A Generic Approach to Preliminary Economic Evaluation of Placer Gold Deposits In Ethiopia,

Tamirat Worku Lemma, Unity University

Abstract

Economic analysis for multiple hypothetical placer gold mine models was conducted and its result is plotted on four graphs, each represents deposits with specific stripping ratio. The analysis was conducted to prove economic feasibility on the hypothetical models and to provide graphs which will help estimate a mine project's NPV. Existence of placer gold deposits and occurrences were investigated from the literatures and technical reports by the Geological Survey of Ethiopia. It is noted that placer deposits occur in four geographical regions in Ethiopia. These are in Adola area of Southern Ethiopia, in Benishangul and Wollega of Western Ethiopia, in the Akobo gold field of Southwestern Ethiopia, and also in the Mekele quadrangle of Northern Ethiopia. Hypothetical 64 mine models were prepared by simultaneously varying deposit stripping ratio, reserve size and production rate. The reserve sizes selected were Small 160,000 m^3, Medium 400,000 m^3, Large 800,000 m^3 and Huge 1,600,000 $m^{3.}$ Four deposit types were modeled based on stripping ratio. These are Mine type-A with 1:1 Stripping ratio, Mine type B with 2:1, Mine type C with 4:1 SR, and Mine type D with 8:1 SR. And four production rates were used for analysis, these are 76, 190, 380 and 765 m^3/day. The 64 models were reduced to 16 models by conducting economic analysis using cash flow tables and lump-sum costs of the models. Consequently, a production rate with maximum NPV for each stripping ratio/reserve size models was selected. Then detailed deposit and mine parameters were prepared and cost estimation was carried out for the 16 models based on their parameters. Again, using cash flow tables the grade requirements for the 16 mine models that would result in specific NPV values (10, 50, 100, and 200 million) were calculated. Reserve sizes and the grade requirements were represented by graph axes and NPV lines were drawn by connecting known points. Feasible scenarios were observed for all the hypothetical reserve sizes initially chosen. Finally a procedure was developed on how to use the resulting graphs of this study.

Key Words*:* Preliminary Economic Evaluation, Placer Gold Deposits**,** Ethiopia

1. Introduction

1.1 Background

The mining sector has been seen to be a major contributor to a county's economic development. It has direct impacts on Gross Domestic Product (GDP), foreign currency earnings, tax and royalty incomes. Additionally, mining provides employment and facilities development of other industrial sectors.

Also for the investor, mining is a high return on investment project. If an economic mineral deposit is realized, large amount of profit could be reaped from it. In Ethiopia the mining sector is at its infant stage especially for metallic minerals. There is only one large scale Gold Mine, i.e. the Legadembi Gold Mine and other two small scale gold and tantalum operations that are run by the government. However, two additional large scale gold mines have finalized their feasibility study and are on their way to development stage.

Gold could be mined from primary mineralized bodies like veins and disseminated deposits or from secondary (placer) deposits. Large scale mining operations on primary deposits usually take long time to start production. Furthermore, they are high capital investments that are almost exclusively left to foreign investors who seek large deposits and high return on investment.

On the contrary, placer mining operations are low capital operations that present new opportunities for domestic investors and miners' cooperatives. They take very less time to explore and need very little development work before production. The Ethiopian government having noticed these at the time of its urgent foreign currency needs, it has given much attention to placer gold mining and brought up a new directive for placer gold mining that limits the exploration and planning period to 6 months (Directive 3, 2007).

Except for a single state owned placer mining operation that has been carried out for half a century in the Adola area, there are no other placer mines in the country. But artisanal gold mining is being carried out in the western and Northern parts of the country which could be an indicator of potential placer deposits which could be large enough to be mined by a mechanized placer gold mining.

Placer gold mining operations, despite their annual production volume being lower, they are low capital projects which could result in large amount of return for the investor and also income for the country, including foreign currency. And a multitude of these would boost the country's gold production and foreign currency earnings.

Furthermore, placer gold mining could be operated by organizing artisanal miners into cooperatives, in turn this will help in solving the negative environmental, social and economic issues associated with artisanal mining. Artisanal miners employ a traditional and manual technique to mine gold from placers deposits. This resulted in very low productivity in addition to the environmental risks that come from land disturbance. In addition, mining is done in an unorganized way which is the reason for improper resource and benefit utilization.

