity of flow in the channel can be computed using empirical equations; one of the mostly used equations is the Manning's equation

$$v = \frac{1}{n} R^{2/3} S^{1/2}$$

$$v = \frac{1.49}{n} R^{2/3} S^{1/2}$$

n is the Manning's coefficient (dimensionless) – values developed from experimentation. For concrete pipes, n=0.015.

The Soil Conservation Services Curve Number (SCS-CN) method is the most widely used technique for estimating surface runoff for a given amount of rainfall from small catchments. Runoff can be calculated using the runoff as shown below:

$$Q = \frac{\left[P - 0.2\left(\frac{1000}{CN} - 10 \right) \right]^2}{P + 0.8\left(\frac{1000}{CN} - 10 \right)}$$

In which, Q means accumulated runoff or rainfall excess; P is rainfall depth and CN is the runoff curve number, which is affected mainly by hydrologic soil group (HSG), cover type, treatment, and hydrologic condition (NRCS, 1986). HSG is determined in Table D-1 below:

Table D-1: Classification for hydraulic soil group

HSG	***Soil textures***
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

The tailing soil texture for the model in this study is defined as category B. The curve number is then selected from Table D-2 below, in which CN is chosen as 75.

Table D-2: Curve number selection

Cover description		Curve number for hydrologic group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadon-continuous grass, protected from grazing and generally mowed for hay.	--	30	58	71	78
Brush-Brushe weed-grass mixture with brush the major element.	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods-grass combination (orchard or tree farm).	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads-buildings, lanes, driveways, and surrounding lots.	--	59	74	82	86

Either probable maximum precipitation (PMP) or 1 in 100 years, 24 hours' storm precipitation is used for the rainfall depth. In this research, flooding because of runoff is a concern, and the probability of extreme flows in 100-year return period is needed. Thus, a PDS-based precipitation frequency estimates is used as 2.05 in Table D-3.

Table D-3: NOAA ATLAS precipitation frequency estimates: NV

	Duration	Average recurrence interval (years)	PDS-based precipitation frequency estimates (in inches)
Winnemucca, NV	24-hr	100	2.05 (1.87-2.20)

(US Department of Commerce, n.d.)

Substituting all parameters into eq. (12), the Q could be obtained as below':

$$Q = \frac{\left[P - 0.2\left(\frac{1000}{CN} - 10\right)\right]^2}{P + 0.8\left(\frac{1000}{CN} - 10\right)} = \frac{\left[2.05 - 0.2 \times \left(\frac{1000}{75} - 10\right)\right]^2}{2.05 + 0.8 \times \left(\frac{1000}{75} - 10\right)} = 0.405712$$

$$\frac{1}{2}Q = \frac{1}{2} \times 0.4057 = 0.2029\,(in)$$

Appendix E- Trapezoidal open channel design

A cross section of a trapezoidal open channel shown in Figure D-1, assumptions on variations of trapezoidal channels (English unit) are made as below:

B=6.5 ft., Y=1.6 ft., Z=2,

From Figure 4-5, the total upstream catchment area is the green area. Adding up the two-catchment area 1541789.97341m^2 and 9407153.82912m^2, the total upstream catchment area is 10948943.8m^2. Table E-1 calculates the runoff using SCS Method. Runoff in meters is 0.0103051 m.

Total volume of flow (m^3) = Upstream catchment area (m^2) * Runoff

Substituting total upstream catchment area and runoff numbers, the total volume of flow is 112829.962m^3.

Side slopes are designed at 2 to 1,

In this case,

$$v = \frac{1.49}{n} R^{2/3} S^{1/2}$$

For concrete pipe, n=0.015,

S is the slope of the channel, and can be expressed as fraction: 0.005.

V=7.649584277, discharge Q= 118.721548 ft^3/s.

The channel must also be designed to hold the peak discharge. Using EFM Chapter 2 Method, the peak discharge can be calculated in Table E-1 below.

The final dimension for the trapezoidal pipe is set at B=7.5 ft., Y=2.5 ft., Z=2.

