



Abandoned Mines: A Feasibility Analysis for Full-Scale Resuscitation of Redwing Gold Mine Operations

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KEYWORDS

Dewatering
Mining
Resuscitation
Feasibility

ABSTRACT

Redwing Mine, historically one of the major gold mines in Zimbabwe operated by Metalon Gold has since been on the brink of closure for over five years. Currently, the mine is merely operating at 10% capacity due to the issuing of mining tributes to small-scale and artisanal miners and poor water management. The artisanal miners are sterilizing an economically viable gold deposit by employing rudimentary mining techniques targeting high grades hence resuscitating the mine should be of national priority. To increase production, revenue, and accountability, the mine needs to be resuscitated to its full operation based on sound mining engineering and economic principles. Resuscitation of abandoned mines to full operation consist of reserve identification, dewatering, review of the ground support system and production planning. Exploration, water measurements, and geotechnical data collection surveys were done to estimate the reserve, select optimum pumps for dewatering and design a ground support system. Production Plans were developed from Redwing Mine's plant capacity, available machinery, and historical production data. Development work and operations necessary to be completed before production can begin were derived from survey plans. The restoration program was evaluated using the Net Present Value method and Internal Rate of Return techniques. Results proved that the project is economically feasible with an internal rate of return as high as 71.91%.

ARTICLE HISTORY

Received 30 January 2023
Received in revised form
3 May 2023
Accepted 21 May 2023
Available online 27 May 2023

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1. INTRODUCTION

In 2018 Redwing mine was put under judiciary management after facing ongoing operational challenges, this was caused by a lack of foreign currency that culminated from the Central Bank of Zimbabwe's decision to restrict revenue payments. The ripple effect of this decision induced limited capital expenditure which subsequently resulted in the influx of and poor management of underground water. A Corporate Rescue Practitioner was appointed to manage the day-to-day operations of the mine which resulted in the issuing of tribute claims to small-scale and artisanal miners. Environmental degradation is conspicuous due to the lack of due diligence by the tribute holders (artisanal miners). The current tributary mining system has reduced the revenue streams to the parent

company, Redwing Mine. The tribute holders do not employ the best mining practice. They largely rely on the rudimentary and unsystematic artisanal extraction of high-grade ores with minimum attention to mine health, safety, and the environment [1].

Redwing Mine is an underground gold mine owned by Metallon Gold Zimbabwe. It utilizes long-hole open stope, underhand room, and pillar mining methods to extract its gold-bearing ore. The mine currently has three major shafts namely, the Redwing Main shaft used to hoist ore, the South Winze Shaft used to transport man and equipment, and the Rezende Shaft used for dewatering purposes. There are 6 ventilation shafts namely Iona, 750, Mecca, 200, West vent, O/W1, and O/W2. O/W1 and O/W2 along with Redwing main, Rezende,

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<https://doi.org/10.56532/mjsat.v3i2.136>

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and South winze shafts are used for air intake whilst the rest of the shafts are used for air exhaustion. Mining development work is currently at level 22. The ore extracted at the mine is processed using floatation method and later smelted to produce gold at a recovery rate of 85.6%. [2][3].

Despite all plans laid by the government to expand the mining industry and the economy of the country, Redwing mine has been operating below capacity. This has resulted in significant loss of revenue, high rate of unemployment in the local Penhalonga area and poor management of the environment. The research seeks to restore Redwing mine to full operation to prevent the highlighted negative impacts of operating below capacity. The success of this project is expected to contribute to the 12 billion Dollar Mining Vision

set by the Government of Zimbabwe. This will also contribute to the expansion of Zimbabwe's economy, foreign currency earnings and the national GDP. The current output of the mine is about 100t/day (3 000t/m), processing 2 000t/m at an average grade 3.00g/t with a recovery of 85.6%. Thus producing 145 Au. ounces (Oz) per month. The current rate of extraction is not fully utilizing the plant capacity and production capacity of Redwing mine. On average, the Mine's potential is known to exceed 600t per day hence the current production is significantly below capacity. [4][5].