To further facilitate the creation of placer gold mines, initial information on the economic feasibility of deposits at hand is invaluable to the prospective investor, the government and other stake holders.

1.2 Problem Statement

As the mining sector is undeveloped in Ethiopia, there is lack of organized information regarding placer gold mining; this is seen as the main problem in this study. Thus this study tries to provide a guideline which can serve as a preliminary assessment tool for the economic feasibility of placer gold deposits in Ethiopia.

The study tries to answer the following questions:

1. What are the capital requirements to start the operation and what are the likely operating costs, considering the spatial distribution and the production rate?
2. What is the optimum production rate to mine a specific reserve?
3. How much quantity of material (grade and volume) is needed to meet a specific NPV value at different reserve/production rate/stripping ratio scenarios?

4. How much is the NPV of a specific deposit (reserve and grade) within certain models of spatial distribution and production rate?

1.3 General Objective

The aim of this research project is to provide a preliminary economic assessment tool for the feasibility of mechanized placer gold mining in Ethiopia. This is achieved by conducting the economic analysis of multiple hypothetical placer mine models created by varying stripping ratio, production rate and deposit size.

1.4 Specific Objectives

i. Show the existence of economic placer gold prospects in Ethiopia
ii. Establish multiple mine models based on production rates, stripping ratios and deposit size
iii. Propose specific mining and processing method for exploitation of placer gold deposits
iv. Conduct capital and operating cost estimates for the various mine models /scenarios/
v. Perform economic analysis for the different mine models and calculate the grade of pay gravel necessary to achieve a positive cash flow for a specific reserve amount and return rate

1.5 Significance of the Study

This study's results are aimed to provide a method for preliminary economic investigation of the feasibility of developing placer gold deposits that are discovered in Ethiopia.

It could be an initial guide to every domestic investor and miners cooperatives who are interested in developing a placer gold deposit. It provides Information on:

a. Placer mining and processing methods
b. Capital requirements and operating costs required to work the specific deposit
c. the grade of pay gravel required to achieve positive cash flow for the specific reserve size under consideration at a desired return rate

Currently the Geological Survey of Ethiopia (GSE) explores placer gold deposit in Ethiopia and passes them to artisanal miners. But this research's findings can be used to discriminate between deposits to be given to artisanal miners and to be mined by mechanized placer mining.

1.6 Scope of the Study

The research dealt only with placer gold mining operations in Ethiopia. Cost estimates and economic evaluation has been conducted based on domestic rates. It has encompassed both small scale and large scale placer gold operation.

1.7 Methodology

Mine models representing the commonly occurring placer deposits configuration have been prepared. This models had been classified based on three parameters, which were overburden depth, reserve size and production rate.

Cost estimation for mining and processing the mine models has been using the following sources.

1. Based on existing placer gold operations
2. Cost estimates of feasibility studied projects
3. Mining Cost services
4. Equipment Vendors

Capital requirements have been listed item by item and estimation of operating cost has been carried out for different production rate, stripping ratio and mine life scenarios. Average of the costs available from the various sources has been assigned for a specific cost item.

And using the cost data collected cash flow analysis has been performed to determine the production rate to mine a specific reserve and the mine models have been filtered based on this. After this, backward cash flow analysis has been done on the remaining mine models to calculate the grade requirements to meet a specific NPV value. This has been achieved through Microsoft Excel software. Finally the grade has been plotted against reserve amount for specific NPV and curves have been generated using the data for the specific mine models.

2. Methodology

2.1 Study Area

The study was carried out in Ethiopia, to analyze the economic feasibility of placer gold mining in the country. The mining cost data was gathered accordingly and the Ethiopian mining laws were followed in the economic analysis.

2.1.1 History of Mechanized Placer Gold Mining

Placer gold deposit in Ethiopia was discovered in the Adola area during World War II by Italian geologists. The Ethiopian Government started placer gold mining in the Adola Belt just after COMINA's (Compania Mineralia Ethiopia) exploration of 1939-1941.

Intensified placer gold mining in the Adola and Wollega regions, along with indications of other mineral resources, enabled the set-up of the Mineral Development Department under the Ministry of Mines and Energy in the early 1960s to organize small-scale mining and semi-mechanized operations in the Adola gold field and elsewhere. Subsequently, operation of hydraulic plants was introduced in the Shanka and Bedakessa valleys.