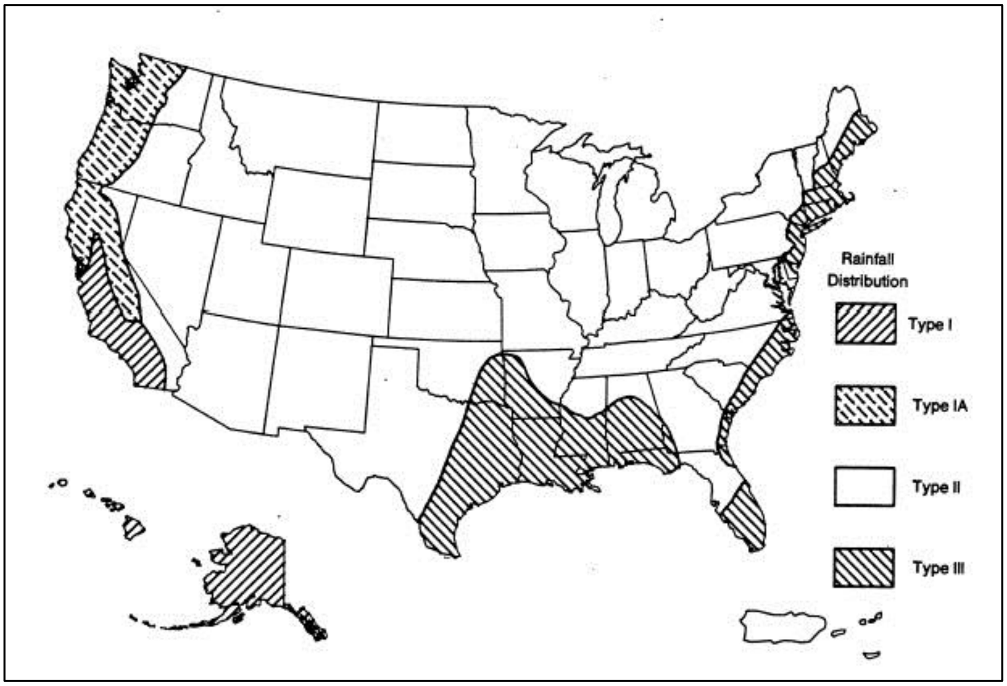


Figure E-1: Geographic boundaries for SCS rainfall distributions

Table E-1: EFM Chapter 2 method to calculate peak runoff

EFM, Chapter 2 method	**Values**
1. Drainage Area, A (acres)	2,705.54
2. Average watershed slope, Y	
3. Curve number	75
4. Return period	100 yrs
5. Using the 100-yr, 24 hr rainfall chart, locate Winnemucca, and read	P=2.05 in.
6. it is determined that Nevada has a Type II storm distribution.	--
7. Flow length, l (ft)	
8. T_c(hrs)	
Rain fall distribution type=	II
Drainage area A=	2,705.54
Runoff curve number CN=	75
Watershed slope, Y=	0.5%
Flow length l(ft)=209$A^{0.6}$=	15,000.00
$T_c = \frac{l^{0.8}(\frac{1000}{CN} - 9)^{0.7}}{1140y^{0.5}}$	7.59029442
9. For CN=75 and P = 2.05 in, Q=	0.405712603
10. I_a=0.667. Determine I_a/P= 0.667 in/ 2.05 in	0.325
11. Using Exhibit 2-II for the Type II storm distribution, find q_u:	qu=0.085 cfs/ac/in
12. Calculate the peak discharge: q_p=q_u A Q (cfs)	**93.30219348**