Fig 1. Redwing Mine Geographical Location

1.1 Dewatering of underground excavations

Groundwater reservoirs are often present in all mining sites. Water will naturally flow into mine workings although the process is speed up by the mining operations themselves. Water inflow into underground mines has adverse effects as it affects both the engineering geology works in the mine and the mine plan itself. Safety is also compromised by groundwater inflow. It is therefore necessary for mines to come up with dewatering strategies. The use of groundwater models is an effective tool for developing best dewatering strategies [6][7].

Dewatering can also be done based on design before installing the actual designed dewatering system. An example of a dewatering system is a combination of stationary and submersible pumps. The dewatering system is designed to suite the mine design which can be expressed in terms of mining method and mine depth. It is important to adjust the dewatering system based on any changes in working ends that as they affect the flowing of groundwater into the mine [5]. [8][9][10].

Abandoned underground mines are often flooded with water from underground reservoirs. Underground water flows in to fill the voids created by extraction processes. The total quantity of water flooding an abandoned mine can be estimated from the total volume of voids covered by the water. Thus, total quantity of water is equal to the total volume of the voids [11].

1.2 Water Discharge Systems

Dewatering systems must include the water discharge system. This refers to how the water will be disposed after pumping. The discharge system must comply with the legal and regulatory requirements from the government, environmental agencies and or any private agency in the area. Discharging water into rivers is often illegal unless it meets the set limitations. Although it may be costly, alternative methods of storing the discharged water are required. These methods may include impounding the water whilst considering the costs associated with it, land acquisition issues and the government requirements. Depending on the purity levels of the water, the water can be supplied to other industries like agriculture, manufacturing or even be recycled back to the mine for future use [12][13][14].

1.3 Underground Water Management

Water in underground mines comes from various sources which include, subterranean waterways, a rise in the water table and from pockets of water found ore bodies. Water management is an ongoing process such that dewatering is done continuously even when the mine is shut down or operating below its capacity. The aim of dewatering is to keep mine working areas dry.

1.4 Criterion for selection of dewatering systems.

Active and reactive dewatering are the two major types of dewatering. The active method is used to dewater surface mines through dropping the water table to reduce ingress into the mine. The reactive method is used to dewater underground mine workings but can be applied to both surface and underground mines. Various pump technologies can be adopted in the reactive dewatering method. Examples of such pumps are the end-suctions, submersible, volumetric and vertical pumps. The most appropriate dewatering method for a selected mine is determined from the following factors [15]

- a. The type of the mine (regulates the best method but maybe override user preferences).
- b. Location (determines the availability of electricity).
- c. Volumetric inflow rate.
- d. Depth of the mine.
- e. Properties of the water (determines the types of pumps to be used).
- f. Mine life (determines whether permanent systems are needed and the range of costs).
- g. Budgeted dewatering system costs.

1.5 Ground support

There are basically two types of ground support, namely natural and artificial support. Natural support uses the rock mass itself to support the ground. Artificial support uses external devices to support the ground. This includes the use of surface support devices (placed on the outside of the rock mass) and rock mass reinforcement (placed inside the rock). A pillar is a good example of a natural support. Examples of artificial support is the use of timber, shotcrete, shepherd crooks, wire mesh, rock bolts etc. Ground support can be selected and designed using rock mass classification systems and application of engineering principles.

1.6 Rock mass classification systems

Rock mass classification systems were developed around 1879 as a methodological way of coming up with designs for tunnels and their suitable support [7]. Rock mass classification schemes can be defined as the process of predicting rock mass performance which is established from its quantified description in relation to like properties of certain groups of rocks. They can be categorized as average tools for forecasting rock mass characteristics of which engineering principles can be applied when evaluating the rock mass characteristics. Rock mass classification schemes help in making engineering designs but do not necessarily substitute any field remarks, measurements, engineering rules as well as any form of logical reasoning. When applying rock mass clarification schemes in rock engineering designs, it is sensible to use more than one system especially in the early stages of the design because the classification systems have diverse weighting on the rock parameters considered. Examples of rock mass classification systems include the RMR, Q index, GSI and the RQD [16]. Diverse parameters with the greatest weightings are considered in the classification systems, these are listed below.