Gold production began to decline from 1962 due to the depletion of high-grade ore as a result of increasing mechanization of mining operations. The Adola Gold Exploration Project (AGEP) was initiated in the late 1970s to carry out systematic exploration of both placer and primary gold deposits with the aim of replenishing production through discovery of new resources. The Project evaluated and assessed two groups of placer gold occurrences. The first group involved the Megado ore belt, more than 90 km from the Ababa and Babicho drainage basin in the north and extending to the Dawa basin in the south. The second group occurs along the lower course of the Mormora drainage and defines the Kenticha gold belt.

Since then nearly 56t of gold has been produced from placers of the Adola area alone, until the end of 1999. No record is available on the gold production of the western and southwestern regions.

The Adola Gold Development Enterprise (AGDE) has been mining the placer gold deposits in the area up to recent years. But it has stopped operation in 2014 due to conflict with locals.

Other private mining companies are also showing interest in placer gold mining lately. About five companies have finalized their feasibility studies, and has submitted their request for a mining license. Of these Stella Mining Co. has been granted a mining license to start placer gold production in the Akobo area.

3.1.2 Placer Gold Deposits and Occurrences

Placer gold is known to occur in four different geographical regions of Ethiopia. These are the Adola area in Southern Ethiopia, in Benishangul and Wollega of Western Ethiopia, in the Akobo gold field of Southwestern Ethiopia, and also in the Mekele quadrangle of Northern Ethiopia.

In the Adola gold field, placer gold deposits with contents averaging 0.1 g/m3 (of gravel) or more of gold and with gold reserves of over 30 kg are classified as ‘‘placer deposits’’, while those with lesser gold values and reserves are termed ‘‘placer occurrences’’. All gold placers are concentrated in the N–S trending Megado Belt. (Dorofeev *et al.*, 1985 cited in Selassie and Reimold, 2000)

In Adola, Gold placers are widespread and occur in the Bedakessa, Shanka, Wollena, Wollebo, Bore, Lega Dembi valleys and in a number of small tributaries of the Awata and Mormora rivers. A total of 173 placer deposits and occurrences of gold are known in the Adola area, comprising 7200 km^2. (Solomon, Jean-Pierre and Yves, 2003).

In west Ethiopia the Sirkole valley with a dimension of 39 x 8 km, is located SW of Asosa town. The Sirkole have been prospected for placer gold. The grade, according to pre-1947 results, varied from 0.01-0.13 g/m^3. A reserve of 1525kg, at an overall content of about 0.35 glm3 and gravel content of 0.9 g/m^3, has been estimated (Selassie and Reimold, 2000).

Also in Western Ethiopia the Degero valley placer gold deposit is located 19 km of Nejo town in the Wollega zone). In 1977/1978, the reserve was estimated at 105kg, at a gravel content of 0.3-0.2g/m^3 over the 4 km length of the valley. Hailu (1981) predicted an overall reserve of 90 kg, with average grades of about 0.2 glm^3.A pilot plant bulk test of 1979-1981, using a wooden prototype sluice box, was found profitable for small-scale mining operations. (Norris, 1980 cited in Selassie and Reimold, 2000).

In Southwest Ethiopia Placer gold exploration activities in the Akobo goldfield of SW Ethiopia, 310 km SW of Jima town, were initially carried out in 1934-1940 by COMINA and in the 1950s by the Department of Mines. Gold reserve estimates varied, but some were as high as 3000 kg. Earlier reserve estimates were upgraded in 1994 by the EIGS (Kebede, 1995), who estimated 3600 kg at grades between 0.07 and 0.5 g/m3. Recently, in 2016 a private mining company has acquired a mining license to produce placer gold in the Akobo area. (Selassie and Reimold, 2000).

The Godere target area occurs in the SW metallogenic belt of Ethiopia. The entire low-grade metamorphic belt (Akobo domain) has been reported as favorable for the occurrence of precious metal mineralization. The Godere placer gold occurrence is a northward extension of the Akobo goldfield. The local gold mining along the Godere drainage, a first-level tributary of the Akobo River, verifies this potential. (Selassie and Reimold, 2000).

In the Mekele quadrangle of eastern Tigray, Northern Ethiopia, alluvial gold is known along the Werri and Bereh Rivers. Potential gold-bearing alluvium along the Werri River is some 30 kilometers long and 20-300 meters wide, and consists of both high and low terraces. (Techno-Economic Consulting, Inc., 1994)

2.2 Mine Model Design

Four general types of deposits are modeled based on the overburden depth covering the pay gravel layer. These are named **A, B, C,** and **D** type deposits with stripping ratios 1:1, 2:1, 4:1 and 8:1 respectively. These deposit types were selected because cost data is readily available from mining cost services for them. And this in turn is due to adequacy of the selected range to cover most of the economic placer gold deposits.