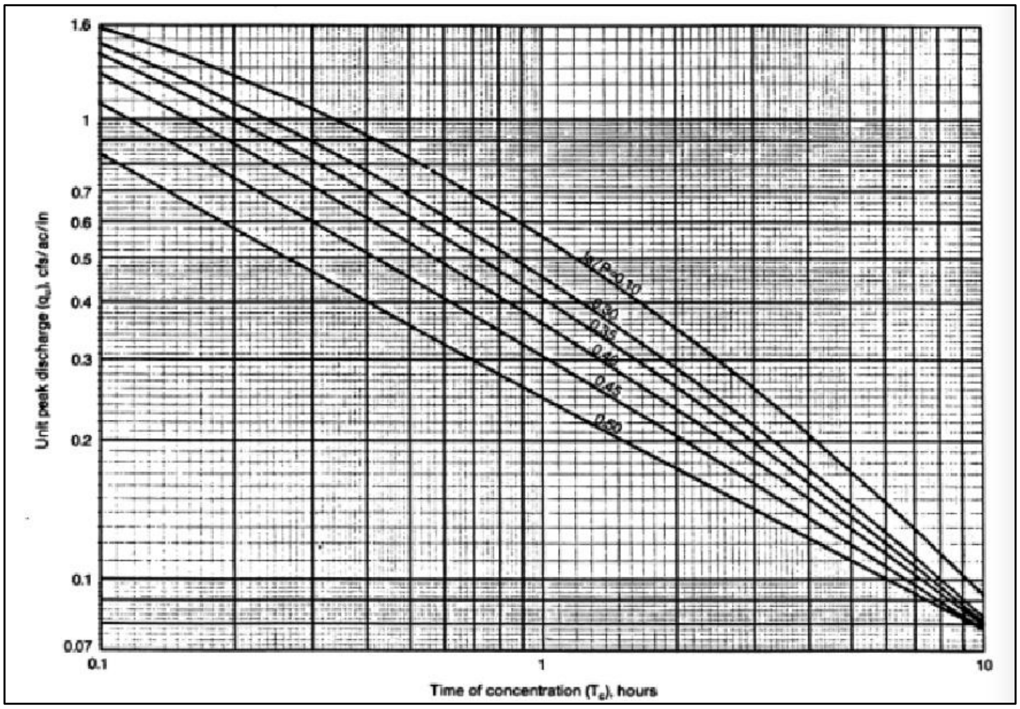


Figure E-2: Unit peak discharge(qu) for SCS Type II rainfall distribution

Table E-2: Runoff calculation process using SCS runoff curve number method

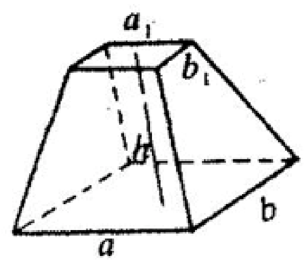
Parameters	Case 1	Case 2
p(inches)	2.05	2.05
CN	39	75
S	15.64	3.33
P+0.8S	14.563	4.717
(P-0.2S)^2	1.1625263	1.91361111
Q(inches)	0.0798	0.4057
1/2Q(inches)	0.03991	0.20286
Q(meters)	0.0020276	0.0103051
1/2Q	0.00101382	0.00515255
upstream catchment area, m^2	10,948,943.80	10,948,943.80
total volume of flow, m^3	22200.52437	112829.962

Table E-3: Open channel design

	SI unit	English unit(ft)	Adjusting
B	2	6.5	7.5
y	0.5	1.6	2.5
z	2	2	2
Area	1.5	15.52	31.25
wetted perimeter, P	4.2361	13.6554	18.6803
hydraulic radius, R	0.3541	1.1365	1.6729
k_u	1	1.4900	1.4900
$v = \frac{K_u}{n} R^{2/3} S^{1/2}$	2.3595	7.6496	9.8982
Discharge Q=v*A	3.5392	118.7215	309.3192
$Q = \frac{K_u}{n} A R^{2/3} S^{1/2}$ m^3/s, ft^3/s	3.5392	118.7215	309.3192
n (Manning's coefficient of channel roughness)	0.0150	0.0150	0.0150

Appendix F- Calculation of reclamation earthwork for MRMF and TMF

F.1 MRMF



$$Surface = [(a_1 + a) \times h' \div 2] \times 4 + (a_1 \times a_1) = [(1200 + 1500) \times 49.6387 \div 2] \times 4 + (1200 \times 1200)$$
$$= 67,012.245 + 1,440,000 = 1,507,012.245\ m^2$$

Unit weight of mine rock is 1.8 tonnes/m^3.