- a. Rock quality designation (RQD)
- b. Ground water (flow and pressure)
- c. Rock strength (Compressive strength and modulus of elasticity)
- d. Rock joint parameter (condition, spacing and orientation)
- e. Chief geological structures (folds and faults)
- f. In-situ rock mass stress

1.6 Production Planning

Production planning for resuscitating an abandoned mine should start from estimating the expected life of mine (LoM). Taylors's rule can be easily applied for such purposes, heeding the United States Bureau of Mines and United States Geological Survey department modifications to the rule to suit other mining situations not covered by it Further, the planning should explore rock engineering and legal considerations for accessing old workings.

1.7 Viability of restoring abandoned mines

Often, abandoned mines are exist because the mines which were once operational were shut down or downsized due to nonviability. This can be prompted by economic, political or geological changes during the mining project mine life. It is therefore crucial to test the viability of resuscitating such abandoned mines under the prevailing conditions. There are several methods used to evaluate the viability of investing in mining projects. Evaluation of mining projects takes various forms inclusive of the discounted cash flow analysis, Monte Carlo Simulation, and decision tree analysis [17].

The discounted cash flow method is popular in evaluating projects. In this method, future cash flows are projected and discounted, the result is the present value which is used to determine feasibility of an investment. When the discounted cash flow value is greater than the initial investment cost, then the investment opportunity is good [18].

2. METHODOLOGY

The literature survey followed an in-depth analysis of extant Redwing Mine exploration data to facilitate pre-feasibility and feasibility studies and to estimate the mineable reserve blocks. Emphasis was put on drill hole data inclusive of collar coordinates, inclination, chemical assays, and ore horizon. This information was used to calculate ore body thickness, ore grade, engineering properties of the host rock, grade continuity, grade distances, block grades and ultimately the mineral reserve using geo-statistical variography. The mineable mineral reserve in a block was calculated using the formula,

$$\text{Mineable reserve } (t) = LWBp \quad (1)$$

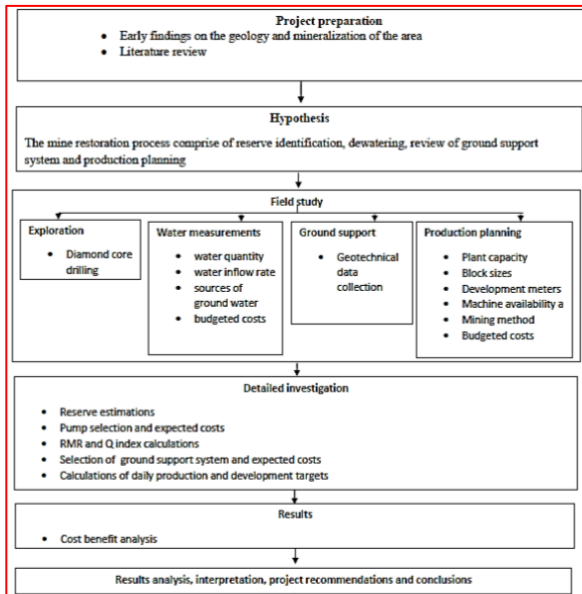


Fig. 2. Research methodology

Where L is the block length, W is the block width, B is the block thickness and ρ is the specific gravity of the ore body. The thickness of the ore body was determined from the Redwing Golder Competent Persons Report. The specific gravity of the rock, length and width of the blocks were derived from mine historical data created from field surveys. The historical data was based on 25m × 20m quartz block sizes and 25m × 50m felsite block sizes. The thickness of each ore body was derived from the 2D variogram models. The depth of the water was computed using the following equation,[7]

$$Water\ depth = D - d \tag{2}$$

Where D is the mine depth and d is the distance from the shaft collar to the surface of the water in underground workings. The quantity of water in the mine was estimated by calculating the total volume of underground voids covered by the water. Therefore, the net volume of underground voids covered by the water was considered as equivalent to the volume of the mine water. Total volume of voids was obtained from both development openings and production openings. The following formula was utilized in the calculations:

$$V = Total\ void\ volume(m^3) = \sum (lhw) \tag{3}$$

Where l, h, and w. were the lengths, heights and widths of the underground openings saturated with water. Water inflow rate in m3/h was also measured using the vernacular method in which water pumps were switched off for a period of two hours and the increase in volume of water in a sump for that period was measured. The inflow rate was measured using the following equation:

$$Inflow = \frac{V}{t} \tag{4}$$

Where t is the period in hours. The budgeted underground dewatering costs were identified from the mine’s historical reports. The obtained information was used to facilitate pump selection, estimate the period to reach the near surface reserves and the deepest levels considering the selected pumps, volume of water to be pumped, water inflow rates, pumping rates and operating time of each pump per day.