The above four mine models are further divided into 16 mine models based on four reserve sizes, which are 160,000, 400,000, 800,000 and 1,600,000 cubic meters of pay gravel. These will be referred in this text as small, medium, large and huge merely for the sake of convenience.

And finally the above 16 models are divided into 64 mine models using four types of mine production rates. The production rates used are 76, 190, 380 and 765 m3 of pay gravel per day.

Table 2.1: 16 Mine Models Within Each of the A, B, C, And D of Deposit Type

Small	Medium	Large	Huge
160,000 m3	**400,000 m3**	**800,000 m3**	**1,600,000 m3**
76 m^3/day	76 m^3/day	76 m^3/day	76 m^3/day
190 m^3/day	190 m^3/day	190 m^3/day	190 m^3/day
380 m^3/day	380 m^3/day	380 m^3/day	380 m^3/day
765 m^3/day	765 m^3/day	765 m^3/day	765 m^3/day

2.3 Deposit and Mine Parameters

Deposits parameters for the A, B, C, and D mine types of the four reserve sizes mentioned are derived from info mine's cost models. The parameter list includes:

1. Transport distance for pay gravel and overburden
2. Transport gradient for pay gravel and overburden
3. Total Resource and total overburden
4. Topsoil Thickness, overburden thickness, pay gravel thickness and recovered bedrock thickness
5. Topsoil swell and overburden Swell
6. Stream gradient and side slope Gradient
7. Average deposit width and average mining panel length
8. Resource recovery
9. Processing Plant Availability

These are detailed in appendix 1 which tabulates the main deposit and mine parameters for small, medium, large and huge reserve deposits of varying stripping ratios.

2.4 Mining Method Selection

Based on the above deposit and mine parameters a mining method and mine equipment have been selected for each of the above mine type/rate models.

The mining method is designed with the use of standard earth moving equipment, i.e. bulldozers, backhoes, trucks and loaders and in one case where the overburden depth is 8 meters, a scraper. The method uses a mobile gravel ore processing plant which is dragged inside the pit as the mining progresses. It utilizes a bulldozer for overburden stripping and a backhoe excavator for feeding ore into the mobile plant. For the 765 m^3/day a dozer will be used to remove the topsoil and a scraper to remove the overburden because of excessive depth overburden, which is 8 meters. Most of the topsoil and overburden material extracted from the pit will be dumped to the adjacent mined out pit.

As for gravel processing, standard set of equipment is used in all models. The run-of-mine gravel is fed at an even rate to hopper which passes it to trommel screen, where oversized material is separated and discarded, and the remaining feed washed. This feed then flows through a sluice box where the gold and heavy metal constituents are collected. Periodically, the concentrates contained in the sluice are removed and fed to a concentrating table to effect final recovery.

2.5 Mine Development and Reclamation

The development and reclamation work required for all mine type/reserve size models have been outline in the following tables. Development includes site clearing, pre-production stripping and site access roads and water provision. In mine reclamation work tailing placement, overburden, and topsoil placement are included.

2.6 Mine Equipment, Personnel and Facilities

Mine equipment for the specific mine type/production rate models have been selected and sized based on the planned production rate, deposit parameters and mine parameters. Mine equipment meeting a specific production rate and overburden ratio is derived from Aventurine Engineering placer mine models.

A personnel planning is based on the case of Ethiopia. Due to lack of mining and machinery knowledge in the country, professionals assigned to do each specific job. Mine equipment, personnel and facilities requirement for each production rate/overburden.

2.7 Cost Estimation

Cost estimation was carried out for the following cost items according to the site preparation, mine equipment, labor and building and facilities required. All the capital cost data and equipment operating cost data were collected from Info Mine's Mining Cost Service publication of year 2011. Cost indexing was applied to convert the costs to year 2016. The labor operating cost was estimated considering local conditions.