The sickness of the soil layer to be placed on top of Mine Rock Management Facility is 300mm, thus the volume of the soil layer can be calculated as below:

$$Volume_{Soil\,layer} = Surface\,area \times Thickness = 1,507,012.245\ m^2 \times 0.3\ m = 452,103.6735\ m^3$$
$$= 591,329.2801\ yrds^3$$

F.2 Tailing management facility

Size of TMF: 2,200m* 2,300m

$$Surface\ area = 2,200\ m \times 2,300\ m = 5,060,000\ m^2$$

Unit weight of soil is 1.8 tonnes/m3.

$$Volume_{Waste\ rock} = Surface\ area \times Thickness = 5,060,000\ m^2 \times 0.3\ m = 1,518,000\ m^3$$
$$= 1,985,469.041\ yrds^3$$

$$Volume_{Soil} = Surface\ area \times Thickness = 5,060,000\ m^2 \times 0.3\ m = 1,518,000\ m^3$$
$$= 1,985,469.041\ yrds^3$$

Total volume of earthwork to be done on the tailing management facility is 3,970.938.082 $yrds^3$.

Total earthwork for MRMF and TMF:

$$3,970.938.082\ yrds^3 + 591,329.2801\ yrds^3 = \ 4,562,267.362\ yrds^3.$$

Appendix G- Building demolition using Sherpa.