Rock Quality Designation was developed from the geotechnical core log datasheets from the mine. Suitable rock mass ratings consistent with obtained information were made using rock mass classification tables. Using the RMR and Q system classification tables, the geotechnical data was used to calculate RQD, RMR and Q index of the rock mass using the following formulas respectively. [19][20][21]

$$RQD = \frac{l}{L_t} \times 100\% \tag{5}$$

$$RMR = \sum C_p + \sum A_d \tag{6}$$

Where the total length of pieces exceeding 10cm, L_t is the total length of the core run, C_p are the classification parameters and A_d are the discontinuity adjustments. Total classification parameters comprise of the Uniaxial Compressive Strength (UCS), RQD value, discontinuity spacing, discontinuity surface condition, groundwater conditions and discontinuity orientation.[22][23][24].

$$Q = \frac{RQD}{J_s} \times \frac{J_r}{J_a} \times \frac{J_w}{S} \tag{7}$$

Where, J_r is the Joint roughness number, J_a is the Joint alteration number, J_w is the Joint water reduction, S is the Stress Reduction Factor, and J_s is the Joint set number. The calculated RMR, RQD and Q values were used to select suitable ground support systems that comply with the mine’s underground opening sizes or equivalent dimension values and the geotechnical structure of the rock. Equivalent dimension values were derived from the formula,

$$D_e = \frac{excavation\ span}{excavation\ support\ ration} \tag{8}$$

Where, D_e is the Equivalent Dimension. Equivalent dimension is used as part of the Q system to select the appropriate support system for the ground. It is a function of excavation span/ height/ diameter and excavation support ration.[25] The research proposed that after dewatering mining levels, pull tests are to be done on installed shepherd crooks to check the strength of the current ground support system and make ground support adjustments were necessary [26][27].

Historical data was used to establish plant stockpile requirements, the capacity and economic cut-off grade of the Redwing Mine Metallurgical plant. The derived data was used to determine ore generation targets and production rates at the

determined grade of the reserve. The mine plan factored in a buffer amount to cater for production fluctuations. Thus,

$$\text{Production rate} = P + S + \text{buffer} \quad (9)$$

Where P is the plant capacity and S is the stockpile requirements.

The development meters requirements before production commencements were identified from the survey plans. Underground development plans to access mining stopes and or ore bodies were laid. Several factors were considered including shift availability, machinery availability and utilization of machinery as well as the expected advance per blast. [28][29][30].

The research assumed resumption of operations based on conventional Redwing standard mining practices determined from field surveys done in the past. the cost benefit analysis was done using the Internal Rate of Return and NPV method. A 5-year period after the initial investment was considered in the calculations. [33]

$$DCF = \frac{\text{Cash flow}_1}{(1+r)^1} + \frac{\text{Cash flow}_2}{(1+r)^2} + \dots + \frac{\text{Cash flow}_n}{(1+r)^n} \quad (10)$$

Where r is the discount rate. Net Present Value (NPV) method and the Internal Rate of Return (IRR) method falls under the DCF method. Both NPV and IRR were computed in excel. The attractiveness of a mining project is directly proportional to the internal rate of return. The greater the IRR value, the greater the attractiveness of the project.

$$NPV = PV \text{ of cash inflows} - PV \text{ of cash out flows}$$

$$= \sum_{n=0}^N \frac{C_n}{(1+IRR)^n} - C_0 \quad (11)$$

Where, n is the period, C_0 is the initial investment and C_n is the cash flow during the period n. [34].

3. RESULTS

The methods highlighted above were used to derive, analyze, and discuss various findings to come up with the best way of restoring Redwing Mine operations to full capacity. Findings included in this research are from exploration analysis done to determine the nature of the reserve, water measurements done to determine the dewatering system to be used, geotechnical data collected to review the current strata support system, and results of the production planning. A cost-benefit analysis was done to determine the feasibility of restoring full mine operations at Redwing mine.