Cost estimates include:

a. Mine development cost (Capital Cost)
b. Mine equipment cost (Capital Cost) and salvage values
c. Buildings and Facilities Cost (Capital Cost)
d. Mine operating cost (Operating Cost)
e. General and administrative cost (Operating Cost)
f. Post-production reclamation

Reserve Size	Mine Type	Production rate (m^3/day)	Capital Cost Before Salvage	Salvage Value Value	Operating Cost (Birr/m3 of Ore
Small 160,000 m3 Deposit	A	76	28,332,480	9,607,400	108
	B		28,405,300	8,124,600	148
	C		34,827,540	8,899,000	144
	D		53,971,060	12,540,000	270
Medium 400,000 m^3 Deposit	A	190	39,973,560	8,360,000	90
	B		41,658,540	6,487,800	106
	C		61,395,400	6,032,400	144
	D		105,722,540	18,772,600	219
Large	A	765	75,981,774	16,766,200	50
	B		84,080,854	15,164,600	56
	C		138,290,394	40,706,600	67
	D		224,248,134	76,461,000	84
Huge 1,600,000 m3 deposit	A	765	73,500,174	14,284,600	50
	B		80,985,454	12,069,200	56
	C		138,290,394	40,706,600	67
	D		222,934,734	75,147,600	84

3. Analysis and Finding

4.1 Economic Evaluation

Economic evaluation was carried out for all the 64 mine type/production rate/reserve size models given in the previous chapter. The economic evaluation is achieved through projected cash flow analysis of the mine models using the cost data gathered. The grade of the ore required to achieve a positive NPV of 10, 50, 100 and 200 million Birr at an 8 percent discount rate was calculated using backward cash flow analysis; i.e. by setting the NPV to a certain rate and determining the required grade, using Microsoft's Excel software.

Gold grade was calculated by setting the price of gold at a conservative price of 1000 USD/Oz. The gold produced is assumed to be sold to National bank of Ethiopia (NBE). Thus the current price offer of NBE at an international AU price of 1240 USD/oz. was noted and a conservative price at 1000 USD/oz. is used. This was achieved by assuming a gold quality to 21 karat (86.84% pure AU) and overall mine recovery of 76% (95% mine recovery and 80% mill recovery). Accordingly, the price of gold used in the cash flow analysis is 633 Birr/gram.

A royalty payment of 7% was considered in the calculation (Mining Operations Proclamation amendment 816/2013). Tax payment of 25% and government free equity of 5% is considered as per the amended mining tax law (FDRE Mining Tax Proclamation amendment 802/2013).The economic evaluation is done in Birr so the cost of other items that are acquired from abroad are converted into Birr. This was achieved using a conversion rate 22 Birr/USD.

Initially, all the 64 mine models were evaluated using a gold grade of 1 g/t to determine the production rate at which their NPV will be maximum. For example a B type (2:1 stripping ratio) mine model with medium reserve of 400,000 m3 ore could be produced at rates of 76, 190, 380 and 765 m3/day resulting in mine lives of 18, 7, 4 and 2 correspondingly. Each production rate would require different equipment, infrastructure and labor; thus the capital and operating cost would vary for each. Additionally the salvage value of the equipment will vary based on their type and the mine life. Accordingly all the four 400,000 m3 B-type models with different production rates were evaluated and the one with the maximum NPV was selected.

With the above procedure the 64 mine models were reduced to 16 mine models. And the results of these are presented in this paper. The 16 mine models are listed out in the following table along with their mine life and capital and operating cost requirement

3.1: Optimum Production Rates for the Different Mine Reserve Models

Reserve Size	Mine Type	Optimum Production Rate (m^3/day)	Mine Life	Capital Cost Before Salvage	Salvage Value	Operating cost (Birrm^3 of Ore)
Small 160,000 m^3 Deposit	A	76	7	28,332,480	9,607,400	108
	B	76	7	28,405,300	8,124,600	148
	C	76	7	34,827,540	8,899,000	144
	D	76	7	53,971,060	12,540,000	270
Medium 400,000 m^3 Deposit	A	190	7	39,973,560	8,360,000	90
	B	190	7	41,658,540	6,487,800	106
	C	190	7	61,395,400	6,032,400	144
	D	190	7	105,722,540	18,772,600	219
Large 800,000 m^3 Deposit	A	765	4	75,981,774	16,766,200	50
	B	765	4	84,080,854	15,164,600	56
	C	765	4	138,290,394	40,706,600	67
	D	765	4	224,248,134	76,461,000	84
Huge 1,600,000 m^3 Deposit	A	765	7	73,500,174	14,284,600	50
	B	765	7	80,985,454	12,069,200	56
	C	765	7	138,290,394	40,706,600	67
	D	765	7	222,934,734	75,147,600	84

Table 3.2 shows a sample cash-flow table that was prepared for 400,000 m3 reserve of the B-type mine with 190 m3/day production. The cash flow analysis was prepared in accordance to the relevant FDRE mining operation and tax laws and their amendments.