Figure G-1: Maintenance shop demolition cost

Figure G-2: Dry demolition cost

Figure G-3: Office demolition cost

Figure G-4: Warehouse demolition cost

Figure G-5: Processing plant demolition cost

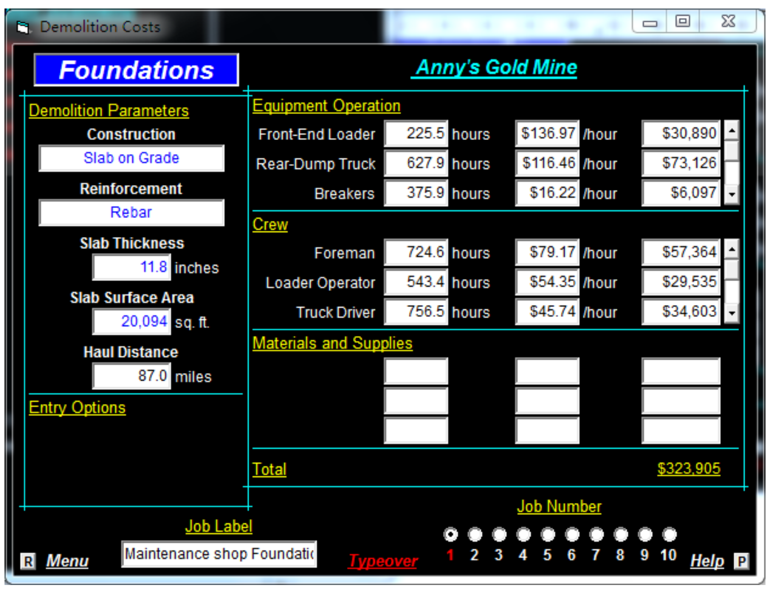


Figure G-6: Maintenance shop foundation demolition cost

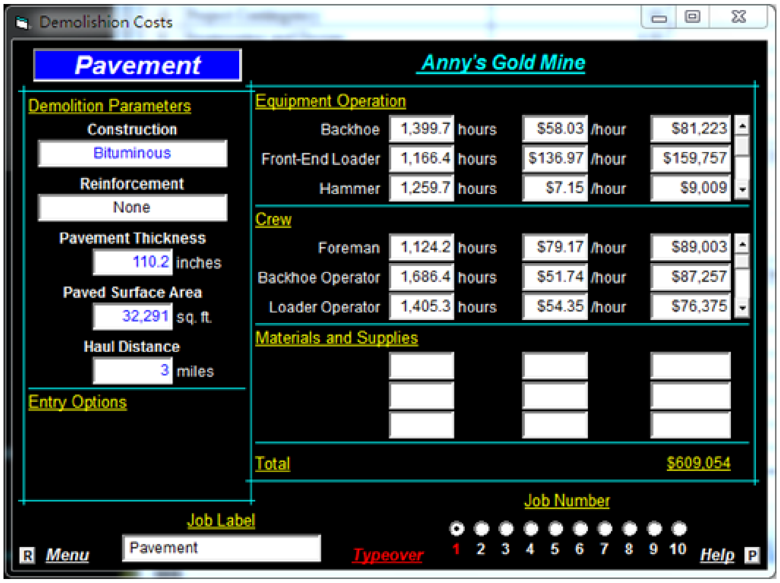


Figure G-7: Pavement demolition

Figure G-8: Fence removal costs

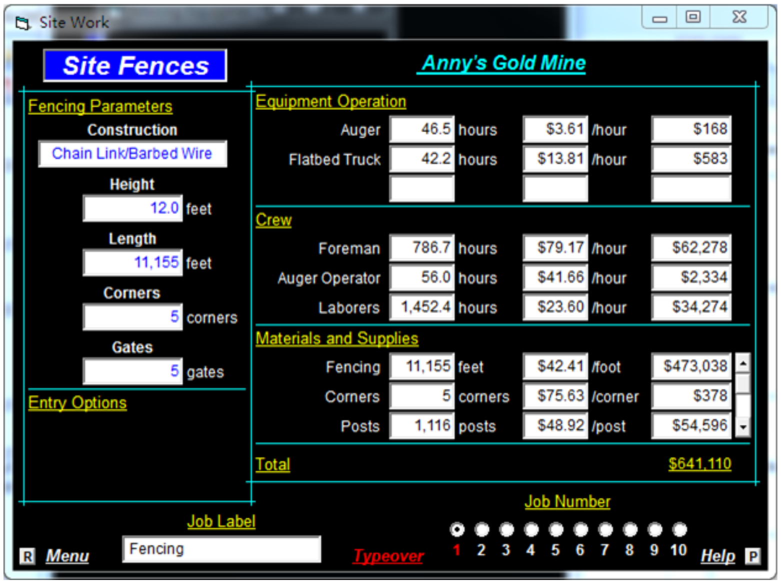


Figure G-9: Site fences removal cost

Appendix H- Disposal costs using Sherpa

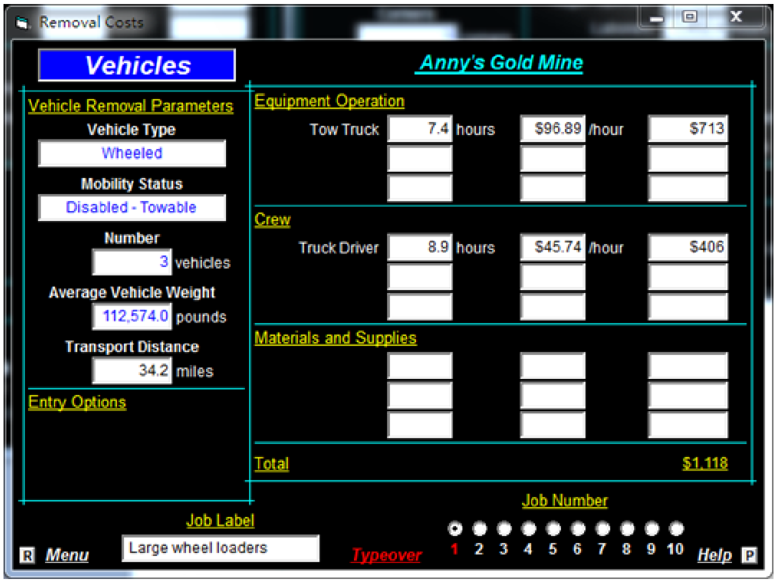


Figure H-1: Vehicle removal cost

Figure H-2: Cyanide disposal costs

Figure H-3: ANFO storage disposal costs

Appendix I- Monitoring and seeding costs using Sherpa

Figure I-1: Well monitoring costs

Figure I-2: Seeding costs

Table I-1

Common Name	Scientific Name	Cost
Grasses		
Thickspike Wheatgrass	Agropyron dasystrachyum	$821,100
Indian Ricegrass	Oryzopsis hymenoides	$240,000
Forbs		
Blue Flax	Linum lewisii	$185,000
Winterfat	Eurotia lanata	$545,300
Total		$1,791,400