Table 1. Summary of Redwing Mine Operational Parameters

Parameter	Index
Average length of the ore body	4.6km
Average width of the ore body	2.5km
Felsite ore bodies have an average thickness*	7m
Quartz ore bodies have an average thickness	1.7m
Cut-off grade of the felsite ore bodies	1.79g/t
Cut-off grade of the quartz ore bodies	2.19g/t
Maximum grade	15g/t
Minimum grade	0.06g/t
Measured and indicated reserve***	10mt
Approximately reserve sitting in water.	85%
Reserves nearest to the surface location	Level 4
*Shallow dipping**Steeply dipping*** At 3.7g/t	

3.1 Mineable Blocks

The standard dimensions for mining blocks at Redwing Mines included a running Length of 25m, Block width of 20m and 50m in the quartz ore body and Felsite ore body respectively. The specific gravity of host rock is 2.7. Thus, using equation (1),

$$\begin{aligned} \text{Mineable reserve in a quartz block}(t) &= 25m \times 20m \times 1.7m \times 2.7 \\ &= 2295t \end{aligned}$$

$$\begin{aligned} \text{Mineable reserve in felsite block}(t) &= 50m \times 25m \times 7m \times 2.7 \\ &= 23625t \end{aligned}$$

3.2 Estimations of water volume

The total volume of water in the mine was estimated using equation (3). The summary of the findings is provided in Table 2.

Table 2. Estimated volume of water

Mine level	Volume $\times 10^6 \text{ m}^3$
48.3m from surface	1.2838
5 – 10	5.1771
11 – 16	0.9719
17 – 22	0.190841
Total volume ($\times 10^6 \text{ m}^3$)	7.624

3.3 Water inflow estimations

Five trials were done to measure the inflow rate of water. For each trial the pump was switched off for 2 hours and the increase in volume of water in the sump was measured. The results are shown in Figure 3. below.

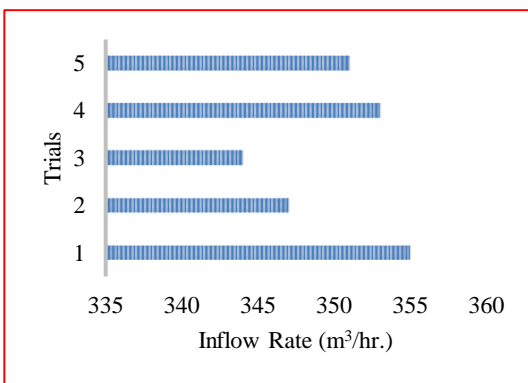


Fig. 3. Water Inflow and rate of accumulation

Water inflow rate was calculated using equation (4) hence, for the first trial water inflow rate was found to be

$$\begin{aligned} \text{Water inflow rate} &= \frac{710m^3}{2hrs} \\ &= \frac{355m^3}{hr} \end{aligned}$$

$$\begin{aligned} \text{Mean Flow Rate} &= \frac{(355 + 347 + 344 + 353 + 351)}{5} \\ &= \frac{350m^3}{hr} \end{aligned}$$

The total budgeted dewatering cost is USD\$2 million. After considering the type of the mine, the depth of the mine, volume of water in the mine, water inflow rate and the budgeted dewatering costs, it was recommended to use 200m head Elsum pumps to dewater the mine. The selected pumps are powered by electricity and have a pumping capacity of 240m³/hr. A total of 8 such pumps are needed to economically dewater the mine of which Redwing already own 2 of such pumps.

3.4 Estimated dewatering period.

Expected dewatering periods from the inception of dewatering processes required to reach the near surface reserves in level 4 and the deepest level 22 were estimated as provided in Table 3.

Table 3. Estimated time to reach level 4 and 22.

Level	Dewatering period (months)
4	3
22	10

3.6 Rock Quality Designation

Table 4 shows the summary of Rock Quality Designation values that were obtained from the geotechnical analysis of the core logs. RQD values were obtained using equation (5). The mean RQD was established to be 64.5 and Redwing mine was classified as having fairground.

