AN INVESTIGATION OF THE MINE CALL FACTOR AT MAZOWE GOLD MINE IN ZIMBABWE

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Declaration

I declare that this report is my own, unaided work. I have read the University Policy on Plagiarism and hereby confirm that no plagiarism exists in this report. I also confirm that no work has been copied, nor is there copyright infringement. I willingly submit to any investigation in this regard by the School of Mining Engineering and I undertake to abide by the decision of any such investigation.

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List of acronyms/abbreviations

ANFO - Ammonium Nitrate Fuel Oil

Au - Gold

BIF- Banded iron formation

CIL- Carbon in leach

CRM- Certified Reference Materials

GA- Giga aeons

G/t - Grammes per tonne

Oz - Ounce

MCF- Mine Call Factor

QA - Quality Assurance

QC - Quality Control

SG - Specific gravity

ROM- Run of Mine

List of definitions

Blanks: They can be pulp or coarse material. They are usually devoid of metal (waste) and are used to check on equipment cleaning effectiveness in the analytical laboratory.

Density: Defined for any substance i.e. solid, liquid or gas.

Discrepancy: The tonnage discrepancy is either a shortfall or excess. A shortfall is given a plus (+) sign because it is added to the surveyor's calculation of tonnage to equal the mill tonnage figure, an excess is given a minus (-) sign because it has to be deducted from the surveyor's figure to equal the mill measurement of ore sent to the mill. The discrepancy normally carries no value.

Duplicates: These are used to check the quality of sample splitting and are used for checking the precision of the analytical laboratory.

Quality Assurance (QA): Describes the methods that a laboratory uses to ensure the quality of the operations.

Quality Control (QC): Describes the operational techniques used by the laboratory to fulfil requirements of quality.

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1. INTRODUCTION

1.1 Chapter overview

Chapter one is an introduction to the background of the research study and the background of Mazowe Mine. An overview of the geology of Zimbabwe, regional and mine geology as well as mineralisation are presented. The purpose of the study, problem statement, research questions, assumptions, research objectives and methods of research are also presented. The chapter concludes by outlining the structure of the research report.

1.2 Purpose of study

The purpose of this study is to investigate the various components of the MCF at Mazowe Mine and establish why it is low. It seeks to compare the actual measurement as well as the reporting practices with protocols. The study also aims to identify apparent and real losses that impact the MCF. The study focuses on exploring recommendations that mitigate losses and improve the MCF.

1.3 Background of Mazowe Mine

Mazowe Gold Mine is owned by Metallon Gold Zimbabwe (MGZ), a subsidiary of Metallon Corporation, which is headquartered in London. The mine is located about 50km north of Harare, in Mashonaland Central Province in Zimbabwe (Figure 1.1). Gold mining commenced in precolonial times and it is estimated ancient miners produced 150,000 ounces prior to the colonization of Zimbabwe by the British in 1890 (Mushayavanhu, 2016). Since modern mining commenced, the mine has produced about 1.5Moz (Mushayavanhu, 2016).

Mazowe is an underground mine operation with a production rate of 10,500t per month. It is currently serviced by the Connaught and Ogilvy Shafts. The mine workings have a strike of about 3km. The mineralisation comprises several shear-zone-hosted east-west trending narrow reefs. To date, more than 15 shear zones have been identified. The reefs have an average northerly dip of 35^0 and occur in the Jumbo granodiorite stock and quartz feldspar porphyries. The reefs link in an anastomosing pattern on dip and along strike. The reefs are characterized by erratic gold grade distribution and a high nugget effect (Mushayavanhu, 2016).

Jackhammer breast stoping and underhand stoping are used. Blocks measuring 30 x 30m are developed, after which a breast stope is mined away from the block raise, or an underhand bench from the top drive breaking into the block raise, is started (Mushayavanhu, 2016). Room and pillar mining is practised. Broken ore is lashed into raises manually and by box scrapers. The ore is trammed using battery locos on 6 level, 8 level and 10 level to Connaught Shaft and hoisted to the surface. Fines sweeps operations are carried out in old stopes and the fines are hoisted via the Ogilvy Shaft (Mushayavanhu, 2016).

Mining is currently concentrated between 3 level and 10 level. At any given time, mining is on different and multiple mining faces. In addition, fines are also harvested from several old stopes at any given time (Mushayavanhu, 2016). The multiplicity of ore sources and the haphazard nature of fines sweeps result in a fairly complex ore flow.

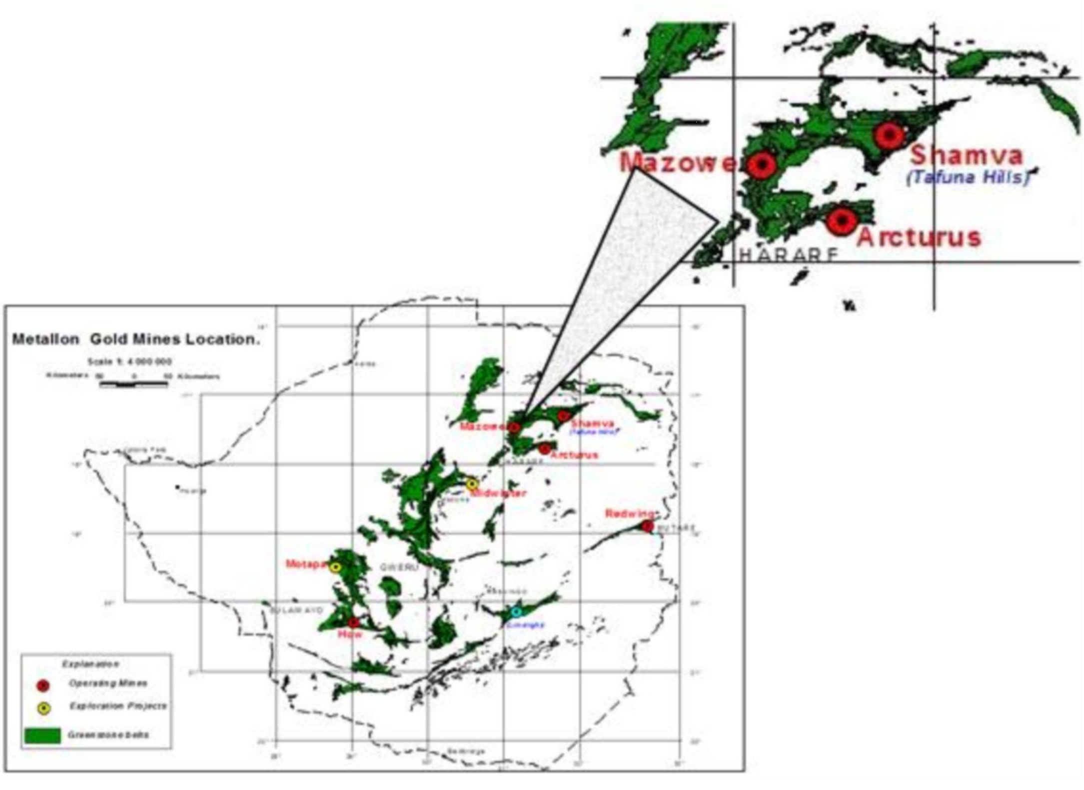

Figure 1.1 Mazowe Mine location map

Source (Metallon Gold Zimbabwe, 2016)

1.4 Geology and mineralisation

1.4.1 *Geology of Zimbabwe: overview*

The geology of Zimbabwe comprises the Archaean Craton surrounded by the Limpopo mobile belt to the south, Mozambique mobile belt to the east, and the Zambezi mobile belt to the north. The Zimbabwe craton is a basement complex comprising significant portions of deformed and undeformed granitoids and granitoid gneisses, with subordinate amphibolites, epiclastic metasediments and banded iron formation (Campbell and Pitfield, 1994). The craton also consists of greenstone belts comprising predominantly mafic, ultramafic and felsic volcanics, volcaniclastics, epiclastics, banded iron formation (BIF) and intrusions (Campbell and Pitfield, 1994). Wilson (1994) considers the cratonisation as a consequence of a series of events occurring primarily between 2.9Ga and 2.6Ga, during which time the essential granite-greenstone character of the craton evolved.

Wilson (1971) proposes three main phases of greenstone belt evolution: the Sebakwian (3.5Ga), Lower Greenstones 3.1Ga – 2.9Ga) and the Upper Greenstones (2.7Ga). The Upper Greenstone dominate most of the greenstone belts while the Lower Greenstone and Sebakwian are generally fragmentary (Campbell and Pitfield, 1994). The tripartite subdivision reflects deformation events at 3.1Ga, and 2.9Ga before the major regional foliation-forming event at 2.65Ga- 2.55Ga (Campbell and Pitfield, 1994). Structurally, the greenstone belts and the adjacent granitoid gneiss have been affected by a dominant regional cleavage and foliation forming event (Campbell and Pitfield, 1994).

Gold deposits in Zimbabwe are largely confined to the Archaean greenstone belts and the immediately surrounding granitoids gneisses and granitoids (Campbell and Pitfield, 1994). However, not all the greenstone belts host significant gold deposits. The bulk of the gold deposits occur in Upper greenstones. Apparently, the gold mineralisation is typically epigenetic and largely structurally controlled. Foster and Wilson (1984) classify gold deposits in Zimbabwe into stratabound and non- stratabound types. Stratabound deposits comprise

BIF-hosted, banded sulphides and volcaniclastic, and clastic-hosted and non-stratabound types consists of veins and mineralised shear zones. According to Foster and Wilson (1984), the bulk of the gold production has come from the non-stratabound deposits (62% from veins and 20% from mineralized shear zones). Campbell and Pitfield (1994) adopted a classification of the gold deposits in the Zimbabwe Craton with a rigorous structural approach.

The metamorphic grades and intensity of deformation vary across the craton from amphibolite facies and (higher in the adjoining Limpopo Belt) and generally more pronounced deformation towards the margins of the craton to lower greenschist facies with locally intense deformation near the centre of the craton (Campbell and Pitfield, 1994). Shear and deformation zones are recognizable within some of the greenstone belts and they also extend through granitoid gneiss (Campbell and Pitfield, 1994).

1.4.2 *Regional geological setting*

The Mazowe group of mines is located in the Harare-Shamva greenstone belt of the Zimbabwe Archaean craton, on the margin of the Chinamhora batholiths. The greenstone belt comprises major volcano-sedimentary sequences, intruded by the Chinamhora batholith. The earliest formation in the greenstone belt is the Iron Mask Formation, which partially encircles the Chinamhora Igneous Complex (Baldock, 1991). It is predominantly consists of metamorphosed felsic volcanics, mainly dacite with lesser amounts of meta-andesite and meta-rhyolite. It comprises lavas, breccias and varied volcaniclastics. Included metasediments are cherty sulphide iron formation, subsidiary phyllite, meta-arenite and quartz schists (Baldock 1991).

Uppermost in the Iron Mask Formation are carbonated metadacites and dacitic metavolcanics, with very thin graphitic schist (Baldock 1991). The Iron Mask Formation is overlain by the tholeiitic basalts of the Arcturus Formation. The Arcturus Formation is in turn overlain by the Mt Hampden Formation, which comprises very thick graphitic schist (Baldock, 1991). The Harare Greenstone belt was intruded and circumscribed by various granitoid complexes to the north and northeast is the Chinamhora Igneous Complex. To the west is the Nyabira Complex, which includes granitized hornblende granodiorite into older leucotonalite. To the south the greenstone belt is bounded by the Harare granite. The Maryvale granite, Jumbo porphyry and granodiorite are younger subvolcanic intrusions into the greenstones. The gold deposits at Mazowe Mine are hosted by the Jumbo porphyry and granodiorite (Baldock, 1991).

1.4.3 *Mine geology*

The Mazowe gold deposit comprises multiple stacked east-west striking shear zones, with some north-south trending crosscutting sets (Mushayavanhu, 2016). The gold mineralization is concentrated around the north eastern tip of the granodiorite stock, but extends eastwards into feldspar porphyry (Figure 1.2). The granodiorite is typically a coarse crystalline quartz-rich porphyritic granite. Feldspar porphyries occur in the eastern and southern parts of the mine complex. They are typically dark grey or black in colour with pronounced white phenocrysts of quartz and feldspar. To the east of the mine feldspar porphyries grade into metabasaltic rocks. These are intercalated the with banded iron formation in places. There are three principal dyke systems in the mine (Mushayavanhu 2016).

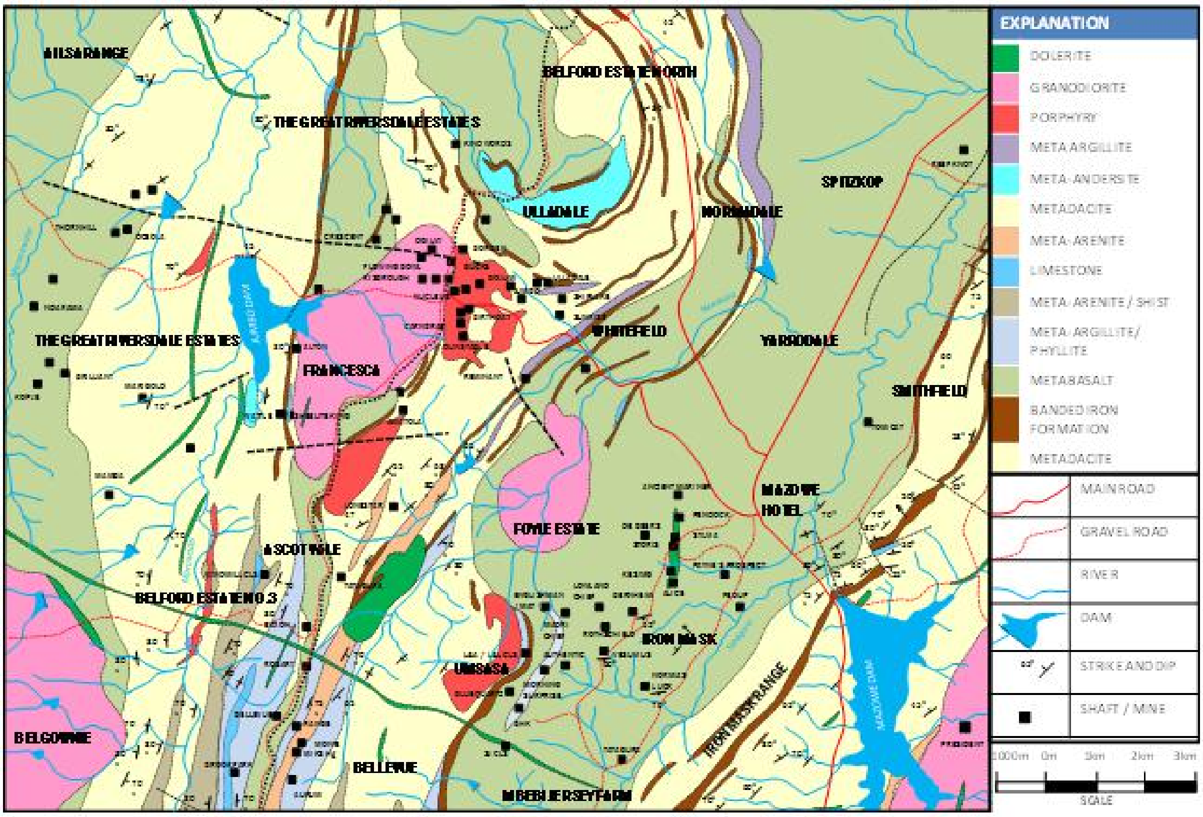

Figure 1.2 Geology of the area around Mazowe Mine

Source (Metallon Gold Zimbabwe, 2016)

1.4.4 *Ore body model and mineralisation*

The mineralization within Mazowe Mine is collectively hosted by granodiorite and feldspar porphyries. These lithologies host a multitude of narrow, subparallel, mineralized shear zones, which form an imbricate thrust shear zone system (Mushayavanhu, 2016). To date, more than fifteen subparallel shear zones have been identified. These narrow shear zones strike east-west and dip north at 10^0-50^0. Generally, they have a shallow dip of about $30^{0'}$. The major reefs consist of more than seven subparallel shear zones dipping north at 10^0-50^0, showing slickenside lineation plunging northeast (Trott, 1997). From north to south, the following mineralized shear zones have been exposed by mining: Flowing Bowl, SOS, Bojum, Connaught, Nucleus, Birthday and Carn Brae (Figure 1.3). These shear zones are anastomosing (Mushayavanhu, 2016).

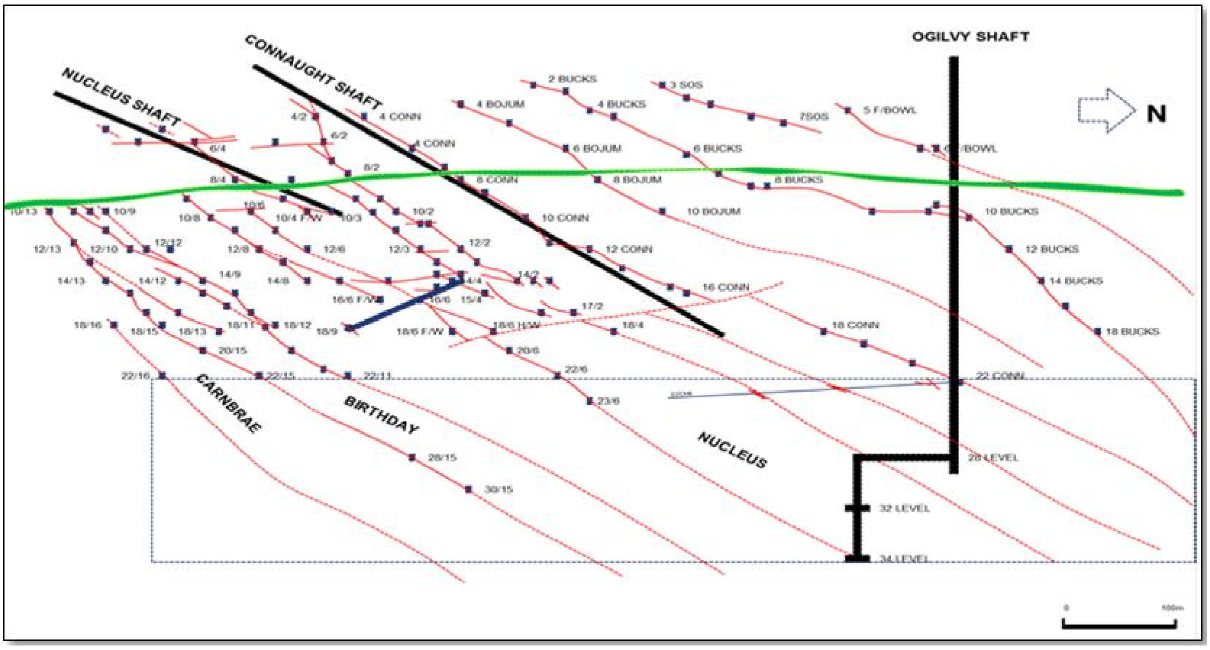

Figure 1.3 Section through Mazowe Mine looking west

Source (Metallon Gold Zimbabwe, 2016)

The east-west trending shear zones show a dominantly reverse oblique sinistral movement, (Trott, 1997). More recently, it has been noted that some mineralized shear zones have a southerly dip of 5-55^0. The reefs dipping north are either displaced or terminated against the south dipping reefs, suggesting that the latter are generally a younger feature (Blenkinsop et. al 1995).

The mineralization varies somewhat with the type of country rock through which the shear passes (Trott, 1997). In most cases, the gold is intimately associated with sulphide mineralization and only to a limited extent vein quartz. The pay shoots range in strike length from 25m to 200m and generally range in width from 5cm to 2 metres (Trott, 1997). In the granodiorite, the principal sulphide is pyrite, with white to grey quartz veins. Scheelite, pyrrhotite and arsenopyrite also occur. Two pyrite generations are apparent. The earlier coarse crystalline pyrite, which is heavily fractured, is intruded by younger quartz and pyrite (Trott 1997). The younger pyrite is fine-grained or massive and contains quartz inclusions. Wall rock alteration of the east-west striking reefs is generally minor (Trott, 1997). The mineralisation is considered to have been formed by pulsating hydrothermal fluids migrating along structurally controlled channels in a reverse sinistral imbricate thrust shear zone system (Mushayavanhu, 2016).

1.5 Research background

Mazowe Mine is grappling with the problem of a low MCF. The mine has faced this challenge for a long time. (Mushayavanhu, 2016). In fact from 2001 to 2016 the MCF was below 100%, with an average of 55%. (Figure 1.4). During this period a total of 308,000 ounces of gold was called for, but only a total of 177,000 ounces was accounted for. Theoretically, there was a gold loss of 45%, implying that 45% of the expected revenue was not realized. According to Storrar (1981), persistent low MCF below 80%, is concerning to management as sampling could be overstating the grade of the processed ore. However, if the procedures are proved to be correct, it becomes imperative to establish where and how the mineral losses are occurring.

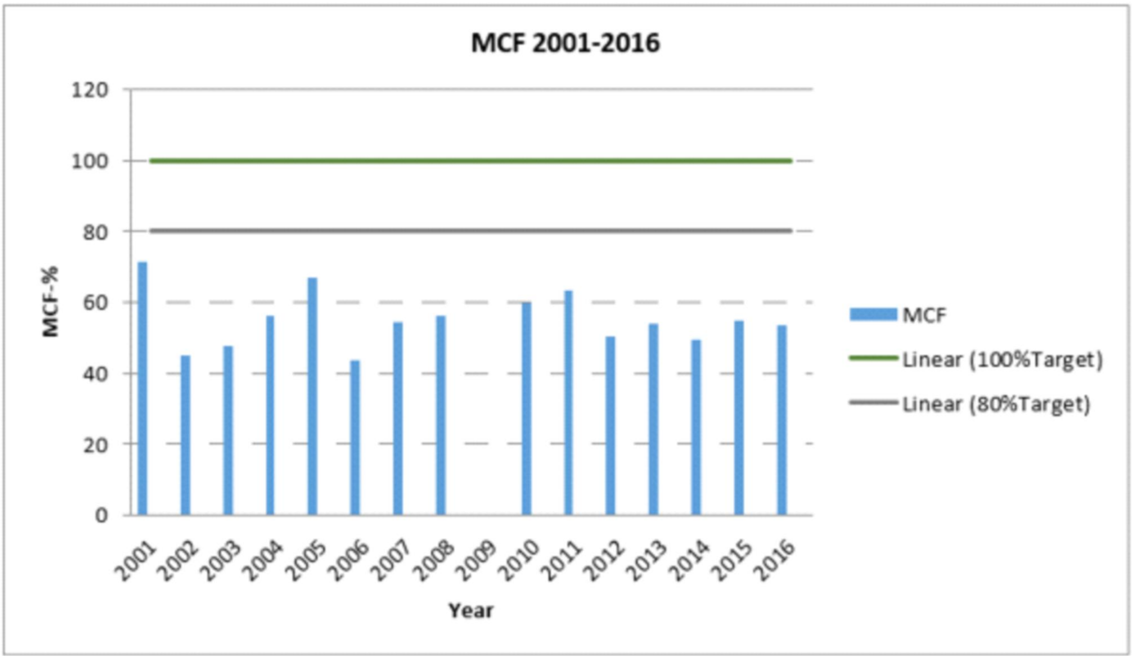

Figure 1.4 Mazowe Mine MCF for the period 2001 to 2016

(Source Mazowe Mine, 2016)

On the basis of gold unaccounted for, it is speculated that about 284,000 ounces of gold have accumulated in underground stopes in the last 50 years (Chifamba, 2016). It is also suggested that this gold is lodged in crevices and cracks in the footwall of stopes (Chifamba, 2016). It has been further argued that the mechanical vamping used to recover fines in underground stopes is not efficient and solution mining is required to recover the gold. (Chifamba 2016).

The low MCF negatively impacts the financial performance of the mine, because there are always significant discrepancies between in situ gold estimates and gold produced in the metallurgical plant (Mushayavanhu, 2016). The latter is always lower, resulting in gold production below budget, hence revenues which are below budget. Consequently, the financial performance is suboptimal.

The low MCF can be attributed to various factors, including the erratic nature of gold mineralization, sampling and subsampling errors, averaging or kriging model, ore density, analytical errors, interpolation errors, dilution, tonnage estimates and the calibration of weightometers (Pitard, 2014). In addition to these, intermittent inefficient fines sweeps, over fragmentation of the reef resulting in loss of gold in fines and mud, long scraping distances and multi-handling of ore are important contributors to the low MCF (Mushayavanhu, 2016).