Table 3.2: Projected Cash flow Analysis for B-type, medium 400,000m3 Deposit at 190 m3/day Production Rate

	YEAR 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year7	Total
Productive Statistics									
Ore Volume Mineral	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	399,000
West Tones Mined	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	710,220
Stripping Ratio	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.78
Average Grade g/m^3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mine Recovery	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Ore Tone Processed	51,300	51,300	51,300	51,300	51,300	51,300	51,300	51,300	359,100
Recovery	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Gold production/gms	41,040,00	41,040,00	41,040,00	41,040,00	41,040,00	41,040,00	41,040,00	41,040,00	28728000
Cumulative Gold production/gms	41,040,00	41,040,00	41,040,00	41,040,00	41,040,00	41,040,00	41,040,00	41,040,00	287,280,00
Price of Gold Birr/gm	603.00	603.00	603.00	603.00	603.00	603.00	603.00	603.00	603,00
Gross Revenue	24,747,120	24,747,120	24,747,120	24,747,120	24,747,120	24,747,120	24,747,120	24,747,120	173,229.640
Royalty	1,237,356	1,237,356	1,237,356	1,237,356	1,237,356	1,237,356	1,237,356	1,237,356	8.661,492
Net Revenue	1,237,356	1,237,356	1,237,356	1,237,356	1,237,356	1,237,356	1,237,356	1,237,356	164,568,348
Cash Production Costs									
Total Operating Costs	8,641,200.00	8,641,200.00	8,641,200.00	8,641,200.00	8,641,200.00	8,641,200.00	8,641,200.00	8,641,200.00	51,847,200

	YEAR 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year7	Total
Capital Expenditures	(41,658,540)								(41659546)
Working Capital		1,773,000						1,773,000	41,658, 540
Depreciation		10,414,635	10,414,635	10,414,635	10,414,635				
Equipment Salvage								6,487,800	71062608
Profit Before Tax		2,680,929	4,453,929	4,453,929	4,453,929	14,868,564	14,868,564	16,641,564	71,062,608
Income Tax @25%		670,232	1,113,482	1,113,482	1,113,482	3,717,141	3,717,141	4,160,391	17,765,652
Profit After Tax	(41,658,540)	12,425,332	13,755,082	13,755,082	13,755,082	11,151,423	11,151,423	12,481,173	53,296,956
Government Equity @5%		621,267	687,754	687,754	687,754	557,571	557,571	624,059	4,747,775
Net Cash Flow	(41,658,540)	11,804,065	13,067,328	13,067,328	13,067,328	10,593,852	10,593,852	47,027,854	77,563,066
Cumulative Net Cash Flow	(41,658,540)	(29,854,475)	(16,787,147)	(3,719,820)	9,347,508	19,941,360	30,535,212	77,563,066	77,563,066
Discount Rate @8%	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Discount Cash Flow	(41,658,540)	10,929,690	11,203,127	10,373,266	9,604,876	7,209,998	6,675,924	29,635,525	48,351,592
Cumulative Discounted Cash Flow	(41,658,540)	(30,728,850)	(19,525,723)	(9,152,457)	452,419	7,662,417	14,338,340	43,973,866	
NPV	48351592								
NPV less Salvage	26,188,060								
IRR	27%								

3.2 Results

Using the above cash flow table in Excel software, it was possible to get the gold grade that would result in a pre-defined value of NPV. Table 3.3 summarizes the results of this analysis.