Table 4. Summary of RQD from geotechnical core logging

Core sample	Drilled length (m)	Core recovery	Core losses	Total length of core pieces > 10cm	% RQD
1	100	95.6	4.4	70.6	70.6
2	300	267.9	32.1	195.6	65.2
3	400	375.2	24.8	241.6	60.4

3.5 Rock Mass Rating

For the purposes of undertaking feasibility of resuscitating Redwing, the research adopted the existing data to facilitate the Rock Mass Rating process. The mine is currently flooded hence no access for up-to-date geological mapping information. The following Redwing Mine data was derived from extant geological reports except for the RQD value which was obtained from the analysis of geotechnical core sample logging.

Table 5. Geological Mapping

UCS of the rock mass	124MPa
RQD value	65.4%
Average joint spacing	1.20mm
Joint condition	slicken-sided
Ground water conditions	dump
Adjustment for discontinuity orientation	Fair impact of joints on workings.

Ratings were assigned to the parameters according to the RMR classification system. The ratings are shown in Table 6.

Table 6. Ratings for RQD parameters

Parameter	Rating
UCS	12
RQD	13
Joint spacing	15
Joint condition	10
Ground water condition	10
Discontinuity orientation Adjustment	-5

The Rock Mass Rating was computed using equation 6 and established to be 55. Hence the ground lies in class iii and is described as a fair ground.

3.7 The Q index.

The following parameters were also derived from the rock mass data from the geotechnical logging exercise,

$$RQD = 65.4\%$$

J_s = there are 3 major joint sets and some few random joint sets.

J_r = the joints are slicken-sided

J_a = The joints have hard infill material

J_w = most of the joints are dump

S= medium stress is acting on the rock mass but generally the rock mass is competent (derived from mine reports)

Table 7. Q system parameters

Parameter	Rating
RQD	13
J_s	12
J_r	1.5
J_a	0.75
J_w	1
S	1

Ratings were assigned to the parameters using the Q classification system. The Q value was computed using equation (7) therefore,

$$Q = \frac{13}{12} \times \frac{1.5}{0.75} \times \frac{1}{1} = 2.2$$

A Q value of 2.2 indicates that the rock mass lies in class D and is described as poor rock mass.

3.8 Excavation Dimension (De)

As part of the Q system the excavation dimension values of each underground opening structure was calculated equation (8). The Excavation Support Ration (ESR) values were derived from Table 8. Excavation support ration classification table. The results are summarized in Table 8.

Table 8. Excavation support ration classification table

Excavation class	ESR value
A , Temporary openings	3-5
B , Permanent openings, pilot tunnels, drifts and heading for large excavations, hydro power water tunnels (except high pressure penstocks)	1.6
C , access tunnels, minor roads and railway tunnels, water treatment plants, surge chambers, storage rooms	1.3
D , main road and railway tunnels, power stations, portal intersections, civil defence chambers	1.0
E , sports and public facilities, railway stations, factories, underground nuclear power stations	0.8

Table 9. DE Values for Underground Structures

Opening	Span (m)	Type of structure	ESR	De (m)
Haulage	3	Permanent	1.6	1.88
Stopes in quartz orebodies	20	Temporary	4	5
Stopes in felsite orebodies	50	Temporary	4	12.5
Shaft	7.5	Permanent	1.6	4.69
Raise	1.5	Temporary	4	0.38
Sub-drive	1.8	Temporary	4	0.45
Winze	2	Temporary	4	0.5

Table 10. Proposed support based on RMR

RMR value	Rock bolts	Shotcrete	Recommendation
41-60	Systematic bolts, 20mm in diameter, 4m long with a spacing of 1.5-2m, installed with wire mesh both on roof and walls	3cm on walls, 5-10cm on roof	Install support after blasting, make sure to complete on areas 10 or more meters from the face

3.9 Proposed support system

Based on RMR result of 55 and RMR guide for selection of ground support, the support design outlined in Table 10 was proposed. The design applies to mine openings $\geq 10m$.

The support system outlined in Table 11. and Figure 4. was proposed based on the obtained Q value, the Excavation Dimensions of mine opening and Q system support chart. Anchor bolt length was computed using equation (10).