There appears to be a problem of an ineffective grade control system. This is evident from the high number of stopes which are prematurely decommissioned due to grade problems. To compensate for the lost production, blocks that are not yet fully evaluated are prematurely commissioned and this may contribute to the low MCF (Mushayavanhu, 2016). An operating mine requires an effective grade control system to manage the risk of sending mineral material to areas other than the appropriate stockpile or waste dump (Rose and Fahey, 2014). The objective of grade control is to predict grade consistently and generate geological information before a round is blasted, so that there are no surprises for the production team (Rose and Fahey 2014).

1.6 Problem statement

The estimated in situ gold often differs with what the plant recovers. This is quite an acute problem at Mazowe Mine, which has a challenge of a low MCF. Throughout the period under review, the MCF was below 100%, with an average of 55%. Theoretically, this suggests that gold losses averaged 45%. In the same vein, 45% of the expected revenue was not realised and this translates into serious financial underperformance. Clearly, the low MCF has a significant impact on the financial performance and constitutes a major risk to the future of the mine. This is manifested by the perennial failure to meet budget.Due to the financial underperformance, the mine fails to fund sufficient development to ensure operational flexibility and reduce production from Inferred Resources.

1.7 Assumptions

The assumptions used in this research study are:

- The MCF is only affected by the possible apparent and real losses highlighted
- Theft of gold in the plant, which is difficult to detect and/or investigate, is not a major contributing factor to the low MCF
- The MCF can be reliably used to indicate areas where gold loss occurs, at Mazowe Mine and
- The higher MCF translates into a better financial performance of the mine.

1.8 Research questions

The research study sought to address questions such as the causes of the low MCF, the contribution of apparent and real losses to the low MCF, whether it is primarily tonnage or gold loss, whether it is primarily apparent or real loss and the corrective actions required to mitigate the losses and improve the MCF. It also sought to establish whether the assertion that approximately 284,000 ounces of gold have accumulated in the underground stopes in past 50 years, is valid. The purported historical accumulations are not classified as resources as they are still a matter of speculation.

1.9 Research objectives

The research study has the following key objectives; to investigate the MCF at Mazowe Mine, to establish the causes of the low MCF, to identify apparent and real tonnage losses and their sources, to identify apparent and real grade losses and their sources, to identify whether it is primarily tonnage or grade loss, to establish whether it is primarily apparent or real loss, to recommend remedial actions to mitigate losses and improve the MCF. The study also sought to establish whether the assertion that 284,000 ounces of gold have accumulated underground in the past 50 years is valid.

1.10 Research methods

The literature research was conducted to gain insights into factors that impact the MCF. Visits were made to the mine to collect data, observe and assess practices and protocols that influence the MCF. The research method involved carrying out a systematic examination of the following:

- Measurement of calibration of the weightometer
- Survey tonnage measurement
- Hoisting tally system
- Weightometer tonnage measurement
- Sampling of the ore sent to the mill
- Evaluation of mineral resources and reserves
- Assaying
- Mine design, mining method and ore movement

- Grade control
- Underground sampling
- Analysis of the mine's ore flow balance sheet
- Fines sweeping and
- Underground accumulation of ore.

Reconciliation to compare resource and reserve estimates to grade control estimates and mined to milled data on a quarterly and an annual basis over the period under review, was carried out for the period 2013 to 2016. Ore flow balance sheet analysis to determine percentage tonnage loss and percentage grade loss in the period in question was conducted.

1.11 Structure of the report

This research report comprises seven chapters. The first chapter presents the introduction, problem statement, background to the study, geology and mineralisation, research questions, research methods and assumptions. The second chapter reviews relevant literature including the theory of metal and ore accounting fundamentals. Chapter Three focuses on the ore flow from the mining face to processing, the production history of the mine, mining, processing and the ore balance sheet. Chapter Four analyses the ore flow to determine percentage tonnage gain/loss and percentage grade gain/loss. It also identifies sources of tonnage gain/loss and sources of grade gain/loss. Chapter Four concludes by identifying whether it is primarily tonnage or grade loss. Chapter Five focuses on apparent tonnage gain/loss, apparent grade gain/loss, real tonnage loss and real grade loss. It concludes by identifying whether it is primarily apparent gain/loss or real loss. Chapter Six summarises the key findings of chapters Three, Four and Five. It also presents the conclusions of the research study. Chapter Seven presents recommendations of the study. Remedial actions to improve resource estimation and actions to minimize the apparent, as well as real grade losses, in the quest to improve the MCF are presented.

2. LITERATURE REVIEW

2.1 Chapter overview

Chapter two reviews the literature related to the study and the theory of metal accounting, against the research questions and issues to be studied. The literature review is intended to garner some insights into the scope of issues pertaining to the problem and background to similar studies to the one in question. It presents the concept of MCF, its investigation and the types of losses that impact it. The AMIRA P754 code, which is at the centre of metal accounting, the ore flow balance sheet and the concept of reconciliation are also presented. Factors that impact the MCF including measurement of mass, measurement of moisture and density, sampling and sampling protocols are covered.

2.2 Mine Call Factor

The theory of MCF though well-known, is not fully understood and MCF issues mine specific (Tetteh and Cawood, 2014). According to the Institute of the Mine Surveyors of South Africa, the MCF is the ratio of the product accounted for from the recovery and residue, to the product the mine's estimation method calls for, expressed as a percentage (Storrar, 1981). Mathematically it is expressed as:

$$MCF = \frac{\text{Metal produced in recovery + residue}}{\text{Metal called for by the mine evaluation method}} \times 100\% \qquad [1]$$

According to the definition of the MCF, where sampling, assaying and tonnage measurement are ideal, without any mineral loss along the flow of ore, the MCF in theory, should be 100% (Tetteh and Cawood, 2014). Discrepancies can either be a shortfall or an excess. A shortfall indicates loss along the value chain, from the source to the processing plant (Tetteh and Cawood, 2014). Losses that affect the MCF are divided into real and apparent losses (Cawood, 2003).

2.3 Previous investigation at Mazowe Mine

In 2015 Mugwagwa conducted a research study at Mazowe Mine with the objective of establishing whether the resource estimation method is a major factor contributing to the low MCF. The research focused on resource estimation and presented results from experimenting with different techniques, including Inverse Distance Weighting (1DW), method of polygons and geostatistics (ordinary kriging and indicator kriging). The estimates were compared with face sample grades and geology for each mining block.

The research study focused on the Nucleus 2, Flowing Bowl and Wimbledon reefs. These three reefs are the first to be evaluated using geostatistical methods at Mazowe Mine. Application of geostatistical evaluation methods is still at an introductory stage and data capturing is in progress. The descriptive statistics of the sample data are shown in Table 2.1.

Table 2.1 Descriptive statistics

Reef	No of samples	Sample site size (m^2)	Mean g/t	Median g/t	CV	Nugget effect (%)	Major axis range (m)
Nucleus 2	3,000	204,909	18.50	6.27	1.9	52	16
Flowing Bowl	700	34,312	13.33	4.89	2.36	50	23
Wimbledon	600	22,397	7.67	2.9	1.86	54	8

Source (Mugwagwa, 2015).

The coefficients of variation (CV) of all the three reefs are greater than 1.5. In such cases, extreme values are normally removed and the CV recalculated (Mugwagwa, 2015). However, in the case of the Mazowe deposit, extreme values were not removed because coarse gold has been noted to constitute about 66% of the total gold (Mugwagwa, 2015). The three reefs evaluated also exhibited a high nugget effect greater than 50%, indicating high random variability over short distances (Mugwagwa, 2015). The grade ranged between 0.01 and 771g/t and the distribution plots of data showed positive skewness and high kurtosis (Mugwagwa, 2015). The descriptive statistics imply that non-linear methods which can accommodate extreme values (local variation) during grade estimation are more suitable for the deposit (Mugwagwa, 2015).

Table 2.2 summarises the results of the various estimation methods used in the research.

Table 2.2 Estimation method comparison

Estimation Method	**Reef**		
	Nucleus 2	Flowing Bowl	Wimbledon
Ordinary Kriging			
Average grade (g/t Au)	11.50	9.56	6.10
Correlation with actual mined grade	0.46	0.57	0.12
Indicator Kriging			
Average grade (g/t Au)	11.46	6.55	4.00
Correlation with actual mined grade	0.47	0.48	0.16
Inverse Distance Weighting			
Average grade (g/t A**u)**	11.61	9.71	6.10
Correlation with actual mined grade	0.43	0.57	0.11
Polygonal			
Average grade (g/t Au)	12.2	8.80	6.00
Correlation with actual mined grade	0.12	0.13	0.10
Actual mining grade	8.45	4.71	7.40

Source (Mugwagwa, 2015).

Variography indicated that the Mazowe gold deposit has a high nugget effect (>50%), attributable to a high coarse gold occurrence, which constitutes up to 66% of the gold (Mugwagwa, 2015). Mugwagwa (2015) states that the coarse gold contributes to estimation errors, which adversely impact the MCF. Mugwagwa (2015) concludes that the low MCF is attributable to real mining losses and apparent loss, due to an unsuitable estimation technique and ore/waste misclassification.

Indicator kriging was recommended as the most appropriate estimation technique for the high nugget Mazowe gold deposit. However, analysis of the comparison results in Table 2.2 does not appear to support this entirely. For instance, in the case of the Nucleus 2 Reef, Indicator kriging yielded an average grade similar to the other techniques, which were all above the actual mined grade of 8.45g/t Au. This is contrary to Mugwagwa’s assertion that Indicator kriging performed better, because it had better sampling densities and sampling grid configuration, which resulted in better estimation results. In the case of the Flowing Bowl Reef, the other three techniques yielded comparable results, whilst Indicator kriging gave a much lower grade, which was closest to the actual mining grade of 4.71 g/t Au. Finally, for the Wimbledon Reef the other techniques yielded virtually the same results, which were close to the actual mined grade, while Indicator kriging gave a grade 2.0 g/t Au below the others and much lower than the actual mined grade. In this case all the estimated grades were below the actual mined grade of 7.40g/t Au. The author is of the opinion that this can be attributed to the fact that the Wimbledon Reef is steeply dipping and all the ore, including high-grade fines, report to the cousin jack boxes under gravity unlike the flatter reefs, which require stope sweeping. Mugwagwa (2015) argues that the other methods perform better for the other two reefs because the current sampling grid has an adverse effect on Indicator kriging. However this is debatable, as all the techniques are affected by the sampling grid, and the method that is deemed appropriate should be more robust.

2.4 Investigations on other operations

Investigations similar to the current research study have been conducted at the following gold mines: Western Holdings in South Africa (de Jager, 1997), Ives in Western Australia (Donaldson, 2014), Iduapriem open pit in Ghana (Tetteh, 2014) and at two open pit mines in Brazil (Chierengati and Pitard 2009). The studies at the first two mines were typical MCF investigations, spanning the entire value chain from the mineral resources to the point where the metal is extracted, whereas the one at Iduapriem focused on establishing the relationship between measurement and measurement protocols, as well as discrepancy at measurement points. The results of the studies at Western Holdings and at Ives indicate that while the MCF is impacted by several factors, resource estimates and grade in particular, is a primary source of a low MCF and/or gold unaccounted for. On the other hand, the study at Iduapriem did not establish the sources of the discrepancies at points of measurements, and recommended a further typical MCF investigation spanning from estimates to production. The study on the two low grade open pit mines in Brazil focused on sampling, mine planning and reconciliation. The results showed that small improvements in sampling practices result in significant improvements in reconciliation.

The Western Holdings Mine was investigated to establish the causes of a low MCF. Apparently, 35% of the gold mined was unaccounted for (de Jager, 1997). The investigation sought to explain the gold unaccounted for, by determining the real gold loss and then inferring the remaining loss to be an apparent loss. In the quest to explain the gold not accounted for statistical analysis and large-scale experimentation on in situ gold estimates, some methods of mining and outcomes in the process plant were used.

De Jager (1997) concluded that the primary causes of apparent gold loss at Western Holdings Mine were the underground sampling method and an overstated specific gravity applied. Another contributing factor to the low MCF was the broken ore that was not brought to surface timeously for processing. No areas with lost large quantities of gold leading to high gold concentration were found. Cracks in the footwall where gold could be trapped were vacuumed, however, no significant quantities of gold were found

The Ives Gold Mine comprises a group of gold deposits within the Norseman-Wiluna greenstone belt in Western Australia and over 10 million ounces have been produced from seven underground mines (Donaldson et al., 2014). It is a complex mine, with multiple individual sources of ore at any one time, including underground, open pits and historical stockpiles (Donaldson et al., 2014). Since 1993 mine to mill reconciliation data is collected on a monthly basis, analysed and interpreted. The MCF is used as the main measure of reconciliation. Due to the multiplicity of ore sources it is difficult to pinpoint issues to a mine (Donaldson et al., 2014).

Since the data collection commenced, a slow but steady improvement in the MCF was noted. Periods of significant improvement in the MCF are ascribed to: improved spotting and appropriate estimation techniques, sampling methods, mining and QA/QC protocols, stockpiling and feed strategies and more importantly, understanding of the geology (Donaldson et al., 2014). On the other hand, periods of declining MCF were found to be associated with increasing dilution, increasing natural geological variance and ore body dimensions, increase in ore sources, change in mining selectivity, cut-off grade without consideration of the grade control model parameters, geological staff competency and local knowledge loss due to a high staff turnover (Donaldson et al., 2014).

An MCF investigation was conducted at Iduapriem Mine in Ghana to determine the relationship of the actual measurement and the measurement protocols (Tetteh, 2014). The study focused on tonnage measurement and quality control methods at a surface gold mine. Reconciliation factors were statistically analysed to determine discrepancies for tonnage and grade. The spot tonnage was generally found to be higher than survey tonnage. However, the correlation coefficient of 0.945 between spot tonnage and survey tonnage indicates that the former is reliable. (Tetteh, 2014).

The mine to mill reconciliation compared production from various sources. Measurement points were established between any two sources and reconciliation factors determined using tonnage, grade and ounces of gold (Tetteh, 2014). The highest grade and tonnage discrepancy were observed between the plant and the stockpile. The grade and tonnage in question had standard deviations of 18% and 17% respectively (Tetteh, 2014). The grade control model and the perimeter design measurement point had the least tonnage and grade discrepancies. The study did not establish sources of variances at measurement points. Consequently, a further typical MCF investigation from the resource throughout the entire value chain, was recommended to establish the causes of the discrepancy (Tetteh, 2014).

Two low grade erratic gold deposits in Brazil were studied (Chieragati and Pitard, 2009). Some sampling problems were discussed and the solutions implemented for mine to mill reconciliation were presented. The problems peculiar to precious metals, particularly gold were highlighted. These problems become more pronounced as the gold grade declines and gold distribution becomes more erratic (Chieragati and Pitard, 2009).

The two operations were evaluated over a year with focus on sampling, mine planning and reconciliation. The objective of the evaluation was to observe Pitard’s conditions for minimizing sampling errors which formed the basis of the study. The problems identified are presented in Table 2.3. The errors of estimate before adjusting reconciliation components are presented in Table 2.4 while Table 2.5 shows the errors of components after adjusting the reconciliation factors.

Table 2.3 Pitard's causes of mine to mill reconciliation problems

Stage	Causes
Geological models	• true, in situ nugget effect • sampling and sub-sampling errors • analytical errors • interpolation errors • excessive rejection of outliers • ore density • definition of ore boundaries
Mining and grade control	• in situ nugget effect • drift of mineralized boundaries upon blast • loss of fines in stockpiles or during sampling • sampling and sub-sampling errors • analytical errors • dilution • blastholes parallel to mineralization • ore grade contouring
Mill and flotation plant	• material balance based on non-probabilistic sampling • process cycles either unknown or misunderstood • calibration of weightometers and flowmeters • inappropriate sampling equipments • analytical accuracy • poor laboratory sub-sampling

Source (Chieragati and Pitard, 2009)

Table 2.4 Errors of estimate before adjusting the reconciliation components

Block No	Gold grade at mine (g/t)	Gold grade at plant (g/t)	MCF (%)	Estimate error (%)
1	0.618	0.460	74.4	34.3
2	0.594	0.437	73.6	35.9
3	0.674	0.429	63.6	57.1
4	0.872	0.396	45.4	120.2
5	0.609	0.419	68.8	45.3
6	0.541	0.396	73.2	36.6
7	0.723	0.437	60.4	65.4
8	0.748	0.400	53.5	87.0
9	0.595	0.467	78.5	27.4
10	0.588	0.400	68.0	47.0
11	0.615	0.410	66.7	50
12	0.664	0.435	65.5	52.6
13	0.727	0.429	59.0	69.5
14	0.709	0.419	59.1	69.2
15	0.727	0.410	56.4	77.3
Average			64.4	58.3

Source (Chieragati and Pitard, 2009)

Table 2.5 Errors of estimate after adjusting the reconciliation components

Block No	Gold grade at mine (g/t)	Gold grade at plant (g/t)	MCF (%)	Estimate error (%)
1	0.649	0.673	103.7	3.57
2	0.548	0.524	95.6	4.58
3	0.583	0.503	86.3	15.9
4	0.386	0.363	94.0	6.34
5	0.685	0.680	99.3	0.74
6	0.540	0.470	87.0	14.9
7	0.470	0.539	114.7	12.8
8	0.720	0.760	105.6	5.26
Average			98.3	8.0

Source (Chieragati and Pitard, 2009)

Table 2.5 essentially summarizes the results of the work. Comparison of the MCF and the estimate error in tables 2.4 and 2.5reveals that small improvements in the sampling practices result in significant improvement in the reconciliation process control (Chieragati and Pitard, 2009). The average MCF improves from 64.4 % to 98.3% while the average estimate error falls significantly from 58% to 8%. These results also show the advantage of proactive reconciliation practice, whereby the reconciliation problem is broken into its elements which are resolved one at a time, over the reactive reconciliation practice which involves applying factors to resource/reserve estimates and grade control predictions (Chieragati and Pitard, 2009).

2.5 MCF investigation

MCF issues vary from mine to mine owing to different mining activities, therefore a systematic scientific approach is required when investigating MCF (Tetteh and Cawood, 2014). Storrar (1981:266) suggested a systematic examination of nine variables in the case of underground gold mines, which include:

- Surveyor's measurement and calculations
- Current sampling of ore sent to the mill
- Rock packed underground as waste
- Rock sorted as waste on the surface
- Ore picked on the surface from waste
- Tipping of ore and car factors under certain conditions
- Losses of theft
- Underground accumulation of ore and sweepings and

- Assay bias and allowance for silver content in gold assaying.

Cawood (2003:202) proposed a method of investigating the MCF which involves "reviewing existing protocols to establish compliance, literature survey, understanding the process of ore flow to the smelter to identify risks, introduce test and observe responses, distinguishing between long term and short research topics and adjusting existing protocols as a result of research outcomes".

2.6 Apparent and real losses

Losses that affect the MCF are classified into apparent and real (Cawood 2003).The effect of both apparent and real losses is to reduce the MCF, on average, to below 100%. Overestimation of metal content during an evaluation process, which gives rise to metal called for that apparently is not present, contributes to apparent loss (Cawood 2003). Factors that also contribute to the apparent loss are improper sampling standards, inappropriate application of standards, as well as the wrong relative density (Tetteh and Cawood, 2014).

At Western Holding Mine, the apparent loss of gold was ascribed to inappropriate sampling methods and incorrect density applied (De Jager, 1997). Pitard (2014) states that major discrepancies between mine estimates and plant metallurgical balance are common in gold and base metal mines world over. He attributes this to the fact many existing practices are based on protocols that are flawed and do not meet basic statistical requirements. He highlights that sampling tools are flawed by design and cannot provide the reliability required to achieve accurate ore grade. These flaws contribute to the apparent loss.

In the case of Mazowe Mine, which is characterized by structurally controlled narrow reefs with highly erratic grade and complex geometry, (Mugwagwa, 2016) suggested that the apparent loss could be reduced by using indicator kriging, rather than the currently used method of polygons for estimation. Overstating of tonnage due to faulty weightometer readings can also contribute to the apparent loss.

Real losses are constituted by actual physical metal losses. They include gold trapped in crevices in the plant, gold lost during blasting, tramming, hoisting, extraction and processing (Tetteh and Cawood 2014). Cawood (2003) conducted an investigation on underground face sampling on the narrow reef, and concluded that the MCF did not reliably indicate the location of gold loss. This was attributed to the fact that a wide range of activities, from the face to the gold produced in the plant were involved. Gold theft underground and/or in the plant also contributes to real losses. However, this difficult to investigate or prove.

2.7 Metal accounting

Metal accounting is a critical component in mineral resource management and its prime objective is to balance the physical metal content (Hills, 2000). The flow of metalliferous ores is a complex process. The complexity of material flow in underground operations is depicted in Figure 2.1. According to Hills (2000), the complexities are attributable to the following:

- Different and multiple mining faces
- Multiple plants with transfers of inter- plant materials and in some cases a refinery supplied with materials from several different mines
- Multiple shafts/pits which in some cases emanate from different mines
- Dilution resulting in loss of production and malpractices such as transferring of waste to plant and ore to waste dump and
- Multiple points of storage as bins and stockpiles.

The complexity is mine specific and the flow may be different from an open pit material flow and may be less complex depending on the number of faces mined (Tetteh, 2014).

Figure 2.1 depicts a complex underground operation material flow. There are multiple faces and ore is hoisted via three shafts. The ore is processed at any of the three mills and this compounds the complexity of the material flow. Such a complexity may give rise to metal accounting problems and makes it difficult to pinpoint the source of MCF issues.

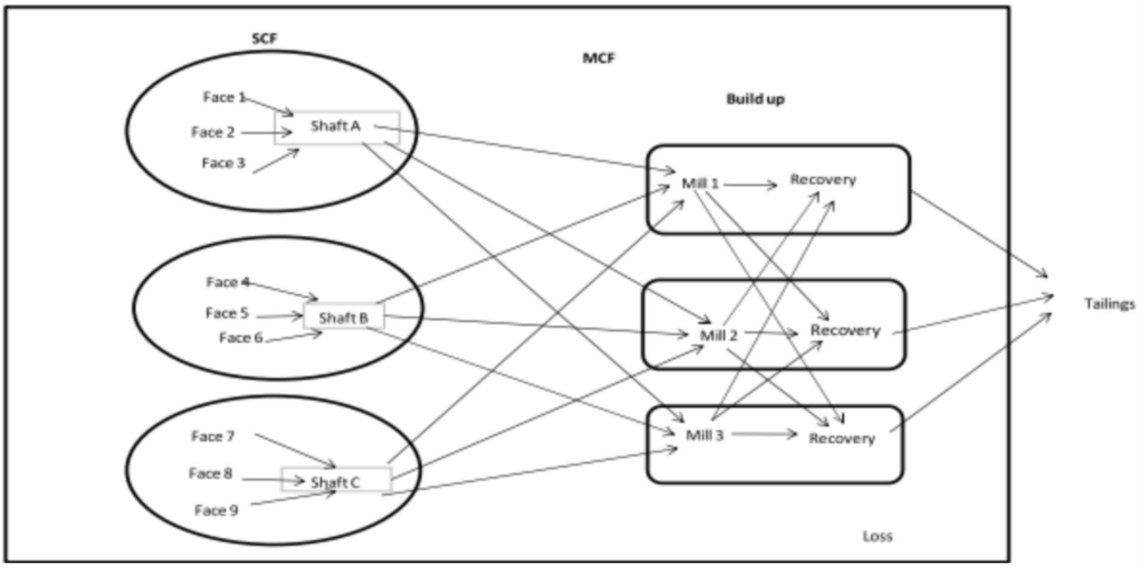

Figure 2.1 Underground mine material flow

Source (Hill, 2000)

Figure 2.2 shows material flow for a surface operation comprising three open pits. The ore is either taken to the plant for processing or stockpiled. The material flow for such an operation can be less complex compared to an underground operation if there are few faces and stockpiles.