Table 3.3: Grade requirements to achieve NPV of 10, 50,100 and 200 million Birr

Mine Type	Reserve Size in '000s	Ore Grade(g/m^3) Required for NPV of			
		10m	50m	100m	200m
	160	0.78	1.66	2.79	5.05
A	400	0.55	0.95	1.46	2.49
	800	0.39	0.58	0.81	1.28
	1600	0.27	0.36	0.49	0.75
	160	0.89	1.77	2.9	5.16
B	400	0.6	1.01	1.52	2.55
	800	0.44	0.63	0.86	1.33
	1600	0.3	0.4	0.53	0.78
	160	1.1	2.12	3.4	5.96
C	400	0.85	1.26	1.77	2.79
	800	0.6	0.79	1.02	1.49
	1600	0.42	0.51	0.64	0.89
D	160	1.74	2.75	4.03	6.58
	400	1.34	1.72	2.33	3.26
	800	0.87	1.06	1.29	1.76
	1600	0.61	0.69	0.81	1.07

The final results of the analysis are drawn on graphs for each of the A, B, C and D mine models. And the graphs are further extrapolated to 2 million m^3sing Excel's automatically generated trend lines. The trend lines are line with equations that closely follow the graphs generated using the data. These equations of the trend lines can used to calculate the grade requirement at a desired reserve size. On the diagrams the graphs are drawn on solid lines and the trend lines are drawn using dotted lines.

4. Conclusion and Recommendation

4.1 Conclusion

Of the placer gold mine models analyzed in the previous chapter, it will be obvious that the deposits with lower overburden and larger reserve are more economically attractive than the others. Their economic attractiveness is measured with the lower grade requirement they exhibit to provide a specific NPV. Accordingly the grade to achieve a certain NPV decreases with decrease in overburden depth and increase in reserve size.

Most of the placer deposits that were previously mined in Ethiopia were with grades lower than 0.5 g/m3 and few of them within the range up to 1 g/m3. Thus it is concluded that mine models that require a grade larger than 1 g/m3 to achieve a certain NPV are rare to find, and thus unattainable. With this in mind, mine models that have grades below 1 g/m3 are classified as economically attractive. These are highlighted in table 5.1. A tolerance of 0.1 is used in filtering these deposits. And the more attractive deposit with grades lower than 0.5 g/m3 are displayed with an asterisk.

Table 4.1: Grade Requirements to achieve NPV of 10, 50,100 and 200 million Birr: Economically Attractive Grades Highlighted

Main Type	Reserve Size in '000s	Ore Grade (g/m^3) Required for NPV of			
A		10m	50m	100m	200m
	160	1.78	1.66	2.79	5.65
	400	0.55	0.95	1.46	2.49
	800	0.39*	0.58	0.81	1.29
	1600	0.27*	0.36	0.49	0.75
B	160	0.89	1.77	2.9	5.16
	400	0.6	1.01	1.52	2.55
	800	o.44	0.63	0.86	1.33
	1600	0.3	0.4	0.53	0.78
C	160	1.1	2.12	3.4	5.96
	400	0.85	1.26	1.77	2.79
	800	0.6	0.79	1.02	1.49
	1600	0.42	0.51	0.64	0.89
D	160	1.74	2.75	4.03	6.58
	400	1.34	1.72	2.33	3.26
	800	0.87	1.06	1.29	1.76
	1600	0.61	0.69	0.81	1.07

As shown in table 4.1.the Small deposit of 160,000 m3 pay gravel were able to achieve NPV of 10 million within the 1 g/m3grade range for stripping ratios of 1:1, 2:1, and 4:1. This depicts that a Small deposit could be mine economically if they are within 4m from surface for 1m pay gravel layer, and 2m for 0.5m gavel layer.

Medium deposit of 400,000 m3 pay gravel were able to achieve NPV of 50 million for stripping ratios of 1:1, 2:1 and 10 million for stripping ratio of 4:1 within the 1 g/m3 grade range. This depicts that a medium deposit also could be mine economically if they are within 4m from surface for 1m pay gravel layer, and 2m for 0.5m gavel layer.

Large deposit of 800,000 m3 pay gravel were able to achieve NPV of 100 million for stripping ratios of 1:1, 2:1 and 4:1 and 50 million for stripping ratio of 8:1within the 1 g/m3 grade range. This depicts that a large deposit could be mine economically if they are within 8m from surface for 1m pay gravel layer, and 4m for 0.5m gavel layer.

Huge deposit of 1,600,000 m3 pay gravel were able to achieve NPV of 200 million for stripping ratios of 1:1, 2:1, 4:1 and 8:1 within the 1 g/m3 grade range for. This depicts that a huge deposit could be mine economically if they are within 8m from surface for 1m pay gravel layer, and 4m for 0.5m gavel layer.

4.2 Recommendation

It is recommended that the result of this research be used to preliminary economic evaluation of placer gold deposits in Ethiopia. This can be useful for the private investor, the regulatory, financiers or any other interested body.