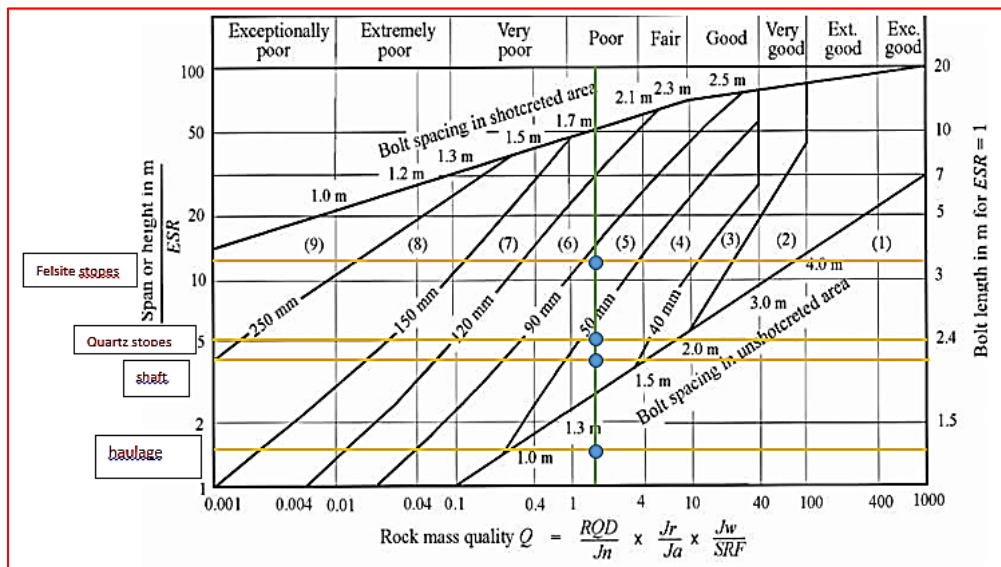


Fig. 4. Ground support design based on Q system

Table 11. Ground support design based on Q system.

Opening	De	Support design	Bolt length
Haulage	1.58	1.4m spacing of anchor bolts	2.28
Stopes in quartz	5	Systematic bolting, 4-10cm unreinforced shotcrete, bolt spacing to be designed by rock engineering officials	2.75
Stopes in felsite	125	Bolts, 5-9cm fiber reinforced shotcrete, bolt spacing to be designed by rock engineering officials	3.88
Shaft	4.69	Systematic bolting, 4-10cm unreinforced shotcrete, bolt spacing to be designed by rock engineering officials	2.70
Raise, sub drive, winze	≤ 1	Where necessary, support is to be re-designed by rock engineering officials.	2.06; 2.07 and 2.08 respectively

$$\text{Anchor bolt length} = 2 + \frac{0.15B}{ESR} \quad (12)$$

investing in the project and restoring Redwing operations to full capacity.

3.10 Production Planning

The production plan assumed full utilization of available machinery and equipment to carry out ore extraction processes and process the gold mineral using the mine's processing plant. The capacity of the processing plant at Redwing mine is 19650t/month. Stockpile supply is set at 1000t/month and the design plant grade is 3.0g/t. The planned production rate was computed using equation (9). The planned production rate should be able to meet the monthly processing plant ore demands while leaving a planned excess as a buffer to carter for situations that may result in ore shortages during production. A buffer of 350t/month was adopted as adequate from the Mine's historical data giving a planned monthly production rate of 21000t/m and annual production rate of 252 000t/yr. A life of mine (LoM) equivalent to 39.7 years was obtained using equation (11). Assuming 26 working days, the daily production rate was set at 808t/day.

$$\text{LoM} = \frac{\text{Reserves (t)}}{\text{Planned Production Rate} \left(\frac{\text{t}}{\text{yr}} \right)} \quad (13)$$

3.12 Revenue Flows

Table 12. below shows the expected cash inflows, cash outflow and the net cash flow for each year. Y_0 represents the initial investment.