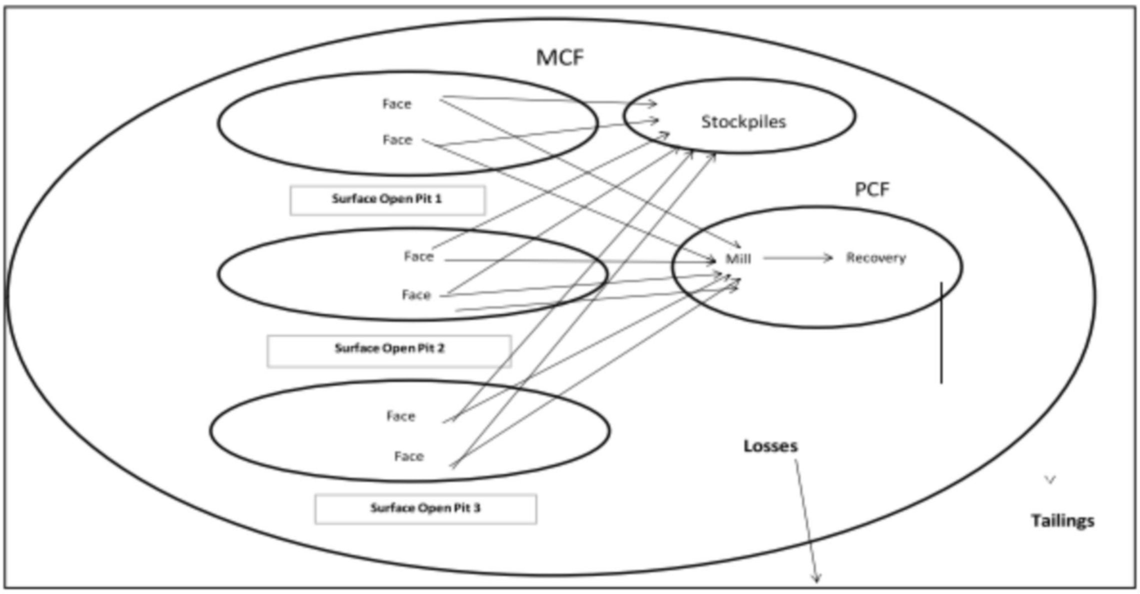

Figure 2.2 Open pit material flow

Source (Tetteh, 2014)

The complex nature of material flow along the mining value chain calls for an efficient code of practice to determine the metal content between any two points along the flow. A metal accounting procedure involves systematic documentation and representation of ore evaluation, grade control and ore processing statistics of a mine (Janisch, 1973). The prime objective is to present statistics in manner that easily and effectively track and monitor material flow along the entire value chain (Tetteh, 2014). Management uses the data to assess performance and potential profitability (Tetteh, 2014)

These statistics are used for generation of reconciliation and efficiency factors including the MCF, which management uses for planning purposes (Tetteh, 2014). The statistics are generated by various departments at the mine. The tonnage is measured and the records compiled by the survey department, while the geology department provides assay data and the metallurgical department compiles processing statistics. The statistics are entered in a spreadsheet and used to compare the actual performance with the budget (Tetteh, 2014). The translation of physical metal losses into monetary value highlights the areas of greatest monetary losses (Storrar, 1981). This helps management to craft corrective measures to mitigate the losses.

2.8 Ore flow balance sheet

The ore flow balance sheet shows all the sources of metals in mining operations (Tetteh, 2014). The various sources of ore that appear on the balance sheet include ore reserves, not in ore reserves (NIR), development and others. The metal content of the total tonnes is obtained by multiplying tonnes from various sources by their respective weighted grades and summing the products (Tetteh, 2014). The quantity and grade of ore supplied to the plant and stockpile are also captured in the records. All the recoveries and losses along the flow must be accurately recorded on the ore flow balance sheet and explained.(Tetteh, 2014). Table 2.6 displays a template of an ore flow balance sheet for an underground mine and Table 2.7 shows production records for a month for an underground mining operation.

Table 2.6 Ore flow balance sheet

Category	%	Mass	grade	content(g)
Pay ore reserve				
+ Not in reserve				
+ Unpay ore reserve				
+ Other sources stoping				
+ Stope reclamalation				
+ Stope Development				
Total broken in stopes				
- Sorted and packed in stopes				
Trammed from stopes				
+ Reef development				
- Reef in ballast				
- Development ore sorted				
total reef trammed				
+/- Discrepancy				
Hoisted as reef				
+ Shaft bins (beginning of month)				
Total in shaft bins for the month				
- Shaft bins (end of month)				
Total from shaft bins				
+ Ore from reef dump or stockpile				
To surface sorting plant				
- Sorting				
+ Ore from reef picking plant				
To mill bins				
+ Mill bins beginning of month				
Total in mill bins for the month				
-Mill bins (end of month)				
- Tons milled				
+ Tons milled				
+ Slimes treated				
Total tons treated (gold called for)				
Mine Call factor				
Recovery/ Residues				
Recovery plus residues (gold accounted for)				

Source (Cawood, 2012)

Table 2.7 Production records for one month

Metallurgical Plant	
Tons treated	280 000 t
Residue value	0.55 g/t
surface sorting	9% of the tonnage received at the sorting plant
Gold recovered	4 360 kg
Mill bins	
Beginning of the month	7 400 t @ value of 12,36 g/t
End of month	9 500 t
Density of solid rock	2,78t/m3
Mined from:	
Pay ore Reserves	51 340 m2 @ 2 127 cm-g/t @ 106 cm
Not in Reserves	17 554 m2 @ 1 740 cm-g/t @ 101 cm
Unpay Block	13 620 m2 @ 745 cm-g/t @ 96 cm
Pillar mining	9 428 m2 @ 1 602 cm-g/t @ 105 cm
Stope reclamation	4 000 t @ 15,00 g/t
Waste from Other Sources	6 000 t
Gully Vamping	3 774 t @ 7,45 g/t
Gully waste	15000
Waste packed in stopes	13 770 t @ 1,34 g/t
Reef develpoment	12 000 t @ 4,72 g/t
Average dimensions of development end	1 000 m
advance @ 2,4 m wide and 1,8 m high	
Heagear Bins	
Beginning of the month	2 800 t @ 15,80 g/t
End of month	3 100 t
Surface Stockpile	
Beginning of the month	3 500 t @ 13,80 g/t
End of month	3 100 t
Surface Stockpile	
Beginning of the month	3 500 t @ 13,80 g/t
End of month	3 100 t

Source (Cawood, 2012)

Table 2.8 demonstrates the application of an ore flow balance sheet to calculate tonnage discrepancy, plant recovery and mine call factor for an underground mining operation. From the ore flow balance sheet, the survey discrepancy (shortfall or excess), the mine call factor and plant recovery are calculated.

Table 2.8 Ore balance sheet

Category	%	Mass(t)	grade(g/t)	content(g)
Pay ore reserve		151289	20.066	3035770.783
+ Not in reserve		49288	17.228	849120
+ Unpay ore reserve		36349	7.760	282083.3854
Pillar mining		27520	15.257	419876.5714
+ Stope reclamalation		4000	15	60000
waste from other sources		6000		
Gully Vamping		3774	7.45	28116.3
Gully waste		15000		
Total broken in stopes		**293220**		**4674967.04**
sorted in stopes		13770	1.34	18451.8
Trammed from stopes		**279450**		**4656515.24**
+ Reef development		12000	4.72	56640
total trammed		**291450**		**4713155.24**
- Reef in ballast				
- Development ore sorted				
+/- Discrepancy		18350		
Hoisted as reef		309800	15.214	**4713155.24**
+ Shaft bins (beginning of month)		2800	15.8	44240
Total in shaft bins for the month		312600	15.219	**4757395.24**
- Shaft bins (end of month)		3000	15.219	45656.38
Total from shaft bins		309600	15.219	**4711738.86**
+stockpile (beginning)		3500	13.8	48300
Total		313100	15.203	4760038.86
- stockpile (end)		3100	15.203	47129.10
Ore to surface sorting plant		310000	15.203	4712909.76
- Sorted	9	27900	0.65	18135
+ Ore from reef picking plant		-		
To mill bins		282100	16.642	4694774.76
+ Mill bins beginning of month		7400	12.36	91464
Total in mill bins for the month		289500	16.533	4786238.76
-Mill bins (end of month)		9500	16.533	157061.38
- Tons milled				
+ Tons milled				
+ Slimes treated				
Total tons treated (gold called for)		280000	16.533	4629177.38
Mine Call factor	97.5			
Recovery				4360000
Residues			0.55	154000.00
Recovery plus residues (gold accounted for)				4514000.00

Source (Cawood, 2012)

In the ore flow balance in Table 2.8 a discrepancy of 18 350t (shortfall), MCF of 97.5% and plant recovery of 96.6% are calculated.

Typically a metal balance sheet has two divisions, one which shows the budget and the other which shows the actual (Storrar, 1981: 226). On the left side is the source of the metal called for while the actual is on the right. The surveyor measures the volume of the rock excavated and applies the density factor to obtain the tonnage. All the mined areas are adequately sampled to determine the grade, which is expressed in grams of metal per tonne of ore or as percentage in the case of base metals such as nickel. The tonnage of the ore fed to the plant is measured using a weightometer (Figure 2.3). A weightometer is a device underneath the conveyor belt which is used for continuous mass determination (Spangenberg, 2012). In metal accounting, the purpose of mass measurement is to determine the quantity of certain material component at a given time, to the required degree of accuracy.

Figure 2.3 Weightometer

Source (Spangenberg, 2012)

Tonnage discrepancy is the difference in tonnage received by the plant, to that calculated as available to the plant by the surveyor (De Jager, 1997) It is called a shortfall if the tonnage calculated by the surveyor exceeds that accounted for in the plant and as an excess if the opposite is true. The metal that the plant ultimately recovers is accurately accounted for, using the residue and recovery data. The mine call factor is derived using the average weighted contribution from various sources of metal content carried through on both sides of the ore flow balance sheet (Tetteh 2014). Ideally, it is expected to be 100%, however, in reality it deviates. It is variable and may be less 100% in a particular month and above in the other. The variation is attributable to the fluctuation in the throughput velocity (Tetteh, 2014). If the deviation from 100% and variation from month to month is due to other causes such as accuracy of measurement, then the matter requires urgent corrective action in order to meet the standards required for auditing purposes (Tetteh, 2014).

2.9 AMIRA P754 code

The problems encountered by people concerned with the metal accounting process include the paucity of the required standard procedures for metal accounting (Gaylard et al 2009). Metal accounting is considered secondary to the efficient running of the plant and consequently, it is delegated to junior and less experienced staff or people without a technical background (Gaylard et al 2009). This practice gives rise to the following problems: inadequate awareness of and attention to precision of mass measurement, sampling and analysis, application of improper methods of calculation of metal recoveries and measurement of lock-up figures. The risk is that senior management may not be aware of the issues of accuracy and reliability concerning the figures reported, which are also used for the compilation of financial accounts reported to the shareholders (Gaylard et al 2009).

The AMIRA P754 code was developed to enhance the auditability and transparency of metal accounting process and to promote good corporate governance (Gaylard et al 2009). The code prescribes the standards and best practices for mass measurement, sampling, sample preparation and analysis, data management and metal balancing, to enable compliance with basic principles. Figure 2.4 shows the structure of the AMIRA P754 code. If an operation is unable to comply with prescribed standards, an exception report outlining reasons for non-compliance (risk, cost etc.) is required and signed off by a competent person. This ensures that senior management and the board of directors are informed about decisions concerning metal accounting which materially impact the reported results and metallurgical efficiencies (Gaylard et al 2009).

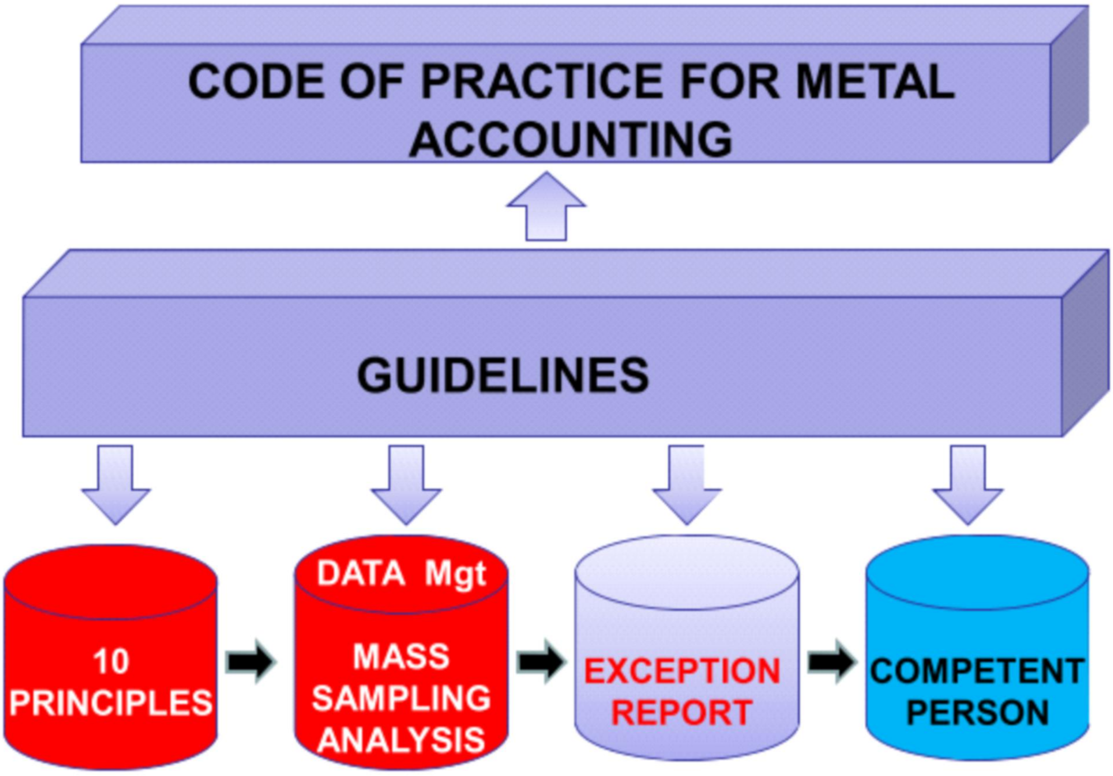

Figure 2.4 AMIRA code structure

Source (Gaylard et al 2009)

To address the problems encountered in metal accounting the code comprises a set of 10 guiding principles for reporting which are:

- The metal accounting system must be based on accurate measurements and metal content. The system must be a full "check in-check out" using best practices in the code.

- Consistency and transparency are critical for the system, and the sources of input data must be clear and understood by all. Outcomes of risk assessment of every aspect must be incorporated into the design.

- There must be fully documented simple accounting procedures for easy use all by involved, to avoid dependence on one person. Calculation procedures must meet the requirements of the code.

- Regular internal and external audits must be carried out, as well as reviews to ensure compliance.

- The accounting results must be made and availed timeously to comply with operational requirements and ensure that the necessary interventions and investigations are carried out.

- Should provisional data be incorporated for the sake of meeting deadlines, then the requisite procedures and levels of authorisation, for the subsequent replacement of such data with the actual data must clearly defined.

- Enough data must be generated to enable data validation, the treatment of metal/commodity transfers and reconciliation of metal/commodity balances, and measurement accuracies and error detection which are free of any consistent biases.

- For all input and output streams used for accounting purposes, the desired accuracies for the mass measurements and sampling analyses must be established. The actual accuracies of metal recoveries premised on actual accuracies derived from the statistical analysis of the raw data over the reporting period, must be stated in the report to the Company's Audit Committee.

- Physical stock takes must be done at prescribed interval, to verify in process inventory figures. There must be clearly defined procedures and authority levels for stock adjustments and handling of losses or gains not accounted for.

- Any bias that may occur in any measurement, sampling and analytical procedure must be quickly established, eliminated or reduced to an acceptable level.

2.9.1 *Mass measurement*

The principal objective of mass measurement for metal accounting purposes is to determine the mass of the particular material or component present at a specific time, or the mass flow of that component over a specified time period, to a prescribed accuracy (Gaylard et al, 2009). According to JKRMC (2008), mass measurements can be classified as:

- For the purposes of transfer of custody and primary metal accounting, a high standard of measurement is required.
- For management control, secondary metal accounting measurement is used. It may also be utilised for cross-checking primary accounting. Measurement for environmental monitoring belongs to this category.

- Measurement solely for plant control

The primary accounting is the most stringent in terms of accuracy requirements. Its requirements are: certified weighing equipment and determination of the distribution of the random error model associated with the mass measurement.

2.9.2 *Accuracy and precision of mass measurement*

Accurate measurements are characterized by a mean which is close to the true value, which is often unknown. Measurements are precise if their standard deviation from their mean, is lower than a distinct dispersion at a particular time (JKMRC, 2008). A precise measurement may not be accurate, though there has been a tendency to use the two terms interchangeably. Accuracy expresses the absence of bias in the mean from an unknown true value.

2.9.3 *Measurement of density and moisture*

In situations which involve measurement of volume, the density of the material need to be established in order to calculate the mass of the solid. Gaylard et al (2009) state that plant audits reveal that this is a major source of error due to the following factors:

- Bulk densities applied are imputed and constant, unaffected by the particle size, level of compression and the age of the material.

- Densities of the solid and liquid components are assumed.

- The calibration of the density meters is not on the material being measured. Representative measurements are rarely taken because the sampling is often done away at points different from where mass measurement takes place.
- The samples collected are unrepresentative of the material on a conveyor belt, or from a bin, or from a stockpile. Sometimes historical values are used resulting in the introduction errors of 1-2% (Gaylard et al 2009).

- Density can be precisely measured using laboratory tests where volumes of materials are measured accurately and the density determined.

Volume is commonly measured using the liquid displacement method (AMIRA code). Determination of moisture involves weighing the materials using an electronic balance, followed by drying in an oven under prescribed conditions for a given period. The material is reweighed after drying to determine the weight loss which is ascribed to moisture. The method can be used for stockpile material, materials from conveyor belts and bulk ore. The level of certainty depends on appropriate sampling.

At Mazowe Mine the specific gravity is determined locally at the assay laboratory, using the Archimedes principle (Mushayavanhu, 2016). The rock specimens are washed and dried in an oven and then weighed using an analytic balance. A one-litre beaker is put in an inclined position and filled with water until it spills over. When the spillage stops a specimen is lowered, using a string, into the still water. This specimen displaces a certain amount of water. The volume of displaced water is measured with a measuring cylinder and its mass determined using an analytic balance. Both the mass and volume of water displaced are used to determine the specific gravity (Mushayavanhu, 2016).

2.9.4 *Sampling*

The overriding objective is to obtain unbiased samples. The principal requirements for achieving unbiased sampling with an acceptable level of precision are proper design, installation and maintenance of a mechanical sampling system (Gaylard et al 2009). The mechanical sampler must sample whilst in motion and its accuracy need to be validated using stop belt samples (AMIRA 754 code). For metal accounting purposes, the sampling of bins and stockpiles, is not recommended due to the challenge of achieving representative sampling.

2.9.5 *Storage of samples and labelling*

All samples must be properly packaged, labelled and assigned a unique sample number to avoid ambiguity, prior to dispatch to the assay laboratory. Suitable packaging must be used and samples must be sealed to avoid loss and cross contamination (Gaylard et al 2009). Samples for moisture must be kept under appropriate conditions to ensure that there is no moisture loss, which would result in low bias on analysis and the consequent high bias on dry weight tonnes determination (Gaylard et al, 2009).

2.9.6 *Sample preparation and analysis*

The AMIRA code requires that a detailed Analytical Protocol needs:

- Well spelt out custody transfer points
- Analysis required
- Analytical methods
- Full calibration details
- QA procedures and
- Turnaround time

In addition, the laboratories are required to implement best practice as regards their calibration of analytical instruments. At least seven standards including a blank must be used. The standards must be closely matrix-matched to the samples and the concentration of the samples should be around the centre of the calibration range.

2.10 Reconciliation

Parker (2014) states that reconciliation is the process of collecting mass, concentration and metal content data from various and ideally independent sources. These include exploration data, production sampling data from blast holes or draw point and process plant data. A comparison of these data is done using factors, namely F1, F2 and F3. The F1 factor relates to the ratio of the short-term model tonnage and metal content to the ore reserves depleted. The

F2 factor relates to the ratio of received at mill tonnages, grade and metal content estimated in the ore reserves, to that delivered to mill. The F3 factor is a product of the F1and F2 factors, which enables assessment of the mine's ability to achieve the tonnage, grade and metal content estimated in the ore reserves. The F1 factor gives a measure of the accuracy of the ore body knowledge in the ore reserve, to the demarcation of ore and waste by grade control, while the F2 factor checks on the unplanned dilution entering the ore stream (Parker, 2014).

Reconciliation must be implicit in the mining process and reconciliation targets must be key performance indicators for mines that are efficiently run (Parker 2014). In most mines the main sources of error are inaccuracies in mineral resources and/or ore reserves estimation and inefficient segregation of ore and waste (Parker, 2014). Pitard, (2014) attributes the major discrepancies between mine estimates and plant metallurgical balances to flawed protocols that do not meet basic statistical requirements. The principal objective of a reconciliation system is to compare what is recovered with what is expected and use the results to tune overall resource, ore reserve grade control, mine production and processing systems over time (Morley 2014). This enables the optimization of all key parts of the operation, leading to the best possible utilization of the resource (Morley, 2014).

2.11 Chapter summary

MCF challenges differ from mine to mine, depending on the mining activities. Consequently, a systematic scientific approach is required when investigating the MCF. The MCF is calculated using the average weighted contribution from various sources of metal content carried through on both sides of the ore flow balance sheet. Ideally it should be 100%, however, in reality it deviates. The losses that affect the MCF are divided into apparent and real. The effect of both apparent and real losses is to reduce the MCM to less than 100%.

The theory of metal accounting is a critical component in mineral resource management. Its principal goal is balancing the physical metal content. The metal that the plant ultimately recovers is accurately accounted for, using the residue and recovery data to calculate backwards. Metal accounting deals with the flow of metal-bearing materials, which is a complex process. The complexity arises from several factors and is mine specific. Typically, a metal accounting balance sheet captures the quantity of ore in tonnes and the quality, expressed in grams per tonne (g/t). It also shows all the sources of metals and accurately captures all recoveries and losses along the flow. Tonnage discrepancies are either a shortfall or an excess. The discrepancy is a shortfall when the tonnage received by the plant is more than that generated by the mine, and it is an excess when the opposite is the case.

The measurements of these quantities and qualities are based on scientific measurements and analyses as detailed in the AMIRA P754 code. A reconciliation and efficiency factor is applied to establish deviations of the actual figures of what was recovered from what was expected. The MCF is commonly employed in predicting future production deviations.

3. ORE FLOW AT MAZOWE MINE

3.1 Chapter overview

Chapter 3 focuses on the ore flow at Mazowe Mine, from the face to processing. The mine comprises several reefs and mining is on different and multiple faces at any given time. Consequently, ore flow is fairly complex. The ore is trammed on three levels and hoisted to the surface via the Connaught Shaft. The production history, mining, processing and the ore flow balance sheet are presented. The ore flow balance sheet indicates all sources of ore. The prime objective of the ore flow balance sheet is the presentation of statistical data in a manner that enables efficient tracking and monitoring of the flow of material from underground to the process plant (Tetteh, 2014). The statistics are used for the estimation of reconciliation and efficiency factors including MCF, which are utilized for planning purposes.

3.2 Production history of Mazowe Mine

Figure 3.1 shows the historical gold production in ounces from 1962 to 2016. Historical production peaked at 55,000 ounces in 1972, then progressively declined to 17,000 ounces. After 1988 annual production was on an upward trend, until it peaked at 40,000 ounces in 1995. After 1995, it progressively declined until the temporary closure of the mine in 2009.

During the period under review, gold production was variable. From 2001 to 2005, gold production at Mazowe Mine was generally on an upward trend. Annual production rose from 12,241 ounces in 2001, to peak at 16,444 ounces in 2005. The highest MCF of 73.1% was attained in the same year (Figure 3.2). In the same year, stope fines sweeps contributed 694 ounces of gold. It is one of the 4 years during the entire period under review, when fines sweeps contributed more than 600 ounces of gold.