To calculate the NPV of a deposit at hand one can follow the following procedure.

a. Select a deposit type (A,B,C or D) based on stripping ratio which is equal to one's deposit stripping ratio or if not available the immediate larger from those considered in this study
b. Go to the graph of the deposit type, and use reserve and grade as coordinates and get the point which marks the NPV
c. Compare with the available NPV lines and interpolate as necessary to get the specific NPV for one's deposit
d. One could also roughly guess one's IRR by fetching the capital costs, operating costs and mine life provided for the closest hypothetical reserve
e. Or one can use the graph or its trend line formula's to know the grade requirement to achieve a specific NPV value for the reserve size at hand
f. Also one can estimate one's capital costs and operating costs by comparing with the costs provided for the hypothetical deposits

It is recommended that deposit with reserves lower than 160,000 and grades lower than 0.78 should be left to artisan gold miners because it is demonstrated here they will not be feasible with mechanized mining. But deposit larger than that should be exploited with mechanized placer mining. It is recommended that the government organize artisan miner into cooperatives and facilitate finance to bring them into mechanized mining. The low capital requirement mine models can be worked with this approach.

The large capital requirement and more economically attractive deposits can be worked by private investors.

Finally, it is recommended that this kind of research be carried out by the government for specific regions in Ethiopia with known placer gold mineral potential. This includes areas in Adola area, Glabella, Benishangul, Wollega and Tigray.

Bibliography

Annels, A. E., 1991. *Mineral Deposit Evaluation.* 1st ed. S.L.:Chapman & Hall.

Böhmer, M., 1986. Prospecting and Exploration of Placer Deposits. In: M. Vanecek, ed.

Prospecting and Exploration of Mineral Deposits. 2nd ed. Prague: Elsevier, pp. 409-426.

Breeding, W. H., 1990. Exploration and Geology Techniques: Placer. In: B. A. Kennedy, ed.

Surface Mining. Littleton (Colorado): Society for Mining, Metallurgy, and Exploration, Inc. (SME), pp. 77-85.

Bullock, R. L., Cruickshank, M. J. & I. S., 2013. Placer Mining and Dredging. In: P. Darling, ed. *SME Mining Engineering Handbook.* 3rd ed. Littleton, CO: SME, pp. 1058-1072.

FDRE, 2010. *Mining Operations Proclamation 678/2010.* S.l.:S.N.

FDRE, 2013. *Mining Income Tax (Amendments) Proclamation 802/2013.* S.L.:S.N.

FDRE, 2013. *Mining Operations (amendments) Proclamation.* S.L.:S.N.

F.-W. W., M. D. & M. W., 2007. *Economic Evaluations in Exploration.* 2nd ed. S.L.: Springer.

Macdonald, E. H., 2007. *Handbook of Gold Exploration and Evaluation.* 1st ed. S.L.: Woodhead Publishing Limited and CRC Press LLC.

Marsden, J. O. & House, I. C., 2009. *The Chemistry of Gold Extraction.* 2 ed. Littleton (Colorado): SME.

Selassie, M. G. & Reimold, W. U., 2000. A review of the metallic mineral potential of Ethiopia. *Chronicle of Mineral Research and Exploration.*

Stebbins, S. A., 1987. *Cost Estimation Handbook for Small Placer Mines,* S.L.: United States Bureau of Mines (USBM).

S. T., J.-P. M. & Y. D., 2003. Geology and mineral potential of Ethiopia: a note on geology and mineral map of Ethiopia. *Journal of African Earth Sciences,* Issue 36, pp. 273-313.

Techno-Economic Consulting, Inc., 1994. *Mineral Investment Opportunities in Ethiopia,* S.L.: UNDP.

T. F., 2008. *Awata-Dawa Placer Gold Exploration,* Addis Ababa: Geological Survey of Ethiopia (GSE).

Torries, T. F., 1998. *Evaluating Mineral Projects.* 1st ed. Littleton, Co.: Society for Mining, Metallurgy, and Exploration, Inc...

Wendt, C. J. & Thomas, S. W., 1990. Placer Sampling and Reserve Estimation. In: B. A. Kennedy, ed. *Surface Mining.* Littleton (Colorado): Society for Mining, Metallurgy, and Exploration, Inc. (SME), pp. 385-392.

W. T. et al., 2014. *Placer Gold Exploration at Meleka And Ropi,* Addis Ababa: Geological Survey of Ethiopia