Table 12. Projected Cash Flows

	Cash in-flow	Cash outflow	Net Cash Flow
Y_0	-	33000000	-33000000
Y1	35791321.78	9361296	26430025.78
Y2	35791321.78	10792908	24998413.78
Y3	35791321.78	11476080	24315241.78
Y4	35791321.78	11531772	24259549.78
Y5	35791321.78	11723292	24068029.78

3.13 Net Present Value

A discount rate of 10% was used to calculate NPV and IRR. Table 13.

Table 13. Project's NPV and IRR

Parameter	Value
Discount rate	10%
Initial investment	USD \$33 000 000
PV of future cash flows	USD \$94 469 495.11
NPV	USD \$61 469 495.11
IRR	71.91%

The positive values of NPV and IRR indicate that the project is attractive. The high value of IRR (71.91%) clearly justifies

4. DISCUSSIONS

The volume of water occupying the mine is approximately 7.624 million m^3 and the depth of the water is about 751.7m. Water inflow is by natural water ingress at an approximate flow rate of 350 m^3 /hr. 200m head Elsum pumps are required to pump out the water. These are powered by electricity and have a capacity to pump 240 m^3 /h. 8 such pumps are required for the dewatering operations. It will take about 3 months from the commencement of dewatering operations to reach level 4 and 10 months to reach the bottom level (22 level). Once 4 level has been exposed, equipping for development is to be done of which development is expected to begin in month 5 from commencement of dewatering.

RMR value indicate that the ground is fair and lies in class iii. The Q index indicate that the ground lies in class D and is poor. The RMR guide for selection of ground support suggested the use of shotcrete and systematic bolts to support the ground. However, this support only applied to stopes since they have opening spans greater than 10m. The rest of the openings will be supported as per the discretion of rock engineering officials. Q system chart suggested the use of rock bolts, unreinforced shotcrete and fiber reinforced shotcrete to support the ground. However, the choice of the support will depend on the equivalent dimension of the opening. Pull tests are to be done on installed support system to check its strength and make ground support adjustments were necessary after dewatering the mine.

The mine has a measured and indicated reserve of approximately 10 million tonnes at an average grade of 3.7g/t of which about 85% of the reserve is sitting in water. Reserves nearest to the surface are found in level 4. The average length and width of the ore body is 4.6km and 2.5km respectively. Felsite ore bodies have an average thickness of 7m whilst quartz ore bodies have an average thickness of 1.7m. The cut-off grade in felsite ore bodies is 1.78g/t and 2.19g/t in quartz. Mineable reserves in a block were estimated to be 2295t in quartz and 23625t in felsite. To meet plant capacity, monthly production targets are set to 21000t. This scales down to 807.69t/day assuming 26 working days a month. After considering stockpile requirements, ore supply to the plant is set at 20 650t/month. At this rate of extraction, the life of the mine is expected to be 40 years.

The research established that the Redwing deposit can be extracted economically using mechanized mining methods instead of the rudimentary techniques employed by artisanal miners. Artisanal mining targeted at high grades sterilizes otherwise conomic deposits within the country. There is need to evaluate the potential of several mines across the country under the operation of artisanal miners for proper extraction of gold. The criteria for resuscitation employed by the reserch established the necessary steps for the evaluation. Resuscitation of abandoned mines to full operation consist of reserve identification, dewatering, review of the ground support system and production planning.

Exploration, water measurements, and geotechnical data collection surveys should be done to estimate the reserve, select optimum pumps for dewatering and design a ground support

system. Development work and operations necessary to be completed before production can begin can be derived from survey plans after full analysis of the old workings. The restoration program was evaluated using the Net Present Value method and Internal Rate of Return techniques. Results proved that the project is economically feasible with an internal rate of return as high as 71.91%.

5. CONCLUSION

The mining project requires an investment of \$33 million. For each year of production, revenue has been estimated to \$35 791 321.78/year. By use of estimated net cash flows for each year of the first 5 years of production and a discount rate of 10%, present value of future cash flows was found to be \$94 469 495. The mining project has an NPV of \$61 469 495.11 and an IRR of 71.91%. This proves that the mining project is economically feasible. Numerical simulations to evaluate the strength of the rock mass support system are necessary upon completion of the dewatering project as the engineering properties of the rock mass have been compromised by prolonged saturation of water in underground workings. This will also prompt a review of Redwing's old drilling and blasting designs and ventilation systems.

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