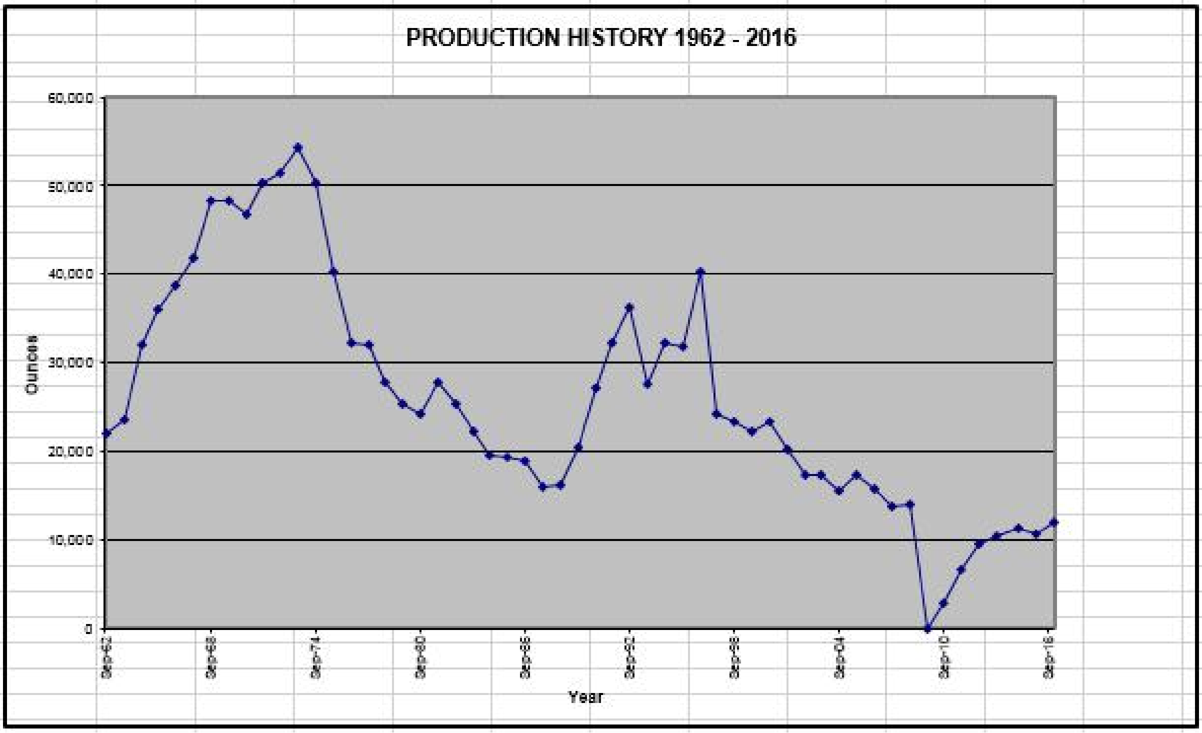

Figure 3.1 Historical gold production from 1962 - 2016 in ounces

Source (Mazowe Mine 2017)

After 2005, there was a marked downward trend in gold production, until the mine temporarily closed for a year in 2009. Production fell steadily from 16,444 ounces in 2005 to a paltry 4,963 ounces in 2008 (Figure 3.1). During the same period, the MCF also fell steadily from 73.1% in 2005 to 46% in 2008 (Figure 3.2).The downward trend in gold production in the period 2005 to 2008, is attributed to the then prevailing unfavourable economic environment. The economy was characterized by hyperinflation and an acute shortage of foreign currency, which negatively impacted the mining industry. Mines were hard hit by the severe shortage of foreign currency, frequent and prolonged power outages, shortage of fuel and other critical inputs. Worse still, the mines were no longer receiving proceeds from mineral sales, as the government was using the money to buy critical commodities such as fuel.

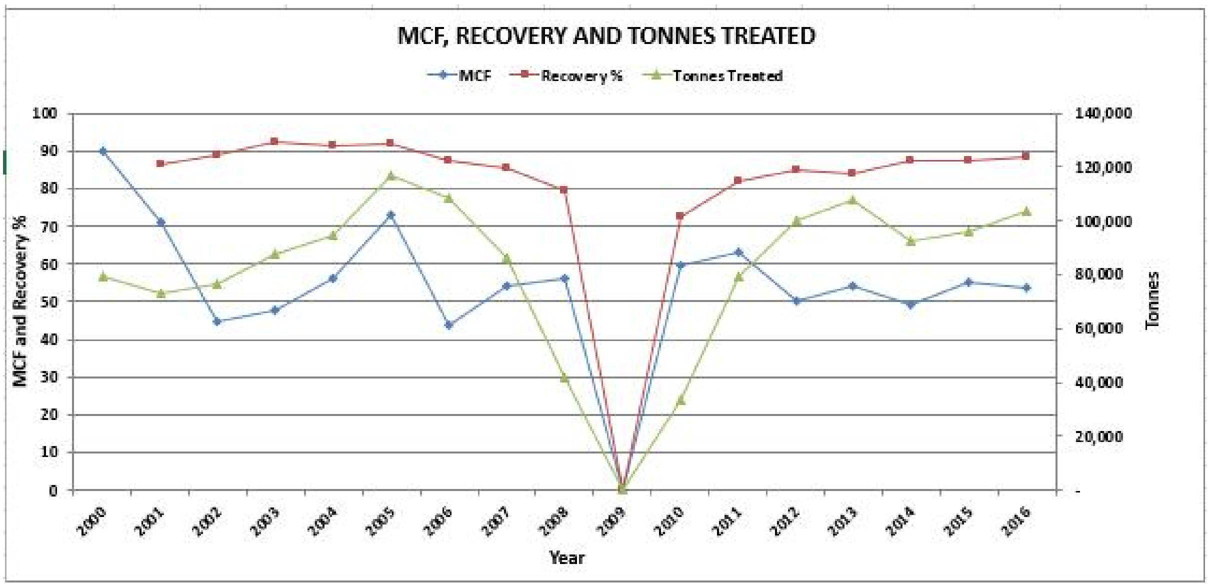

Figure 3.2 MCF, recovery factor and ore treated 2001-2016

Source (Mazowe Mine, 2017)

The mine reopened in 2010 after dollarization of the economy. Production started on a low note in 2010, with a total production of 2,717 ounces of gold. Production was mainly sustained by exploiting accumulations and mining some remnant pillars. Gold production rose steadily to peak at 13,667 ounces in 2016.

3.3 Mining operations

Mazowe is an underground mine operation which is currently serviced by two shafts. The mine workings have a strike of about 3km. Several reefs are currently mined. The spacing between the main reefs ranges from 20m to 110m (Mushayavanhu, 2016). Two mining methods are used, namely jackhammer breast stoping and underhand stoping. Mining blocks measuring 30m x 30m are developed, after which a breast stope is mined away from the block raise, or an underhand bench from the top drive breaking into the block raise, is started. Box raises are mined at a 7m spacing from the bottom tramming drive concurrently with the advancing face (Mushayavanhu 2016). Room and pillar mining is practised.

In a single stope face, blast holes are drilled in a chevron pattern, with a burden of 1m and spacing of 0.6m, to a depth 1.5m. The holes are charged with ANFO using stope fuse as a primer. A minimum stope width of 0.80m is supposed to be applied, but generally it is about 1.0m, resulting in unplanned dilution (Mushayavanhu 2016). After blasting, scrapers and hand lashing are used to move the ground down raises and stopes into boxes. From the boxes the ore is trammed to Connaught Shaft, where it is hoisted to the surface. The method of ground lashing is not efficient, because up to 20% of the ore can be left in the stope and it is difficult to measure (Mushayavanhu 2016). This contributes to losses which impact the MCF.

The current drilling pattern results in over fragmentation of the gold-bearing vein quartz in the shear zone. This generates fine material, which ends up as dust and mud. Some gold is lost in the mud, which is swept away during watering down and fines that are not swept (Mushayavanhu 2016). The gold is concentrated in drains, sumps and dams, where it is vulnerable to theft. Loss of gold to fines is considered a significant contributor to low MCF. This is evident from the fact that when fines sweeping is not done, the MCF drops (Mushayavanhu 2016).

3.4 Processing plant

The processing plant at Mazowe Mine has a capacity to treat 10 500t per month, with a target head grade of about 4.0g/t. The major unit operations are crushing, milling, gravity concentration, thickening, leaching, adsorption, elution and smelting, to yield an overall recovery of 88%. About 70% of the gold is recovered by gravity concentration (Mushayavanhu, 2016). The ore is generally clean and pyrite is the predominant sulphide. This suggests that recovery is good (Mushayavanhu, 2016). However, the erratic nature of the mineralization presents problems. The indicated gold based on milled tonnage and mill feed grade is often higher than the gold accounted for (recovered gold and gold contained in tailings).

3.4.1 *Sampling in the processing the plant*

Sampling in the plant is done using an automatic hammer sampler on the mill feed conveyor belt to determine the head grade. The sampling is done at 15-minute intervals on average. After the eight-hour shift, the sample is split, using a riffle to obtain a representative sample. A sample for each shift is submitted to the mine assay laboratory for analysis and a duplicate is retained for reference purposes (Mushayavanhu, 2016).

3.5 Survey volume measurement

At month end, underground excavations are surveyed using a total station and volumes are calculated using Vulcan software. The tonnage (broken tonnage) is calculated by multiplying the volume of the excavation with a specific gravity of 2.9 t/m^3. Stockpiles are measured using a total station and the tonnage is the product of the volume and a bulk density factor of 1.5t/m^3.

3.6 Trammed tonnage

Mazowe Mine employs track mining, with 2.5t battery locos on 6, 10 and 14 levels. Scrapers are used, together with hand lashing, to move broken ground down raises into boxes. The ore is then loaded into one-tonne cars pulled by a battery loco and tipped into ore passes. The total trammed tonnage in a shift is determined by counting the number of cars. This number is generally unreliable; because the cars may not be full and a there may be a deliberate overstating of the number of cars pulled (Mushayavanhu, 2016).

3.7 Hoisted tonnage

To determine the tonnage hoisted, each skip of ore hoisted through the Connaught Shaft is logged separately by the hoist driver and gang leader. The hoisted tonnage per shift is computed based on the number of hoisted skips and the skip factor (Mushayavanhu, 2016). Fines from stope sweepings are hoisted through the Ogilvy Shaft. Skips hoisted are logged independently by the hoist driver and the gang leader. A factor of 3.5 is applied to obtain the tonnage hoisted. The hoisted tonnes are reconciled against the milled tonnes based on weightometer measurement as validation of the skip factor being used and is constantly monitored (Mushayavanhu, 2016). A moisture content factor of 3% is applicable to the hoisted tonnage. This figure is based on a number of tests done at the mine laboratory (Mushayavanhu, 2016).

3.8 Milled tonnage

In the process plant, ore is drawn from the fine ore bin over the weightometer and automatic sampler. The milled tonnage is measured using weightometers mounted just after the fine ore bin on conveyors (Mushayavanhu, 2016). Readings are taken at the beginning and end of the shift and the difference in the readings is the milled tonnage. Errors associated with the use of weightometers are overestimation or underestimation of tonnage. This occurs when the weightometer is not calibrated regularly as per schedule (Mushayavanhu, 2016). Patched conveyors result in weightometers giving false readings (Mushayavanhu, 2016). The state of some conveyors causes spillage, which is a major problem in the process plant. The weightometer measures tonnage. Figure 3.3 shows a weightometer mounted just after the fine ore bin. The automatic sampler (Figure 3.4) takes a sample every 15 minutes and at the end of the shift the composite sample is collected. One sample is taken to the mine assay laboratory and this constitutes the mill feed grade. A reject sample is kept for reference (Mushayavanhu, 2016).

Fines from underground stope sweepings bypass the weightometer and automatic sampler. They are fed into a hopper with a volume of $12m^3$ and a bulk density of 1.3 t/m^3 is applied to obtain the tonnage (Mushayavanhu, 2016). Each hopper is augured and the sample stored in a box. At the end of the shift, the composite sample is split and a subsample submitted to the assay laboratory to determine the average grade of fines fed. A plant discharge sample is taken to determine the amount of gold contained in the residues sent to the tailings storage facility. A solid and solution sample is taken every hour. The samples collected over the shift are submitted to mine assay laboratory for analysis at the end of the shift (Mushayavanhu, 2016).

Figure 3.3 Weightometer in the process plant

Figure 3.4 Automatic sampler

3.9 Mazowe Mine ore flow balance sheet

The integrated ore flow balance sheet of Mazowe Mine for the period 2013 to 2016, is presented in Table 3.1. The ore flow balance sheet shows all the sources of metal at the mine. These include ore reserves, mineral resources, not in reserve (NIR) accumulations. Also shown are the quantity and grade of ore sent to the plant and stockpile. During the period under review, the tonnage discrepancy was an excess of 21,1175t (-6%) and the average MCF was 57%.

The annual ore flow balance sheets for the years 2013, 2014, 2015 and 2016 are shown in Appendices 1, 2, 3 and 4 respectively. In 2013 the tonnage discrepancy was an excess of 16,907t (-22.5%) and the MCF was 53.8% (Appendix 1). In 2014 the tonnage discrepancy was an excess of 2,912t (-3.2%) and the MCF was 49% (Appendix 2). In 2015 the tonnage discrepancy was a shortfall of 1013t (1.1%) and the MCF was 62% (Appendix 3). In 2016 the tonnage discrepancy was an excess of 8368t (-8.5%) and the MCF was 63.5% (Appendix 4).

The integrated ore flow balance sheet indicates that tonnage discrepancy is essentially an excess and it is not extreme, except in 2013. Generally, from 2013 to 2016, there was an improvement in the discrepancy, suggesting an improvement in tonnage measurement. Generally, there was an improvement in MCF from 2014 onwards. This improvement in MCF is largely attributed to increasing production from ore reserves and progressive reduction of production from NIR. However, despite the upward trend, the MCF is still unacceptably low. Ore from reserves constitutes a paltry 16%, whereas, ore from resources and NIR account for 55.8% and 18.8% respectively. This is likely to negatively impact the MCF.

Table 3.1 2013-2016 Ore flow balance sheet

	Tonnes	%	ACTUAL Grade (g/t)	Au content (g)
MINING (Survey Measurement)	Tonnes	%	Grade (g/t)	Au content (g)
Stoping from Ore Reserves	73331	16.3	6.3	464815
Stoping from Mineral Resources	251288	55.8	5.8	1466022
Secondary Development ex Reserves	5209	1.2	6.6	34547
Stoping not in Reserves	84689	18.8	7.6	641052
Secondary Development not in Reserves	6920	1.5	5.9	40964
Primary Development	29186	6.5	5.3	156005
Other Sources				
Total tonnes Broken	**450624**	**100.0**	**5.4**	**2803405**
RECONCILIATION OF TONNAGE				
Mineral Broken (Survey Measurement)	451072	100.1	6.2	2805017
To Accumulation (-)	-20130	-4.5	6.0	-121133
From Accumulation (+) and Spillage	23449	5.2	3.3	78051
Corrected for Stope Accumulation	443095	98.3	6.1	2709931
Ore Passes (+ -)	-8409	-1.9	4.7	-39706
Total Tonnes hoisted	437832	97.2	6.2	2718858
Sundry Surface Sources(+ -) Low-grade ex-Ogilvy	-490	-0.1	3.0	-1450
Corrected for Sundry Surface Sources	447753	99.2	6.2	2731293
Surface Sorting(-)	0	0.0	0.0	0
Corrected for Surface Sorting	447753	99.2	6.2	2731293
Mill Bins and Surface Stockpile (+) Ex Stockpile	-9921	-2.2	4.8	-46623
Tonnage losses unaccounted for(spillages)	-5993	-1.3	6.0	-35852
Corrected for Mill Bins=Survey tonnes	424334	94.2	6.2	2648158
Shortfall+/Excess(-) on Mill tonnes	-27175	-6.0		-522323
Tonnes Milled	379253	84.2	3.8	1442408
ASSAY PLAN FACTOR				
Gold or value called for	424334	94.2	5.7	2428758
Gold or value accounted for = Recovery	369920	82.1	3.37	1247541
+Residues	369920	82.1	0.55	204035
+Waste Sorted				
+Slags				
TOTAL	369920		3.9	1451576
MCF %				57

Source (Mazowe Mine, 2017)

3.10 Chapter summary

Mazowe Mine comprises several reefs and production necessarily involves mining multiple faces, resulting in a complex ore flow. Mining is focussed between 3 level and 10 level, but will soon extend to 14 level. Breast stoping and underhand stoping are used. Scrapers are used to move broken ground, together with hand lashing down raises and stopes into boxes. The ore is trammed on 6, 8 and 10 levels using 2.5t battery locos and hoisted to the surface through the Connaught Shaft.

The various sources of metal include mineral reserves, mineral resources, not in reserves (NIR) and accumulations. Only 16.3% of the ore came from ore reserves, whereas 55.8% and 18.8% came from mineral resources and NIR respectively. Mining from largely inferred resources, as is the case at Mazowe Mine, negatively impacts the MCF. The ore flow balance sheet for the period 2013 to 2016, shows that the discrepancy was an excess of 27,175t (-6%) and the average MCF was 57%. This is indicative of a fairly reliable tonnage measurement. During this period, the tonnage discrepancy ranged from an excess of 22.5% in 2013, to a shortfall of 1.1 % in 2015. Generally, there was an improvement in the discrepancy from 2013 to 2016. The MCF also showed an improvement from 53% to about 64%. However, despite the upward trend, the MCF was still unacceptably low.

4. TONNAGE OR GRADE GAIN/ LOSS

4.1 Chapter overview

This chapter assesses the mining value chain at Mazowe Mine, to identify possible sources of tonnage and grade gain/loss that impact the MCF. These include sampling, mining, grade control, QA/QC protocol, tonnage measurement and evaluation. Quantification of the contribution of identified sources of tonnage and grade gain/loss to the MCF shortfall is also attempted. A summary of the analysis of the ore flow, to identify percentage grade gain/loss and percentage tonnage gain/loss and the mine to mill reconciliation is presented.

4.2 Analysis of the ore flow

The summary of the ore flow analysis for the four-year period, 2013 to 2016, to determine percentage tonnage and grade losses is shown in Table 4.1. The full ore flow balance sheet is presented in Table 3.9 in chapter 3.

Table 4.1 2013-2016 Ore flow summary

	Tonnes	Percent	Grade (g/t)	Gold (oz)
Gold called for	424334	94.2	5.70	2428758
Gold called for = Recovery	369920	82.1	3.37	1247541
+ Residues	369920	82.1	0.55	204035
+ waste sorted				
+ slags				
Total	369920		3.9	1451576
Mine Call Factor (%)				57.0

Source Mazowe Mine, 2017)

The following are the salient points from the ore flow analysis:

- The total ore broken in the period under review is 450,620t @ 5.4 g/t Au (78,243 ounces)
- The gold called for is 424,334t @ 5.7g/t Au (77,772 ounces) and it constitutes 99% of the gold contained in the total broken tonnage.

- The gold accounted for is 369,920 @ 3.9g/t Au (46,389 ounces)
- The percentage tonnage loss is 13%
- The percentage grade loss is 32%

4.3 Sources of tonnage gain/loss

4.3.1 *Inefficient stope lashing*

At Mazowe Mine inefficient stope lashing is one of the factors that contributes to tonnage loss. The broken ore is lashed using scrapers. In most cases, the stope configuration is not conducive to efficient lashing and, as a result, a significant amount of broken ore remains in the stope. The broken ground left in the stopes constitutes tonnage loss and the resultant gold loss cannot be accurately measured. The unfavourable stope configuration is due to premature commissioning of stopes. Stopes are prematurely commissioned due to lack of operational flexibility. The ore loss is compounded by long scraping distances of up to 110m. Scraping is not efficient beyond a distance of 75m (Mandidi, 2016).

4.3.2 *Lack of blasting barricades*

Use of blasting barricades ensures that the blasted ore is confined to a limited space and can be efficiently lashed with minimum tonnage loss. Currently, blasting barricades are not used and broken ore is spread over a wide area in open stopes. Some of the broken ore lands in areas which are inaccessible to lashing and constitute tonnage loss.

4.3.3 *Derailments*

Derailments are frequent in some parts of the Connaught Shaft and this results in tonnage loss. Derailments are also frequent on the tramming levels because the tracks are in a bad state of repair. These also contribute to tonnage loss, as some of the spilt ore is not lashed back into the cars.

4.3.4 *Inaccurate weightometer measurement*

Inaccurate weightometer measurements have tended to inflate milled tonnage at Mazowe Mine. Reliable tonnage measurement is indispensable for credible and transparent metal accounting (AMIRA code). In addition, it is essential to establish the accuracy and precision of each of the measurements included in the metal accounting. At Mazowe Mine, tonnage is measured in the plant using a two idler belt scale. Such equipment must be calibrated regularly using approved techniques and standard procedures are required. Although this can be done in-house, regular checks by outside bodies are essential (AMIRA code). However, at Mazowe Mine this is not strictly adhered to. The weightometer sometimes goes beyond the prescribed periods without calibration by independent experts (Mushayavanhu, 2016). At the time of the visit by the researcher, there was no current valid calibration certificate.

There are periods when the Technical Services Department, which includes geology and survey, has expressed reservations about the accuracy of the plant tonnage figures, which show significant discrepancy with theirs (Mushayavanhu, 2016). According to the Technical Services department the state of the weightometer allows for manipulation of figures by the metallurgy department to mask inefficiencies and this adversely impacts the MCF. However, the correlation coefficient between the hoisted and the milled tonnage is indicative of strong correlation. This suggests that though tonnage gain may occur in the plant due to inaccurate weightometer measurement, it is not a serious problem.

The issues in the processing plant can be highlighted by what transpired in November 2015. For the week 7-13 November the actual smelt figure fell short of the indicated or called for production figure by 2.7 kg. The gold called for was 8.7 kg and the final smelt figure was 5.96 kg. The production was achieved against a background of thorough sweeping in the plant and a consistent tonnage of 344t per day at a grade of 4.13 g/t. An independent internal audit team was appointed by the Mine Manager to investigate and establish the cause of the discrepancy. The team sought to check tonnage measurement, grade and the possibility of loss through the plant processes.

The audit team concluded that the findings showed that a lot of work needs to be done to improve metallurgical accounting. About 1.77kg of the shortfall was attributed to tonnage which was overstated (Mandidi, 2015). To overcome tonnage measurement issues in the plant which may result in an apparent gold loss, it is critical to regularly service and calibrate the weightometers. Record keeping and calibration, correction and readings to enable error detection as well as statistical analysis must be done properly to enable determination of the accuracy of measurement (AMIRA code).

4.3.5 *Mining remnant blocks*

Currently, mining is widely dispersed because the mainstay of production is remnant blocks. Remnant blocks are generally small and were abandoned in the past for various reasons, including lower grades than expected. When mining remnant blocks, some of the blasted ore is lost to old stopes, and this is exacerbated by the lack of blasting barricades. The long scraping distances involved and multi-handling result in further tonnage loss.

4.3.6 *Specific gravity*

A specific gravity (SG) of 2.9t/m^3 is used at Mazowe Mine. This appears to be overstated for granodiorite which is the host rock. Prior to 2003 a specific gravity of 2.7 was used. The change from 2.7t/m^3 to 2.9t/m^3 translates to an increase of 7.4%. The effect of an inflated specific gravity is to overstate the tonnage and gold estimated during the estimation process. Consequently, the gold can be overcalled due to the overstated specific gravity. This contributes to the apparent gold loss. In terms of ore discrepancy, this results in an excess.

Two methods are applied for calculating the specific gravity at Mazowe Mine and the average used. For the purposes of calculating the specific gravity, samples are collected from the current working areas (Mushayavanhu, 2016). The samples are dried, washed and weighed using an analytic balance. A beaker in an inclined position is filled with water until it spills over. When the spilling stops, a sample is lowered, using a string, into the still water. This displaces a certain amount of water. The spilt water is collected and its volume is measured using a measuring cylinder and its mass, using an analytic balance (Mushayavanhu, 2016).The specific gravity is calculated using the volume and the mass of the displaced water, as shown in the two formulas below.

$$SG = \frac{\text{Mass of sample}}{\text{Mass of displaced water}} \quad [2]$$

$$SG = \frac{\text{Mass of sample}}{\text{Volume of displaced water}} \quad [3]$$

The two methods yield comparable values, but those based on the mass of the displaced water are generally slightly higher. Figure 4.1 shows that the values based on the two methods have a strong positive linear relationship with a correlation coefficient of 0.97. A statistical analysis of 53 SG measurements, with a minimum of 2.23t/m^3 and a maximum of 3.72t/m^3, yielded a mean of 2.89t/m^3, with a standard deviation of 0.33t/m^3.

The SG values are highly variable and the extreme values are largely associated with small samples. This is most probably due to measurement errors. It is unlikely that the extreme variation is due to geological variation because mineralisation is largely hosted by sheared and altered granodiorite and the samples used for SG determination are essentially geologically similar. The small sample will displace a small volume of water, which also has a relatively small mass. The small mass and volume of the displaced water constitute the denominator in the formulas above. As a result of small denominator, the SG value is overstated

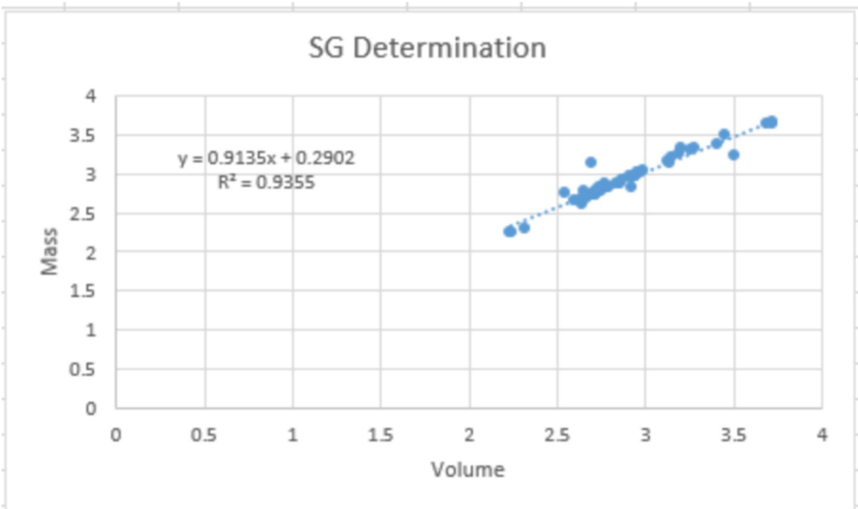

Figure 4.1 Specific gravity determination

Source (Mazowe Mine, 2017)

4.3.7 *Spillage and leaks in the process plant*

Spillage and leaks are major challenges in the processing plant at Mazowe Mine. The excessive spillage and leaks are considered a contributing factor to tonnage loss in the plant. The spillage largely consists of fines which are considered to be high-grade. Conveyor belts in the plant are in a poor state of repair, which results in significant accumulation of fines on the ground (Figure 4.2). The fines are not cleaned for long periods of time because the process is labour intensive and there is a shortage of labour (Mushayavanhu, 2016). There is also a lot of spillage in the gravity concentration section. The excessive spillage and leaks contribute to tonnage loss and gold loss, which adversely impacts the MCF. To reduce spillage and the associated gold losses, worn out equipment must be replaced. It is imperative to replace all worn out rollers and belts and the program to increase the rollers troughing angles to curb conveyor spillages must be implemented (Mushayavanhu, 2016).

Figure 4.2 Fines spillage in the plant

Figure 4.3 Leaks in the process plant

4.3.8 *Comparison between survey, hoisted and milled tonnage*

This section presents scatter plots showing the correlation between broken or survey tonnage, hoisted tonnage and milled tonnage for 2016.

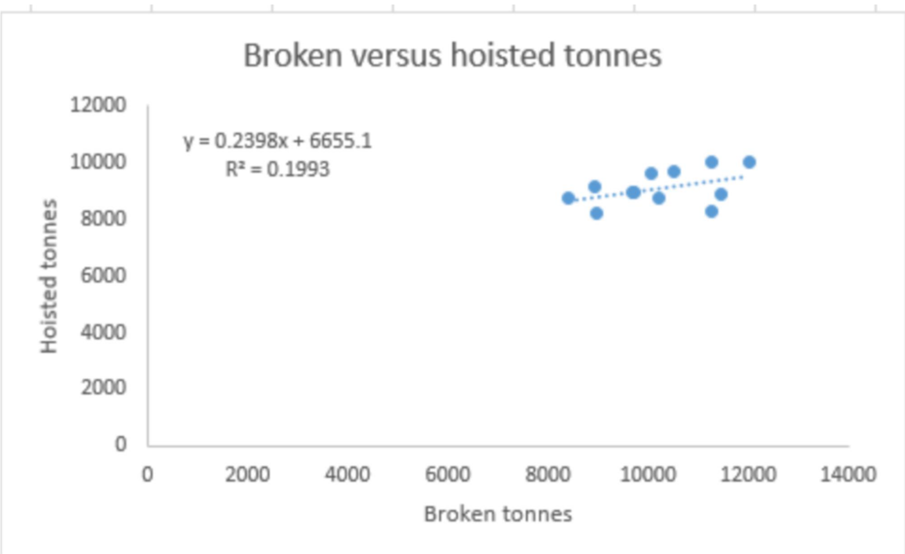

Figure 4.4 Comparison between broken and hoisted tonnage

Source (Mazowe Mine 2017)

Figure 4.4 shows that there is poor correlation between the broken and hoisted tonnage. The low correlation coefficient of 0.45 indicates that hoisted tonnage is not a good indicator of the broken ore. The two figures should compare favourably because there are no underground or surface stockpiles at the mine. Essentially all the broken ore is hoisted and milled. The poor correlation could be due to overstated broken tonnage and losses due to inefficient stope lashing and spillage.

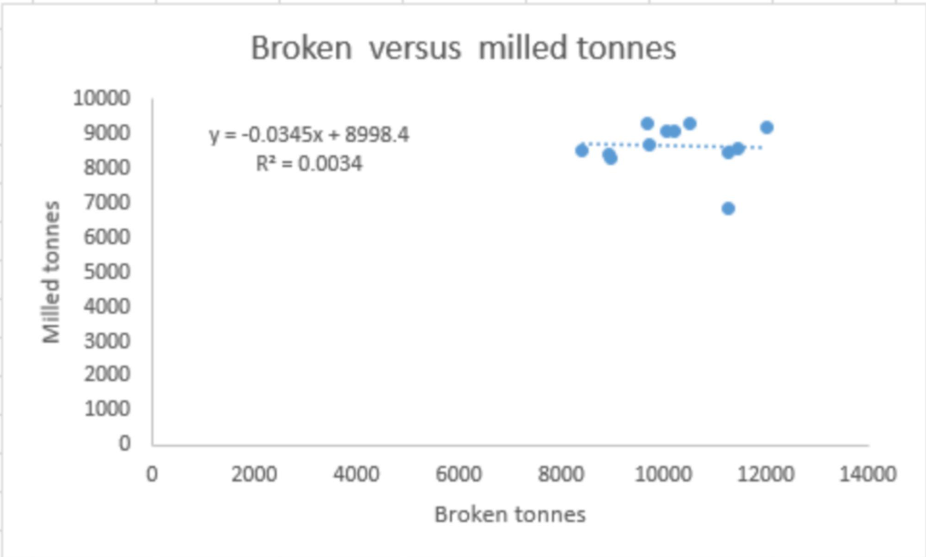

Figure 4.5 Comparison between broken and milled tonnage

Source (Mazowe Mine, 2017)

Figure 4.5 shows that there is a very poor correlation between the broken and milled tonnage. The extremely low correlation coefficient of 0.06 indicates that the broken tonnage is not a good indicator of the milled tonnage. Generally, the broken tonnage is significantly higher than the milled tonnage. This is despite the absence of any significant stockpile. The poor correlation is attributed to the reasons given above in the case of the correlation between broken and hoisted tonnes.

Figure 4.6 shows that the hoisted tonnage and milled tonnage have a strong positive correlation. The correlation coefficient of 0.99 is close to 1, indicating a strong linear relationship between the hoisted and milled tonnage. The strong relationship is consistent with the fact that all the hoisted ore is milled, as there is no significant stockpile at any time. It is concluded that the hoisted tonnage is an accurate indicator of the milled tonnage and therefore a reliable check on the milled tonnage.

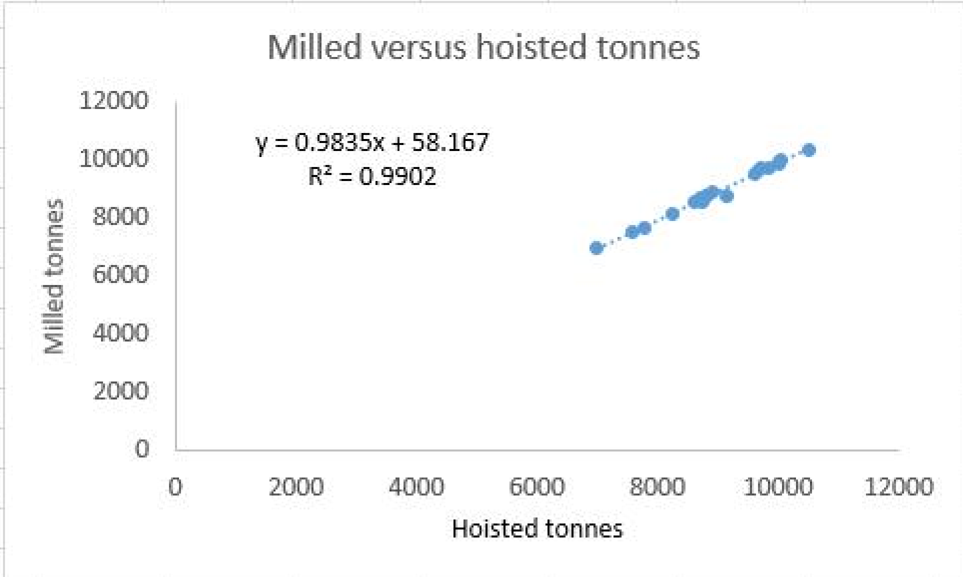

Figure 4.6 Comparison between hoisted and milled tonnage

Source (Mazowe Mine 2017)

The milled tonnage is deemed the most reliable because it is measured more accurately using weightometers. However, there have been periods when calibration is overdue and the accuracy of the weightometer is questionable. At Mazowe Mine, generally, all the broken ground is hoisted and all the hoisted tonnage is milled during the month. The only time a stockpile builds up on the surface is when there is a breakdown in the plant (Mushayavanhu, 2016). There is very limited storage capacity in the ore pass system and when there is a stoppage in the plant, stoping operations are also affected.

The set up allows for easy comparison of broken, hoisted and milled tonnage. Generally, the survey (broken tonnage), hoisted and milled compare reasonably well, although the broken tonnage is generally higher than the hoisted and milled tonnage (Mushayavanhu, 2016). The broken tonnage may be higher due to overstating and inefficient stope lashing, where some of the broken ore is left in the stope. Scatter plots for the period 2013 to 2016, indicate that there is a poor correlation between broken and hoisted tonnage and a very poor one, between broken and milled tonnage. Hoisted and milled tonnage generally compare closely, as evident from the correlation coefficient, which is close to unity. In the cases where discrepancies are excessive, milled tonnage is accepted because weightometers are considered more accurate, as long as they are serviced/calibrated regularly.

4.4 Sources of grade gain/loss

4.4.1 *Over- fragmentation of ore*

Some of the grade losses which impact the MCF at Mazowe are attributed to the mining process which pulverizes the reef. Currently, blast-holes are drilled on a burden spacing of 60cm in order to maintain a stope width of one metre after the blast. The mineralized shear zone, which is the highest grade portion of the ore, is shattered and pulverized into fine ore fragments that may not be realized by the current ore lashing methods. Fines therefore accumulate in the stopes, such that significant gold may remain as fines in the stope, contributing considerably to real gold loss. The fines with high gold values may be lodged in cracks in the footwall of the stope, or washed away during watering down. The effect of generation of high-grade fines which are lost, is grade loss.

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4.4.2 *Shaft spillage*

Shaft spillage consists predominantly of fines which are associated with high gold values. The shaft spillage is not recovered and this constitutes gold loss which results in grade loss.

4.4.3 *Waste to ore tipping*

There are no adequate underground waste handling facilities at Mazowe Mine. Consequently, when there is a significant development in waste and there are no old stopes nearby to tip into, tramming crews secretly tip waste into ore passes. This leads to dilution and as a result, gold accounted for will be less than gold called for.

4.4.4 *Drilling water*

Drilling water sweeps away the fines in stopes and they are deposited as mud in the drains. There is often an excessive amount of water because both production and development machines will be drilling. The fines, which have high gold values, turn into mud when watered. This results in real gold loss and consequent grade loss because there is no mud loading. The mud is lashed from the drains and piled along the drives and not recovered. The mud has a high concentration of sulphides and sampling indicates that they are associated with high gold values (Mushayavanhu, 2016).

4.4.5 *Vacuuming*

Vacuuming reduces areas of potential loss as the gold is recovered directly at the working face. However, there has been no vacuuming since the mine reopened in 2010. Prior to 2010 manual sweepings and vacuuming were practised. The lack of vacuuming results in a gold loss which is a source of grade loss.

4.4.6 *Footwall cracks*

Some of the minute free gold particles are lodged in the cracks in the footwall of stopes. The gold loss is caused by the blasting, scraping and sweeping operations in the stope (de Jager 1991). Due to the small particle size, the gold particles can easily enter the cracks. This problem is likely to be pronounced at Mazowe, where there is a high proportion of free gold, to the extent that up to 70% is recovered by gravity concentration (Mushayavanhu, 2016). The use of water for dust suppression, dissolving noxious gases and transporting broken ore and wash over of the stope promote the loss of gold into cracks in the footwall (de Jager, 1991). The loss of gold lodged in the cracks in the footwall of stopes gives rise to grade loss.

Chifamba (2016) suggests that the bulk of the unaccounted for gold at Mazowe Mine, is lodged in the footwall cracks in stopes. He further suggests that this gold cannot be effectively recovered by physical means, but chemical or solution mining. The proposed process involves using a new chemical (Goldix 570 patented in China 2011) to dissolve the gold by spraying a solution that contains the chemical, contacting all exposed surfaces in the underground workings (Chifamba 2016). The solution will leach any gold particles it comes into contact with. After dissolution, the gold bearing solution is harvested and pumped to the surface where the gold will be recovered using carbon.

A feasibility study has been completed and the results of underground trials were encouraging. Equipment is awaited to commission the process. Figure 4.7 shows a schematic diagram of the process. The results of solution mining will help to unravel the problem of a low MCF at Mazowe. It will also test the assertion that the bulk of the unaccounted for gold is lodged in footwall cracks in stopes and establish whether this is fact or myth.

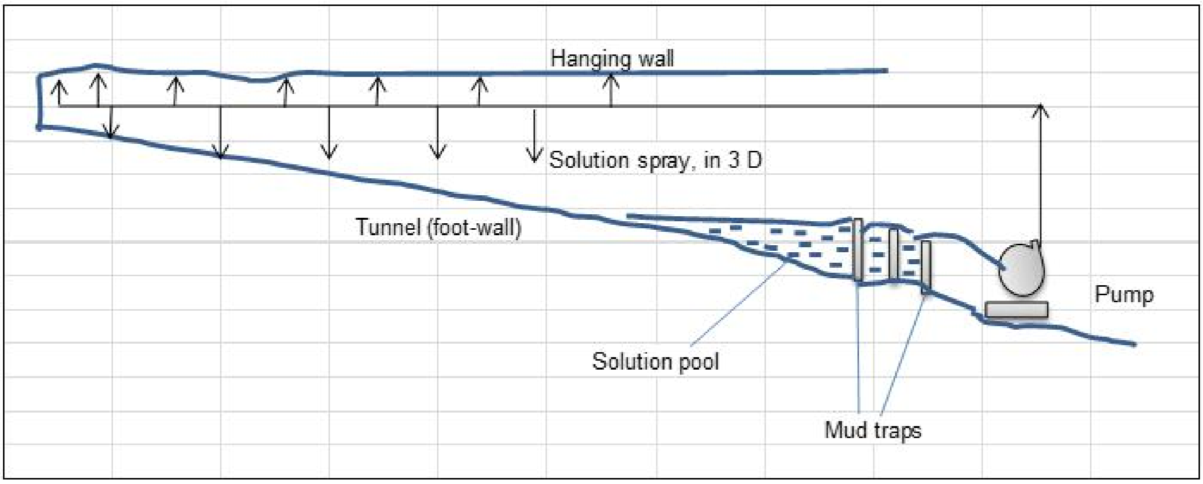

Figure 4.7 Schematic solution mining process

Source (Mazowe Mine, 2016)

4.4.7 *Unplanned dilution*

Mazowe Mine mineralization comprises shear zone-hosted reefs characterized by a high nugget effect. The mineralized shear zones are easily identifiable and distinguishable from the under-formed barren granodiorite. However, ore/waste delineation poses a challenge because of the high variability of grades. Within the high nugget environment, confidence in the tonnage estimate is variable depending upon geological continuity, though it is usually higher than confidence in the grade estimate (Dominy 2014).

There is a high risk of ore/waste misclassification. This contributes to dilution of ore, resulting in apparent gold losses with the associated grade loss. This appears to be a major problem at Mazowe Mine judging by the high number of stopes that are prematurely abandoned due to grade challenges at the production stage (Mushayavanhu, 2016). A more effective grade control system is required, with more frequent grade control sampling, to overcome this problem.

4.4.8 *Lack of operational flexibility*

Ore reserves are the most important asset of any mining project or operating mine, and are generated through exploration and development (Mohloki and Musingwini 2010). Ore reserves depletion at a faster rate than generation results in a shortage of mining places, or lack of operational flexibility. Currently, there is an acute lack of operational flexibility due to development, which is lagging behind at Mazowe Mine (Mushayavanhu, 2016).

Due to the shortage of mining places the mine is forced to produce from blocks, with inadequate sampling and not fully evaluated. Production is predominantly in inferred resource blocks Mushayavanhu, 2016). The high grades based on sparse sampling are largely overstated and this contributes to apparent gold loss which result in grade loss. When mining from inferred resources, it is common for 50% - 85% to be economically viable (Dominy 2014). To de-risk the existing uncertainties, it is essential to mine from areas where there is strong geological knowledge as well as adequate evaluation.

4.4.9 *Stope sweeps*

Fines are generated during mining and are largely lost in the stope. Sweeps recover the fines, which are considered to be associated with the highest grade portion of the ore. Generally, it is considered that the scale and efficacy of the sweeping have an impact on the MCF (de Jager, 1997). Ideally fines sweeping operations should be carried out in tandem with stoping to get a representative MCF. However, at present, stope sweeping is not done in current stopes and this results in grade loss.

At Mazowe Mine, fines sweeping is currently done in old stopes, where there are no services. The fines are swept using shovels and hard brooms, then bagged and transported on foot, or using wheelbarrows (Mushayavanhu, 2016). This is labour intensive and, consequently, small volumes of fines are achieved. No water is used to clean the footwall and therefore some of the gold is left behind contributing to grade loss.

The current practice, which involves conducting fines sweeps in old abandoned stopes, without sweeping in the current stopes, distorts the MCF. Whilst the fines sweeps impact the MCF positively, it may not be a true reflection of the MCF of the current stopes. Sweeping is not done in current stopes because they are wet and muddy, making it difficult to use brooms. This is aggravated by the fact that stopes are not lashed clean and a significant amount of ore is left behind (Mushayavanhu, 2016).

There is a need to adequately resource the fines reclamation operations in order to increase the volume of fines and improve the MCF. Table 4.2 shows that quantities of fines recovered over the years have generally progressively declined. The years that registered relatively high MCF, produced in excess of 600 ounces from fines. In the years2000, 2001 and 2005, the respective gold production from fines was 1,377 ounces, 745ounces and 694 ounces, while the MCF was 90.49%. 71.3% and 73.1% respectively.

In order to get a true reflection of the MCF in current producing areas, sweeping must be done concurrently with stope blasting operations. The fines sweeping should be done once the blasted ore is lashed from the stope, using brooms. The final stage should involve washing the footwall with water under appropriate pressure, to recover the gold left behind. This is more efficient and gives a true reflection of the MCF of the current stopes.

Table 4.2 Gold production from fines 2000 – 2016

Year	Total gold (oz)	Gold from fines (oz)	MCF (%)
2000	14,609	1,377	90.49
2001	13,033	745	71.3
2002	12,848	358	44.9
2003	14,414	0	47.6
2004	12,178	68	56.1
2005	15,022	694	73.1
2006	10,868	364	43.8
2007	8,825	721	54.3
2008	3,957	231	56.4
2009	266	0	
2010	2,783	90	59.8
2011	6,615	207	63.3
2012	9,952	42	50.2
2013	8,949	47	54
2014	11,378	135	49.4
2015	10,694	17	62
2016	11,782	126.6	63.3

Source (Mazowe Mine, 2017)

Table 4.3 Impact of fines sweeping on the MCF for July to December, 2016

	MCF WITHOUT FINES			MCF WITH FINES		
Month	Gold called for	Gold accounted for	MCF (%)	Gold called for	Gold accounted for	MCF (%)
07/2016	63926	35947	56.2	63926	37763	59.1
08/2016	69784	37488	53.7	69784	39538	56.7
09/2016	62912	35064	55.7	62912	39371	62.6
10/2016	54760	33882	61.9	54760	39082	71.4
11/2016	38940	34050	87.4	38940	38474	98.8
12/2016	37957	29744	78.4	37957	34530	91.0
Total	328279	206175	62.8	328279	228758	69.7

Source (Mazowe Mine, 2017)

Table 4.3 shows that fines sweeping clearly significantly impacts the MCF. On a monthly basis, the MCF increased by up to 11% when gold produced from fines was included. The average MCF for the six months increases by about 7% when gold produced from fines is included.

4.4.10 *Sampling*

The estimation of gold contained in the ore mined, impacts the accuracy of gold loss in the mine. The method of sampling interpretation is assessed in this section to establish its impact on the MCF. At Mazowe Mine, channel and drill-hole assays are used for evaluation. The channel samples are obtained using a diamond saw cutter in drives and raises. A sample interval of 2 metres is used when sampling drives and raises.

The channel samples are collected on a plastic sheet and bagged into plastic sample bags. Sometimes the plastic sample bags are washed using water and reused. The re-use of sample bags is cause for concern because it can potentially cause contamination. Preparation of high-grade and low-grade samples is not done separately. This can potentially result in contamination and overestimation of the low-grade samples. The fact that mill-reconciled gold grades are often significantly lower than the resource/reserve grades, may be suggestive of overstated grades. This suggests that flawed sampling or assaying protocols are contributing to apparent gold losses.

Some extremely high gold values of up to 400g/t Au are encountered. Table 4.4 shows the top cutting of high values in the various reefs in the past. Even the cut grades are too high and result in overstated average grades and subsequent grade loss. Currently, high values are arbitrarily capped at 20g/t Au (Mushayavanhu, 2016). This decision was taken by mine management to minimize the discrepancy between the predicted gold production and the actual gold produced. Mine management was concerned with the discrepancy which was invariably negative and suspected that the high grades were overstated (Mushayavanhu, 2016). This can be considered as an attempt to minimize the MCF shortfall. However, it was not based on any rigorous statistical analysis.

Table 4.4 Grade top cutting

Reef	Top cut grade (g/t)	Sampling method
Nucleus 2	400	Diamond saw sampling
Nucleus 3	340	Diamond saw sampling
Nucleus 4	140	Chip sampling
Nucleus 5	65	Chip sampling
Nucleus 6	90	Chip sampling
Birthday	195	Diamond saw sampling
Birthday	385	Diamond saw sampling
Connaught	195	Diamond saw sampling

Source (Mazowe Mine)

Grab samples are used for grade monitoring at Mazowe Mine. The sampling is biased towards fines which are high grade. The grab sampling may lead to ore waste misclassification, which results in apparent gold loss and grade loss (Mushayavanhu, 2016). Grab samples are taken from box holes, tramming level tips and chutes. Scoops of broken ground are collected from the centre and the four corners of the cocopan. All the samples are put in container. At the end of the shift the samples are mixed, quartered and submitted to the assay laboratory (Mushayavanhu, 2016).

4.4.11 *Estimation method*

Currently, resource estimation at Mazowe Mine is done manually using the polygonal method. However, computerization of the geological database to facilitate geological modelling and geostatistical resource estimation is at an advanced stage. Channel samples taken at 2m intervals in drives and block raises that define mining blocks are used for estimation. Figure 4.8 shows mineral resource blocks and their classification.

The use of the polygonal method for a deposit characterized by narrow reefs and high nugget effect, yields unreliable results. Mugwagwa (2016) suggests that due to the nature of the Mazowe gold deposit, the non-linear geostatistical method is more suitable and recommended the adoption of geostatistical methods in resource estimation. The level of accuracy of the resource estimation process and estimation method suitability has an impact on the MCF (Dominy, 2001).

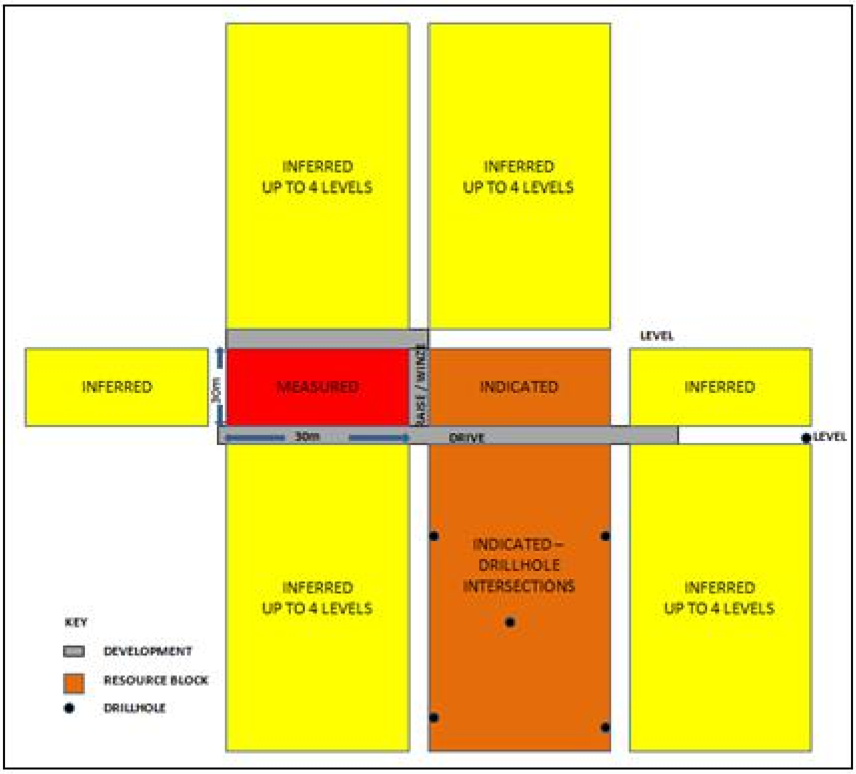

Figure 4.8 Resource block classification

Source (Mazowe Mine, 2017)

The current estimation method is prone to overstating the grade, or giving high grades an undue influence. This is considered to be one of the main causes of apparent gold losses and grade loss. High-grade values have an undue effect on the average value and have a similar effect on blocks in the vicinity of the given sample (Dominy, 2014). High nugget estimates generally have a high conditional bias and are global in nature and consequently selective stope panels are difficult (Dominy 2014). When a cut-off grade is applied, local predictions may be unreliable, leading to ore/waste misclassification (Dominy, 2014)

The challenge that arises is the lack of ore to feed the plant and production not yielding the planned tonnage and grade. This is because the mine plans are based on over-optimistic resource/reserve, which is associated with inherent high uncertainty. It is the researcher's opinion that the unsuitable resource estimation method results in overstated grades, which contribute significantly to apparent the gold loss and the accompanying grade loss. This in turn, negatively impacts the MCF.

Indicator kriging is considered the most suitable estimation technique for the Mazowe gold deposit (Mugwagwa, 2015). Indicator kriging has a wide application in the mining industry as an estimation technique over a broad range of deposits (Daya, 2013). It is a non-parametric method which does not make assumptions of the underlying samples and can handle data from mixed populations (Daya, 2013). The data is coded into 0 and 1 and this renders the predictor robust to outliers (Antunes and Albiquerque, 2013). In this regard, it suitable for the Mazowe gold deposit which is characterised by erratic mineralisation and extreme values.

Indicator kriging entails calculating and modelling indicator variograms at a range of cut offs that covers the range of input data (Daya, 2013). At an unsampled location, the value estimated represents the probability of an attribute to exceed a given threshold. At Chardoma mine in Iran, indicator kriging was applied to analyse iron mineralisation. The exploration data analysed was sparse, irregularly spaced and with a bimodal distribution (Daya, 2013). The salient features of the analysis are minimum low grade estimate and the higher grade estimate are lower than that of the raw data (Daya, 2013).

4.5 Contribution of sources of tonnage and grade gain/loss to MCF shortfall

This section presents an attempt to quantify the contribution of the identified sources of tonnage and grade gain/loss to the average MCF shortfall of 45% during the period under review. The identified sources are presented in sections 4.3 and 4.4. However, the contribution of every identified source cannot be reasonably estimated in this study, because it requires carrying out some experiments which were not done in this case. Instead, the sources have been lumped together into six groups and the contribution of each group estimated.

The resultant sources used for quantification of the contributions include: loss of fines (comprising over-fragmentation, stope sweeps, vacuuming and lodgement of fine gold in cracks in the footwall of stopes), dilution (consisting of unplanned, dilution, tipping waste to ore, mining inferred resource blocks which are not fully evaluated due to lack of operational flexibility), loss of tonnage (inefficient stope lashing, lack of blasting barricades, shaft spillage, derailments, mining of remnant blocks resulting in loss of ore in old open stopes, spillage in the plant, inaccurate weightometer reading and tipping ore to waste), sampling (flawed sampling practices and protocols and ore/waste misclassification contributing to apparent loss), specific gravity (use of an overstated S.G which contributes to apparent loss) and estimation method (the method of polygons used is not appropriate for a structurally controlled deposit with narrow discontinuous reefs characterized by a high nugget effect, and yields unreliable results)

The ore flow analysis for the period 2013 to 2016 showed that there was a grade loss of 32% and tonnage loss of 13%. From this observation it is concluded that grade related losses contributed more to the MCF shortfall than the tonnage related losses. In addition, over the same period, the reconciliation factors of tonnage and grade were estimated at 63% with standard deviation of 14% and 97% with a standard deviation of 15%, respectively. Consequently, in the estimation of the contribution to the MCF shortfall, grade related sources were apportioned greater weight than tonnage related sources. The estimates of the contribution of the six amalgamated sources of tonnage and grade gain/loss to the MCF shortfall are presented in Table 4.5.

Table 4.5 Contribution of identified sources to MCF shortfall

Source	Contribution to 45% MCF shortfall (%)	Remarks
Loss of fines	12	Contributes to real loss
Tonnage loss	6	Contributes to real loss
Dilution	7	Contributes to apparent loss
Specific gravity	2	Contributes to apparent loss
Sampling	6	Contributes to apparent loss
Estimation method	12	Contributes to apparent loss
Total MCF shortfall	45%	

Source (Mazowe Mine, 2017)

Table 4.5 shows that apparent losses contribute 60% of the MCF shortfall while real losses contribute 40%. It also shows that grade related sources contribute about 80% to the MCF shortfall whereas tonnage related sources contribute about 20%. However, further work in the form of experiments is required to quantify the contribution of all the identified sources of tonnage and grade gain/loss to the MCF shortfall accurately.

4.6 Quality assurance and quality control (QA/QC)

The QA/QC at Mazowe Mine involves inserting standards in the grade control samples analysed for gold at the mine assay laboratory. The QA/QC protocol includes:

- Standards or Certified Reference Material (CRM) to check the accuracy of the analytical laboratory;
- Duplicates to check the quality of sample splitting and laboratory precision and
- Blanks to check contamination and sample mix up.

High-grade internal standards are made from representative mill feeds, while low-grade internal standards are made from carbon in leach (CIL) tails and waste rock. These are sent to an external certified laboratory, where they are thoroughly and homogeneously mixed, then sent to different laboratories to determine the assay values which are averaged (Mushayavanhu,2016). Samples from these are regularly sent through the assay stream to monitor the performance of the assay process. Blank samples are also inserted into the system to check contamination. External standards are procured from Rocklab, New Zealand. These are inserted into the systems to monitor the assay process (Mushayavanhu, 2016).

Samples are arranged into batches of 35. In each batch there is at least one blank, CRM and a repeat. The whole batch is rejected if the CRM is beyond 3 standard deviations from the expected. Results are also rejected when two consecutive batches show CRM results of two standard deviations on the same side of the mean (Mushayavanhu, 2016). Where QC samples have failed, the laboratory is asked to re-analyze samples within the batch that begin with the sample immediately after the last successfully analysed QC sample, to the sample immediately before the next successfully analysed QC sample (Mushayavanhu, 2016). The performance of the mine laboratory and quality of sampling is assessed for results of high, medium and low-grade standards and duplicate analyses are shown in the plots below.

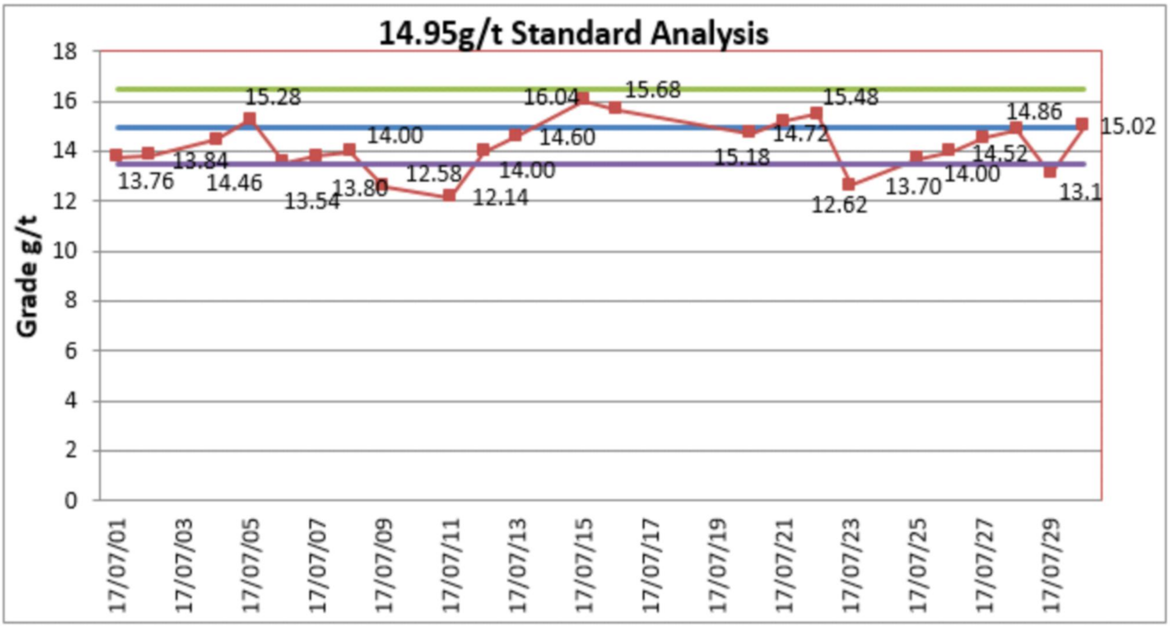

Figure 4.9 Analysis of high-grade standard

Source (Mazowe Mine, 2017)

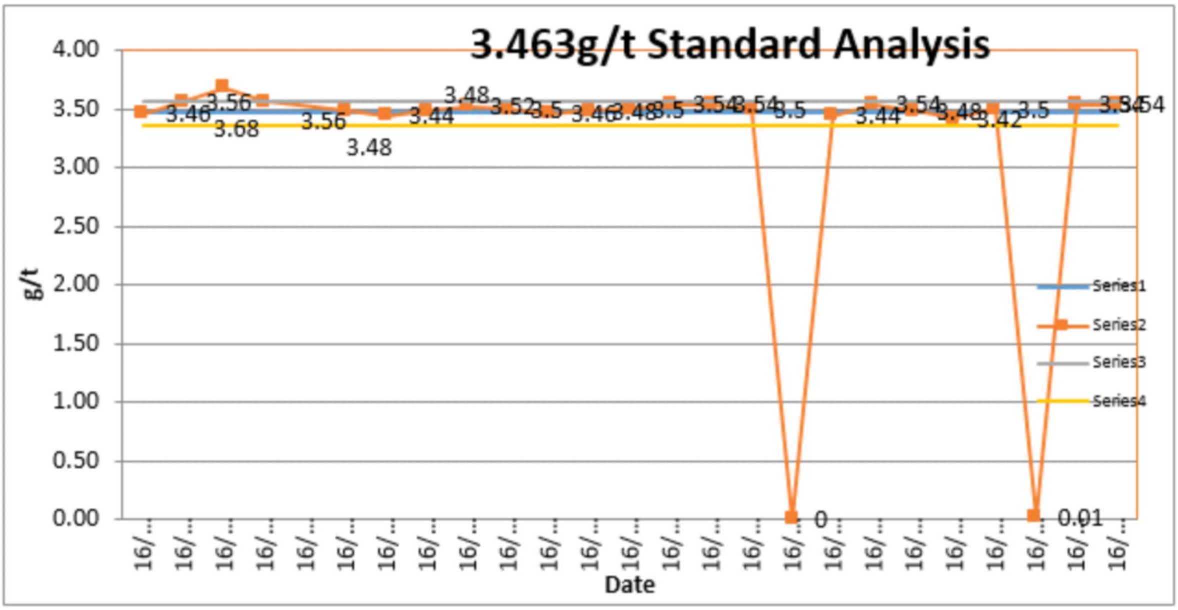

Figure 4.10 Analysis of medium-grade standard

Source (Mazowe Mine, 2017)

The medium grade is a Rocklab standard and was last used in 2016. Since then the mine has yet to acquire more certified reference materials from Rocklab (Mushayavanhu, 2016). During the period it was used, two values failed below the lower limit. However, these were isolated cases, an indication of day work anomalies. This could be attributed to spillage, as the values are below the detection limit. The standard was within limits for most of the time during the period under review.

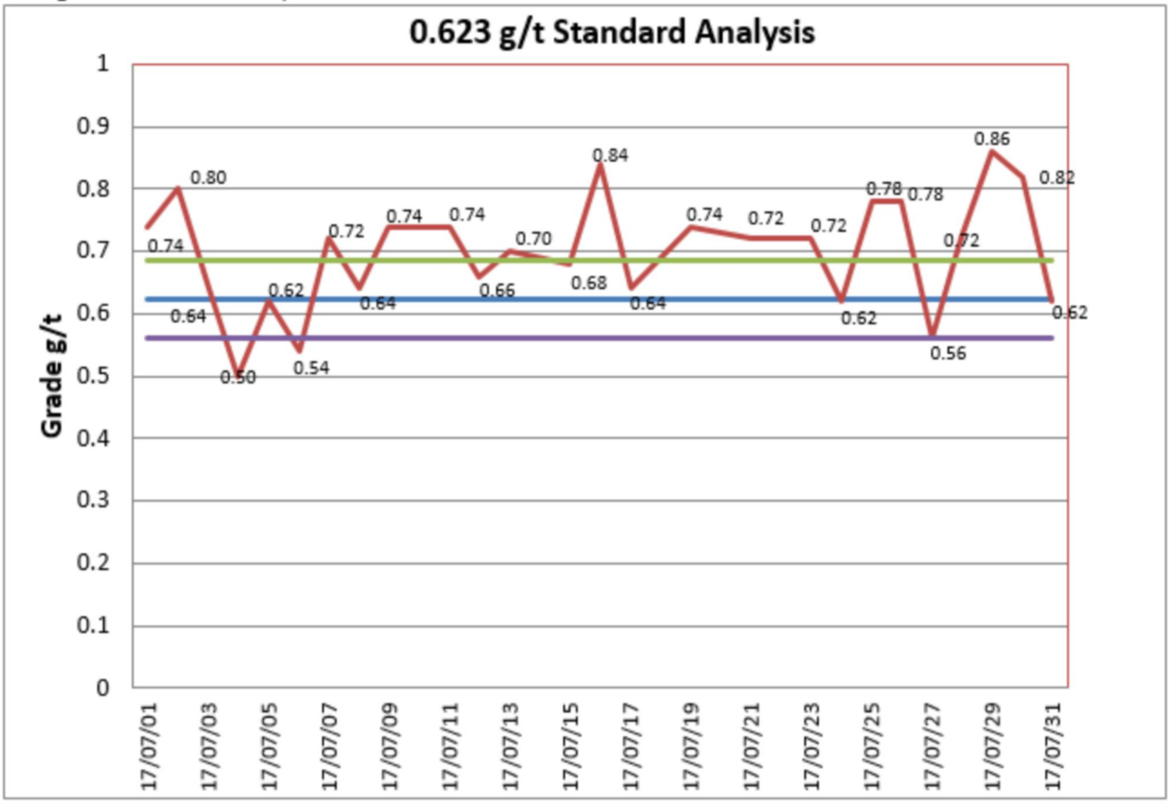

Figure 4.11 Analysis of low-grade standard

Source (Mazowe Mine, 2017)

Figure 4.11 shows that 14 samples failed above the upper limit and 2 samples failed below the lower limit. The results suggest that there is a positive bias and this may result in overestimation of grades which impact the MCF.

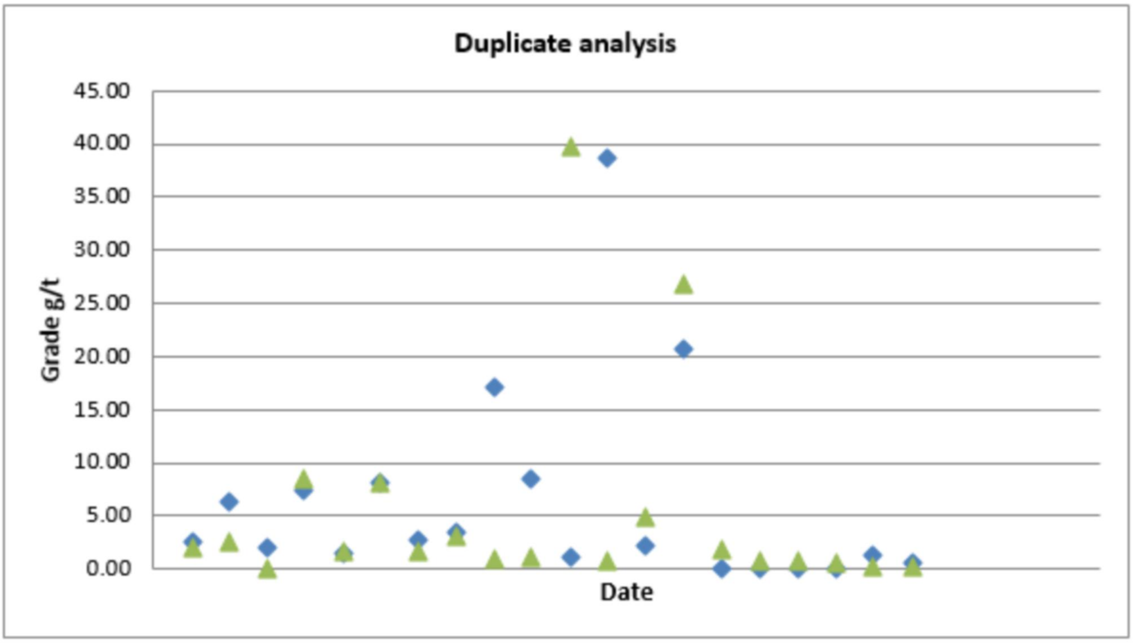

Figure 4.12 Duplicate analysis

Source (Mazowe Mine, 2017)

Figure 4.12 shows poor precision above 10 g/t.

Blank samples are materials which are barren of gold. They are used for monitoring contamination during sample preparation and analysis. At Mazowe Mine blank samples are prepared from waste rock. If there is no contamination or sample mix-up, blanks should give a value of zero g/t Au, or very close to it. Figure 4.13 shows the results of the blank analysis for the month of July 2016. The results indicate that there was contamination in the assay laboratory.

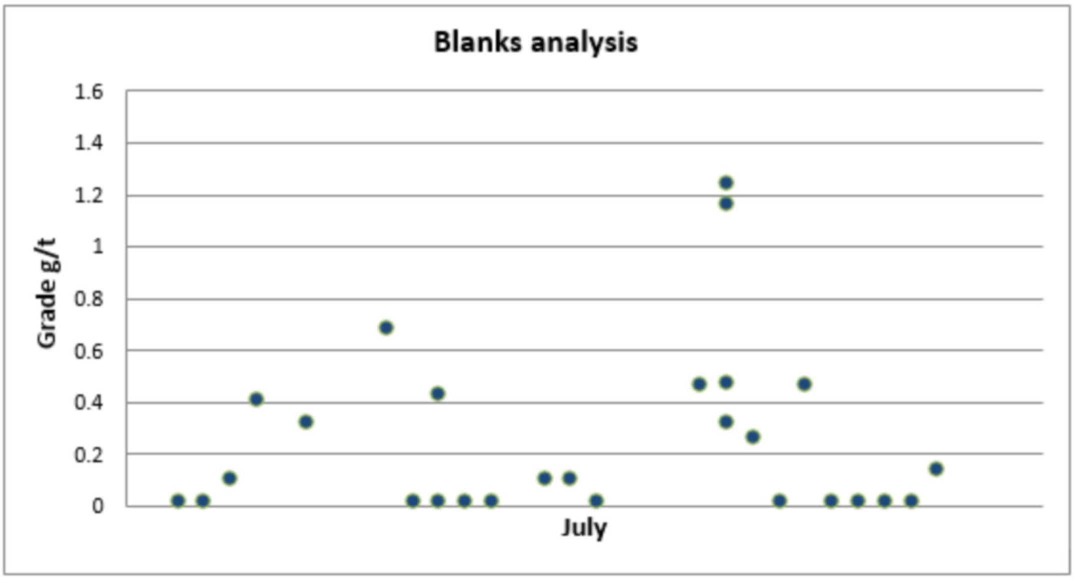

Figure 4.13 Blank analysis

Source (Mazowe Mine, 2017)

4.6.1 *QA/QC conclusion*

The mine's protocol stipulates that for assays to be acceptable, the standards must have a mean value ± 2 SD and blank samples must have a value of 0.04 g/t Au. Figure 4.11 shows that the measurement exceeded the upper limit. The high-grade standard displays a moderate negative bias. Figure 4.12 shows that while precision was good for values below 10 g/t, it was poor for values above 10 g/t. The low-grade standard showed a positive bias in July 2016. Figure 4.13 shows that the blank exceeded 0.04 g/t and gave the highest value of 1.1 g/t. Au. The values do not meet the requirements and it is therefore argued that there was evidence of contamination of the laboratory equipment during sample preparation and analysis

4.7 Mine to mill reconciliation

Mine to mill reconciliation encompasses comparison between production estimates from various sources: resource model, grade control model, mine design, plant and stockpile, hoist tally, stockpile and plant feed and plant received at the mine over a given period (Tetteh 2014). The prime goal of any reconciliation system should be to enable adjustment of processes to ensure that results are within acceptable margins of error (Hargreaves and Morley, 2014).

Reconciliation is the reality check and the ultimate challenge in high nugget systems such as Mazowe Mine and, in many cases, the estimated grade is overstated (Dominy, 2014). The reconciliation challenges are attributable to specifics during estimation and/or mining, but generally, fundamental causes associated with sampling errors (Dominy 2014). In high nugget systems reconciliation over short periods such as monthly, is fraught with difficulty due to high variability, but longer periods may yield better results (Dominy, 2014).

Figure 4.14 depicts the current resource model to plant reconciliation at Mazowe Mine. The mine to mill reconciliation data for the period 2013 to 2016 is presented in Tables 4.6a and4.6b.

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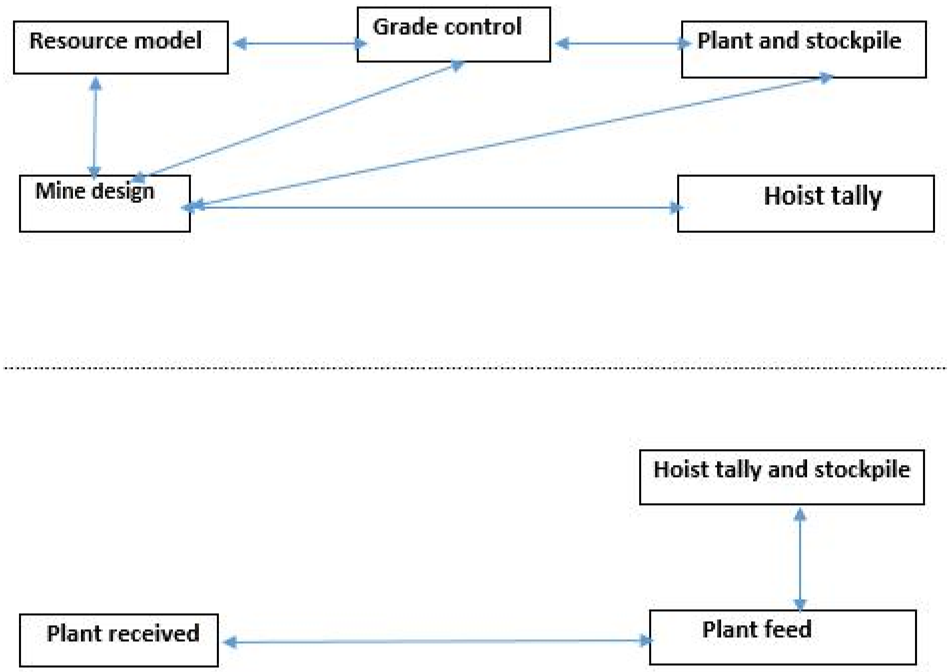

Figure 4.14 Resource model to plant reconciliation at Mazowe Mine

Source (Adapted from Tetteh, 2014)

In Figure 4.14 measurement points are established between two points and the reconciliation factors calculated. The dotted line demarcates the boundary between the top part, which is the source (resource model) and the bottom part, which is the plant represented by plant received and plant feed. The mine to mill reconciliation data at Mazowe for the period 2013 to 2016, is presented in Tables 4.6a to 4.8b, statistically analysed and discussed.

Table 4.6a Mine to mill reconciliation at Mazowe Mine 2013-2014

	Month By Month Results							
				Mill			Performance)	
	Probable Ore Reserves			Reconciled Head Grade			(Mill /Reserves)	
Month	Tonnes	g/t Au	content (g)	Tonnes	g/t Au	content (g)	Tonnes %	Grade %
Jan-13	8333	6.63	55248	10506	3.67	38557	126	55
Feb-13	10024	6.01	60244	11004	3.5	38514	110	58
Mar-13	10653	6.47	68925	11512	3.45	39716	108	53
Apr-13	9115	6.02	54872	10742	3.79	40712	118	63
May-13	10446	5.17	54006	11140	3.44	38322	107	67
Jun-13	11883	4.84	57514	12702	2.94	37344	107	61
Jul-13	8412	6.18	51986	9120	2.91	26539	108	47
Aug-13	8252	5.00	41260	8253	3.18	26245	100	64
Sep-13	8423	7.40	62330	8931	4.16	37153	106	56
Oct-13	7095	11.00	78045	6532	3.73	24364	92	34
Nov-13	7965	8.91	70968	7260	3.76	27298	91	42
Dec-13	8633	7.26	62676	7042	3.35	23591	82	46
Total	109234	6.57	718074	114744	3.47	398354	105	53
Jan-14	7050	6.36	44838	6325	3.55	22454	90	56
Feb-14	9756	8.95	87316	6625	4.70	31138	68	53
Mar-14	8692	7.34	63799	7788	4.50	35046	90	61
Apr-14	7562	8.34	63067	6417	4.03	25861	85	48
May-14	8436	8.33	70272	7485	3.55	26572	89	43
Jun-14	9493	8.30	78792	6274	4.91	30805	66	59
Jul-14	9004	7.20	64829	8515	3.75	31931	95	52
Aug-14	8425	7.50	63188	7873	4.30	33854	93	57
Sep-14	8930	7.60	67868	7844	4.66	36553	88	61
Oct-14	9597	5.50	52784	8833	5.02	44342	92	91
Nov-14	10004	6.10	61024	8905	5.16	45950	89	85
Dec-14	10162	7.06	71744	8824	4.92	43414	87	70
Total	107111	7.37	789520	91708	4.45	407919	86	60

Source (Mazowe Mine, 2017)

Table 4.6b Mine to mill reconciliation 2015-2016

	Month By Month Results							
				Mill		Performance)		
	Probable Ore Reserves			Reconciled Head Grade			(Mill /Reserves)	
Month	Tonnes	g/t Au	content (g)	Tonnes	g/t Au	content (g)	Tonnes %	Grade %
	Probable Ore Reserves			Reconciled Head Grade			(Mill /Reserves)	
Jan-15	8855	7.60	67298	7790	3.91	30459	88	51
Feb-15	9745	6.20	60419	8151	4.55	37087	84	73
Mar-15	10449	6.70	70008	8805	4.47	39358	84	67
Apr-15	9999	7.10	70993	7314	4.56	33352	73	64
May-15	7047	6.80	47920	7844	4.25	33337	111	63
Jun-15	9038	6.50	58747	8428	3.63	30594	93	56
Jul-15	8509	6.10	51905	7443	3.63	27018	87	60
Aug-15	5949	6.50	38669	7799	3.75	29246	131	58
Sep-15	7380	8.10	59778	7564	3.29	24886	102	41
Oct-15	7904	6.00	47424	9438	3.14	29635	119	52
Nov-15	7365	6.30	46400	7226	4.12	29771	98	65
Dec-15	7659	6.40	49018	8246	4.25	35046	108	66
Total	99899	6.69	668577	96048	3.95	379789	96	59
Jan-16	9146	6.85	62650	8601	4.2	36124	94	61
Feb-16	9088	4.98	45258	9071	3.82	34651	100	77
Mar-16	7583	4.42	33517	8302	4.24	35200	109	96
Apr-16	6859	6.47	44378	8509	4.02	34206	124	62
May-16	7409	4.95	36675	8432	3.53	29765	114	71
Jun-16	10004	4.87	48719	6853	3.85	26384	69	79
Jul-16	9682	6.56	63514	8472	4.46	37785	88	68
Aug-16	10000	5.9	59000	9194	4.3	39534	92	73
Sep-16	9387	6.63	62236	9274	4.25	39415	99	64
Oct-16	9088	5.64	51256	9057	4.32	39126	100	77
Nov-16	9496	4.18	39693	9311	4.13	38454	98	99
Dec-16	8463	4.40	37237	8678	3.98	34538	103	90
Total	106205	5.50	584133	103754	4.10	425184	98	75
Grand	442449	6.53	2760304	406254	3.97	1611246	96	61

Source (Mazowe Mine, 2017)

Table 4.7 Quarterly mine to mill reconciliation 2013-2016

Quarterly Reconciliation 2013-2016									
				Mill			Performance		Nominal Resource
	Probable Ore Reserve		Content()	Reconciled Head Grade		Content	(Mill /Reserves)		Classification
Quarter	Tonnes	g/t Au	(g)	Tonnes	g/t au)	(g)	Tonnes %	Grade %	
Q1	29010	6.36	184417	33022	3.54	116787	114	56	Inferred
Q2	31444	5.29	166392	34584	3.37	116378	110	64	Inferred
Q3	25087	6.20	155576	26304	3.42	89937	105	55	Inferred
Q4	23693	8.93	211689	20834	3.61	75253	88	40	Inferred
	109234	6.57	718074	114744	3.47	398354	105	53	Inferred
2014 Quarterly Results									
Q1	25498	7.69	195953	20738	4.27	88637	81	56	Inferred
Q2	25491	8.32	212131	20176	4.13	83238	79	50	Inferred
Q3	26359	7.43	195884	24232	4.22	102338	92	57	Inferred
Q4	29763	6.23	185552	26562	5.03	133706	89	81	Indicated
Total	107111	7.37	789520	91708	4.45	407919	86	60	
2015 Quarterly Results									
Q1	85541	5.92	506385	93910	3.44	323102	110	58	Inferred
Q2	80224	6.65	533657	81722	3.45	281567	102	52	Inferred
Q3	134732	6.78	914027	135482	3.59	486992	101	53	Inferred
Q4	81613	7.27	593567	70970	4.50	319281	87	62	Inferred
Total	382110	6.67	2547636	382084	3.69	1410942	100	55	
2016 Quarte ly r Results									
Q1	134732	6.78	914027	135482	3.59	486992	101	53	Inferred
Q2	81613	7.27	593567	70970	4.50	319281	87	62	Inferred
Q3	192652	6.73	1295905	185618	3.94	731020	96	59	Inferred
Q4	296569	6.88	2041251	288174	3.77	1087840	97	55	Measured
Total	705566	6.87	4844751	680244	3.86	2625133	96	56	Inferred

Source (Mazowe Mine 2017)

The reconciliation factors estimated for tonnage, grade and gold contents in ounces are 97%, 63% and 61% respectively (Tables 4.8a and 4.8b). During the four years under review, the average tonnage reconciliation factor was 97%, with a standard deviation of 15%, while the average grade reconciliation factor was 63%, with a standard deviation of 14%. The average ounces reconciliation factor was 61%, with a standard deviation of 16%.

Table 4.8a Reconciliation factors for 2013-2014

MILL TO MINE RECONCILIATION %				
Month	Tonnes	Grade	Ounces	ource classificat
Jan-13	126	55	70	Infered
Feb-13	110	58	64	Infered
Mar-13	108	53	58	Infered
Apr-13	118	63	74	Infered
May-13	107	67	71	Infered
Jun-13	107	61	65	Infered
Jul-13	108	47	51	Infered
Aug-13	100	64	64	Infered
Sep-13	106	56	60	Infered
Oct-13	92	34	31	Infered
Nov-13	91	42	38	Infered
Dec-13	82	46	38	Infered
Jan-14	90	56	50	Infered
Feb-14	68	53	36	Infered
Mar-14	90	61	55	Infered
Apr-14	85	48	41	Infered
May-14	89	43	38	Infered
Jun-14	66	59	39	Infered
Jul-14	95	52	49	Infered
Aug-14	93	57	54	Infered
Sep-14	88	61	54	Infered
Oct-14	92	91	84	Infered
Nov-14	89	85	75	Measured
Dec-14	87	70	61	Measured

Table 4.8b Reconciliation factors for 2015-2016

MILL TO MINE RECONCILIATION %				
Month	Tonnes	Grade	Ounces	Resource classification
Jan-15	88	51	45	Inferred
Feb-15	84	73	61	Inferred
Mar-15	84	67	56	Inferred
Apr-15	73	64	47	Inferred
May-15	111	63	70	Inferred
Jun-15	93	56	52	Inferred
Jul-15	87	60	52	Inferred
Aug-15	131	58	76	Inferred
Sep-15	102	41	42	Inferred
Oct-15	119	52	62	Inferred
Nov-15	98	65	64	Inferred
Dec-15	108	66	71	Inferred
Jan-16	94	61	58	Inferred
Feb-16	100	77	77	Indicated
Mar-16	109	96	105	Measured
Apr-16	124	62	77	Inferred
May-16	114	71	81	Inferred
Jun-16	69	79	54	Inferred
Jul-16	88	68	59	Inferred
Aug-16	92	73	67	Inferred
Sep-16	99	64	63	Inferred
Oct-16	100	77	76	Indicated
Nov-16	98	99	97	Measured
Dec-16	108	90	93	Measured
Average	**97**	63	61	

Source (Mazowe Mine, 2017)

Table 4.8b shows that the best monthly reconciliation factors were achieved in November 2016 (tonnage 98%, grade 99%, ounces 97%). Other months with commendable reconciliation factors are December 2015 (tonnage 103%, grade 90%, ounces 93%) and March 2016 (tonnage 109%; grade 96% and ounces 105%). The three months with the best reconciliation factors are characterized by production entirely from measured resource blocks (Tables 4.8a and 4.8b)

The 4th quarter of 2016 yielded the best average quarterly reconciliation factors in the 4 years under review, (100%, 87% and 87% in terms of tonnage, grade and ounces, respectively). This is attributable to the fact that during this quarter production came mainly from measured resource blocks.

Table 4.8b shows that 2016 had the best annual average reconciliation factor - 98% for tonnage, 75% for grade and 73% for ounces. This is attributable to the fact that in 2016, more production came from measured and indicated resource blocks, compared to the 3 prior years, when production was mainly from inferred resource blocks. In 2014, the two highest grade reconciliation factors were achieved in November and December, when production was in measured resource blocks.

4.8 Chapter summary

The ore flow analysis for the period 2013 to 2016 shows that the tonnage and grade losses are 13% and 32% respectively. Mine to mill reconciliation over the same period yielded an average tonnage reconciliation factor of 97%, with a standard deviation of 15% and a grade reconciliation factor of 63%, with a standard deviation of 14%. These statistics are indicative of greater confidence in tonnage measurement than the grade. Consequently, there is a greater discrepancy between resource estimate grade and the mill reconciled grade, than between the resource model tonnage and the milled tonnage.

Underground sources of tonnage loss include inefficient stope lashing, mining of remnant blocks, which involves long scraping distances, lack of blasting barricades, multi-handling as a result of sub optimum mine design, derailments and spillage. Tonnage gains from accumulation and tonnage loss to accumulation are 5.2% and 4.5% respectively.

Unaccounted for loss which amounts to 1.3%, is insignificant. In the process plant, the sources of tonnage loss were excessive spillage due to worn out conveyor belts and poor design and excessive leaks. Other sources of tonnage loss are an overstated specific gravity and inaccurate weightometer readings due to lack of timely service and calibration.

The main sources of loss of grade include the loss of fines, which are associated with high gold values. The blasting pattern employed pulverizes the reef, resulting in the generation of high- grade fines, which are lost in the stope. The fines are lost due to lack of blasting barricades, lack of vacuuming and lack of sweeping in current stopes. Some of the fines are swept away as mud during watering down and are not recovered since mud loading is not currently done. Some fine gold particles are lodged in cracks in the footwall of stopes. The fines sweeping operations are only carried out in old stopes and are poorly resourced.

Unplanned and undetected dilution also contributes to loss of grade. Unplanned dilution is evident from the high number of stopes that are prematurely abandoned due low grades. The lack of operational flexibility results in the mine producing predominantly from remnant reserve blocks and Inferred resource blocks. This increases the risk of unplanned dilution and ore/waste misclassification which impacts the grade. The estimation method which is not suitable for the high nugget effect gold deposit, yields overstated grades and is a major source of loss of grade. In the processing plant, the excessive spillage and leaks due to the poor state of equipment, result in a loss of gold which is a source of grade loss.

In conclusion, the main loss at Mazowe Mine is grade, rather than tonnage. This is evident from the average grade loss of 32%, compared to the average tonnage loss of 13%. This is corroborated by the reconciliation factors of tonnage and grade which are 97%, with a standard deviation of 15%, and 63%, with a standard deviation of 14% respectively. A rudimentary quantification of the contribution of identified sources of tonnage and grade gain/loss to the MCF shortfall also indicate that grade related issues account for about 80% while tonnage related issues contribute 20%.

5. APPARENT GAIN/LOSS OR REAL LOSS

5.1 Chapter overview

This chapter focuses on the tonnage and grade gain/loss along the mining value chain at Mazowe Mine. Resource modelling, mining, fines sweeps, tramming, survey volume measurement, sampling and assaying QA/QC are assessed to identify the contributing factors to tonnage and grade gain/loss. Identifying the main contributing factors is essential for crafting practical mitigating measures which ultimately impact the MCF positively. The key focus areas are apparent tonnage gain/loss, apparent grade gain/ loss, real tonnage loss and real grade loss.

5.2 Apparent tonnage loss

The unaccounted for tonnage loss during the period 2013 to 2016 amounts to 5,993t (6%). This is an apparent loss tonnage loss which is attributed to overstated survey measurement. At month end, the survey department measures underground excavations and apply a specific gravity of 2.9t/$m^3$to calculate tonnage. The specific gravity appears overstated for a granodiorite which is the host rock. The specific gravity was changed from 2.7tm^3 to 2.9t/m^3, an increase of 7.4% which is a potential source of apparent tonnage loss. An inflated specific gravity gives rise to overstated tonnage during the estimation process. This results in apparent tonnage loss and in terms of discrepancy, it is an excess.

Inaccurate weightometer measurements are also a source of apparent tonnage loss at Mazowe Mine. When the weightometers are due for service, the metallurgical department tends to overstate the processed tonnage, resulting in apparent tonnage loss. In 2015 there was a shortfall of 2.7kg of gold in one week in November. An investigation revealed that about 1.8kg was attributable to overstated processed tonnage due to inaccurate weightometer tonnage measurement. Fines from underground stope sweeps bypass the weightometer and the automatic sampler. They are fed into a hopper with a volume of 12m^3 and a bulk density of 1.3 t/m^3 is applied to obtain the tonnage. This tonnage measurement is not accurate and is a potential source of apparent tonnage loss.

5.3 Apparent grade loss

Channel samples which are used for evaluation and grade control are sometimes bagged in reused plastic sample bags. This practice can potentially cause contamination, which results in an overestimation of lower grades and the accompanying apparent grade loss. In addition to channel sampling, grab samples are used to monitor grade. The samples are collected from every car during tramming, but they are biased towards fines which are high-grade and consequently, the low-grade material is also taken to the plant and this contributes to apparent grade loss.

Extremely high grades are encountered and these may have an undue influence on the estimated average grades, giving rise to apparent grade loss. In the past, high grades were capped at 65g/t Au, up to 400g/t Au, depending on the reef and on whether it is chip sampling or diamond saw sampling. Currently, all the high grades are arbitrarily capped at 20g/t Au. However, this may still yield overstated grades and a more rigorous statistical approach is required to establish how best to treat high-grade values.

Due to the lack of operational flexibility, the bulk of the mining is in inferred resource blocks. There is high inherent uncertainty, as these blocks have not been adequately evaluated and a high risk of undetected dilution is a contributing factor to apparent grade loss. The problem of grade uncertainty is indicated by the high number of stopes that are prematurely abandoned due to grade problems. There is a tendency to prematurely commission stopes before they are fully evaluated, due to the lack of mining ends, and this results in serious grade control challenges. Unplanned dilution is also a source of apparent grade loss at Mazowe Mine. The nature of the mineralization, structurally controlled narrow, discontinuous reefs, pose a challenge of ore and waste delineation. Within such a high nugget effect environment, realistic local grade predictions may be difficult, giving rise to ore/waste misclassification.

The current estimation method is not suitable for a gold deposit such as Mazowe, characterized by narrow reefs with complex geometry and high nugget effect. When the polygonal method is used on the Mazowe deposit which has a high nugget effect, high-grade values tend to have an undue effect on the average value. Consequently, mine plans are based on overoptimistic resources/reserves, which are associated with inherent high uncertainty. The predicted reserve/resource grades are higher than grades realized when the blocks are mined and this is a major source of apparent grade loss. The unsuitable estimation method appears to be major contributing factor to grade loss and the low MCF.

In the assay laboratory, preparation of high-grade and low-grade samples is not done separately and this increases the risk of contamination and resultant overestimation of low grade samples. This gives rise to apparent grade loss. The fact that blanks yield assay values well above zero g/t indicate that at times, contamination of equipment occurs in the Mazowe assay laboratory.

5.4 Real tonnage loss

The contributing factors to real tonnage loss at Mazowe Mine are: inefficient stope lashing, lack of blasting barricades, multiple handling, derailments during tramming and derailments in the incline shaft, shaft spillage, spillage and leaks in the plant.

At Mazowe Mine, inefficient stope lashing is one of the major factors that contribute to tonnage loss. The broken ore is lashed using scrapers. Quite often the stope configuration is not conducive to efficient lashing and, as a result, a significant amount of broken ore remains in the stope. The broken ground left in the stopes contributes to real tonnage loss. The unfavourable stope configuration is due to the premature commissioning of stopes, before all the necessary development is in. The stopes are prematurely commissioned due to the lack of mining ends, because production has caught up with development. The ore loss is compounded by long scraping distances of up to 110m and multi-handling. Scraping is not effective beyond a distance of 75m (Mandidi 2016).

The use of blasting barricades ensures that the blasted ore is confined to a limited area and can be efficiently lashed with minimum tonnage loss. Currently, blasting barricades are not used and blasted ore is spread over a wide area in open stopes. Some of the broken ore lands in areas which are inaccessible to lashing, constituting tonnage loss.

Currently, mining is widely dispersed, because the mainstay of production is remnant blocks. Remnant blocks are generally small and were abandoned in the past for various reasons, including lower grades than expected. When mining remnant blocks, some of the blasted ore is lost to old stopes and this is aggravated by the lack of blasting barricades. The long scraping distances necessitate the use of scrapers in a series, and this multi-handling gives rise to tonnage loss.

Derailments are frequent in certain sections of the incline Connaught Shaft and this results in tonnage loss. The shaft spillage is not lashed because the shaft bottom is flooded and this a source of tonnage loss. Derailments also occur during tramming because the tracks are in a bad state of repair. These also contribute to tonnage loss, as some of the spilt ore is not lashed back into cars.

Spillage and leaks are major challenges in the processing plant at Mazowe Mine. The excessive spillage and leaks are considered a contributing factor to tonnage loss in the plant. The spillage largely consists of fines which are considered to be high grade. Conveyor belts in the plant are in a poor state of repair, which results in spillage and significant accumulation of fines on the ground.

5.5 Real grade loss

At Mazowe Mine real grade loss emanates from the loss of fines, which are associated with high gold values, in the underground stopes. The blasting pattern employed results in over-fragmentation of the reef and generation of fines. Such fines are recovered by fines sweeps operations in the stopes. However, fines sweeps operations are not conducted in current producing stopes and are only carried out in old stopes in abandoned areas. Consequently, high-grade fines in the producing stopes are not recovered and this gives rise to real grade loss. The loss of fines is aggravated by the lack blasting barricades.

The water used to suppress dust and to transport ore after a blast, washes away the fines and deposits them as mud in drains in drives. This contributes to real grade loss as mud-lifting is not done. The mud is only lashed to clear the drains and it is piled along the sides of the drives where it accumulates. When the water is clear, it can be observed that the mud in the drains is rich in sulphides and assays show that the mud is associated with high gold values. The fact that inclusion of gold from fine sweeps significantly improves the MCF, demonstrates the significant impact of real grade loss due to loss of fines. From 2001 to 2016, the years with a relatively high MCF, had a significant gold production (in excess of 600 ounces) from fines sweeps.

Some of the minute fine gold particles are lodged in the cracks in the footwall of stopes. The gold loss is caused by the blasting, scraping and sweeping operations in the stope (de Jager 1997). Due to the small particle size, the gold particles can easily enter the cracks. This problem is likely to be pronounced at Mazowe, where a high proportion of the gold is free gold and up to 70% is recovered by gravity concentration (Mushayavanhu, 2016). The use of water for dust suppression, dissolving noxious gases, transporting broken ore and wash-over of the stope, promote the loss of gold into cracks in the footwall (de Jager, 1997). The loss of gold lodged in the cracks in the footwall of stopes contributes to real grade loss. Chifamba (2016) suggests that the bulk of the unaccounted for gold at Mazowe Mine is lodged in the footwall cracks in stopes. He also suggests that this gold cannot be effectively recovered by physical means, but only by chemical or solution mining.

5.6 Chapter summary

This chapter dealt with apparent tonnage gain/loss, apparent grade gain/loss, real tonnage loss and real grade loss. The apparent tonnage loss is insignificant and was estimated at 6%. It is mainly attributed to the overstated specific gravity, inaccurate weightometer measurements due to overdue service and inaccurate measurement of the weight of fines. Real tonnage loss is also insignificant and is attributed to inefficient stope lashing, lack of blasting barricades, spillage during tramming, shaft spillage and spillage and leaks in the plant.

The apparent grade loss is significant and is considered a key driver of the low MCF. The main contributing factor to the apparent grade loss is an estimation method which is not suitable for a high nugget effect deposit. The high-grade values have an undue effect on the average grade. Consequently, mine plans are based on overoptimistic resources/reserves, with inherent high uncertainty. The other contributing factors are undetected dilution and unplanned dilution and ore/waste misclassification.

The real grade loss is attributed primarily to the loss of high-grade fines that are generated during blasting. The fines are lost in the stopes because there are no fine sweeps in the current stopes. The lack of blasting barricades also contributes to the loss of fines. The fines are also washed away by water during watering down of stopes. The importance of the real grade loss due to loss of fines is demonstrated by the impact of fines sweeps on the MCF. Real grade loss is also attributed to the loss of fine gold particles that are lodged in cracks in the footwall of stopes.

In conclusion, both apparent grade loss and real grade loss occur and are significant. However, the apparent grade loss is deemed more pronounced. The apparent grade loss is primarily attributed to the estimation method, which is considered unsuitable for the type of deposit, while the real grade loss is largely attributable to the loss of high-grade fines. The grade loss is more pronounced than tonnage loss and has a greater impact on the MCF.

6. CONCLUSIONS

6.1 Chapter overview

Chapter 6 presents the conclusions of this research study. The conclusions are primarily premised on the findings of Chapters 3, 4 and 5. The chapter summarizes the key findings of the research study. These include the MCF trends during the period under review, tonnage gain/loss, grade gain/loss, sources of tonnage gain/loss and sources of grade gain/loss, apparent tonnage gain/loss, apparent grade gain/loss, real tonnage loss and real grade loss. The chapter identifies whether it is primarily tonnage gain/loss or grade gain/loss, as well as whether it is primarily apparent gain/loss or real loss.

6.2 MCF trend

During the period 2001 and 2016 the MCF at Mazowe Mine was generally low, averaging 55%. During the entire period it was below 100%, but was relatively high in the years with significant gold production from fines sweeps in underground stopes. In the period under review, a total of 307,749 ounces of gold was called for, but only 170,448 ounces were accounted for. Unaccounted for gold amounted to 137,301 ounces or 45%. Theoretically, this translates into a loss of 45%, implying that 45% of the potential revenue was not realized. Such a significant shortfall adversely impacts the mine's financial performance.

On an annual and monthly basis, the unaccounted for gold averages 9,153 ounces and 763 ounces respectively. Assuming a gold price of $1,200 per ounce, this amounts to a potential revenue loss of $915,600 a month, or about $11 million per year, which is very significant. It is therefore critical to investigate the issue of the low MCF at Mazowe Mine and implement corrective measures. The situation obtaining at Mazowe Mine is similar to the case of Free gold, where gold unaccounted for was estimated at 2.5t per month (de Jager, 1997).

6.3 Summary of key findings

This study revealed that there is an acute perennial problem of a low MCF at Mazowe Mine and it averaged 55% in the period under review. The ore flow balance sheet analysis for this period shows a tonnage loss of 13% compared to the grade loss of 32%. The mill to mine tonnage reconciliation factor for the period was 97%, with a standard deviation of 15%, compared to 63%, with a standard deviation of 14% for the grade.

For the period 2013 to 2016, the tonnage discrepancy was primarily an excess and was estimated at -8%. The sources of apparent tonnage loss are mainly an overstated specific gravity and inaccurate weightometer measurements when the weightometers are overdue for service. The sources of real tonnage loss are; lack of blasting barricades to prevent loss of ore during blasting, inefficient stope lashing, spillage during tramming and hoisting and spillage and leaks in the process plant. The inefficient scraping is attributed to long scraping distances and unfavourable stope configuration. Stopes are not lashed clean and considerable broken ore remains in the stope, constituting tonnage loss. Some of the mining is done in remnant blocks, which are adjacent to old open stopes. Some of the blasted ground lands in these old stopes and cannot be recovered. This is aggravated by the fact that blasting barricades are not used. Tonnage-related issues do not seem to impact the MCF as severely as the grade-related issues.

The loss at Mazowe Mine is primarily a grade loss. The MCF is impacted by the estimation process, inaccurate grade interpolation, difficulty in local grade prediction and ore/waste misclassification, which result in grade loss. The current estimation method is not suitable for a gold deposit such as Mazowe, characterized by structurally controlled narrow reefs with complex geometry and high nugget effect, greater than 50%. It yields overstated grades which is a major source of grade loss. Other key contributing factors to grade loss are a loss of high-grade fines in underground stopes, inefficient fine sweeps operations, loss of fine gold lodged in cracks in the footwall of stopes, lack of blasting barricades and lack of mud loadings, undetected and unplanned dilution.

The mill-reconciled grade is often significantly lower than the resource/reserve estimate grade. This indicates that resource grades are overstated. This is due to the fact that the current method of resource estimation and grade interpolation is not suitable for the deposit. The level of accuracy of the resource estimation process suitability has an impact on the MCF.

When the polygonal method is used on the Mazowe deposit which has a high nugget effect, high-grade values tend to have an undue effect on the average value. Consequently, mine plans are based on overoptimistic resources/reserves, which are associated with inherent high

uncertainty. The predicted reserve/resource grades are higher than grades realized when the blocks are mined. This constitutes a significant source of grade loss and apparent gold loss.
The nature of the mineralization, structurally controlled narrow, discontinuous reefs, pose a challenge of ore and waste delineation. Within such a high nugget effect environment, realistic local grade predictions may be difficult, giving rise to ore/waste misclassification. This is aggravated by the lack of operational flexibility whereby the bulk of mining is in inferred resource blocks, which are not adequately evaluated. Grab samples are used for grade monitoring and this may also lead to ore/waste misclassification. The loss of grade due to unplanned dilution contributes to the apparent gold loss.

Loss of fines, which are associated with high grades, is considered a significant source of grade loss. The drilling pattern used generates a lot of fines which are lost in the stope. In addition, no blasting barricades are used, so fines are not confined to the current stope. Fine sweeps operations are not carried out in current stopes. Fines sweeps are done in old, abandoned areas, with no services such as water, compressed air and tracks. The fines sweeping is done manually and fines are carried in bags on foot, or transported using wheelbarrows over long distances.

Generally, the fines sweeps operations are poorly resourced and poorly planned. There is no program showing targets and planned production and fine sweeps operations appear to be haphazard. Consequently, small tonnages are achieved, despite the fact that it has been demonstrated that fine sweeps impact the MCF positively.

Some of the fines generated in the stopes are swept away by drilling water and deposited as mud in the drains along tramming routes. This also constitutes source of gold loss because mud loading is currently not practiced. The mud is simply lashed to clean the drains and piled along the tramming routes. It is imperative to include and prioritise vamping of tramming routes as part of stope sweeps operations to mitigate gold loss.

Gold is also lost as fine particles lodged in the footwall cracks and this is deemed one of the major factors contributing to grade loss. The gold loss is caused by blasting and lashing activities in stopes. The use of water for dust suppression, transporting broken rock and wash over of the stope promotes the lodging of fine gold particles in the footwall cracks. This can be mitigated to some extent, by avoiding using water under excessive pressure.

It has been suggested that fine gold particles lodged in cracks may not be efficiently recovered by physical means, but by solution mining. A feasibility study of solution mining has been completed and the process will be commissioned when the equipment is procured. Though results of trial solution mining were encouraging, it remains to be demonstrated whether a significant amount of gold is lodged in footwall cracks and whether solution mining can efficiently recover this gold.

6.4 Grade loss

The MCF at Mazowe Mine is generally low, primarily due to grade loss. Ore flow balance sheet analysis for the period 2013 to 2016 shows that the grade loss was 32%. The grade reconciliation factor for this period was also low at 63%, with a standard deviation of 14%. The grade was consistently significantly less than the resource/reserve estimate grade. The grade loss is partly attributed to the estimation method, which is not suitable for the deposit and results in inaccurate grade interpolation and overestimation of the grade and the associated apparent grade loss. Unplanned and undetected dilution also contributes to the apparent grade loss.

Loss of fines, which are considered to be high grade, is a major source of real loss of grade. Some of the fines are lost during blasting operations because blasting barricades are not used. Fine gold is also lost as minute particles trapped in the cracks in the footwall of stopes. This is caused by blasting and lashing activities in the stopes. The use of water for dust suppression, transporting broken ore and stope wash-over promotes the loss of gold in this way. It has been suggested that this is one of the main contributing factors to real grade loss at Mazowe Mine. Fines are also lost as spillage during tramming and hoisting operations.

6.5 Apparent grade loss

The low MCF at Mazowe Mine is attributed to grade loss. The grade loss is primarily apparent and is largely due to the unsuitable estimation process which gives rise to inaccurate grade interpolation and overestimation of the grade. Unplanned and undetected dilution also contributes to the apparent grade loss. Although apparent grade loss due to the estimation method and nature of mineralization is deemed the key driver of the low MCF, real grade loss associated with generation and loss of high-grade fines, is a significant contributing factor. This is evident from the fact that when fines sweeps operations are ramped up, the MCF improves significantly. The positive impact of fines on the MCF has been demonstrated.

6.6 Limitations of the study

Another school of thought is that the main contributing factor to the low MCF is the loss of fine gold particles which are lodged in footwall cracks and this gold can be recovered by solution mining. To this end, a feasibility study was conducted and solution mining will be commissioned in the near future. Trial solution mining in some old stopes yielded some encouraging results. If solution mining is successful, it may turn out that the apparent loss and real loss have equal impact on the MCF.

The study could not establish the validity of the assertion that about 284,000 ounces of gold have accumulated over the past 50 years as fine particles trapped in cracks in the footwall of stopes. It remains to be demonstrated that gold of that order of magnitude is lodged in cracks in the footwall of stopes. The planned solution mining process will help resolve this issue.

The study could also not establish whether gold theft has an impact on the MCF. However, incidences of gold theft are quite common, particularly underground. A number of employees have been dismissed for conducting panning activities underground. They tend to work in syndicates which include supervisors.

Quantification of the contribution of identified sources of tonnage and grade gain/loss to the MCF shortfall was not rigorously done because the requisite experiments were not carried out due to time constraints. It is imperative to carry out the necessary experiments to enable more rigorous and more accurate quantification of the contribution of the various sources of tonnage and grade gain/loss to the MCF shortfall, which averaged 45% during the period under review.

6.7 Chapter summary

The findings of the research study were summarized. Grade loss is the main contributing factor to the low MCF. Both real and apparent losses impact the MCF. However, it seems the apparent loss has a greater impact. The grade loss is partly due to the loss of high-grade fines. The loss of fines occurs primarily in the stopes, but also occurs during transportation and in the plant. The loss of gold associated with fines constitutes the main real loss. The apparent loss is largely attributable to the estimation method which overstates grade because it is not suitable for the style of mineralization characterized by erratic grade distribution and high nugget effect. The lack of operational flexibility also contributes to apparent loss because it promotes unplanned and undetected dilution and ore/waste misclassification, due to mining of inferred resource blocks, which are not adequately evaluated. Geostatistical methods of evaluation and more efficient fines reclamation operations are required to minimize losses and improve the MCF. Further research, which incorporates the results of the planned solution mining, is required to establish whether a significant amount of gold is trapped in cracks in the footwall of stopes.

7. RECOMMENDATIONS

7.1 Chapter overview

This chapter presents the recommendations of this research study. The recommendations are based on the conclusions presented in chapter six. The recommendations are essentially remedial actions to review and improve practices and protocols, improve efficiencies and minimize losses in order to improve the MCF.

7.2 Actions to improve grade estimation techniques to minimize apparent loss

- Mazowe Mine must stop using the polygonal method which overestimates grade and adopt a more suitable geostatistical method for resource estimation. Geostatistics is considered a powerful method of resource estimation if correctly applied according to geological understanding (Dominy, 2014). In addition, the impact of the nugget effect associated with kriging of block grade, is generally considered negligible if a large enough number of samples is used in the estimate. (Dominy, 2014)

- Indicator kriging is the recommended estimation method for the Mazowe deposit (Mugwagwa, 2015). It is a non-parametric geostatistical method and does not make assumptions of the underlying sample distribution. The data is coded into 0 and 1 and this renders the predictor robust to outliers (Antunes and Albiquerque, 2013). At an unsampled location, the value estimated represents the probability of an attribute to exceed a specified threshold (Antunes and Albiquerque, 2013).

- The major issue of high nugget ore bodies such as Mazowe, is the effect of high grades or extreme values, which have an undue influence on average values and grade estimation of any blocks in their vicinity. In order to reduce overestimation at Mazowe Mine, top cutting of grade is recommended, but it should be based on a rigorous statistical analysis.

- An improvement or redesign of the sample protocol in order to reduce fundamental sampling errors, which together with other sampling errors, contribute to the nugget effect, is recommended. The higher the nugget effect, the greater the potential error during estimation. Continual training of the sampling personnel to improve the quality of samples is critical.

- It is recommended that the recycling of plastic sample bags be discontinued forthwith to avoid contamination. The contamination gives rise to overstated grade, which in turn results in apparent gold and grade loss.

- Analysis of QA/QC graphs shows that there is contamination in the mine assay laboratory and the low-grade standard exhibited positive bias. This suggests that low grade values have a positive bias and if they are used for estimation they contribute to apparent losses. In view of this, it is recommended that Mazowe Mine joins with other laboratories, particularly accredited ones, to deal with the QA/QC issues.

- It is recommended that the mine ramps up development in order to create operational flexibility and minimize production from inferred resource blocks, which are not fully evaluated. At Mazowe Mine resource blocks are placed in the inferred category if the mineralised shear zone is exposed on a single level and extrapolated up-dip or down-dip to a maximum of 4 levels, depending on the available diamond drill information. The old accumulations do not fall is this category. Currently, the bulk of the production is from inferred resource blocks. The inadequate sampling in inferred blocks, coupled with the erratic nature of mineralisation, is likely to result in erroneous estimations which contribute significantly to apparent grade loss.

- Comprehensive geological mapping is recommended to attain a high level of understanding during evaluation and mining and also to minimize ore/waste misclassification, which also contributes to grade loss.

- Increase in the frequency of stope sampling to more than once per week is recommended to minimize ore/waste misclassification and dependence on grab sampling for grade control.

7.3 Actions to minimize real losses

The critical success factor is to eliminate, or at least significantly reduce, the real losses along the value chain that were identified. These losses give rise to the real financial loss, because costs are incurred in mining the gold, which currently does not generate sufficient revenue to at least cover the costs.

- The loss of gold is associated with the pulverization of the reef and the generation of fines which are lost in the stopes. To minimize the generation of fines, the drilling pattern and/or the charging pattern, must be modified to optimize fragmentation and minimize the generation of fines.

- The use of blasting barricades to minimize the loss of broken ore and high grade fines to old stopes, where it cannot be recovered, is recommended.

- Inefficient stope lashing results in a significant proportion of ore, including high-grade fines, remaining in the stope. To minimize this loss, scraping distances must be reduced and optimal stope configuration for scraping must be achieved.

- Fines sweeps operations are currently confined to old stopes, with no compressed air, water and tracks. The sweeping operations are essentially manual, where crews use shovels, bag the fines and carry them to the shaft. The operations are not well planned or adequately resourced. Whilst fines sweeps in old stopes impact the MCF positively, they do not give an accurate reflection of the MCF of the current producing stopes. To overcome this problem, it is recommended that fines sweeps be carried out concurrently with stope blasting operations. The fines sweeps operations should be done once the blasted ore is lashed using hard brooms and the final stage should involve washing the footwall with water under appropriate pressure to remove gold particles left behind. This is more efficient and gives a more accurate reflection of the MCF of the current producing areas.

- Currently, fines sweeping is not regarded as a critical integral part of the mining operation, but a fall-back position when there are production challenges. This is despite the fact that fines sweeps improve gold production and the MCF significantly. Prioritization of fine sweeps is recommended so that it is properly planned and adequately resourced.

- Mud loading is recommended in order to recover some of the gold in fines that are washed away and deposited in drains during stope wash-over.

- Some of the minute free gold particles are lodged in cracks in the footwall of stopes. This is caused by blasting, scraping and fines sweeping operations. This loss is aggravated by the use of water for dust suppression, transporting broken rock and stope wash-over. It has been suggested that this is a major source of grade loss at Mazowe Mine. Vacuuming is recommended to recover the gold lodged in cracks in the footwall of stopes.

- It has been suggested that physical methods are not effective in recovering gold lodged in cracks. To this end, the implementation of the solution mining process is recommended to test this assertion.

- To enhance security in the plant, the number of CCTV cameras in the plant must be increased and the maintenance of existing ones must be improved. The current situation whereby it takes up to two months to repair broken down cameras compromises security and can potentially impact not only the MCF, but the financial performance through gold theft.

7.4 Further research

There is a school of thought which suggests that about 284,000 ounces of gold have accumulated underground over the years, as fine gold lodged in cracks in the footwall of stopes. According to this school of thought, physical methods cannot efficiently recover this gold, and solution mining is required. It is further proposed that the problem of a perennial low MCF at Mazowe Mine is largely attributable to this loss. This research was not able to resolve this issue. Further research is therefore recommended after solution mining is commissioned. The proposed research must aim to assess the impact of solution mining and determine whether the assertion that substantial gold has accumulated underground is fact or myth.

7.5 Chapter summary

Recommendations to improve the MCF at Mazowe Mine based on the key findings of this research study are presented. The mill-reconciled grade at Mazowe Mine is consistently significantly lower than the resource estimate grade. The researcher is of the opinion that the main contributing factor to the low MCF is grade loss. This chapter recommends measures to mitigate grade loss which adversely impacts the MCF. The recommendations specifically aim to minimize apparent loss, principally attributed to the estimation process and real losses along the value chain, which also significantly impact the MCF. Further research is recommended to test the validity of the assertion that about 284,000 ounces of gold have accumulated underground over the years, as fine gold lodged in cracks in the footwall of stopes. The proposed study would benefit from the solution mining process, which is planned to be commissioned in the near future.

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APPENDICES

Appendix 1: Ore balance sheet for 2013

				ACTUAL	
MINING (Survey Measurement)		**TONNES**	**%**	VALUE	**CONTENT**
Stoping from Ore Reserves		9,167	8.4	5.9	53,968
Stoping from Mineral Resources		66,524	60.6	5.6	373,301
Secondary Development ex Reserves		722	0.7	6.2	4,512
Stoping not in Reserves		27,583	25.1	6.1	169,108
Secondary Development not in Reserves		1,358	1.2	5.1	6,946
Primary Development		4,403	4.0	6.4	28,018
Other Sources					
Total tonnes Broken		109,757	100.0	5.8	635,854
RECONCILIATION OF TONNAGE					
Mineral Broken (Survey Measurement)		109,757	115.7	5.8	635,854
To Accumulation (-)		-1,030	-1.1	5.2	-5,322
From Accumulation (+)		4,196	5.6	0.9	3,906
Corrected for Stope Accumulation		112,923	150.4	5.6	634,438
Ore Passes (+ -)		-588	-0.8	4.4	-2,564
Total Tonnes hoisted		112,335	149.7	5.6	631,874
Sundry Surface Sources(+ -)		-490	-0.7		-1,450
Corrected for Sundry Surface Sources		111,845	149.0	5.6	630,424
Surface Sorting		0	0.0		0
Corrected for Surface Sorting		111,845	149.0	5.6	630,424
Mill Bins and Surface Stockpile		-60	-0.1	-0.1	3
Corrected for Mill Bins=Survey tonnes		111,785	148.9	5.6	630,427
Shortfall+/Excess(-) on Mill tonnes		-16,907	-22.5	17.3	-292,810
Tonnes Milled		94,878	100.0	3.56	337,617
ASSAY PLAN FACTOR					
Gold or value called for		111,785	148.9	5.6	630,427
Gold or value accounted for =Recovery		94,722	100.0	2.92	276,878
	+Residues	94,722	100.0	0.65	61,977
	+Waste Sorted				
	+Slags				
	TOTAL	94,722		3.57	338,855
MCF	**%**				**53.8**

Source (Mazowe Mine, 2017)

Appendix 2: Ore flow balance sheet for 2014

	TONNES	%	ACTUAL VALUE	CONTENT
MINING (Survey Measurement)	**TONNES**	**%**	**VALUE**	**CONTENT**
Stoping from Ore Reserves	15968.4	13.6	6.5	103,527
Stoping from Mineral Resources	62354.0	53.3	5.6	348,318
Secondary Development ex Reserves	648.0	0.6	7.7	5,012
Stoping not in Reserves	30460.8	26.0	9.5	290,676
Secondary Development not in Reserves	2374.0	2.0	6.3	14,897
Primary Development	5259.0	4.5	4.7	24,791
Other Sources				
Total tonnes Broken	**117064**	**100.0**	**6.7**	**787220**
RECONCILIATION OF TONNAGE				
Mineral Broken (Survey Measurement)	117,064	128.3	6.7	787,220
To Accumulation (-)	-3,502	-3.8	7.3	-25,653
From Accumulation (+) and Spillage	3,274	3.6		22,692
Corrected for Stope Accumulation	116,836	128.0	6.7	784,259
Ore Passes (+ -)	-2,686	-2.9		-19,262
Total Tonnes hoisted	114,150	125.1	6.7	764,997
Sundry Surface Sources(+ -) Low-grade ex-Ogilvy	0	0.0		0
Corrected for Sundry Surface Sources	114,150	125.1	6.7	764,997
Surface Sorting(-)	0			0
Corrected for Surface Sorting	114,150	125.1	6.7	764,997
Mill Bins and Surface Stockpile (±) Ex Stockpile	-2,072	-2.3	6.7	-13,950
Corrected for Mill Bins=Survey tonnes	112,078	122.8	6.7	751,047
Shortfall+/Excess(-) on Mill tonnes	-2,912	-3.2		-94,334
Tonnes Milled	91,260	100.0	4.06	370,370
ASSAY PLAN FACTOR				
Gold or value called for	112,078	122.8	6.7	751,047
Gold or value accounted for = Recovery	90,260	100.0	3.82	321,274
+Residues	90,260	100.0	0.54	45,662
+Waste Sorted				
+Slags				
TOTAL	90,260		4.36	366,936
MCF %				49

Source (Mazowe Mine, 2017)

Appendix 3 Ore flow balance sheet for 2015

MINING (Survey Measurement)	TONNES	%	ACTUAL VALUE	CONTENT
Stoping from Ore Reserves	22,297	21.4	6.6	146,118
Stoping from Mineral Resources	53,448	51.2	6.9	368,227
Secondary Development ex Reserves	2,252	2.2	6.8	15,359
Stoping not in Reserves	15,886	15.2	6.6	105,075
Secondary Development not in Reserves	1,840	1.8	4.8	8,827
Primary Development	8,681	8.3	4.6	39,887
Other Sources				
Total tonnes Broken	**104404**	**100.0**	**6.5**	**683492**
RECONCILIATION OF TONNAGE				
Mineral Broken (Survey Measurement)	104,404	110.3	6.5	683,492
To Accumulation (-)	-10,365	-11.0	5.7	-59,303
To spillage (-)				
From Accumulation (+) and Spillage	8,903	9.4		33,395
Corrected for Stope Accumulation	95,115	100.5	6.4	605,581
Ore Passes (+ -)	-2,943	-3.1		-14,655
Total Tonnes hoisted	95,318	100.7	6.7	639,559
Sundry Surface Sources(+ -) Low-grade ex-Ogilvy	0	0.0		0
Corrected for Sundry Surface Sources	95,318	100.7	6.7	639,559
Surface Sorting(-)	0			0
Corrected for Surface Sorting	95,318	100.7	6.7	639,559
Mill Bins and Surface Stockpile (+) Ex Stockpile	-1,713	-1.8	4.7	-8,071
Corrected for Mill Bins=Survey tonnes	93,605	98.9	6.7	631,488
Shortfall+/Excess(-) on Mill tonnes	1,013	1.1		-84,969
Tonnes Milled	94,618	100.0	3.67	347,440
ASSAY PLAN FACTOR				
Gold or value called for	93,605	98.9	6.7	631,488
Gold or value accounted for = Recovery	91,698	100.0	3.69	313,669
+Residues	91,698	100.0	0.55	46,403
+Waste Sorted				
+Slags				
TOTAL	91,698		4.24	360,072
MCF **%**				57

Source (Mazowe Mine 2017)

Appendix 4 Ore flow balance sheet for 2016

			ACTUAL	
MINING (Survey Measurement)	**TONNES**	**%**	**VALUE**	**CONTENT**
Stoping from Ore Reserves	25899	21.7	6.2	161203
Stoping from Mineral Resources	68962	57.8	5.5	376176
Secondary Development ex Reserves	1587	1.3	6.1	9665
Stoping not in Reserves	10759	9.0	7.1	76193
Secondary Development not in Reserves	1348	1.1	0.0	10294
Primary Development	10843	9.1	5.8	63309
Other Sources				
Total tonnes Broken	**119398**	**100.0**	**5.8**	**696839**
RECONCILIATION OF TONNAGE				
Mineral Broken (Survey Measurement)	119846	121.7	5.8	698451
To Accumulation (-)	-5233	-5.3		-30856
From Accumulation (+) and Spillage	7076	7.2		18059
Corrected for Stope Accumulation	118220	120.0	5.8	685653
Ore Passes (+ -)	-2192	-2.2	0.0	-3225
Total Tonnes hoisted	116028	117.8	5.9	682428
Sundry Surface Sources(+ -) Low-grade ex-Ogilvy	0	0.0	0.0	0
Corrected for Sundry Surface Sources	116028	117.8	5.9	682428
Surface Sorting(-)	0	0.0	0.8	0
Corrected for Surface Sorting	116028	117.8	5.9	682428
Mill Bins and Surface Stockpile (+) Ex Stockpile	-3170	-3.2	3.6	-11380
Tonnage losses unaccounted for(spillages)	-5993	-6.1	6.0	-35852
Corrected for Mill Bins=Survey tonnes	106865	108.5	5.9	635196
Shortfall+/Excess(-) on Mill tonnes	-8368	-8.5	6.0	-50210
Tonnes Milled	98497	100.0	3.93	386981
ASSAY PLAN FACTOR				
Gold or value called for	106865	108.5	3.9	415795
Gold or value accounted for = Recovery	93240	`	3.41	335720
+Residues	93240	100.0	0.51	49993
+Waste Sorted				
+Slags				
TOTAL	93240		2.84	264802
MCF %				**64.0**

Source (Mazowe Mine, 2017)